Implementing Plastic and Polymer Composite Lightweighting Solutions to Meet 2025 Corporate Average Fuel Economy Standards

An analysis of mass reduction opportunity studies demonstrates 2025 Corporate Average Fuel Economy (CAFE) Standards are achievable; plastics and polymer composites can yield further lightweighting benefits.

1 Introduction

Since the Energy Policy and Conservation Act of 1975, the National Highway Traffic Safety Administration (NHTSA) has been mandated by Congress to regulate fuel economy standards of automobiles to strategically boost our nation's economy, improve energy security, and reduce greenhouse gas emissions.[1] In 2011, President Obama and 13 major automakers reached an agreement to incrementally raise these miles-per-gallon (mpg) requirements for model year 2025 vehicles to more than 50 mpg CAFE.[2] The resulting staged standards must be finalized at least 18 months prior to the beginning of a given vehicle model year, and must be set at the maximum possible level in terms of solutions that are technically feasible and economically practicable for implementation by vehicle manufacturers.

To attain well-informed estimates of targets that are realistically achievable by automakers, NHTSA relies on numerous economic studies and scientific analyses, including the development of mathematical functions that represent vehicle attributes related to fuel economy. Accordingly, NHTSA's rulemakings to increase CAFE standards are based in a methodology that gives thoughtful consideration to potential impacts on vehicle safety, retail prices, functionality, and performance—at a minimum.

Vehicle mass reduction is one of the most effective pathways to increasing the fuel economy of vehicle fleets. As such, NHTSA's mid-term evaluation process—a prerequisite tool for proposing CAFE standards—aggregates several expert analyses focused on vehicle lightweighting technologies.[3] In collaboration with the Environmental Protection Agency (EPA) and the California Air Resources Board (CARB), NHTSA is gathering data from a variety of stakeholders in preparation for the mid-term evaluation on April 1, 2018, which is set to determine fuel economy standards for vehicle model years (MY) 2022–2025.[4] Ultimately, the mid-term evaluation will determine whether the draft MY2022–2025 fuel economy standards are to remain consistent with EPA's finalized set of emissions-based MY2025 standards requiring the equivalent of 54.5 mpg CAFE.

Plastics and polymer composites, which already dominate vehicle interiors, exteriors, trim, and lighting, are gaining use in other vehicle systems as lightweight, value-producing materials that can meet increasingly challenging automotive requirements. These materials' many advantages have enabled them to grow their share of the materials mix in the automotive industry over the past 40 years. As the push to lightweight vehicles intensifies, projections indicate that plastics and polymer composites can and should play an even more substantial role in the automotive industry through 2025 and beyond.

This paper examines the importance of vehicle weight reduction for meeting CAFE standards and provides recommendations for the implementation of advanced plastics and polymer composites as a key mass-reduction-enabling technology. It presents an overview of the mass reduction advantages of plastics and polymer composites, examples of successful implementation efforts by original equipment manufacturers (OEMs), and current R&D pursuits to increase their technology maturity and acceptance. This paper also examines several agency-sponsored mass reduction studies (summarized below in Table 1) to assess the soundness of their assumptions and findings and their overall consideration of plastics and polymer composites for reducing vehicle weight.

Table 1. Summary of Analyzed Agency-Sponsored Mass Reduction Studies

STUDY TITLE	SUPPORTER	RELEASE	SUMMARY OF VEHICLE MASS REDUCTION ESTIMATES AND CONSIDERATION FOR PLASTICS AND POLYMER COMPOSITES
Mass Reduction for Light-Duty Vehicles for Model Years 2017–2025	National Highway Traffic Safety Administration (NHTSA)	August 2012	• **Estimate of achievable mass reduction by automakers: 22% for MY2017–2025** • Advanced high-strength steel (AHSS) intensive vehicle design • No polymer composite materials considered in final design
Evaluating the Structure and Crashworthiness of a 2020 Model-Year, Mass-Reduced Crossover Vehicle Using FEA Modeling	California Air Resources Board (CARB)	August 2012	• **Estimate of achievable mass reduction by automakers: 31% for MY2020–2025** • Aluminum-intensive multimaterial structure • Body-in-white contains 5% composite materials by mass
Light-Duty Vehicle Mass Reduction and Cost Analysis – Midsize Crossover Utility Vehicle	Environmental Protection Agency (EPA)	August 2012	• **Estimate of achievable mass reduction by automakers: 18% for MY2017–2020** • Polymer composites used frequently in interior body, engine, and braking systems
Mass Reduction and Cost Analysis – Light-Duty Pickup Truck Model Years 2020–2025	Environmental Protection Agency (EPA)	June 2015	• **Estimate of achievable mass reduction by automakers: 20% for MY2020–2025** • Aluminum-intensive design • Minimal-to-no use of polymer composites in lightweight vehicle design
Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles	The Committee on Assessment of Technologies for Improving the Fuel Economy of Light-Duty Vehicles (Phase 2; established upon the request of NHTSA)	June 2015	• **MY2015–2020:** Committee estimates polymer composites will be limited to nonstructural components • **MY2020–2025:** Committee estimates polymer composites will be limited to case-by-case multimaterial configurations

