Executive Summary of
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

7-December-2007

Abstract

The objective of this study is to benchmark, in terms of their life cycle greenhouse gas (GHG) emissions, vehicle body-in-white designs based on Advanced High-Strength Steels (AHSS), like ULSAB-AVC, as well as aluminium, compared to designs based on mild steel. For this purpose a parametric spreadsheet model has been developed which calculates life cycle GHG emissions attributable to vehicles as a function of their material composition and powertrain characteristics. Using this model, comparisons were made as to the GHG emissions produced over a vehicle life cycle. A key finding of the study states that based on an attributional LCA and current data uncertainty, there is no conclusive evidence that aluminium-intensive vehicle designs offer any GHG emission savings relative to AHSS-intensive designs like ULSAB-AVC.

1. Anthropogenic GHG Emissions and Climate Change

The Greenhouse Effect is the process by which the Earth's atmosphere absorbs infrared radiation coming from the planet's surface and radiates some of it back to the ground. This phenomena leads to a cycling of heat between the Earth's surface and atmosphere which increases the planet's average surface temperature to a level that supports life forms dependent on water in its liquid state. Greenhouse gases (GHG) are the naturally occurring gaseous components of the atmosphere that contribute to the Greenhouse Effect. Anthropogenic greenhouse gas, on the other hand, are those emissions produced by human activity (e.g. burning fossil fuels, land use changes) and are mainly CO_2, CH_4, N_2O and Halocarbons. The increasing levels of these anthropogenic GHGs increase the capacity of the atmosphere to absorb the infrared radiation emitted from the Earth and re-radiate a portion back to the planet, called the anthropogenic Greenhouse Effect. These emissions increase the earth's natural Greenhouse Effect, which in turn raises the mean surface temperatures of the Earth and the troposphere. This is known as Global Warming, and the consensus among relevant scientific communities is that this anthropogenic Greenhouse effect is changing the Earth's climate.

The transportation sector is a major contributor to anthropogenic GHG emissions, in particular, through the use of internal combustion engines (ICE) vehicles. It is therefore not surprising that reducing GHG emissions from the transportation sector in general and ICE vehicles in particular is seen as an important part of any GHG reduction strategy. Consequently, this is the subject of many new regulations being implemented around the world, and of continual efforts by world automakers to reduce their products' environmental impact.

2. Vehicle Design for GHG Emission Reduction

2.A Life Cycle Assessment

According to L'Organisation internationale de normalisation (International Organization for Standardization) standard ISO 14040, Life Cycle Assessment (LCA) is a technique compiling a quantitative inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts associated with those inputs and outputs; and interpreting the results of the inventory and impact phases in relation to the goal and scope of a study.

In standard LCAs, the product system is investigated with regard to a variety of environmental impact categories, such as resource depletion, ozone depletion, acidification, eutrophication, photochemical oxidation, toxicity and also climate change. This creates tradeoffs across environmental impacts, considering the possibility that changes in the product system decrease some environmental impacts but increasing others (e.g. reduce ozone depletion but increase climate change). These trade offs cannot be assessed scientifically but need to be evaluated based on the relative importance of environmental impact categories, i.e., value judgments.

A second important aspect of LCAs is its emphasis on the life cycle of a product. It is not just vehicle use that causes GHG emissions but all of its life cycle stages, from material production and vehicle manufacturing to vehicle end-of-life (EOL) management. Adopting a life cycle perspective is critical since changes in the product system, such as using aluminium instead of steel in body-in-white applications, may decrease the use phase global warming potential at the expense of increasing the material production global warming potential. It is precisely these potential trade-offs within one environmental impact category, climate change, but across different stages of a vehicle life cycle that are the subject of this study.

Those interested in achieving significant net reductions in GHG emissions from the use of vehicles in transportation should adopt a life cycle assessment methodology to avoid the possibility that trade offs go unnoticed and that design changes are recommended, subsidised or mandated that have a negligible or even adverse climate change impact. Unfortunately current policy initiatives focus on the vehicle use phase, ignoring all other GHGs and all other processes of the vehicle life cycle.

An additional important distinction also needs to be made between attributional and consequential LCAs. Whereas attributional LCA assesses a product system in a given state, consequential LCA aims at quantifying the environmental impacts of a product system change. To date, assessments of the GHG impact of material choices to achieve vehicle weight reduction have been based on attributional methodology, even though the relevant questions behind such assessments are clearly of consequential nature. Allocation is an accounting issue rather than a scientific question since attributional LCA is a form of environmental accounting. A more scientific way to assess a vehicle life cycle is through a consequential LCA, and therefore it is one of the study's recommendations for further research.

