DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

Materials Technical Team Roadmap

October 2017

This roadmap is a document of the U.S. DRIVE Partnership. U.S. DRIVE (Driving Research and Innovation for Vehicle efficiency and Energy sustainability) is a voluntary, non-binding, and non-legal partnership among the U.S. Department of Energy (DOE); USCAR, representing FCA US LLC, Ford Motor Company, and General Motors; five energy companies – BP America, Chevron Corporation, Phillips 66 Company, ExxonMobil Corporation, and Shell Oil Products US; two utilities – Southern California Edison and DTE Energy; and the Electric Power Research Institute (EPRI).

The Materials Technical Team is one of 13 U.S. DRIVE technical teams whose mission is to accelerate the development of pre-competitive and innovative technologies to enable a full range of efficient and clean advanced light-duty vehicles, as well as related energy infrastructure.

For more information about U.S. DRIVE, please see the U.S. DRIVE Partnership Plan, www.vehicles.energy.gov/about/partnerships/usdrive.html or www.uscar.org.

In March 2012, DOE announced a 10-year vision for plug-in electric vehicles (PEVs) called the "EV Everywhere Grand Challenge." EV Everywhere aims to enable American innovators to rapidly develop and commercialize the next generation of technologies to achieve the cost, range, and charging infrastructure necessary for widespread PEV deployment. As demonstrated in its guiding "Blueprint" document, EV Everywhere aligns with U.S. DRIVE technical areas focused on electrochemical energy storage, electrical and electronics, materials, vehicle systems and analysis, and grid interaction. For additional information about the EV Everywhere initiative, please see the EV Everywhere blueprint at http://www.eere.energy.gov/vehiclesandfuels/electric_vehicles/pdfs/eveverywhere_blueprint.pdf.

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1. Materials Technical Team Mission and Scope

Materials play a major role in the U.S. DRIVE Partnership by enabling vehicle lightweighting of structures and systems, thereby improving fuel economy and reducing demands on the vehicle powertrain and ancillary systems (e.g., braking).

The Materials Technical Team (MTT) focuses primarily on reducing the mass of structural systems such as the body and chassis in light-duty vehicles (including passenger cars and light trucks). Mass reduction also enables improved vehicle efficiency regardless of the vehicle size or propulsion system employed.

The MTT mission is to identify technology gaps, establish research and development (R&D) targets, and develop roadmaps for materials and manufacturing technologies aimed at high-volume production of vehicles. These efforts enable and support the simultaneous attainment of the following long-term objectives:

- 50% mass reduction @ equal affordability (stretch objective long-term)
- USDRIVE Target 2025* – 25% weight reduction (Glider) < $5/lb
- Equal performance (Crash, NVH, Durability, Reliability & Recyclability)
- Comparator (2012 Midsized 5 passenger sedan, 200K UPA, fully amortized)

The team's technical scope encompasses advancements in design, joining, corrosion mitigation, crash energy management, predictive and computational tools, and component manufacturing processes to facilitate the widespread use of lightweight materials. These include polymer composites, light metals, advanced high-strength steels, and mixed material sub-systems to enable the U.S. DRIVE Partnership to reach its goals.

2. Materials Technical Team Strategy

The MTT strategy continues to focus on stretch but realistic goals and objectives to develop lightweight, high-performance, cost-effective structural materials for vehicle lightweighting. An integral part of this strategy is to engage the steel, aluminum, magnesium, carbon fiber, polymer composite, and plastic industries while working closely with suppliers to develop the infrastructure of advance manufacturing enablers for forming, casting, molding, joining, and assembly of light materials systems for automotive applications. One of the new strategic directives incorporated in this roadmap focuses on the development of multi-material systems, technologies and enablers.

The MTT strategy includes delivery of computational tools and methods with the goal of reducing the time and cost of developing and validating new materials, material processing methods, and manufacturing techniques and technologies. This includes tools capable of predicting the performance of materials, joints, and parts to optimize performance and mass. Working closely with national laboratories, academic institutions, and industrial research laboratories, the integration of constitutive models ranging from fundamental alloy to advanced manufacturing process methods plays an integral part of the MTT strategy.