2 Enabling Vehicle Mass Reduction with Plastics & Polymer Composites

The current focus on increasing efficiency and decreasing emissions levels is putting pressure on the automotive industry to take as much weight out of their vehicles as possible. Automakers recognize that reducing vehicle mass carries trade-offs that may impose significant technological and manufacturing risks. Plastics and polymer composites deliver several key benefits that can enable vehicle mass reduction without compromising performance or safety, allowing automakers to comply with future CAFE standards.

OFFER UNPARALLELED WEIGHT SAVINGS

To meet progressively increasing efficiency and emissions standards by 2025, it is critical that automakers continue to find new ways to lightweight vehicles. Ducker Worldwide estimates that 400 pounds—about 10 percent of vehicle weight—needs to be removed from the average car to meet proposed EPA emissions standards equivalent to 54.5 mpg.[5] Industries that produce plastics and polymer composites and metals such as aluminum and advanced high-strength steel (AHSS) are working to attain lightweighting gains to help meet these needs.

Plastics and polymer composites deliver significant weight savings to automakers today, and improve aesthetics, aerodynamic design, and value in many interior and exterior applications. Plastics and polymer composites—particularly fiber-reinforced composites—are also growing as a more competitive option for structural applications like body-in-white (BIW) and chassis components due to their ability to drastically reduce overall vehicle weight while maintaining or improving safety and performance. Carbon fiber-reinforced polymer composites (CFRP) are 50% lighter than conventional steel and 30% lighter than aluminum,[6] which is encouraging more and more parts suppliers and automakers to take notice. For example, BMW is using the material as the body structure of its electric vehicle, the i3.[7] DuPont has also run computer simulations that have shown that replacing metal-based components with polymer composites provides both cost and weight savings.[8] With even more innovation under way, the plastics and polymer composites industry is well poised to meet and exceed the lightweighting needs of the automotive industry.

PROVIDE HIGH ENERGY ABSORPTION FOR IMPROVED STRENGTH AND SAFETY

As automakers strive to make cars lighter, they will also face the challenge of maintaining and improving strength and safety. Both NHTSA and the Insurance Institute for Highway Safety (IIHS) are currently pursuing stricter crash-test rating systems to improve both pedestrian and passenger safety through increased crash avoidance technologies and better crashworthiness.[9]

In addition to reducing vehicle weight, plastics and polymer composites have high energy-absorption qualities that can help vehicles meet strict collision safety standards.[10] In demanding industries such as motorsports and aerospace, polymer composites have been a material of choice for years due to their high strength-to-weight and stiffness-to-weight ratios. The high strength and energy absorption of structural polymer composites can also improve crash safety by strengthening vehicle compartments to help protect passengers during crashes.[11] On the other end of the materials spectrum, energy-absorbing, injection-moldable materials such as polypropylene or polycarbonate blended with polybutylene terephthalate (PC+PBT) as well as low-density foam polymer materials are already being incorporated into vehicle bumpers in Europe to meet new pedestrian protection guidelines set forth by the European Commission.[12]

REALIZE ALTERNATIVE POWERTRAIN VEHICLES

Alternative powertrain vehicles—such as electric, hybrid, plug-in hybrid, compressed natural gas, liquefied petroleum gas, and flex-fuel vehicles that can operate on E85—are becoming a larger part of the vehicle mix due to drivers like the new CAFE standards. Some experts estimate that more than one-third (36%) of new passenger vehicles will be equipped with alternative powertrains by 2025.[13] Because these new vehicles are using different fuels with varying chemical compositions and combustion temperatures, they require powertrains composed of materials that can withstand these different conditions.

By providing vehicles with lighter powertrains that can better withstand the conditions of alternative vehicles, plastics and polymer composites are and will continue to significantly aid in the market realization of these new vehicle technologies.