2.B Life Cycle Vehicle GHG Emissions

Most of the vehicle design options for reduction of life cycle GHG emissions focus on the vehicle use phase. This is not surprising since it is during this phase that 80-90% of the life cycle GHGs are emitted. However, it is necessary to use LCA methodology because design changes can yield emission changes at several life cycle stages that are in the same order of magnitude, however disparate the absolute emission values of the life cycle stages might be. As mentioned previously, decreases in GHG emissions that are achieved in one phase of a life cycle may lead to increased total life cycle emissions. Another important observation is that as use phase share of life cycle GHG emissions decreases, the percentage share (and relative importance) of the other life cycle stages increase.

The design strategy that is the subject of this report is vehicle weight reduction based on material substitution, specifically the use of aluminium to replace steel. Material choices in vehicle design potentially impact GHG emissions at all stages of a vehicle life cycle, the most obvious being the materials production stage. The total global warming potential per kg of automotive material is typically given as so-called cradle-to-gate GHG emissions in kg CO_2eq, which includes all upstream production processes (mining, refining, etc.). There are not only large variations in cradle-to-gate GHG emissions between different materials but also between different production routes, technologies and sites for the same type of material. This study uses process inventory data for material production published by the global steel and aluminium associations, which are worldwide averages. It explicitly accounts for different material production routes, i.e., primary and secondary up to the point when material is shipped to an automotive manufacturing plant. But the study does not account for GHG emissions of the different automotive manufacturing processes, such as forming and joining technologies because the effect of different materials is relatively small.

2.C Impact of Material Choice on Vehicle GHG Emissions

GHG emissions from the vehicle use phase are dominated by fuel production, delivery and combustion, to the extent that the emissions of other aspects of the use phase, like vehicle maintenance and repair, are typically neglible. This means that the single most important influence of material choice on use phase GHG emissions is its impact on vehicle fuel consumption, even though it also may impact other aspects. The only relationship between material choice and vehicle fuel consumption that is studied in literature and known to this study's author is the mass savings potential of the material. The relationship between vehicle mass reduction and fuel consumption reduction is sometimes not clearly understood and many studies use the so-called 5% - 10% rule, which says that every 10% of saved vehicle mass increases fuel economy by 5%. Research carried out by Forschungsgesellschaft Kraftfahrwesen Aachen mbH (fka) through a Weight Elasticity Study shows that the relationship is much more complex and that the assumption of a constant elasticity is not a good approximation. To avoid the fundamental problems associated with this methodology, the more direct concept of absolute fuel savings (in litres/100 km) per 100 kg of mass savings is used. Once this relationship is established, the total GHG emissions from the vehicle use phase (including the fuel cycle) can be calculated for mass-reduced vehicles, given other known parameters.

3. Survey of Previous Studies

A critical review was conducted encompassing ten separate studies disclosed to the public that contain comparative assertions of the life cycle GHG emissions (or energy consumption) of steel-and aluminium-intensive vehicles. Full details of this review can be found in the study report. All of these studies use attributional LCA methodology. None of the existing studies are entirely without problematic data or modelling assumptions. Most studies present their findings as facts rather than model outcomes that directly depend on data choices and modelling assumptions and methodology. And most existing studies have not been subject to a critical review by a panel of interested parties as required by ISO 14040 and 14044.

4. IISI WorldAutoSteel Study

The objective of this study is to benchmark, in terms of their life cycle GHG emissions, body-in-white designs based on advanced high-strength steels (AHSS), like ULSAB-AVC, and aluminium, compared to designs based on mild steel. For this purpose a parametric spreadsheet model has been developed which calculates life cycle GHG emissions attributable to vehicles as a function of their material composition and powertrain characteristics. The parametric model is made up of three different modules: vehicle material composition, material production and recycling GHG emissions, and vehicle use phase GHG emissions. For each scenario, three different vehicle designs are considered: 1) conventionally designed baseline vehicle; 2) an AHSS-intensive vehicle design based on ULSAB-AVC design principles and 3) an aluminium-intensive vehicle design. The model currently includes the impact of co-producing prompt scrap, but does not include the actual emissions from the vehicle manufacturing processes because review of previous studies provides some evidence that manufacturing and assembly of an aluminium-intensive vehicle generates the same or more GHG emissions than manufacturing a steel-intensive vehicle, regardless of the AHSS content. Omission of these processes should thus produce model results which are conservative with regard to steel-intensive designs.

