Background

Life Cycle Assessment (LCA) is a methodology that considers a vehicle's entire life cycle, from the manufacturing phase (including material production and vehicle assembly) through the use phase (including production and combustion of fuel) to the end of life phase (including end of life disposal and recycling).

Current automotive emissions regulations around the world are aimed at reducing Greenhouse Gas (GHG) emissions of automobiles, but focus only on tailpipe emissions (Figure 1), which are only a part of the actual life cycle impact of an automobile.

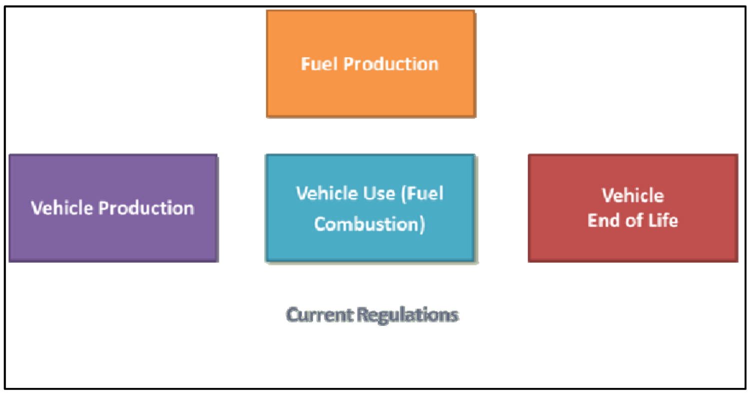


Figure 1 – Sources of GHG Emissions in a Vehicle's Life Cycle

Emphasis on the tailpipe alone may have the unintended consequence of increasing GHG emissions during the vehicle life. For example, many automakers, in order to comply with increasingly stringent tailpipe emissions regulations, are turning to new materials in an effort to reduce mass. By reducing the mass of a vehicle, it is possible to reduce the fuel consumption and, consequently, the tailpipe emissions. However, many of these materials can have impacts in the other life cycle phases that outweigh any advantage that may be gained in the use phase. This means that, contrary to the stated objective of reducing the GHG emissions of automobiles, tailpipe-only regulations may have the unintended consequence of actually *increasing* the GHG impact. This is why WorldAutoSteel is participating in the development of LCA tools and methodology and encouraging the use of LCA in the formulation and implementation of automotive emissions regulations.

A Case Study

As an example of the impact of material choices on life cycle GHG emissions, consider the following case study: Increasingly stringent tailpipe emissions regulations have forced the manufacturer of a full-size Sport-Utility Vehicle (SUV) to consider changing to an all-aluminium design. The manufacturer expects to save 300 kg by replacing mild steel with aluminium in the body-in-white (BIW), closures (doors, hood, liftgate), suspension, and subframes. Using the University of California Santa Barbara Automotive Materials Energy and GHG Comparison Model v4 (UCSB v4), this case study will investigate the life cycle GHG impact of this change, as well as the impact of an alternative design substituting Advanced High-Strength Steel (AHSS) instead of aluminium.

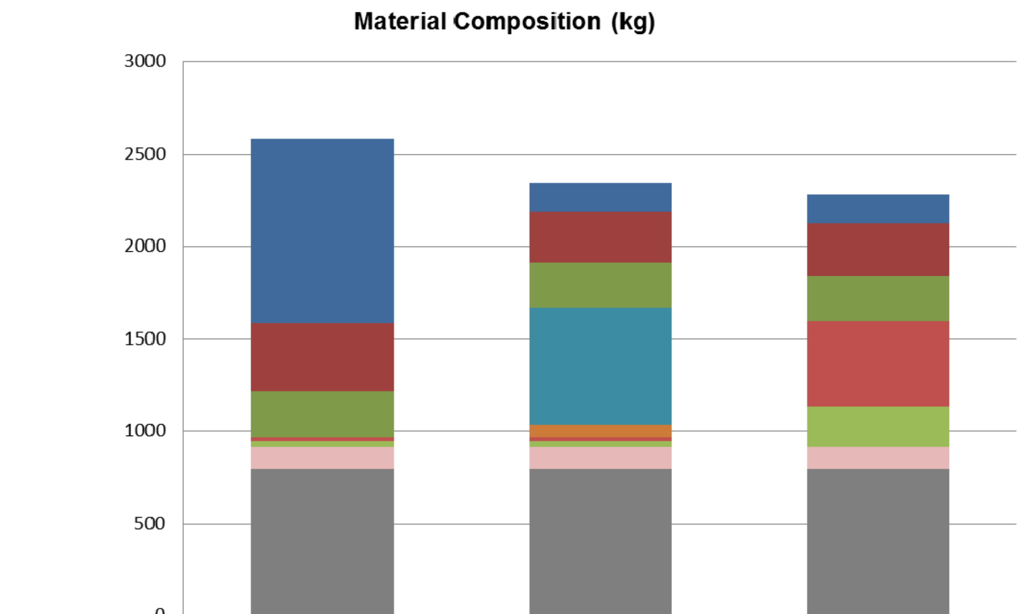
The UCSB model, developed by Dr. Roland Geyer of the University of California Santa Barbara, is designed to quantify the energy and GHG impacts of automotive material substitution on a total vehicle life cycle basis, under a broad range of conditions and in a completely transparent fashion. The model methodology has been peer-reviewed by members of the LCA community and the aluminum industry. The UCSB model, including a comprehensive User Guide, is available for free download at www.worldautosteel.org.

