Automotive Steel Performance Advantages (ASPA)

Introduction

As environmental and climate change concerns escalate, pressure is being applied in every industry to reduce the GHG emissions produced by our modern lifestyles. Consequently, the automotive industry is receiving increasing pressure to reduce its environmental impact while maintaining safety and affordability.

In the process, **an erroneous perception has emerged that automotive light weighting and reduced GHG emissions are primarily associated with the application of low-density materials,** like aluminium, magnesium and plastics.

Based on published research such as the studies shown in the Reference Section of this document, steel, and in particular AHSS, is indeed the light weight material that best addresses society's need for **reduced GHG emissions without compromising safety and affordability**.

AHSS, currently the fastest growing material in automotive applications, is relatively new to vehicle design and is significantly different from the conventional steel it replaces. Its light weight capability results from its unique combination of strength and ductility. These attributes stem from complex composite structures of several different steel phases, each with unique material properties.

AHSS provides for light weight automotive solutions that are low cost and environmentally friendly, providing peace of mind and unmatched safety for automotive manufacturers and consumers. As automakers address the climate change impact of their products, steel remains the right choice for vehicle applications. The following are highlights of research that summarize automotive steel performance advantages.

Mass Reduction

Mass Reduction at a Glance:

Studies show the mass reduction potential of optimized designs with AHSS and aluminium. Compared to mild steel designs, ***AHSS provides a 21-25% mass reduction****. Aluminium provides only a further 11% on the average.*

A *Mass Reduction Potential Study* (see http://www.worldautosteel.org), conducted by fka, investigated the mass reduction claims made by the steel and aluminium industries compared with results of many design projects and specific vehicle programmes.

The steel industry documents that vehicle mass can be reduced by 25% through the application of modern high-strength and Advanced High Strength Steels (AHSS). Aluminium advocates sometimes claim up to 50% mass savings by replacing steel with aluminium.

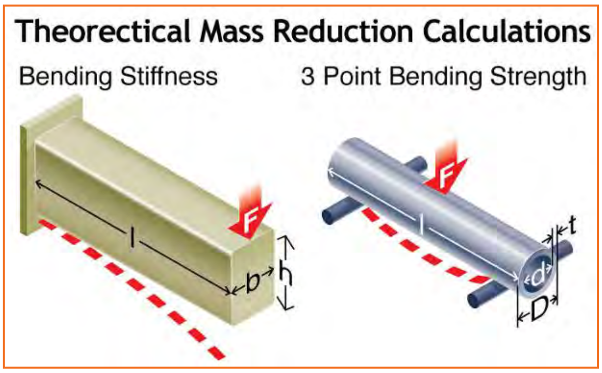

Figure 1: Theoretical mass reduction calculation

The study documents some specific simplified scenarios where aluminium provides a 50% reduction over mild steel, confirming the 40% increase in package space requirements. The study also demonstrates that in alternative simple load cases using high-strength steels (Figure 1), the reverse actually can be true - mass can be reduced by 25% by replacing aluminium with high-strength steel applications, while favourably reducing package space requirements by 60%.

Unfortunately, fundamental load cases using mild-strength steels and unconstrained package space has very little to do with actual automotive structural designs.

Automotive applications do not lend themselves to such simple load scenarios. They are structures with multiple and complex loading conditions that are vital to vehicle handling and performance, strength, durability and safety. These design criteria create extreme demands on the material that are not easily satisfied. In addition, package space is rigidly constrained by the need to maximize the space for powertrain and passengers. These combined conditions result in significant barriers when trying to reduce mass with lower density materials like aluminium.

Data cited in the study indicates that **actual aluminium body structures demonstrate mass savings between 16 and 40% relative to the conventional steel designs** they replaced.

However, the replaced conventional steel body structures were outdated, non-optimized designs constructed using traditional manufacturing techniques and conventional automotive steels.

In comparison, optimized **AHSS designs have demonstrated 21 to 25% mass savings relative to the conventional steel designs** they replace.

