

# The engineering challenge of developing lighter, fuel-efficient automobiles

## White Paper

To meet stricter regulations aimed at significantly reducing emissions and improving fuel efficiency, automotive companies must drastically rethink the way vehicles are engineered and manufactured. Lightweighting has been identified by the industry as a critical way to comply with these government regulations. Reducing vehicle weight introduces challenges that affect all parts of the vehicle and engineering processes, as well as with the software applications used from conceptual design through final manufacturing. These challenges will require automakers to not only redesign vehicles and consider the use of alternative materials, but also to rethink their engineering processes, manufacturing methods and software technology.

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# Executive summary

According to a study published by the analyst firm Aberdeen Group in January, 2014<sup>1</sup>, the top strategy automakers are adopting to meet enhanced fuel efficiency and emissions standards is to make the drive train more efficient so that it burns less fuel. However, in-depth analysis and studies have shown that this alone will not be enough. Automotive original equipment manufacturers (OEMs) also recognize the need to reduce vehicle weight so that less fuel will be needed to propel it.

Weight reduction of the Body in White (BIW) has a spiraling impact on overall vehicle weight reduction; a lighter body results in a lighter chassis, requiring a smaller engine and less battery and/or fuel tank capacity. Lightweighting drives fundamental changes in how cars are designed and built.

The impact of fuel economy regulations on car design is already evident in vehicles such as the 2015 Ford F150 truck, in which the use of riveted and glued aluminum has replaced a large percentage of the traditionally welded steel structure. These changes are removing barriers to entry for even more weight-efficient materials, such as composites, which cannot be easily introduced into a welding assembly line.

Lightweighting strategies will drive a shift to alternative materials and assembly methods from those used in current steel welded BIW structures. Unlike today's common welded steel manufacturing method, new processes will lead to lighter, more fuel-efficient vehicles potentially composed of

a mix of materials assembled in a "no sparks" process. This is a fundamental change in vehicle design: automotive engineers will be forced to rely more on engineering tools than on experience as they adopt these new materials and assembly processes.

The impact will be felt in all engineering disciplines from design to the factory floor and beyond. These changes will create new demand for a variety of engineering software applications, which will be used from the earliest stages of analysis and design to detailed design, as well as tools for manufacturing simulation and product lifecycle management (PLM).

A mixed material strategy will have an ever-increasing impact on engineering tools, with software increasingly required to assist engineers when conducting part and assembly complexity studies earlier in the process. The software will help them determine appropriate joining methods, and enable the analysis of performance, cost and producibility. Ultimately, a new generation of engineering software applications will be required to help select the appropriate mix of materials, joining and assembly methods. In the end, these applications must help engineers reduce time-to-market by efficiently providing them the data they need to develop optimal designs with the appropriate balance of weight savings and cost-to-manufacture, while meeting performance criteria.

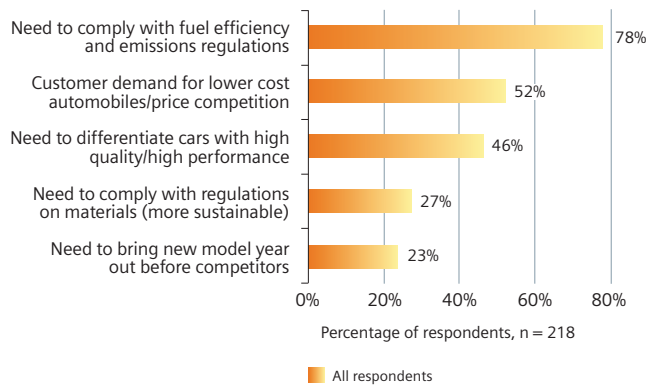
# Strategies to meet fuel efficiency regulations

New fuel efficiency regulations in the United States require the average vehicle fuel economy to increase from the 2013 level of 29 miles per gallon (mpg) to an average of 54.5 mpg by 2025. European cars must meet even more stringent emissions standards by 2020. These regulations are fueling an unprecedented and fundamental change to the very composition of the automobile, leaving little time for automakers to prepare. Automotive companies report that meeting fuel efficiency and emissions standards are the top challenges that they face<sup>1</sup>.