Plastics and polymer composites can not only help reduce the weight of powertrains, they can also withstand many of the alternative fuel environments that other materials cannot. Thanks to this advantage and other material properties, over 200 tons of plastics and polymer composites were used in electric vehicle applications in 2010 for powertrains, battery casings, thermal management systems, and wire and cables, a figure that is projected to increase to 26,000 tons by 2017.[14] By providing vehicles with lighter powertrains that can better withstand the conditions of alternative vehicles, plastics and polymer composites are and will continue to significantly aid in the market realization of these new vehicle technologies.

CREATE VALUE THROUGH PARTS CONSOLIDATION

Traditionally, vehicles are constructed by manufacturing a large number of individual components, combining them into systems, and assembling these systems together using joining techniques like spot welding and mechanical fasteners. While necessary, this process can add both cost and weight to vehicle production, as well as create weaknesses at joining points.

Through parts integration, plastics and polymer composites provide automakers with the ability to manufacture one complex part instead of joining multiple parts together. This advantage results in faster processing times and the elimination of expensive joining and assembly tooling. For example, the 2013 Ford Escape features a two-shot window lift carrier plate that replaces a metal-intensive assembly comprising 21 components produced with 16+ processing and assembly steps with a plastics-intensive, 10-component unit produced in 10 assembly steps.[15] The result delivers design flexibility, weight and cost savings, simplified assembly, and a reduction of process steps.[16]

ENABLE NOVEL MULTIMATERIAL VEHICLE DESIGNS

Multimaterial design approaches allow automakers to selectively integrate lightweight materials in specific vehicle regions. While spot welds, rivets, and fasteners designed for metals cannot be used to join plastic and polymer composite parts to each other or to metals, polymer-based structural adhesives offer high-performance structural bonds for joining composites and other dissimilar materials. In addition to permitting lightweight construction, these adhesives can be used to improve vehicle crash behavior and reduce noise, vibration, and harshness. Polymer-based structural adhesives have become an indispensable bonding technology in vehicle design and are strongly positioned to enable the integration of plastic and polymer composite components in next-generation lightweight multimaterial vehicles.[17]

MAY BENEFIT FROM NATURAL GAS SUPPLY BOOM

Natural gas is typically used to make plastic and polymer composite materials. The recent boom in U.S. shale gas production has the potential to aid the plastics and polymer composites industry in making these materials a cost-competitive option for reducing vehicle weight. In 2010, about 412 billion cubic feet (Bcf) of natural gas were used to make plastic materials and resins (about 1.7% of total U.S. natural gas consumption); however, only 13 Bcf were used as feedstock while 399 Bcf were burned as fuel.[18] Chevron Phillips Chemical Company has suggested that the development of shale gas may encourage the plastics and polymer composites industry to invest $30 billion to construct new petrochemical units that convert natural gas into plastics.[19] As a result, the plastic and rubber products industry could experience a 17.9% boost (equivalent to $33.28 billion) in industry output above the 2010 baseline in the 2015–2020 period.[20]

Commercial Integration of Plastics & Polymer Composites in the Automotive Industry

Due to the benefits offered by plastics and polymer composites, these materials are being increasingly used in commercial vehicle applications. This section highlights two key examples of automakers whose implementation of plastic and polymer composite lightweighting technologies is several steps ahead of the automotive industry as a whole.

MASS PRODUCTION OF A CARBON FIBER-REINFORCED POLYMER BMW I3

While some automakers are hesitant to use high-performance polymer composites as a chief vehicle lightweighting technology, BMW has successfully manufactured a composite-intensive vehicle to improve fuel economy and reduce greenhouse gas emissions. Fulfilling their 2009 pledge to design a 4-door passenger vehicle composed primarily of CFRP composites, BMW is competitively manufacturing a composite-intensive all-electric vehicle, called the i3. Using highly automated robotics to ensure efficiency and repeatability, BMW's production facility in Leipzig, Germany manufactures composite i3 vehicles at a considerable production rate of 70 vehicles per day.[21] Carbon fiber-reinforced polymer composites are used in the vehicle's roof, powertrain, body, chassis, battery, and interior to provide a total weight savings of 770 pounds compared to a conventional vehicle of similar size.[22] The weight savings demonstrated in BMW's i3 vehicle are similar to those achieved in metal-intensive lightweight vehicle designs found in major mass reduction studies sponsored by NHTSA and EPA.

