Updated Automotive Lifecycle Assessment Model Launched

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Introduction

The *Automotive Life-Cycle Assessment Model* is a tool developed by a group of aluminum and automotive industry experts for calculating the greenhouse gas (GHG) emissions that can be saved through lightweighting of passenger cars. First published in 2014, the Microsoft Excel-based calculator is the product of more than ten years of collaboration between European Aluminium and the International Aluminium Institute (IAI) with support by Ricardo Energy & Environment. The IAI recently introduced a number of refinements to the calculator, including new data, an improved layout, case studies, and options for users to select the source of the primary aluminum used and its carbon footprint.

The tool enables comparison of a baseline automobile model (employing a mild steel structure and body) with alternative lightweight options, using either aluminum, advanced high strength steel (AHSS), or a combination of the two. The full lifecycle (materials production, vehicle production, vehicle use phase, and end-of-life stage) is taken into account in the calculation of total GHG emissions for internal combustion engine (petrol and diesel), plug-in hybrid electric (petrol and diesel), and battery electric vehicles.

The objective of the calculator is to provide transparent, indicative comparisons with a reasonable level of accuracy using appropriately referenced and robust data sources and assumptions. With the 2019 refinements and updates, the *Automotive Life-Cycle Assessment Model* is now simple to use, effective for testing different lightweighting options and allows the user to specify the attributes of the baseline vehicle and lightweight car variants, using their own materials mix data or using a set of prefilled default values.

2019 Updates

Improved Layout: The IAI refinements include an enhanced layout (Figure 1) for improved usability, while maintaining a high transparency level as in the previous version.

Regionalized LCI Data for Primary Aluminum: Primary aluminum is an energy intensive metal, requiring significant amounts of electricity in its production[1] and its carbon intensity (cradle-to-gate) is highly variable depending on the electricity source.[2] For instance, primary aluminum produced using hydropower has a carbon intensity of around one quarter of that produced with coal-fired electricity.[3]

In previous versions, the primary aluminum production emissions data reflected a singular European average. Now the user is able to select a global, regional, country, or their own data source for the aluminum used and its carbon emissions profile is updated accordingly in the calculator. The carbon intensity of aluminum production in a given region/country were modeled in GaBi 7.3.3 software[4] using data from the IAI's 2015 lifecycle inventory for primary aluminum production.[3] To gain data on GHG emissions for primary aluminum use (supply) in a specific region or country the GaBi modeled footprints were combined with a material flow trade model.[5]

Updated Data: All raw data were updated with the latest data available, including GHG emissions for steel production (from the World Steel Association and personal communications), fuel combustion emissions data for calculating the electricity grid,[6] and GHG emissions for recycled aluminum and aluminum finishing based on data from European Aluminium[7] and the U.S. Aluminum Association.[8] A range of driving cycles were used to calculate use-phase fuel and electricity savings based on IAI-sponsored work by the Institut für Energie- und Umweltforschung Heidelberg (IFEU).[9]

Pre-Entered Case Studies: For users who do not have access to specific vehicle data, but who would like to understand the impacts of different lightweighting scenarios, a number of case studies have been included. These explore four different vehicle types (family car, second car, taxi, and business car) based on information from IFEU[9] and Bertram, et al.,[10] as well as five replaced components (bumper, wheel, front hood, body-in-white, generic 400 kg of mild steel) based on Bertram, et al.[10] The "Summary of Data Input" sheet in the *Automotive Life-Cycle Assessment Model* shows all pre-entered data,