Model Parameters

BOM calculations

The bill of materials (BOM) for each design was calculated to give a 300 kg mass savings (from the baseline mass of 2580 kg) for the aluminium-intensive design. Resulting substitution is 930 kg of mild steel replaced by 630 kg of aluminium and, for the AHSS design, 698 kg of AHSS. This resulted in a final vehicle mass of 2280 kg for the aluminium-intensive design and 2347 kg for the AHSS-intensive design. The UCSB model contains default values for the distribution of each material as a percentage of curb mass. These defaults include a distribution in the body structure of 90% flat/10% long for steel designs, and 70%flat/30% extruded for aluminum designs.

Material Composition



	Baseline	AHSS-intensive	Al-intensive
Total	2580.0	2347.4	2280.0
Flat carbon steel	992.8	155.6	155.6
Long & special steel	372.3	279.3	279.3
Cast iron and steel	248.2	248.2	248.2
Stainless steel	0.0	0.0	0.0
Flat AHSS	0.0	627.9	0.0
Long & special AHSS	0.0	69.8	0.0
Cast AHSS	0.0	0.0	0.0
Rolled aluminum	24.8	24.8	466.0
Extruded aluminum	24.8	24.8	213.9
Cast aluminum	124.1	124.1	124.1
Rolled magnesium	0.0	0.0	0.0
Cast magnesium	0.0	0.0	0.0
SMC	0.0	0.0	0.0
GFRP	0.0	0.0	0.0
CFRP	0.0	0.0	0.0
Other	793.0	793.0	793.0

Figure 2 – Material composition

Other key parameters

- **Recycling methodology** – in accordance with the Declaration by the Metals Industry on Recycling Principles[1], the avoided burden method was used, in which credit is given for producing material (scrap) that allows a downstream user to avoid production of primary material.
- **Power train** - for purposes of determining the use stage impacts, a conventional diesel powertrain has been assumed.
- **Lifetime Driving Distance (LTDD)** – because automotive GHG modeling is very sensitive to this parameter, results were calculated using LTDD values ranging from 150000 km to 250000 km.
- **Powertrain resizing** – because the model is also very sensitive to the decision whether or not to resize the powertrain to take full advantage of mass reduction, results have been calculated both with and without resizing.
- **Secondary mass change** – because both the aluminium-intensive and the AHSS-intensive designs involve almost all of the structural systems of the vehicle, all achievable mass savings is assumed to be inherent in the design, and no additional secondary mass effects have been considered.
- **Driving cycle** – the New European Driving Cycle (NEDC) was used.
- **Fuel consumption** – the UCSB model relies on baseline fuel consumption and weight elasticity values (WEV) developed by Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka)[2]. For purposes of this case study, the baseline fuel consumption and WEV for the SUV class (NEDC driving cycle) was used. This WEV equates to a fuel reduction value of .162 l/100kg/100km with no changes to the powertrain, and .295 l/100kg/100km when the powertrain is resized to take maximum advantage of the mass savings. The SUV class baseline fuel consumption given by fka is 7.30 l/100km at 2195 kg.
- **Material data** – Because this is a study of the effects of a material decision for a high-volume vehicle, global LCI data has been used for all materials where available.