BMW recognizes the substantial mass reduction savings offered by CFRP composite vehicle lightweighting technologies. In addition to CFRP composites' high levels of fatigue resistance, corrosion resistance, and energy absorption, BMW has stated that they offer 30% weight savings compared to aluminum, and 50% compared to steel. The use of resin-transfer-molded carbon non-crimp fabrics also permits greater part consolidation, resulting in two-thirds fewer parts and 50% less production floor space compared with a steel vehicle design.[23] Furthermore, BMW indicates that composites have led to the elimination of the traditional paint process used for steel- and aluminum-bodied cars, thereby reducing energy consumption by 50% and water consumption by 70%.[24]

BMW continues to invest heavily in high-performance CFRP composite materials as a core vehicle lightweighting technology.[25] Building upon previous expertise in the production of carbon fiber roof panels for their M3 and M6 vehicle models, BMW has effectively reduced cycle times by 30% and realized cost savings of 50%.[26] Although reductions in cycle time are partially attributed to their high CFRP adhesive hardening rates (which are 10 times faster than the baseline), BMW has also developed a thermal process for key adhesion areas to accelerate the curing by a factor of 32.[27] Due to the high deformation resistance and energy absorption characteristics of CFRP composites, the i3 meets or exceeds all crash performance requirements based on the results of 100 crash safety tests.[28] The success of BMW's i3 demonstrates the potential of polymer-based composite materials as a major vehicle lightweighting technology that can help automakers meet increasingly stringent CAFE standards.

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DEMONSTRATION OF CARBON FIBER-REINFORCED POLYMERS IN FORD'S MULTI MATERIAL LIGHTWEIGHT VEHICLE (MMLV)

Because plastics and polymer composites can enable the consolidation of multiple automotive parts, they are advantageous lightweighting technologies in the design of multi-material vehicle structures. Using this benefit to their advantage with the Multi Material Lightweight Vehicle (MMLV) effort, Ford Motor Company and Magna International jointly demonstrated the lightweighting potential of a five-passenger sedan as part of a three-year project sponsored by the U.S. Department of Energy (DOE).[29] Their MMLV Mach-I design uses commercially available materials and production processes to achieve a 23.5% vehicle mass reduction compared to the baseline model.[30] Ford is continuing to manufacture and test prototypes of the Mach-I to validate the lightweight vehicle's performance, safety, and viability for OEM production.[31]

The Mach-I vehicle uses lightweight plastic and polymer composite materials in the engine components and interior systems. Long carbon fiber thermoset composites simultaneously meet rigorous structural requirements of vehicle applications while helping to reduce the mass of the timing drive front cover by 24% and the oil pan by 41%.[32] The cam carrier—which reduces the overall cylinder head mass by 15%—is designed with a structurally sound and recyclable carbon fiber-reinforced phenolic resin material. In addition to enabling 17% weight savings in the front seat structure and 30% in the instrument panel/cross-car beam (IP/CCB), carbon fiber-reinforced polymers significantly reduce the number of total vehicle parts used in the construction of the IP/CCB—from 71 parts to 21 parts.[33]

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Ford and Magna International are working toward a 50% mass reduction target in the next design phase of the MMLV project while using CFRP composite materials as the chief vehicle lightweighting technology.[34] To do so, the team is basing the methodology for the Mach-II design on the replacement of metallic parts with polymer-reinforced composite parts where possible. Composed of 45% CFRP material, the current BIW of the Mach-II consists of structurally efficient composite panels that are designed with increased recyclability and repairability. Throughout the entire vehicle, composites make up 30% of the vehicle's material distribution.[35] Ford's heavy reliance on composites in the MMLV design supports the growing recognition that these materials will play a crucial role in meeting future fuel economy targets.

Advancing the State of Automotive Plastics & Polymer Composites Technology

Research is under way to unlock opportunities and eliminate barriers that limit automakers' ability and willingness to adopt plastics and polymer composites. Three such efforts are described in this section.

EFFICIENT ASSEMBLY AND JOINING: REVERSIBLE BONDED JOINTS USING NANO-FERROMAGNETIC PARTICLES

Multimaterial vehicle designs could help achieve the mass reduction requirements needed to meet 2025 CAFE standards, which would create opportunities to gradually introduce plastics and polymer composites lightweighting technologies. However, innovation is needed to enable the joining of dissimilar materials at high production volumes and establish a proper end-of-life recycling infrastructure.

The Composite Vehicle Research Center (CVRC) at Michigan State University (MSU) is currently developing a novel technology to address the need for a fast, robust automotive assembly process for joining polymer composites and other dissimilar materials.[36] Using thermally activated thermoplastic-based adhesives reinforced with conductive nano-ferromagnetic particles, advanced composites can be rapidly assembled, dissembled, and re-assembled. Such an innovation represents a significant milestone for permitting the repair of polymer-based composite parts while enabling efficient load transfer and part consolidation.