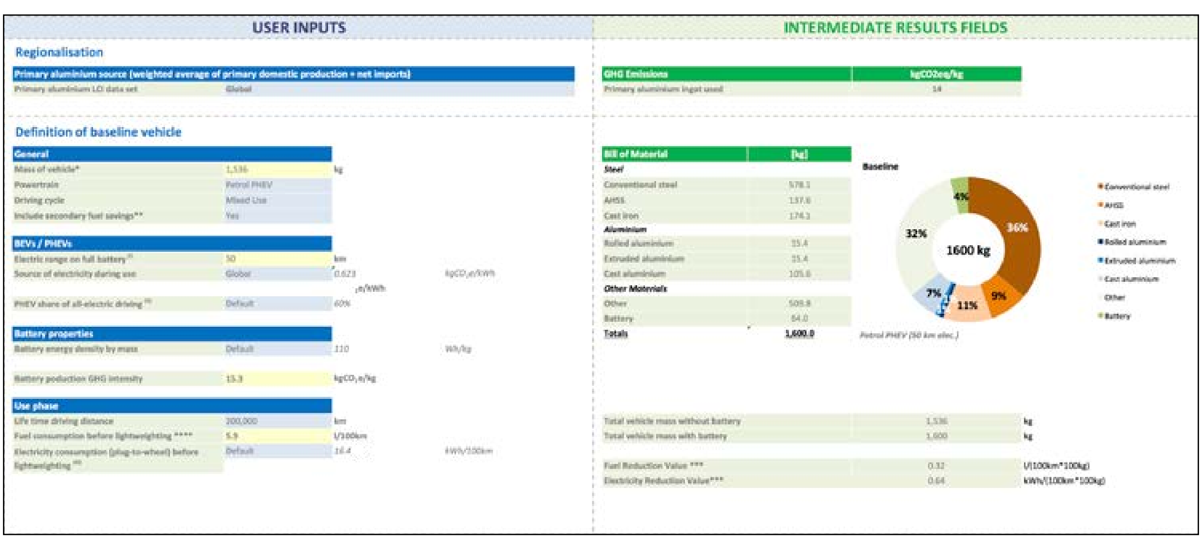

Figure 1. Screenshot of the *Automotive Life-Cycle Assessment Model* user input page.

making the model 100% transparent. Two of the case studies are illustrated hereafter.

Case Studies

The case studies in the *Automotive Life-Cycle Assessment Model* assess mass reduction by comparing specific examples of a mild steel component versus an aluminum sheet or AHSS component, meeting identical performance criteria based on Bertram, et al.[10] The case studies represent hypothetical models and it is recommended that the metrics included should be replaced with data supplied by vehicle manufacturers wherever possible in order to achieve more specific results.

For the two case studies explored in this paper, a recycled metal content of 40% is assumed for mild steel and AHSS, and 35% for aluminum sheet. The global average recycled content of aluminum rolled products is 40%.[11] Since this metric varies significantly depending on the automotive producer and its supplier, the body-in-white (BIW) case study also includes a 0% recycled content scenario for mild steel, AHSS, and aluminum (Figures 2-3). The end-of-life (EOL) recycling rate is assumed to be 90% for all versions. A material lightweighting factor of 0.75 kg per kg of mild steel and 0.6 kg per kg of mild steel are selected for AHSS and aluminum, respectively.

BIW of a Family Car: The hypothetical gasoline family car in the study has a mass of 1,600 kg and a lifetime driving distance in the U.S. of 250,000 km.[12] The driving distance is based on a mixed-use driving cycle with a fuel reduction value (including a secondary fuel savings from an optimized drive train) of 0.32 l/(100 km*100 kg) based

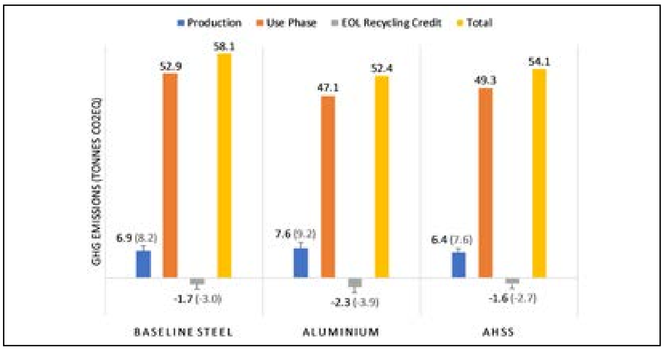

Figure 2: Lifecycle CO_2e emissions by stage comparing a mild steel, aluminum, and AHSS BIW for a family car with a gasoline internal combustion engine. Error bars and values in brackets represent the results with zero percent recycled metal content.