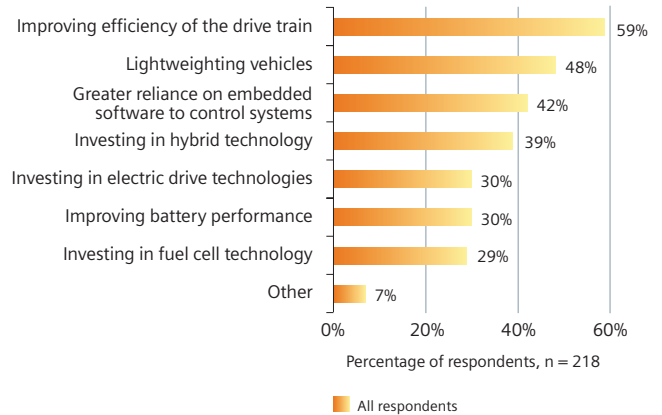
With time a critical factor, automotive companies must vigorously explore new strategies. There is greater pressure than ever to provide innovative solutions while maintaining profitability and meeting delivery expectations. In fact, the new requirements are so significant that a single strategy will not suffice.

Automakers must have multiple strategies to meet these regulations, as each will contribute to lower fuel consumption and cleaner emissions. The top strategy is to improve the efficiency of the drive train so that less fuel is burned<sup>1</sup>. However, that alone will not be sufficient. The next most popular strategy is to reduce the weight of the vehicle so less fuel will be needed to propel it<sup>1</sup>.

## Top pressures driving the development of new automobiles



## Strategies to achieve fuel efficiency and emission standards



# Reducing vehicle weight

Lightweighting strategies will drive a shift to alternative materials and assembly methods radically different than those used in current steel-welded Body in White (BIW) structures. This seismic shift is unlike anything that the industry has seen in more than 50 years and is causing a fundamental change in vehicle designs. Automotive engineers will be forced to rely more on engineering tools than experience as these new materials and assembly processes are adopted.

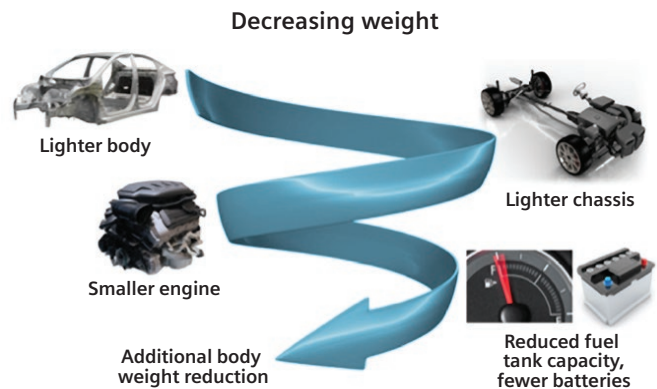
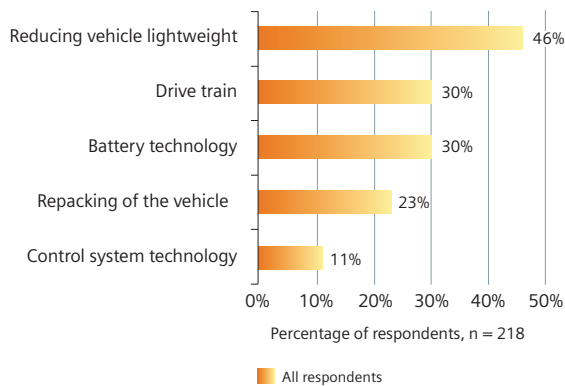
Despite being seen as a top strategy for meeting the fuel efficiency regulations, lightweighting vehicles is also clearly viewed as being one of the most difficult strategies. In fact, the top strategy for achieving fuel efficiency and emission standards is reducing vehicle weight<sup>1</sup>.