As preliminary concepts of this reversible joining technology are applied to vehicle closures, MSU will give equal consideration to non-destructive evaluation techniques to increase joining efficiency and experimentally validate both models and databases, thus accelerating the implementation of CFRP materials in lightweight vehicle design. MSU is collaborating with OEMs to assess the technology's practical feasibility for introduction into the automotive supply chain.

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EVALUATING CRASHWORTHINESS OF CFRP AUTOMOTIVE STRUCTURAL COMPONENTS

One consideration in vehicle lightweighting is maintaining vehicle crashworthiness. As composites are more widely adopted to reduce vehicle mass, automakers will need to ensure that advanced composite materials fully comply with safety standards.

Research is under way at highly qualified research institutes—including George Mason University,[37] the University of Delaware Center for Composite Materials,[38] and the National Center for Manufacturing Sciences[39]—to study crashworthiness by developing computer models of CFRP structural vehicle components, simulating impact crash concepts, and validating the accuracy of results through rigorous crash safety tests. Simulation of CFRP components will not only help automakers evaluate safety in vehicle design, but will support topology optimization modeling efforts to accurately predict mass savings quickly and cost effectively.

ENHANCING PREDICTION ACCURACY OF CFRP PROCESS MODELS

An intrinsic aspect of lightweight vehicle design is the use of engineering tools to computationally model and predict the performance of vehicle components. Some of these modeling efforts involve simulating manufacturing processes to identify ways to design optimized parts that satisfy the intended performance requirements of vehicle subsystems. Furthermore, process modeling is a crucial enabling technology for reducing part processing cycle times—especially when simulating the complexity of advanced CFRP composites.

Oak Ridge National Laboratory (ORNL) is generating key model validation data by characterizing injection molded long-fiber-reinforced thermoplastic (LFT) microstructures, and Honda is using the data to explore mass reduction opportunities with lightweight composite materials.[40] Meanwhile, to optimize CFRP part performance, Virginia Tech is developing injection molding process models capable of predicting composite fiber orientation.[41]

Robust and reliable predictive modeling tools are critical for proving the quality and performance of plastics and polymer composite parts. These advances will help automakers adopt CFRP materials in greater amounts to meet and surpass 2025 fuel economy targets.

3 Analysis of Agency-Sponsored Mass Reduction Studies

Five mass reduction studies have recently been published by NHTSA, EPA, and CARB. These studies examine the lightweighting potential for future model year vehicles under defined constraints such as cost and production volumes. The following section assesses these mass reduction studies to determine their validity and the extent to which the studies accurately factored in the potential of plastics and polymer composites.

Mass Reduction for Light-Duty Vehicles for Model Years 2017–2025[42]

Sponsored by the National Highway Traffic Safety Administration (NHTSA), August 2012

Electricore and George Washington University (GWU) performed a two-year study for NHTSA beginning in 2010 to determine the mass reduction potential for vehicle models available in years 2017–2025. The team used an existing vehicle (i.e., a 2011 Honda Accord) as the baseline for a future midsize lightweight vehicle (LWV) design. They also constrained their vehicle mass reduction estimates with a set of boundary conditions requiring that their design maintain (or improve) safety, crashworthiness, size, performance, and retail price parity (within ±10%), and be capable of achieving high-volume automotive production on the order of 200,000 units per year. Although the team's boundary conditions also allowed for powertrain downsizing to account for lighter vehicle weight, alternative powertrain configurations—including hybrid electric, battery electric, and diesel—were not considered in this study.

To achieve the study's goal of providing NHTSA with a basis for setting future CAFE standards for vehicle model years 2017–2025, the team also focused on using materials and manufacturing technologies for the future LWV design that OEMs could feasibly implement within the timeframe of the rulemaking. According to the team, OEMs normally mitigate the risks associated with designing and manufacturing future vehicles by first introducing new materials, technologies, and manufacturing processes in low-volume, high-cost automotive production lines before migrating those technologies to high-volume production lines over time. The team's consideration of these typical OEM risk-mitigation strategies permitted sound, defensible conclusions about mass reduction potential that support NHTSA's mission of setting future CAFE standards.