3. Key Issues and Challenges

The task of reducing the mass of the glider by 25% while meeting government regulations and consumer requirements is a formidable challenge.

While parts consolidation and the potential for simplified designs can offer reduced costs, the raw materials and the manufacture of components increases the net cost to implement lightweight materials. Therefore, reducing both the cost of primary material production and the cost of manufacturing using lightweight materials is critical to achieving mass reduction and affordability targets. In order to lower the cost of processes such as forming, casting, molding, machining, joining, and assembly, cycle time needs to be reduced. In addition, the ability to predict performance for material, joints, and parts would allow for optimized design while minimizing cost. An integrated suite of computational models would enable accelerating the product development cycle time from initial materials development to prediction of parts performance.

As the use of lightweight materials increases, the development of recycling technologies becomes more important. In addition, methodologies for vehicle disassembly are also important as they affect cost, affordability, and repairability.

4. Gaps and Technical Barriers

Traditionally, reduction of vehicle weight involved 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.

The use of lightweight materials, high-strength steels, aluminum, and composites has been the subject of extensive research and development over many years. To achieve significant vehicle weight reduction, it will be necessary to increase the content while also adding lightweight materials with higher potential for weight reduction such as magnesium, carbon fiber composites, and the next generations of advanced high strength steels. The lack of infrastructure for producing these materials remains a barrier and technical challenge to achieving both near- and long-term goals.

The most promising materials for application in body and chassis include advanced high-strength steels, aluminum, magnesium, carbon fiber-reinforced polymer composites, and combinations of these as mixed-material systems. Additionally, materials such as polycarbonate, acrylics, and metal matrix composites, and approaches to their use must be considered for certain applications where few alternatives exist.

Figure 1. Summarizes the significant technological challenges to widespread use of lightweight materials. It is structured such that each row (reading from right to left) indicates the increasing severity of the challenge to achieving widespread application of each material. The materials are listed vertically in order of their potential to decrease the mass of a vehicle through maximized use.

Material Technology Roadmap

USDRIVE

Increasing Need for R&D

Increasing Impact on Reducing Vehicle Mass

Material	Critical Challenges				
Multi-Material Systems Enablers	High Volume Joining (Fusion, Mechanical, Adhesives)	Engineered Surfaces (Corrosion, Wear, Friction)	Predictive Modeling	NDE & Life Monitoring	Recycling
Carbon-Fiber Composites	Low-cost High-Volume Manufacturing	Low-Cost Fibers	Predictive Modeling	Joining, NDE, Life Monitoring & Repair	Recycling (OFFAL / Vehicle)
Aluminum	Low-cost Al Manufacturing Processes	Improved Alloys (Body/Powertrain) for Performance & Manufacturing	Joining Mixed Al Products	Recycling Vehicle	
Ultra High-Strength Steels	Improved Alloys for Room Temp Forming	Weldability for Dissimilar Steel Alloys	Predictive Modeling (Formability, Crash)		
Magnesium	Low Cost Feedstock, Low Carbon Footprint Production	Galvanic Corrosion Protection	Improved Alloys for Energy Absorption	Manufacturing (Sheet and Extrusions)	Recycling
Glazings	Low Cost Feedstock for Polymer Glazings	Low Temp Processed Chemically Toughened Glass	Durable, Scratch Resistant, UV Resistant Coatings		
Metal / Ceramic Composites	Feedstock Cost	Compositing Methods	Powder Handling	Compaction	Machining & Forming

Figure 1. Materials Technical Team Roadmap

5. Technical Targets and Status

Under the U.S. DRIVE Partnership, the MTT adopted a 2025 partnership research target of a 25% glider[1] mass reduction, relative to comparable 2012 vehicles, at an added cost of no more than $5 per lb. of weight saved. This target is the team's primary focus. The MTT has established interim performance and cost targets for the most promising materials system. These targets support overall efforts to achieve the 2025 partnership research target as indicated in Figure 2.