## The spiral impact of decreasing weight

Reducing vehicle weight will be a challenge with respect to many parts of the vehicle, especially highly structural parts such as the BIW, which constitutes a significant portion of the overall weight. Weight reduction strategies cannot independently target individual components because optimal weight reduction can only be achieved with a systems approach to lightweighting. In addition, meeting weight reduction targets will require designing for lighter weight from the start.

Weight reduction of the BIW has a spiraling impact on overall vehicle weight reduction. When companies design for lightweighting, they can take advantage of the weight reduction spiral in which a lighter body results in a lighter chassis, which requires a smaller engine, which requires less battery power or reduced fuel tank capacity, which requires less braking, resulting in additional body weight reductions. Consider the redesign of Ford's F150 truck with an all-aluminum riveted chassis. Ford was able to find a 450-pound reduction in the BIW, which helped result in a 750-pound reduction in overall vehicle weight with a corresponding 25 percent increase in fuel economy.

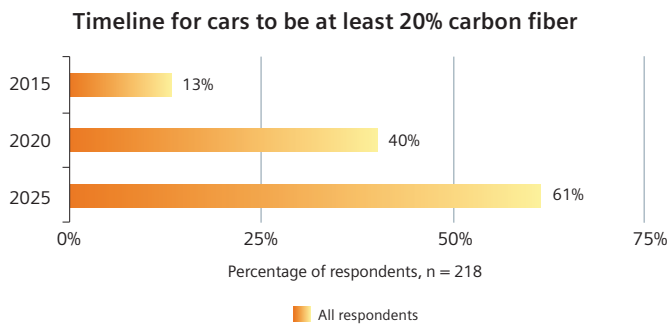
**Top challenges of achieving fuel efficiency and emission standards**



# Making the case for composites

When considering alternative materials for lightweighting, carbon fiber composites is a very appealing material because it has low corrosion properties, is naturally light in weight and requires less material to achieve stiffness requirements and meet impact resistance needs, to name just a few of the benefits. But at the same time, there is uncertainty about designing and manufacturing new components with composites. Risks include the relative expense of carbon fiber, lack of composites design and manufacturing knowledge and long manufacturing cycle times for composites parts.

The use of composite materials is expected to grow over the next decade and, by 2025, automakers expect that 60 percent of their vehicles will be comprised of at least 20 percent carbon fiber<sup>1</sup>.

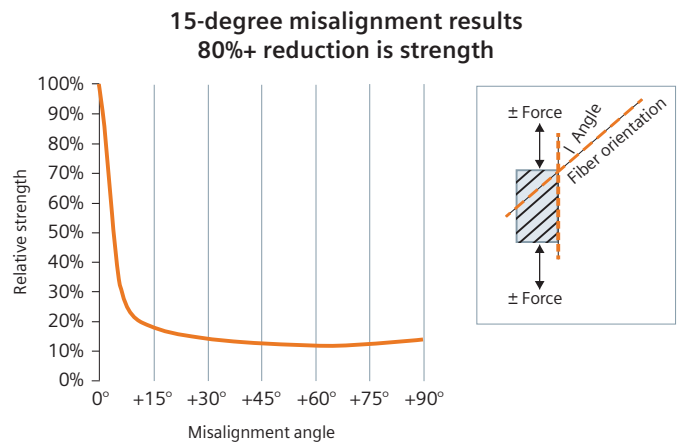


## The challenge of using composites

If properly designed, carbon fiber composites can offer significant improvement in performance-to-weight ratios compared to both aluminum and steel. For many years, the composite performance advantage has made it the preferred material in many aerospace applications, as recently demonstrated by the Boeing 787. Now automakers are either considering, or have started to develop the use of composites to help them meet their goals to reduce vehicle weight. However, the application of composites in high-volume automotive applications is significantly different from the way that composites are used in the aerospace industry.