While the study acclaimed that composites offer several benefits over traditional materials, no composite materials are used in the final LWV body structure due to their low-volume manufacturability. Instead, the proposed LWV design is composed almost entirely of AHSS, resulting in a total weight savings of 22% compared to the baseline. The study asserts that significant progress—including advances in the cost of carbon fiber, manufacturing cycle time, understanding of crashworthiness, repairability of damaged structures, and effective techniques for joining composite or dissimilar parts—is needed to ready composite materials technologies for high-volume automotive production.

In spite of this rationale for not selecting composite materials, several peer reviewers of the mass reduction study stated that the final LWV design may have been too conservative in its consideration of composite materials, including glass- and carbon-fiber-reinforced polymer composites. A particular critique offered by the peer review disputed the team's assertion that composite materials are unsuitable for high-volume production and stated that composite panels have actually been in production for nearly 20 years.[43] Regardless of whether the study gave adequate consideration to the use composite materials, the team did in fact recognize their superior lightweighting potential based solely on mass savings. When compared to 22% mass reduction using AHSS and 35% using aluminum, a composite-intensive body structure is estimated to deliver 50% mass reduction compared to the baseline vehicle—more than doubling the weight savings achieved in the final LWV design.

Evaluating the Structure and Crashworthiness of a 2020 Model-Year, Mass-Reduced Crossover Vehicle Using FEA Modeling[44]

Sponsored by the California Air Resources Board (CARB), August 2012

Lotus Engineering conducted a study for CARB to design a mass-reduced 2020 model year vehicle that would be ready for wide commercialization in 2025. Basing their design on the results of a Phase 1 study conducted in 2009, Lotus Engineering studied the potential for using advanced materials and manufacturing processes to cost effectively meet an aggressive mass savings target of 30% for a 2009 Toyota Venza baseline vehicle. The project relied on crash simulations to demonstrate the vehicle's ability to meet the structural and impact requirements of both the Federal Motor Vehicle Safety Standards (FMVSS) and the IIHS.

The team offers a sound approach for the design of a 2020 production-ready mass-reduced vehicle by factoring in materials manufacturability, processability, and the build sequence of parts used in a characteristic automotive assembly plant. Lotus also involved suppliers of automotive materials, structural reinforcements, joining technologies, coatings, and adhesives to provide input on the design feasibility, and relied on an internationally recognized methodology known as "Intellicosting" for the cost analysis. While the study's peer review team concluded that the design process undertaken by Lotus was generally credible, it was noted that the study did not provide a detailed description of the materials and selection process including trade-offs for replacing vehicle components.[45]

Using composite material in only a small fraction of the vehicle floor, the final Phase 2 vehicle design is an aluminum-intensive multimaterial structure with 31% total mass savings. Lotus' Phase 2 BIW contains significantly less composite material (5% mass) compared to its Phase 1 counterpart (21% mass). Though Lotus asserts that the changes in overall material selection are primarily driven by structural requirements and crash performance, they explicitly cite "manufacturing reasons" as the motivation for moving to a more aluminum-intensive floor structure. Based on the study's claim that composite materials and manufacturing techniques are no longer prohibitively expensive for widespread use in the automobile industry, it is probable that cost was not the primary motive for replacing composite materials in the updated Phase 2 vehicle design. Elsewhere in the study, Lotus states that carbon fiber is an acceptable material choice for production vehicles, except for load-bearing components of heavier-duty vehicles due to durability concerns. Yet, Lotus upholds that composite structures are designed and tested to withstand the extreme forces of high-speed collisions and are proven to be exceptionally safe in motorsports.

Light-Duty Vehicle Mass Reduction and Cost Analysis – Midsize Crossover Utility Vehicle[46]

Sponsored by the Environmental Protection Agency (EPA), August 2012

The EPA and The International Council on Clean Transportation (ICCT) contracted FEV, an engineering services firm, to study the potential for mass reduction in a future mid-size crossover utility vehicle (CUV) ready for production in 2017–2020. Similar to the two-year NHTSA-sponsored mass reduction study (2010–2012), FEV's boundary conditions specified that the redesign of a 2010 Toyota Venza baseline vehicle could not increase direct manufacturing cost by more than 10% nor compromise safety, functionality, or performance. Instead of studying the maximum feasible weight reduction possible for the future vehicle design, the team pursued a target goal of 20% mass savings. This goal was based on a competitive benchmarking that considered state-of-the-art mass reduction technologies, materials innovations, and component integration and assembly using existing facilities.