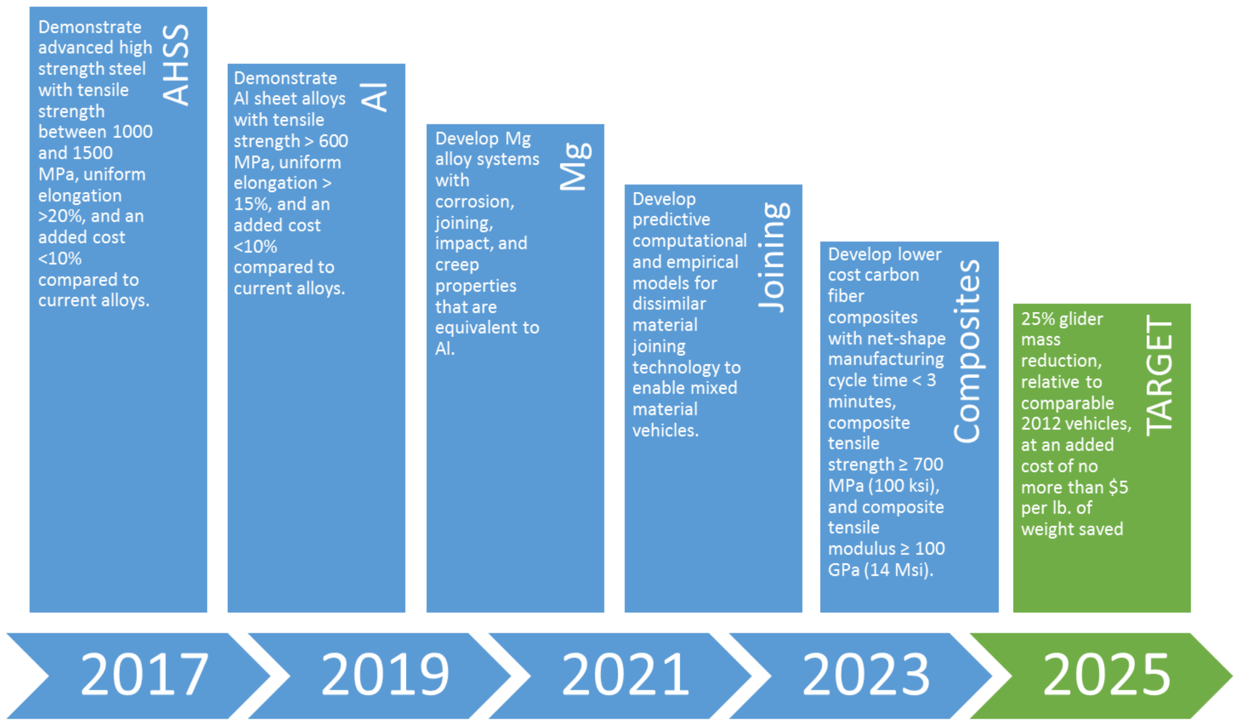

Figure 2. Significant Materials Technical Team Targets, 2017–2025

The following sections describe the basic state of technology for the principal materials of focus as agreed to and understood by the MTT.

Detailed analyses of the needs, gaps, and metrics for lab year[2] near term (2020), midterm (2030), and long term (2050) goals are contained in working documents used to develop this roadmap. The MTT maintains technology assessments of each of the aforementioned material systems, which it will monitor and update periodically.

5.1 Multi-Material Systems

Future vehicles will increase the use of mixed material systems to deliver lightweighting solutions needed to maximize vehicle performance and efficiency. All of the aforementioned materials enable lightweighting. However, integration of more and / or improved lightweight materials in mixed materials

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[1] Glider is defined as the total vehicle minus propulsion system, fuel and energy storage, wheels, and tires.

[2] As defined by the Autonomie model as the lab year in which pre-commercial technology is demonstrated (approx. ~5 years to implementation)

systems present unique challenges in developing cost-effective and high-volume solutions in joining, assembling, inspection, painting, and processing of vehicles within the current infrastructure of automotive assembly.

The development of unique body structures, closures (e.g., doors, hoods, trunks, etc.) and chassis structures offer many opportunities for mixed material lightweighting; however, new designs will have to meet performance, durability, and corrosion requirements equal to those of today's vehicles.

5.2 Carbon Fiber/Polymer Matrix Composites

This roadmap considers polymer matrix composites (PMC) for both components and body-in-white (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 [CF] systems). Efforts focus on overcoming key challenges to using these materials, including cost reduction (for precursor materials and CF conversion), supplier capability, high-volume manufacturing, joining (including joining with other materials), and understanding, predicting, and improving durability. Other opportunities include enhancing crash energy management, optimizing mass reduction and improved recycling of CF materials.