The fka findings mentioned earlier regarding fuel savings per mass savings was fully integrated into the parametric model which returns a value based on a choice of input parameters, including vehicle class, powertrain type, driving cycle (NEDC vs. Hyzem) and whether the engine and powertrain system has been re-sized to provide equivalent acceleration performance for the mass reduced vehicle. The model allows for any combination of these parameters, and it supplies comparative values for the baseline, AHSS, and aluminium vehicle designs.

To demonstrate the impact of bio fuel use, the model uses well-to-wheel GHG emissions of a user-specified mix of gasoline and ethanol. The type of fuel crop (grain-, sugar- or cellulose-based) is specified as well.

The model uses attributional LCA and, in accordance with the requirements of ISO 14044, it supports several applicable allocation methods, namely the sliding credit/debit system and the multi-step recycling method. Both of these methods require knowledge of a variety of recycling rates. Due to availability of data, the model uses one set of recycling rates for all iron and steel, and one set for all aluminium.

Model results and a detailed sensitivity analysis can be reviewed in the study report.

5. Summary Conclusions

Conclusions were made based on the model results using a variety of data parameters and a subsequent sensitivity analysis of key individual parameters. Seventy two different scenarios for each material design comparison were input to the model, using three vehicle classes, two driving cycles, four powertrain options, and three end-of-life recycling allocation methods.

The results show that vehicle mass reductions based on replacing Bodies-in-White (BIWs) made of mild steel with BIWs made from Advanced High Strength (AHSS) or aluminium reduce life cycle GHG emissions of vehicles. However, the significance of the GHG emission reductions depends on the exact circumstances of the mass reduction, such as the amount of primary and secondary mass savings, the vehicle type, the powertrain type, the fuel type, and the driving pattern.

For a broad range of data, modeling and allocation choices, the life cycle GHG emissions attributable to AHSS and aluminium BIWs are fairly similar. However, the way in which the two designs achieve these reductions is quite different. Relative to mild steel, AHSS BIWs reduce GHG emissions at all stages of a vehicles life (production, use, and end of life). Displacing mild steel with AHSS will thus never increase life cycle GHG emissions, there are no trade-offs to consider. Aluminium may have a higher mass savings potential than AHSS, therefore reducing fuel consumption and use phase emissions. However this use phase advantage does not offset the increased GHG emissions of aluminum production, which are six times higher per kilogram than the steel it replaces.

In a Life Cycle Assessment (LCA) approach aluminium can possibly offset its higher production phase emissions with a combination of the use phase and the end-of-life avoided burden recycling credit. Recycled aluminum can displace primary aluminum production (aluminum from bauxite ore) and recycled aluminium produces less GHG emissions than primary aluminium. The problem is that there is no established approach for allocating credit for this recycled aluminum advantage. It could be totally allocated to the vehicle from which it came, to the next products to which it will be applied, shared between the vehicle and the next products, or shared between the next several generations of products to which it will be applied. Aluminum can demonstrate a small advantage over steel only under the scenario where the credit is applied to the vehicle from which it came. In all other scenarios AHSS steel is the preferred material on a life cycle GHG emissions basis.

In summary, the study states that, based on an attributional LCA and current data uncertainty, there is no conclusive evidence that aluminium-intensive vehicle designs offer GHG emission savings relative to AHSS-intensive designs like ULSAB-AVC. It is also not consistent to claim that AHSS-intensive vehicle designs offer GHG emission savings relative to all aluminium-intensive designs.

The model methodology was subjected to a critical peer review, in accordance with ISO requirements. The model methodology reproduces results of previous studies and provides a sound basis for scientific LCA comparisons.

Overall, the study results suggest that light-weighting as a GHG reduction strategy should not be done in isolation from other GHG reduction strategies, such as powertrain modifications and alternative fuels, since they interact with each other. Whether the GHG savings that GHG-intensive light-weight materials can achieve in the vehicle use phase outweigh their GHG emission increases at the material production phase depends on many factors of the vehicle design and life cycle analysis.

Finally, the study concludes that attributional LCA may not be the most appropriate methodology to assess the GHG emissions. With some additional data and modeling, it is possible to convert the attributional study to a consequential analysis, which is a better methodology for the given research question. The study, therefore, includes the recommendation to convert the current model to a consequential analysis. Other recommendations include extending the model to include magnesium and fiber-reinforced plastic, to add a fuel cell powertrain option and to include a GHG emissions model of vehicle manufacturing.

The parametric model is available for use at www.worldautosteel.org or by contacting WorldAutoSteel member company representatives.