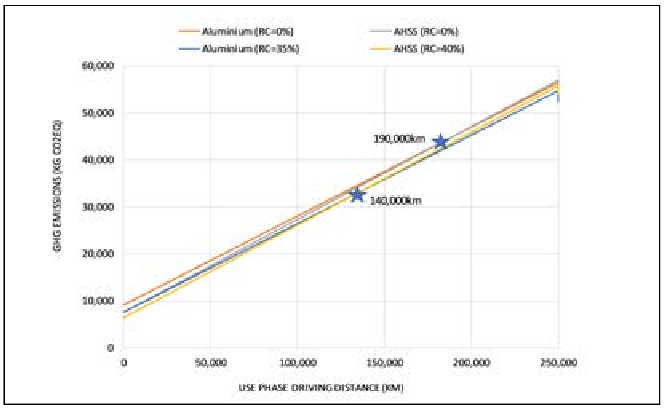

Figure 3: Cumulative lifecycle emissions (by distance driven) for a family car (gasoline internal combustion engine) with an aluminum and AHSS BIW incorporating a range of recycled contents (RC). The distance at which a family car with an aluminum BIW begins to save lifetime GHG emissions compared to an AHSS vehicle (at a recycled content of 0%/0% and 35%/40%) are indicated by a star.

on IFEU.[9] It is assumed that this vehicle would be produced in the U.S. Therefore, the carbon footprint for primary aluminum supplied to the U.S. market is used in the study.

Two options are considered for lightweighting of the car's mild steel BIW (total mass of 475 kg)—one using 100% aluminum sheet (total mass of 285 kg) and one using 100% AHSS (total mass of 356 kg). In addition, an indirect weight savings of 35% (achieved when other parts in the car are made lighter as a consequence of the overall lighter vehicle). Total effective weight savings are 257 kg and 160 kg for aluminum and AHSS respectively.

What this means in terms of full lifecycle GHG emissions savings is shown in Figure 2. Emissions for vehicle production (including materials), use phase (driving), and recycling credits are shown against each of the three vehicle options (baseline steel, aluminum, and AHSS). Equation 1 describes the calculation for recycling credits resulting from the substitution of primary metal by the net production of recycled metal issued from the product system, e.g., deducting the recycled content fraction already considered at the production stage. The error bars for production and recycling credits represent results with zero percent recycled metal content in comparison to a 40% for mild steel and AHSS, and 35% for aluminum. While the emissions for production increase, the credits for EOL recycling also increases, in the same proportion. This has no effect in terms of full lifecycle GHG emissions. Equation 1 is as follows:

$$\text{EOLCredit} = (\text{EOL} - \text{RC}) * \text{Total} * (\text{GHG}_{\text{PRIM}} - \text{GHG}_{\text{REC}}) \qquad (1)$$

in which, EOL = end-of-life recycling rate (%), RC = recycled content (%), Total = total metal content of the vehicle (kg), GHG_{PRIM} = GHG emissions from primary metal used for the vehicle (kg CO_2e per kg primary metal), and GHG_{REC} = GHG emissions from recycled metal used for the vehicle (kg CO_2e per kg recycled metal).

Results of this case study indicate that, if only the production phase is considered (blue bar in Figure 2), the AHSS version has the lowest emissions. However, when taking into account the full lifecycle, including production, use, and the EOL stage (yellow bar in Figure 2), the aluminum model has the lowest carbon footprint. Savings of approximately 5,700 kg CO_2e are achieved when using the aluminum BIW and about 3,900 kg CO_2e when using an AHSS BIW compared to mild steel.

As shown in Figure 3, after a mileage of around 140,000 km (including recycled content) and about 190,000 km (0% recycled content) the aluminum version will recuperate the higher impacts of production versus the AHSS version. This is because—while aluminum has a higher GHG emissions profile per kilogram than both mild and advanced high strength steels—much less of it is required to achieve the same functionality, reducing the mass of the vehicle and saving more emissions when driving over the same distance.

Front Hood of an Electric Taxi: The baseline version of a hypothetical electric taxi in this study weighs 1,900 kg, and has an assumed lifetime driving distance of 300,000 km with an urban-use driving cycle having energy reduction value of 0.65 kWh/(100 km*100 kg) based on IFEU.[9] Two options are considered for lightweighting the car's mild steel hood (total mass of 17.5 kg)—one using 100% aluminum sheet (direct weight savings of 7.2 kg) and one using 100% AHSS (direct weight savings of 4.5 kg).

Four primary aluminum GHG datasets based on energy source are explored in this case study:

• Mix: Aluminum produced using electricity from mixed sources (coal, gas, and hydro), which is typical for aluminum used in Europe. Mix has a cradle-to-gate carbon footprint of 9 kg CO_2e/kg Al.

• Hydro: Aluminum produced using 100% hydropower electricity with a carbon footprint of 6 kg CO_2e/kg Al, which is typical for aluminum used in Norway, Iceland, Russia, and Canada.
• Coal: Aluminum produced using 100% coal-fired electricity with a carbon footprint of 20 kg CO_2e/kg Al, which is typical for aluminum used in China.
• Global: The global weighted average of primary aluminum used in the automotive industry based on vehicle production by region/country is 14 kg CO_2e/kg Al.