This achievement is reflected in the ULSAB family of research, as well as in automakers' own body structure designs in recent years. These projects and vehicles feature designs that make extensive use of AHSS and holistic design optimization and improve performance and crash safety along the way. Automakers have embraced these steel-intensive solutions and have established clear material strategies for their future that reflect the benefits of using these advanced steels.

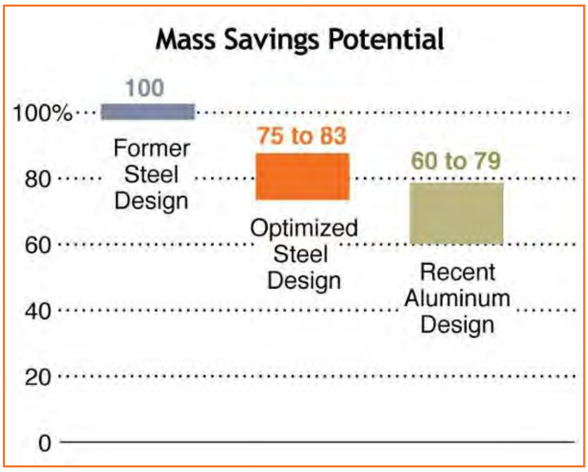

Figure 2: Mass savings potential

Overall, when looking at the evidence and the current state of the art in technology, the fka study concludes that aluminium designs provide 5 to 20% mass savings compared to an advanced steel design (Figure 2). In fact, the **average mass reduction advantage of aluminium is only 11%**, far less than the 40-50% reduction often communicated.

Weight reduction / fuel consumption

Study at a Glance:

*The study scientifically documents fuel consumption reduction achieved by weight reduction. It describes that **there is no simple ratio between fuel consumption and weight reduction** and that **powertrain resizing is a critical factor**. Advanced powertrains, such as hybrids and fuel cell vehicles, do not see the same large variation in weight/fuel consumption elasticity as internal combustion engines.*

Another fka study, *Determination of Weight Elasticity of Fuel Economy for Conventional ICE Vehicles, Hybrid Vehicles and Fuel Cell Vehicles (see www.worldautosteel.org)*, researched mass savings versus fuel consumption and considered the influence for different vehicle classes, driving cycles and powertrains.

A statistic often seen in the media is that a 10% reduction in mass can result in a 6 to 8% reduction in fuel consumption. The study concludes that **weight elasticity values can vary from 1.9 to 8.2%** (Figures 3a and 3b) depending on driving cycle, vehicle size, powertrain selection and whether or not the powertrain is adjusted for equivalent acceleration for the reduced weight vehicle.

Weight elasticity values of 6 to 8% are possible with powertrain resizing for equivalent acceleration using conventional gasoline powertrains. **The effect of powertrain resizing has more influence on fuel savings than does mass reduction**, especially for urban driving cycles. Therefore, these impressive fuel economy gains of 6 to 8% usually are not realized in real vehicle designs for several reasons:

- Vehicle manufacturers do not have enough engine and powertrain system options to apply to every incremental step in vehicle weight.
- Market forces have caused significant increases in acceleration performance rather than the resizing of powertrains to equivalent performance.
- Data collected by the U.S. National Highway and Traffic Safety Administration in its “2004 Automotive Fuel Economy Update” and by the European Automobile Manufacturers Association indicate significant gains in engine technology over the past two decades, but this technology is applied to vehicle acceleration performance rather than to fuel economy.

When engine and powertrain system resizing is not achieved, this study concludes that weight/fuel consumption elasticity values of only 2 - 4% are applicable.

The fka study also considers advanced powertrains, such as hybrids and fuel cell vehicles. The study concludes that these advanced future drivetrains, which take advantage of regenerative braking, do not see the same large variation in weight/fuel consumption elasticity with powertrain resizing as conventional internal combustion engines do. Historically, the often-stated weight elasticity figure of 8% has not been achieved. Such a high reduction in fuel consumption will be almost totally out of reach as hybrid and fuel cell power trains become more widely used.