Parameter Distributions/Sensitivity Analysis

Most LCA case studies of this kind are conducted using a single set of parameters, giving a “snapshot” of the results that would be achieved only if all of the real-life parameters happen to conform exactly to the values used in the study. This type of analysis is of limited value, as many of the parameters will vary from the values used in the study. The international standard governing Life Cycle Assessment, ISO 14044:2006, requires that the results of an LCA be examined for sensitivity to changes in parameter values. For purposes of this case study, results will be examined for sensitivity relative to the two most critical parameters, LTDD and FRV. The use of such an approach for the LTDD is obvious—different vehicles are driven different distances over their lifetimes. The need for this approach regarding the FRV is slightly less obvious. Many studies of this kind assume that the powertrain will be optimally resized to take the utmost advantage of the mass savings; however, almost all vehicles are offered with a variety of powertrain options, many automakers share powertrains among different vehicles, and even a single model may have many available variations in body style or trim level. All of these things make it virtually impossible for a powertrain engineer to achieve optimal resizing for any mass value, so consideration should be given to a range of possible FRVs.

In order to analyze the given designs across a range of possible parameter values, a Monte Carlo-style approach has been used in this study. This approach involves assigning a probability distribution, instead of a single value, to a parameter. The model is then run multiple times (in this case 5,000), and each time the parameter value is randomly selected from the given distribution. Using a Monte Carlo-style approach yields results that cover the whole potential range of differences.

For purposes of this study, a uniform distribution has been applied to both the LTDD and the FRV, ranging with equal probability from the minimum selected value to the maximum. Future studies may include the assignment of different probability distributions, conceivably a different type of distribution for each parameter studied.

Results

Results are presented in two principal ways: as the minimum and maximum of all the runs, and as a series of histograms depicting the distribution of the head-to-head results of all of the individual runs. Both are important for a full understanding of the potential impacts of the material decision.

Min/Max Results

Min/Max results depict the maximum and minimum life cycle results that would be expected for each material design given the range of parameters selected. The minimum result is that achieved with theoretically optimum powertrain resizing (FRV = .295 l/100kg/100km) and the lowest LTDD (LTDD = 150000 km). The maximum value is that achieved with no powertrain resizing (FRV = .162 l/100kg/100km) and the highest LTDD (LTDD = 250000 km). It should be noted that the Baseline results are independent of the FRV. Min/Max absolute results are shown in Table 1 and Figure 3.

Table 1 - Min/Max Results by Phase

		Baseline	AHSS-intensive	Al-intensive
Production	Minimum	13,743	12,968	22,852
	Maximum	13,865	13,089	22,973
Use	Minimum	36,891	33,752	32,842
	Maximum	61,486	58,613	57,779
End of Life	Minimum	(4,111)	(3,793)	(9,794)
	Maximum	(4,111)	(3,793)	(9,794)
Total	Minimum	**46,524**	**42,927**	**45,899**
	Maximum	**71,239**	**67,909**	**70,958**