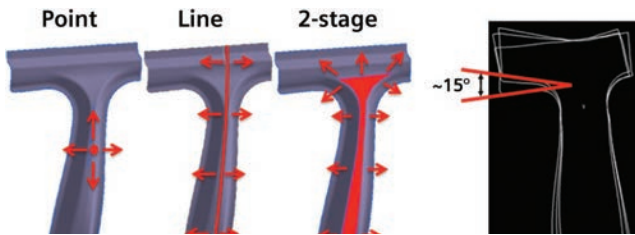
Tight packaging requirements in automotive applications drive up part shape complexity relative to those encountered in the majority of aerospace applications. The shorter automotive product time-to-market means faster design cycle

times, increasing the frequency of design changes. In addition, a greater variety of material forms and manufacturing processes, including forming, pultrusion and braiding, are also being considered to reduce cost. It is this combination of complex shape, material and process choice coupled with frequent design changes that make the engineering of composites especially challenging in high-volume automotive applications.



Composite structural properties are sensitive to fiber orientation. Complex geometric shapes typical in BIW automotive applications can cause fiber orientations to stray from initially specified values as composite materials are conformed to such complex shapes.

Even changes in processing parameters can have a significant impact on fiber orientation and, consequently, part performance. For instance, how a forming tool initially contacts a preform can alter fiber orientation and its performance properties. In the three examples below, shape, material and laminate design are identical; only the forming process parameters vary. Changing the initial contact of the tool on the composite material from a point to a line to a two-stage region impacts the 2D pattern and causes a 15-degree change in fiber orientation along the edge of the part. This process parameter change consequently has an impact on part properties and performance in this region of the part.



To meet such design challenges for automotive composite applications, a tighter coupling is required between analysis, design and manufacturing engineering. A bi-directional interface between the software tools used by analysts and design engineers is needed to facilitate the exchange of information, such as laminate configuration and fiber orientation. This will allow for the efficient assessment of the impact on part performance of changes to part shape material configuration and manufacturing methods.

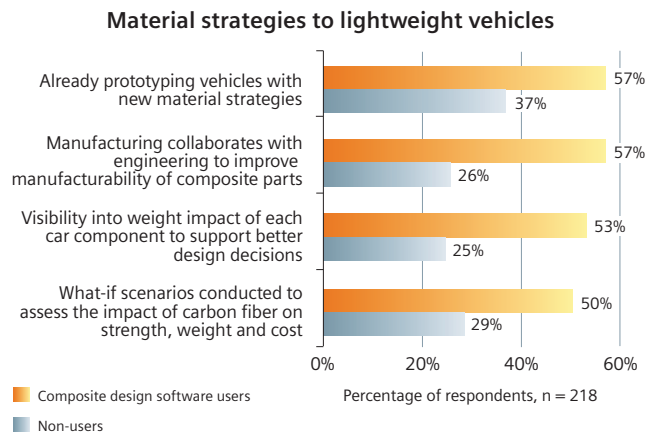
#### Assessing the impact of composite design software

To provide assistance when designing composite parts, many companies turn to composite design software to assist them. Companies using composite design software have been rewarded with 139 percent greater weight reduction in parts than those that did not use any software simulation solution<sup>1</sup>.

In addition to this benefit, using composite design software also helps automakers improve the overall design process. Software can provide technical guidance for making better design decisions, improving efficiency, enabling those companies that use the software to be 54 percent more likely to prototype vehicles with new materials<sup>1</sup>. The software also makes it easier to share information between engineering and manufacturing, improving collaboration between disciplines and ensuring that composite parts can be manufactured successfully.