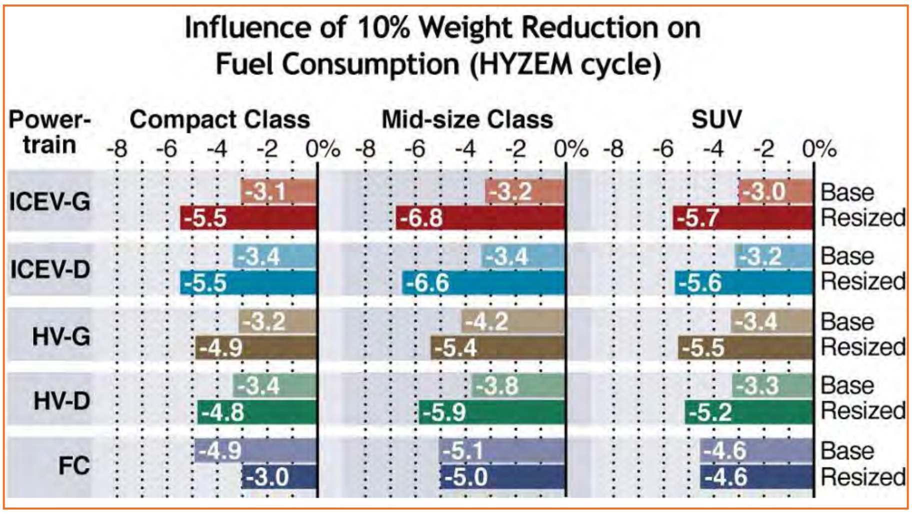

Figure 3a: Influence of 10% Weight Reduction on Fuel Consumption (HYZEM)

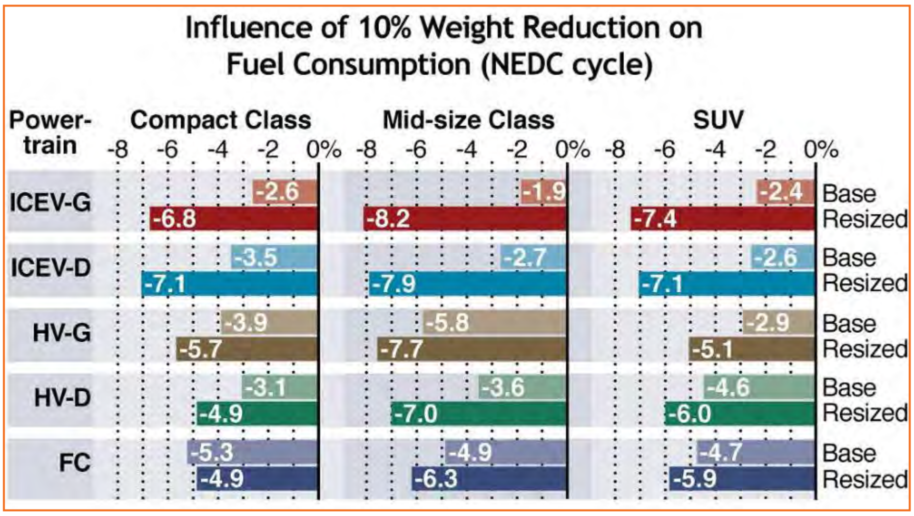

Figure 3b: Influence of 10% Weight Reduction on Fuel Consumption (NEDC)

Climate Change and GHG Emissions

Climate Change at a Glance

*The study shows that **Life Cycle Assessment of a vehicle environmental footprint is critical for material selection decisions**. GHG emissions from material production and end-of-life recycling credits may more than offset use phase tailpipe emissions reductions.*

In addition, as more efficient powertrain systems are implemented the emissions from material production will become relatively more important, placing greater emphasis on selecting a low GHG-intensive material such as steel.