5.3 Aluminum

There are several types of vehicle body designs that make use of aluminum in all of the major product forms – sheet, casting, and extrusions. For chassis applications, 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 U.S. DRIVE targets. The biggest challenge faced in increasing the use of aluminum, especially with higher strength aluminum alloys, is in reducing material cost to achieve parity with incumbent materials at a systems level. High-volume manufacturing techniques (sheet forming, casting, extruding, machining, joining, etc.) for aluminum components of all types based on conventional manufacturing processes are approaching maturity, however, manufacturing capacity and cost limits widespread application. Further weight reduction opportunities exist with the development of higher-strength, higher-ductility aluminum alloys. Additional opportunities include development of new innovative computational modeling tools and process technologies to reduce material and manufacturing costs and to increase capability in areas such as production of large, thin walled, complex castings and extrusions.

5.4 Ultra High-Strength Steels (UHSS)

Detailed roadmaps are expanding to include development of later generations of AHSS for automotive applications, and significant work is underway to achieve both high strength and improved ductility as part of the third generation of affordable advanced high strength steels.

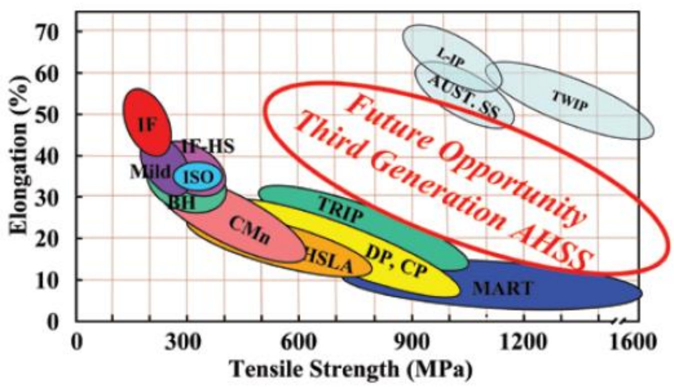


Figure 3. Overview of Tensile Strength and Total Elongation (%) Combinations for Various Classes of Conventional and Advanced High-strength Sheet Steel (AHSS) Grades.

As shown in Figure 3, first-generation AHSS (e.g., Dual Phase, Complex Phase, transformation-induced plasticity [TRIP], and Martensitic) differ from conventional mild steels because they are manufactured using a combination of alloy compositions and processing methods to achieve high strength. While the added strength contributed to vehicle lightweighting, the higher strength and lower ductility necessitate changes to stamping, trimming, joining, and assembly. Second-generation AHSS (twinning-induced plasticity [TWIP], lightweight steels with induced plasticity [L-IP], and austenitic stainless) steels deliver high strength and greatly enhanced ductility, but have met with limited applications due to the complexity in stamping and joining these materials. Thus, the focus for future research is the development of a third generation of AHSS and the manufacturing technologies to make these economical on a high volume scale. Since third-generation steels are complex multiphase structures, concurrent development of the next-generation joining technologies is required to ensure their compatibility with current manufacturing infrastructure.

5.5 Magnesium

Magnesium is a lightweight 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 ongoing research, key efforts in increasing the use of magnesium focus on supporting the development of a low-cost, environmentally friendly production capability in North America; development of affordable creep resistant and corrosion resistant magnesium alloys; production of large magnesium cast structures; and next-generation joining technology. Additional research needs include improved manufacturing technologies; cost-effective, durable protective coatings; economical methods for production of magnesium sheet materials; forming technology; and methods for recycling magnesium, especially in mixed material applications. In addition, the atmospheres currently in use for reducing oxidation while handling molten magnesium such as SO_2 or SF_6 are toxic, offering opportunities for developing next generation cover gases to mitigate toxicity, and environmental impact.