Another advantage of using composite design software is the ability to automatically calculate and make accessible key information gathered in the design-to-manufacture process. Companies using composite design software have access to dashboards telling them the weight impact of each component in the vehicle, making them 112 percent more likely than non-users to have access to this information<sup>1</sup>. This is important because components that exceed weight targets can be easily identified so that other design alternatives can be explored to look for lower weight options. Engineers are enabled to more easily conduct trade-off analysis studies on key criteria, such as weight, cost and strength. By using the software to help make the calculations, these analyses can be done more efficiently and all factors can be optimized to manage profitability, while still meeting design requirements and regulations.

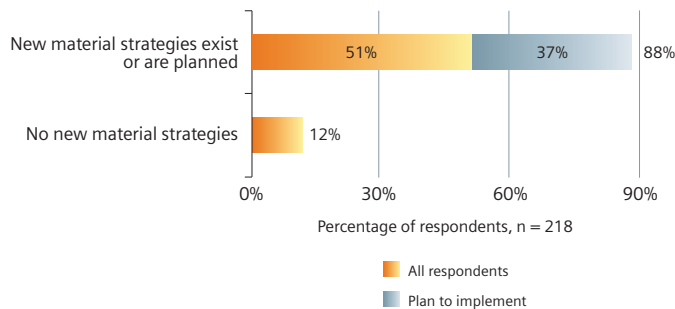
All of these factors make it easier to make better decisions about the use of composites, removing some of the challenge of bringing lightweight composite vehicles to market. With this greater efficiency, over the next two years, those who use composite design software expect to have 31 percent more programs using new materials than those who are not using software solutions today<sup>1</sup>. With more programs ready with new materials, companies taking advantage of composite design software will already be steps ahead of their competition, winning the race to create more fuel-efficient, greener cars.



# Considering alternative materials

One of the most obvious ways to remove weight from a vehicle is to consider alternative materials that are lighter, yet strong enough to withstand the impact of a crash. Consequently, it is not surprising that 88 percent of auto-makers either have strategies or plan to develop strategies for using new materials<sup>1</sup>.

Timeline for cars to be at least 20% carbon fiber



## Understanding the complexities of using mixed materials

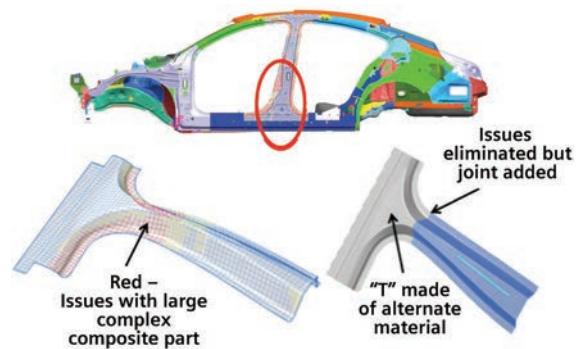
When considering alternative materials for lightweighting and related material strategies, most companies are considering using a mix of materials. Whether it is an individual hybrid part combining plastic, metal and composites, or a mixed material assembly, a trend for the future is a BIW consisting of some combination of high-strength steel, aluminum, magnesium, plastics and composites.

Such a mixed material strategy will also have an impact on engineering tools because software will be required to conduct part assembly complexity tradeoffs, helping determine appropriate joining methods, as well as assessing the balance needed between performance, cost and manufacturability.



As an example, consider a part/assembly design tradeoff in which a single all-composite part is used versus a mixed material assembly. Making the part entirely out of composites may not be feasible due to the complex shape geometry because composite material cannot conform to the shape without wrinkling. Alternatively, the simpler areas of the

part could be made from composites, while the more complex portions may be made from metal. However, this comes at the expense of the added complexity of a new joint being added to the assembly process.