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FEV established credibility in their mass reduction methodology by presenting a selection of materials and technologies that are currently in production or have undergone significant research and development by OEMs, part suppliers, or raw material suppliers. Accompanied by well referenced examples, these material replacement options are presented alongside a highly extensive breakdown of vehicle components by weight, mass reduction potential for the material considered, and the risks and trade-offs associated with the application of these technologies. The team's approach to crash test modeling and estimation, appropriate use of sources and databases, and proper evaluation of manufacturing implementation readiness and risk are endorsed by peer reviewers as valid approaches that give integrity to the team's mass reduction estimates.[47]

The team used a significant amount of plastic and polymer-based composite materials in their vehicle redesign. Although consideration for BIW components was not given to plastics or polymer-based composites, the frequent use throughout the interior body, engine, and braking systems contributed a portion of the 18% total mass savings achieved in the final vehicle design. The study provides a detailed breakdown of virtually all vehicle components by the mass reduction and cost impact of each lightweighting technology, but it does not offer a high-level summary of the mass savings as a function of each material.

Nevertheless, the team's assessment of plastic and composite components throughout the vehicle strongly suggests that they will play an essential role in helping automakers meet future CAFE standards.

In cases where polymer-based composites were not considered in the vehicle's design, cost was cited as the principal impediment to manufacturing implementation. Conversely, the team presented a number of mass reduction ideas in which plastics and polymer composites provided a combination of weight savings, cost savings, and performance benefits when replacing traditionally metallic parts. Examples of some notable mass reduction concepts presented in the study include the following:

- Although durability and cost negatively impact implementation feasibility, carbon fiber composite engine cylinder blocks offer an estimated 75% mass reduction in place of aluminum. Magnesium only provides a 25% mass reduction.
- Most automakers currently produce brake caliper pistons made from phenolic glass-filled plastics, which provide 60%–70% mass savings compared with machined steel. According to the team, these savings exceeded the potential offered by most metals, including titanium, aluminum, and magnesium.
- Depending on the component of the cooling subsystem, replacing aluminum parts with plastics provides an estimated 50% mass savings, and up to 80% mass savings over existing steel parts.

In support of these claims, the peer review team confirmed that the use of plastic lightweighting materials throughout this mass reduction study were in line with their expectations of available technology in the 2017–2020 timeframe.

FEV also provided specific conclusions about the use of plastics and polymer composites as alternative lightweighting materials. Molded LFTs were not considered in this study but were suggested as viable alternative materials for parts of the Toyota Venza since they have already been demonstrated in the automotive industry in body panels, sound shields, front-end assemblies, structural body parts, truck panels and housings, doors, tailgates, and fender sections. The team also recognized carbon fiber-reinforced polymers as a promising alternative materials choice, and mentioned that research should be pursued to reduce the cost of carbon fiber, thereby enabling automakers to realize the material's significant lightweighting benefits.

Mass Reduction and Cost Analysis – Light-Duty Pickup Truck Model Years 2020–2025[48]

Sponsored by the Environmental Protection Agency (EPA), June 2015

Following the results of EPA'S 2012 mass reduction study for 2017–2020 production-ready crossover vehicles, FEV was awarded a new contract to study cost-effective mass reduction opportunities for light-duty trucks in the 2020–2025 time frame. Using similar boundary conditions as those employed in their previous mass reduction study, FEV redesigned a 2011 Chevrolet Silverado that achieves less than a 10% increase in direct manufacturing costs without architectural changes to the powertrain or compromises to safety, function, or performance.

With a target of 20% mass savings, FEV employed the same credible methodology used to conduct the 2012 crossover utility vehicle study: selecting mass reduction ideas that are already in production or have gone through significant research and development by OEMs, part suppliers, and material suppliers. Although this approach lowers the risk of technology implementation for vehicle manufacturers, it also significantly limits the use of advanced materials such as carbon fiber-reinforced polymers. In fact, FEV explicitly states that their strategy was to minimize the use of composite materials in the lightweight vehicle design. Even though the total mass savings attributed to composite materials is unclear, just as with the previous Toyota Venza study, FEV's conservative approach supports the notion that automakers can feasibly achieve 20% mass reduction to help reach fuel economy targets.

FEV's conclusions about the use of composite materials as vehicle lightweighting technologies remain largely unchanged since their earlier mass reduction study. Of the considerations given to thermoplastic composites as viable materials for lightweighting, FEV notes that the materials have good stability and performance capabilities, are environmentally advantageous compared to steels, and carry the potential for both high-volume manufacturability and replacement of automotive structural parts.