Globally, existing or proposed regulations regarding vehicle GHG emissions address only the use phase (driving) of a vehicle's total life cycle. From this perspective it is easily understood that, assuming all other things are equal, a lighter weight vehicle results in reduced fuel consumption and consequently reduced use phase GHG emissions.

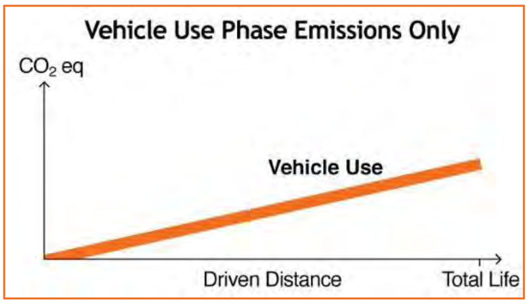

Figure 4: Vehicle Use Phase Emissions Only

Material choices that result in the lowest mass vehicle may be preferred if one considers only a vehicle's use phase (Figure 4).

However, to fully assess a vehicle's environmental footprint, all vehicle life phases must be considered. This includes the GHG emissions resulting from materials production, the manufacturing of the vehicle, the use phase and the end-of-life phase.

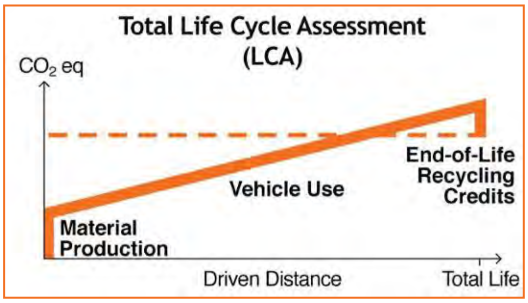

Figure 5: Total Life Cycle Assessment (LCA)

This approach, which considers all aspects of vehicle life (Figure 5), is called Life Cycle Assessment (LCA) and it is recommended for evaluating a product's impact on climate change.

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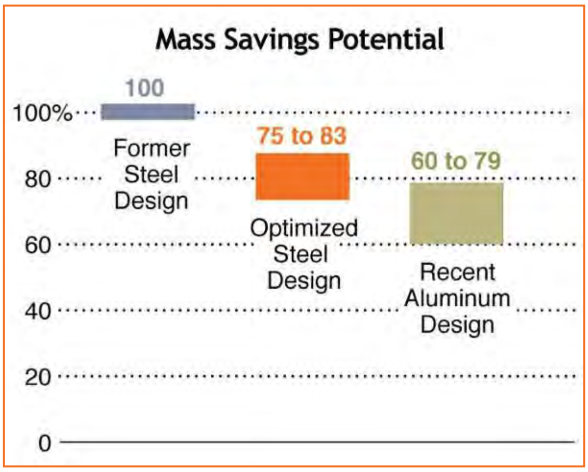

Figure 2: Mass savings potential

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GHG emissions from steel production consist of only carbon dioxide, whereas GHG emissions from aluminium production consist of carbon dioxide and up to 20% perfluorocarbons (CF_4 and C_2F_6), and magnesium production generates up to 20% Sulphur Hexafluoride (SF_6).

Consequently, alternative material applications front-load the environment with more GHG emissions resulting from material production than the steel application they replace. In the case where the alternative material results in reduced mass and reduced fuel consumption, the GHG emission improvement achieved during the driving phase is unlikely to offset the upfront loading of the material production phase when compared to optimized designs with AHSS.

Typical vehicles built with alternative materials will often net more GHG emissions during their lives than AHSS-intensive vehicles.

An LCA approach is the correct approach for assessing a vehicle's climate change footprint and requires vehicle manufactures to balance the possible driving phase improvements against the manufacturing phase disadvantages when considering GHG - intensive materials, such as aluminium, magnesium and plastics.