## Appreciating the value of engineering software tools

Leveraging software to provide insight and guidance on design and manufacturing tradeoffs can save significant time and cost. The impact of joining method choices is critical with a mixed material strategy, and understanding the tradeoffs of joining methods is not insignificant. Consider that when using a single material you may have two or three joining options. If you have five or more material choices available, the potential joining method choices increase to 25 or more! The appropriate joining methods for a particular application will depend on the materials being joined, the relative cost, performance and structural requirements.

In the end, a new generation of engineering software applications that are tightly integrated with existing engineering applications will be required to help select the appropriate mix of materials, joining and assembly methods. The optimal choice will depend on how much a company is willing to pay for performance at a lighter weight. If high performance at a lightweight and high cost is tolerable, then the right choice may be unidirectional hand-laid prepreg composites, such as those used in F1 racing applications. If cost is the main design driver, and reducing weight is less of a consideration, then a traditional steel-welded structure may suffice. However, the appropriate material mix for applications between these two extremes will be more difficult to determine, but no doubt the next generation of engineering software tools will be invaluable in helping users figure that out.



# Understanding the impact of vehicle lightweighting

Vehicle lightweighting drives fundamental changes to how cars are designed and built. As alternative materials are adopted for lightweighting, the impact will be felt not only in design, but across all disciplines, from earliest definition to the factory floor and beyond.

Vehicle repackaging with alternative materials will take place, such as in the BMW i3, in which the use of composites enabled a production design without a B pillar. New materials will have an impact on part manufacturing because new methods of part fabrication will be considered. A significant effect on assembly and joining will also occur because welding will be replaced by “no sparks” joining methods, such as gluing, riveting and specialty fastening systems. Software technologies will have to evolve to help you analyze and simulate structural, crash, noise, vibration and harshness

(NVH) and durability behaviors of structures that utilize alternative materials and joining methods.

The greatest change may be in the factory. Consider the possibility of a 50 percent reduction in floor space requirements resulting from more compact fabrication methods made possible by using materials such as composites. Composites may also eliminate the need for painting of some parts, resulting in a reduction of space required for the paint room, which can be a significant portion of a factory.

These changes will affect a variety of engineering software applications used from the earliest stages of analysis and design to detailed design, as well as to the tools used for manufacturing, simulation and PLM.

# Conclusion

The automotive industry is facing a period of unprecedented change. New fuel economy and emissions standards are driving significant change across the industry. Producing lighter-weight vehicles is one of the top strategies to meet these regulations, but it is also the one that is most challenging.

New material strategies, including the use of carbon fiber composites, will be critical for taking weight out of vehicles. The promise of lightweighting vehicles will only be fully realized if automakers adopt innovative manufacturing and engineering tools and processes that enable them to take full advantage of mixed materials, including composites.

Engineering processes and the supporting software applications must evolve to enable engineers to efficiently make the optimal design choices required to deliver cost-effective, lighter, more fuel-efficient products to market in a timely manner.

In the end, the optimal choice will depend on how much a company is willing to pay for efficiency and performance at a lighter weight. These considerations will help automotive companies achieve the success they need to meet upcoming regulations, creating a competitive advantage.

## References

1. "How Prepared Is the Automotive Industry? Solutions for Meeting Fuel Efficiency and Emissions Standards" Aberdeen Group, Inc., January, 2014.

### **About Aberdeen Group**

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## Siemens Industry Software

### Headquarters

Granite Park One  
5800 Granite Parkway  
Suite 600  
Plano, TX 75024  
USA  
+1 972 987 3000

### Americas

Granite Park One  
5800 Granite Parkway  
Suite 600  
Plano, TX 75024  
USA  
+1 314 264 8499

### Europe

Stephenson House  
Sir William Siemens Square  
Frimley, Camberley  
Surrey, GU16 8QD  
+44 (0) 1276 413200

### Asia-Pacific

Suites 4301-4302, 43/F  
AIA Kowloon Tower, Landmark East  
100 How Ming Street  
Kwun Tong, Kowloon  
Hong Kong  
+852 2230 3308

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