5.6 Glazing

Glass (i.e., glazing) performs many crucial functions in a vehicle. In addition to allowing drivers and passengers to view their surroundings, it also contributes greatly to the styling of modern vehicles and contributes to the structural integrity of the passenger cabin. The glass also helps maintain occupant comfort by limiting road noise transmission and can also contribute to reducing vehicle energy consumption, by reducing heat and thermal radiation into the passenger compartment. It also can protect against intrusion into the vehicle and can help secure occupants in the event of an accident. Glazing represents approximately 5% of the mass of a typical automobile. Lightweight glazing alternatives can result in a significant weight reduction (up to 50%) compared to conventional glazing materials.

However, current lightweight alternatives must overcome hurdles with cost, manufacturability, durability, and regulations.

To enable extensive use of lower-mass glazing, several challenges will have to be overcome, including improvements in material durability and development of improved ultraviolet (UV) and infrared (IR) blockers, to mitigate material degradation and to reduce cabin heat load. Remaining technical challenges include methods to model and reduce noise transmission as well as techniques to increase the durability (i.e., impact resistance, clarity, and color) that can meet federal and international performance requirements.

5.7 Metal Matrix Composites (MMCs)

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), to create 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 applications with the use of MMCs due to their improved mechanical behavior and physical properties. Physical limitations of MMCs 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. 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 development is still needed in the areas of rapid, low-cost, near-net-shape forming and machining. Magnesium MMCs could also offer further weight reduction, but require development of affordable processing and manufacturing methods. Major challenges include increasing the modulus to be equivalent to aluminum and improving magnesium's creep and corrosion resistance without the addition of expensive rare earth materials.

6. High Priority Research Needs

After extensive consideration of the numerous significant research needs identified, the OEM representatives selected the following topics for research as the high priority areas (listed here in no particular rank order) to be pursued to meet 2025 goals.

Mat'l.	Research Topics	Specific Aspect(s)
Al	Continuous Cast Al Sheet (CCAS)	- Process development of continuous cast process to produce 6xxx aluminum sheet at less than $1/lb. with properties similar to current products.
Al	High strength Aluminum Alloys incl. High strength aluminum (HSA) sheet alloys with equivalent formability to steel	- High Strength (>600 MPa) Aluminum for body structure - Methods to improve formability limits of HSA, and identify the parameters which can achieve that
Al	High Integrity Al High Pressure Die Casting (HPDC)	- High vacuum / High Integrity Al HPDC die construction materials / coatings for improved die life

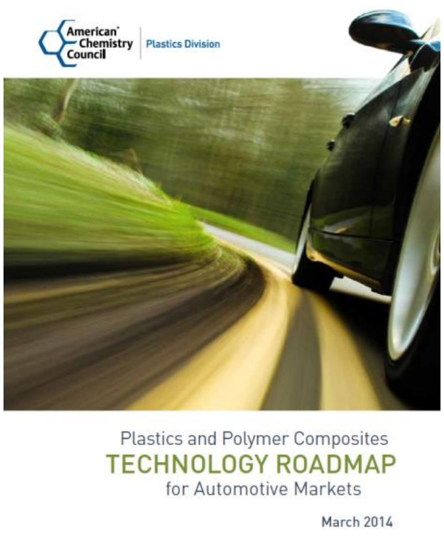
Mat'l.	Research Topics	Specific Aspect(s)
Al	Aluminum Pretreatment	- Low cost coatings for galvanic isolation; Incl. comprehensive investigation of aluminum pretreatment for adhesive bonding & correlation of coupon tests to vehicle field performance
Al	High strength/high elongation casting alloys using low cost casting processes	- Methods to attain higher strengths and higher elongations in cast alloys for high volume low-cost casting processes.
Al	Al uni-alloy for enhanced recycling	- Common sheet / casting alloy to leverage high value scrap and eliminate sorting
PMC	Light Weight Mixed Material Engine Blocks	- Process development of hybrid carbon fiber composite engine blocks with metal inserts through injection/compression molding.
PMC	Carbon composite materials' modeling and response prediction	- Robust and accurate predictive tools for combined durability, fatigue, joining, and dynamic crush using novel methods.
PMC	Ability to place and orient fibers as desired for structural and semi-structural parts (strategic placement & orientation)	- Processing cost and cycle time conducive to high volume manufacturing.
PMC	Reduction in manufacturing variations of advanced lightweight materials and Fiber Reinforced composites via improved manufacturing methods, and modeling tools	- ICME type activities with well-defined and focused tools that can be deployed towards optimizing the manufacturing process with all its attributes.
PMC	Reduce affinity of natural fiber for moisture	- Less than 1 wt% moisture uptake after extended high humidity exposure (e.g., 10 days at 90%RH, 40^{o} C)
Mg	Continuous Cast Mg Sheet (CCMS)	- Process development of continuous cast process to produce AM50/AM60 magnesium sheet at less than $2/lb. with properties similar to current products.
Multi	Multi-material joining, carbon fiber composites, Al, AHSS and other lightweight materials	- Joining methods that meet durability/crash and can be manufactured/made at high production rates. - Development of next-generation joining technologies of mixed materials and coating development for performance (including corrosion) improvement.
Multi	Low Cost Tooling Insert	- Additive Manufacturing of laser-sintered steel die inserts for stamping, HPDC and Injection molding dies.