To investigate the aspects of material selection on automotive LCA GHG emissions, a study entitled *The Impact of Material Choice in Vehicle Design on Life Cycle Greenhouse Gas emissions - The Case of HSS* and *AHSS versus Aluminium for BIW applications* (see www.worldautosteel.org) was conducted at the University of California, Santa Barbara (UCSB) Bren School of Environmental Science and a peer review model for material comparisons was developed.

Replacing conventional steel with AHSS requires little or no increase in cost and reduces lifecycle GHG emissions by 5.7%. Replacing AHSS with aluminium costs 60-80% more and increases life cycle GHG emissions by 2.6%.

Consider two case study examples, using the UCSB model, based on a C-Class vehicle with a gasoline internal combustion engine. The case studies focus on the body-in-white and assume 25% mass reduction from a conventional steel baseline for AHSS and 11% further mass reduction for aluminium, along with additional secondary weight savings in both cases. Fuel savings and driving cycles are based on the fka study.

The UCSB model calculated GHG reduction that is achieved by optimizing the design with AHSS compared to conventional mild steel (Figure 8a). **This is the situation of 'steel re-inventing itself' and replacing former steel materials and design with new steel materials and design**.

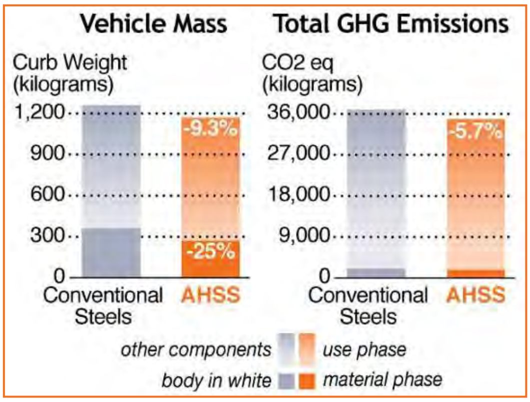


Figure 8a: Life cycle GHG comparisons – Conventional Steel and AHSS

The effect of 25% mass reduction in the body-in-white (the equivalent of a 9% total vehicle mass reduction when secondary mass savings are also included) is to reduce CO_2 equivalent emissions in both the material production and use phase so that the vehicle's total life cycle emissions are reduced by 5.7%. This is accomplished at no additional cost.

The UCSB model also compared an optimized aluminium design with the AHSS design (Fig. 8b). Although, this scenario assumes some additional mass savings can be achieved with aluminium, **the increase of CO_2 equivalent emissions from the material production phase more than offsets the reductions generated in the use phase**.