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Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles[49]

The Committee on Assessment of Technologies for Improving the Fuel Economy of Light-Duty Vehicles (Phase 2), June 2015

Established upon the request of NHTSA, the Committee on Assessment of Technologies for Improving the Fuel Economy of Light-Duty Vehicles (Phase 2) was tasked with providing a congressionally mandated study under the National Academy of Sciences (NAS) to inform the mid-term evaluation process for solidifying fuel economy targets. This study aggregates and reviews other mass reduction studies and provides an expert assessment through generalized expectations of OEM vehicle lightweighting practices. In addition to delivering an independent review of mass reduction technologies, the Committee offers a general review of the CAFE program and the feasibility of manufacturer compliance.

Using the same credible approach as other agency-sponsored mass reduction studies, the Committee bases its methodology on cost estimation of various material technologies used for vehicle lightweighting opportunities. In general, the Committee recognizes that greater levels of mass reduction typically coincide with higher cost, greater risk, and more manufacturing trade-offs for automakers. Yet, even if the manufacturing costs do exceed projections, the Committee suggests that lifetime fuel cost savings for consumers will still outweigh incremental cost estimations. Lifetime fuel cost savings are not only stated as the largest benefit of increasing CAFE standards, but such savings may be significantly underestimated as gas prices are expected to increase in the long term. Because consumers may not fully understand or value lifetime fuel savings, the Committee recommends that NHTSA conduct additional research to comprehend the impact of fuel costs on the private costs and benefits of new CAFE standards. Ultimately, the NAS study indicates that 2025 CAFE standards will not lead to undue burden on automakers in terms of cost and vehicle safety.

While the Committee acknowledges a steady increase in the use of plastics and polymer composites for vehicle lightweighting over the past 20 years, it estimates that more widespread integration will be limited to nonstructural vehicle composites in model years 2015–2020 and to case-by-case multimaterial configurations in model years 2020–2025. Recognizing that carbon fiber composites are largely constrained by cost, long production times, joinability, repairability, and a less-developed supply chain, the Committee also acknowledges the commercial success of the BMW i3 which already uses advanced composites heavily in structural vehicle components. In spite of the notable progress that has been made in the automotive industry, the NAS study asserts that it will take at least 15 years of development and supply chain advancement before automakers broadly adopt advanced composite technologies for vehicle lightweighting.

4 Call to Action

With two years remaining until the mid-term evaluation for setting 2025 CAFE standards, numerous regulatory impact analyses suggest that NHTSA's rulemaking process will not impose excessive economic and technological challenges upon automakers as they engage in mass reduction opportunities. These studies have considered the needs and capabilities of automakers to safely and feasibly achieve future fuel economy targets. Due to the thoroughness of these studies, there is greater confidence that 2025 CAFE targets are not only feasibly achievable, but superior value can be delivered through aggressive development and implementation of plastics and polymer composites.

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In response to shifting CAFE standards that drive mass reduction opportunities, ACC developed their 2014 technology roadmap, Plastics and Polymer Composites Technology Roadmap for Automotive Markets, which offers an effective industry-wide strategy for encouraging the integration of plastics and polymer composites to reduce vehicle weight while maintaining safety, performance, and functionality.[50] This roadmap provides the insight and guidance necessary to accelerate innovation of automotive plastics and polymer composites with the intention of stimulating collaborative innovation among the plastics and polymer composites industry, automotive industry, government agencies, and academic researchers.

Several efforts are actively under way to pursue the most critical initiatives identified in ACC's technology roadmap. However, further technology development is needed to realize the full potential offered by plastics and, especially, polymer composites. Other organizations such as The Institute for Advanced Composites Manufacturing Innovation (IACMI)—which holds shared interests with ACC to advance the state of composite manufacturing technologies—also understand that composites represent a significant opportunity for energy savings on a lifecycle basis.[51] IACMI, a $259 million public-private partnership, will initiate collaborative R&D opportunities within the automotive industry aimed at reducing many of the technical gaps that limit the widespread implementation of advanced composites, including processability, repairability, and joinability.[52] This Institute complements several other industry-wide R&D and demonstration efforts funded by industry and government.

These investments provide an excellent foundation, but far more investment and effort is needed to transform the multi-billion-dollar automotive supply chain. Overcoming the challenges identified within and outside of ACC's technology roadmap will require more resources and focused R&D efforts to ensure plastic and polymer composite technologies can sustain the pace of innovation required by automakers in pursuit of the vehicle mass reduction opportunities needed to meet proposed 2025 CAFE regulations.

For more information, please visit: www.plastics-car.com

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