To show the impact of the electric vehicle use-phase based on the power grids used in the regions in which the vehicle is driven, the following datasets are provided:
• EU: European Union – mixed power grid (0.4 kg CO_2e/kWh)
• NOR: Norway – hydro-intensive grid (0.07 kg CO_2e/kWh
• POL: Poland – coal-intensive grid (0.9 kg CO_2e/kWh)
• US: U.S. – mixed power grid (0.6 kg CO_2e/kWh)
• CHN: China – coal-intensive grid (0.8 kg CO_2e/kWh)
• GLO: Global average grid mix (0.6 kg CO_2e/kWh)

Figure 4 shows the total GHG savings for the different aluminum datasets and use-phase electricity sources, compared to the baseline and AHSS vehicles. In all cases, the aluminum version has a lower full lifecycle carbon footprint compared to the baseline vehicle. The highest savings in the case of Mix/POL (163 kg CO_2e savings), since the grid mix in Poland is mostly based on coal, so there is more opportunity to reduce use-phase emissions by driving a lighter car. Conversely, the lowest reduction is achieved in Mix/NOR (11 kg CO_2e savings) since Norway's grid mix is mostly based on hydroelectricity. An overall clear savings of aluminum versus AHSS is also shown in this case study (up to 46 kg CO_2e savings), with the exception of Mix/NOR (11 kg CO_2e increase) for the same reasons noted.

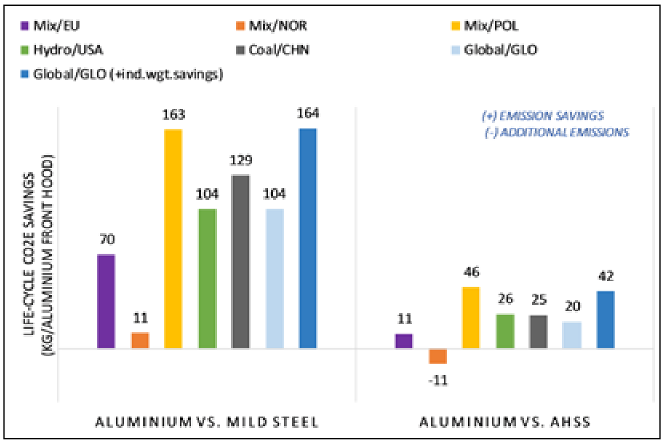

Figure 4: Total lifecycle CO_2e savings for an aluminum front hood used in a battery electric vehicle taxi compared to a mild steel or an AHSS front hood. A 35% indirect weight savings can be applied to visualize GHG savings from downsizing of the vehicle components.

In practice, lightweighting strategies lead to downsizing of vehicle components, especially regarding batteries, which is highly beneficial in terms of carbon intensity of the car production. These benefits are only considered in the global scenario Global/GLO (+ind.wgt.savings). To visualize the additional GHG savings from downsizing, include an additional 35% indirect weight savings to the data in Figure 4, while keeping all other data input for Global/GLO the same. For this case study, an additional savings of 164 kg (mild steel) and 42 kg (AHSS) can be achieved by downsizing with aluminum.

Conclusion

The *Automotive Life-Cycle Assessment Model*, which has been developed following the ISO standard 14040 framework, is a flexible tool for automotive and other industry experts, including designers, specifiers, and lifecycle practitioners. The purpose of the calculator is to provide indicative comparisons of the impacts of different material selections for weight reduction of typical passenger cars.

The four case study results included within the *Automotive Life-Cycle Assessment Model* demonstrate the GHG benefits of using aluminum as a lightweighting material. In all scenarios (with one exception)—including gas and electric vehicles—CO_2e emissions savings are achieved with aluminum compared to mild steel and AHSS. Nevertheless, the results are sensitive to variations in the EOL recycling rate, the lifetime driving distance of the vehicle, and driving behavior of the user. Therefore, any information and results are subject to the accuracy of data inputs and care should be taken by practitioners when making informed estimates on these inputs. All results should be checked and tested before any reliance, publication, or use.

The IAI and European Aluminium welcome user feedback on the calculator, the data used, and the case studies explored. Assistance and training in the use of the tool is available on request. The calculator can be downloaded online at: www.world-aluminium.org/publications.

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