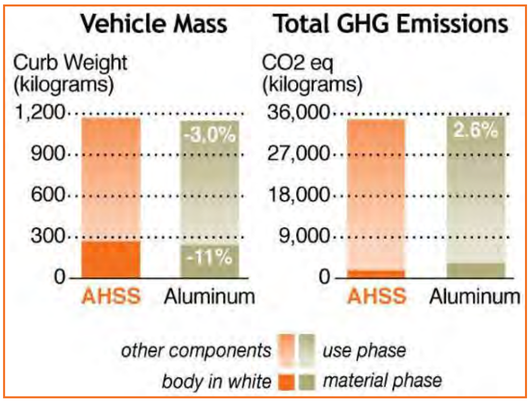


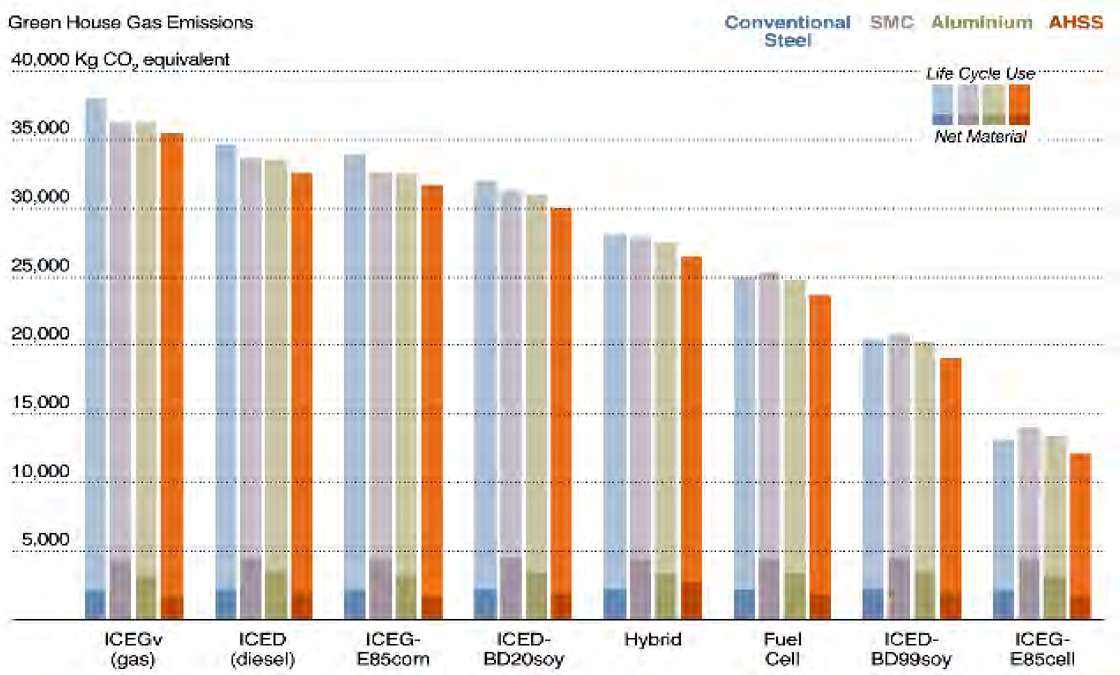
Figure 8b: Life cycle GHG comparisons – AHSS and Aluminium

The vehicle's total life cycle emissions are increased by 2.6%. Furthermore, this environmental burden also comes with a significant cost increase.

A key finding is that the AHSS design advantage over aluminium depicted in this case study only represents a small percentage of the total vehicle GHG emissions.

In fact, the preferred material depends on the assumptions and inputs for the specific application and manufacturing processes. So although the preponderance of reasonable inputs demonstrates AHSS to be the preferred material over aluminium, there are sets of assumptions where the conclusion could be reversed.

Regardless of all reasonable inputs, the impact of material production and recycling on LCA GHG emissions are relatively small compared to total emissions, and significant improvements in reducing automotive GHG emissions will not be made



by material substitution alone.

Using the LCA approach, comparisons can be made among other advanced automotive capabilities, such as powertrain, fuel choices and driving scenarios that are emerging into mainstream automotive technologies.

Figure 9 compares an AHSS body to an aluminium body and the cumulative impact of these technologies on the total LCA of GHG emissions. The comparison finds that use of these upcoming technologies can have a dramatic influence on the total LCA GHG emission of a vehicle. The use of advanced powertrains (such as hybrids), advanced fuels (such as grain and cellulose ethanols) and improved driving cycles (such as the implementation of timed lights and roundabouts) can result in a dramatic reduction in the use phase GHG emissions.

Figure 9: Life cycle GHG comparisons – powertrains & fuels

A key point, demonstrated by this graph, is that **although the material production phase GHG emissions remain the same, they become a much more significant percentage of the total LCA GHG emissions as use phase efficiencies are achieved**.

It is concluded that as other green technologies that improve vehicle GHG emissions are implemented in mainstream vehicle designs, the emissions from material production will become more important, placing greater emphasis on selecting a low GHG-intensive material such as steel.

Conclusions

When these collective findings are placed in the context of a real-world 5-passenger compact vehicle (Figure 10) evidence shows that replacing former conventional steel designs with optimized AHSS designs will, on average, gain:

- **21 to 25% reduction in body-in-white weight,**
- **9% reduction in curb weight,**
- **5.1% reduced fuel consumption,**
- **5.7% reduced life cycle GHG emissions (CO_2 equivalent) and,**
- **Little or no increase in total system manufacturing costs**.