Mat'l.	Research Topics	Specific Aspect(s)
Multi	High strength materials modeling and response prediction	- Robust and accurate predictive tools for dynamic crush and fracture of aluminums & UHSS. - Robust and accurate predictive tools for combined durability, fatigue, joining, and dynamic crush of composites and multi-material systems.

7. Detailed External Road Maps

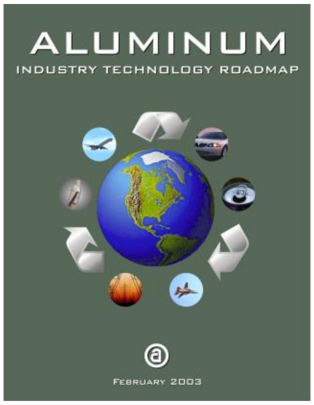
In addition to the information contained in this roadmap, there are much larger and more detailed complementary material-specific roadmaps that exist today. Hyperlinks to polymer materials, aluminum, magnesium and steel roadmaps can be found below. Many MTT participants, both past and present, have and will continue to contribute to the detailed roadmaps that are found in these hyperlinks, and these roadmaps have and will continue to influence the MTT. Access to these external roadmaps is provided for those who would like to go beyond the technical gaps and targets listed in this document and are easily accessible for review.

Plastics



http://www.plastics-car.com/Tomorrows-Automobiles/Plastics-and-Polymer-Composites-Technology-Roadmap/Plastics-and-Polymer-Composites-Technology-Roadmap-for-Automotive-Markets-Full-Report.pdf)

Aluminum

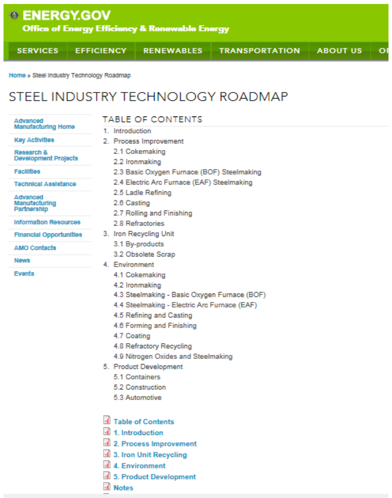


https://www1.eere.energy.gov/manufacturing/resources/aluminum/pdfs/al_roadmap.pdf

Magnesium

http://www.uscar.org/commands/files_download.php?files_id=240.

Steel & Iron



http://energy.gov/eere/amo/downloads/steel-industry-technology-roadmap

http://www.nist.gov/mml/acmd/structural_materials/ahss.cfm

8. Glossary

Al	Aluminum
AHSS	Advanced High-Strength Steels
CF	Carbon Fiber
CFC	Carbon Fiber Composites
DOE	U.S. Department of Energy
EPRI	Electric Power Research Institute
IR	Infrared
L-IP	Lightweight Steels with Induced Plasticity
Mg	Magnesium
MMC	Metal Matrix Composites
MTT	Materials Technical Team
NVH	Noise Vibration and Harshness
PEV	Plug-in Electric Vehicle
PMC	Polymer Matrix Composites
R&D	Research and Development
TRIP	Transformation-Induced Plasticity
TWIP	Twinning-Induced Plasticity
UHSS	Ultra High-Strength Steels
UV	Ultraviolet

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