On the other hand, if optimized AHSS body-in-white applications are replaced with aluminium applications in a 5-passenger compact vehicle (Figure 11), the replacement will, on average, gain:

- **Only an 11% further reduction in body-in-white weight,**
- **3% further reduction in curb weight,**
- **1.8% further reduction of fuel consumption,**
- **2.6% increased life cycle GHG emissions (CO_2 equivalent) as well as the introduction of potent perfluorocarbons (PFC) not produced by steel,**
- **65% increased total system production costs for body-in-white**.

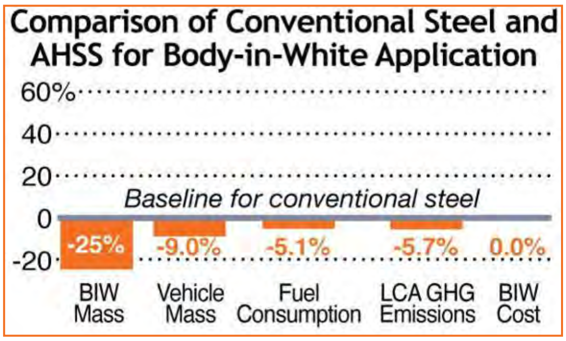


Figure 10: Conventional steel versus AHSS body-in-white application

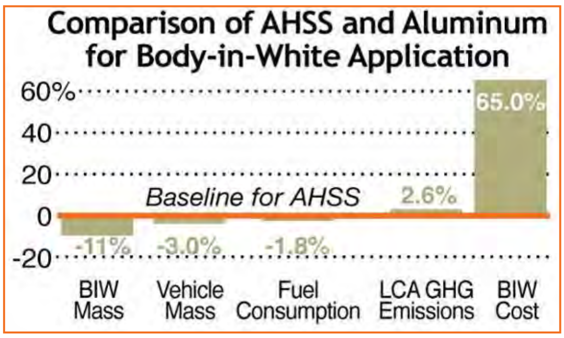


Figure 11: Comparison of AHSS and Aluminium for body-in-white application

References

Mass Reduction

Wohlecker, R; Henn, R (2006) *Mass Reduction Potential Study* by Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka). (Report available for WorldAutoSteel members at https://extranet.worldsteel.org/C17/Automotive/default.aspx and publicly at http://www.worldautosteel.org).

Weight / Fuel Consumption Elasticity

Wohlecker, R; Johannaber, M; Espig, M (2007) *Determination of Weight Elasticity of Fuel Economy for Conventional ICE Vehicles, Hybrid Vehicles and Fuel Cell Vehicles* by Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka). (Report available at http://www.worldautosteel.org).

Climate Change and Greenhouse Gas Emissions

Geyer R (2007) *Life Cycle Greenhouse Gas Emission Assessments of Automotive Materials. The Example of Mild Steel, Advanced High Strength Steel and Aluminium in Body in White Applications*. **Project Report**. On behalf of WorldAutoSteel, IISI. Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, USA – (report available to WorldAutoSteel member companies for internal use at https://extranet.worldsteel.org/C0/CO2COMM/default.aspx)

Geyer R (2007) *Life Cycle Greenhouse Gas Emission Assessments of Automotive Materials. The Example of Mild Steel, Advanced High Strength Steel and Aluminium in Body in White Applications*. **Methodology Report** and **Model Version 4.0**. On behalf of WorldAutoSteel, IISI. Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, USA – (Report and model available at https://extranet.worldsteel.org. An approved limited-content page is also available publicly at http://www.worldautosteel.org)

Cost

Field, F; Kirchain, R; Roth, R (2007) *Process Cost Modelling: Strategic Engineering-Economic Evaluation of Materials Technologies* by the Massachusetts Institute of Technology (MIT). (Report available for WorldAutoSteel members at https://extranet.worldsteel.org/C17/Automotive/default.aspx and publicly at http://www.worldautosteel.org).