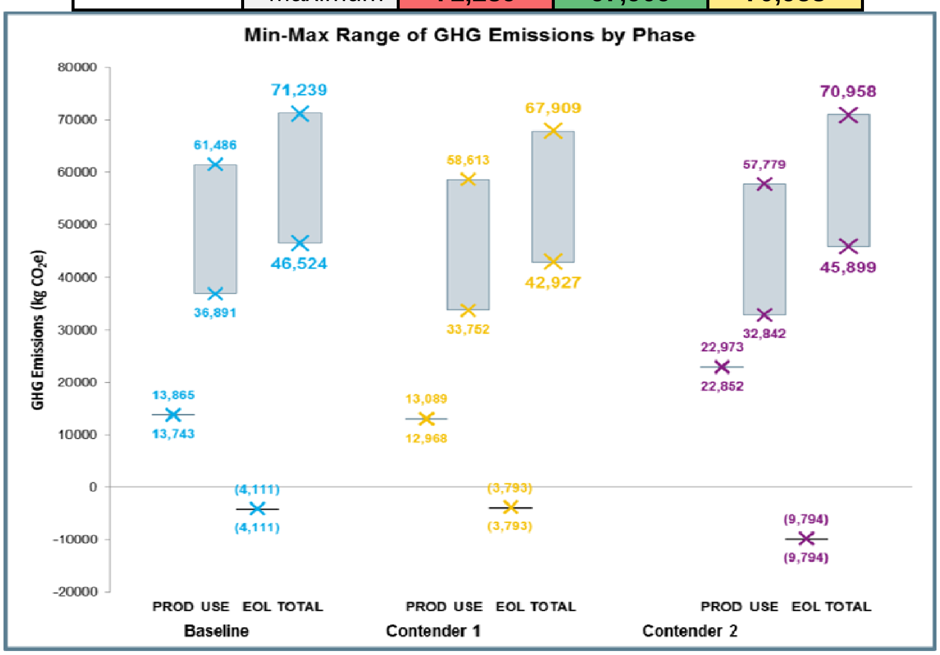


Figure 3 –Life Cycle Emissions Relative to Baseline

The Min/Max results in Table 1 show that, for both the minimum and maximum scenarios, the AHSS-intensive design yields the lowest life cycle GHG emissions, with savings over the baseline mild steel designs of from 3330 kg CO_2e under the maximum scenario, to 3596 kg CO_2e in the minimum scenario.

The aluminium-intensive design shows a 281 kg CO_2e savings over the baseline for the maximum scenario and a 624 kg CO_2e savings in the minimum scenario.

Individual Run Results

Of course, the minimum and maximum values, while helpful, do not tell the whole story. Just as important as the range of possible *values* for each design is the range of possible *differences* between the various designs, which can be very different. It is possible that, while both the maximum and minimum parameter scenarios favor one design over another, a different combination of parameters may yield a different result.

A clearer understanding of the results is made possible by looking at the distribution of the relative results for each run of the model (i.e. for each combination of LTDD and FRV). The following histograms show the frequency of the relative results over the entire 5000 runs of the model.

Figure 4 shows relative results of the Baseline vs the AHSS-intensive design. A positive difference indicates that the Baseline design has higher emissions. For all runs of the model, the AHSS-intensive design showed lower emissions than the baseline design.

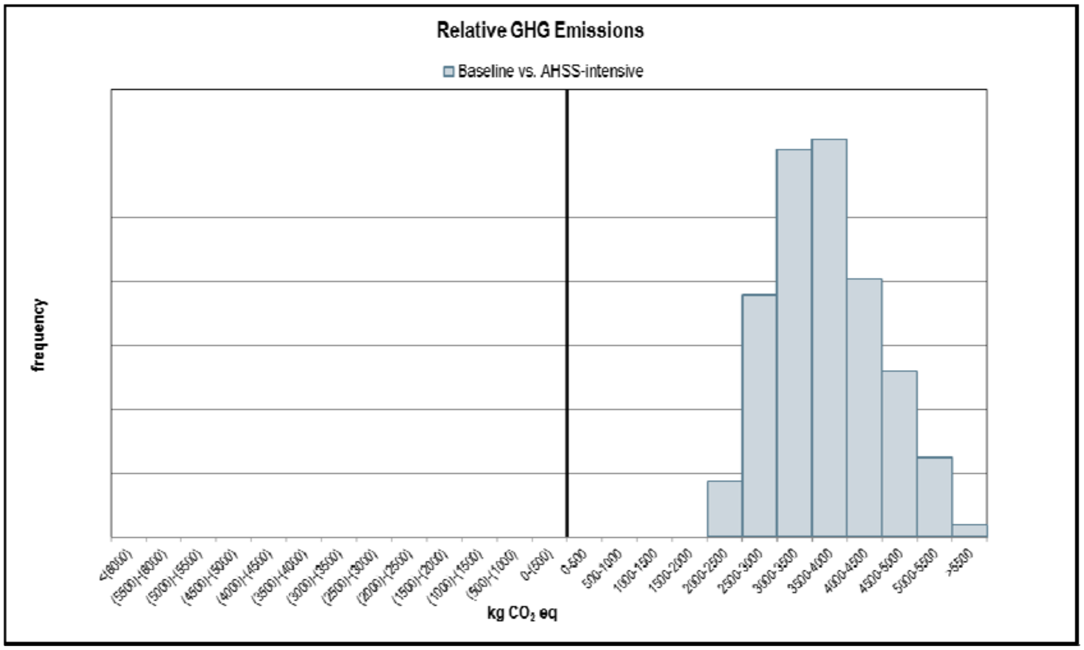


Figure 4 – Distribution of Relative Results: Baseline vs. AHSS-Intensive

Figure 5 shows the potential for unintended consequences with the Al-intensive design. Again, a positive difference indicates that the Baseline design has higher emissions; a negative difference indicates that the Al-intensive design has higher emissions. Figure 5 clearly illustrates that with a given combination of LTDD and FRV parameters the Al-intensive design will have higher GHG emissions than the Baseline design. This unintended consequence occurs in approximately 23% of the LTDD/FRV parameter scenarios covered in this study.

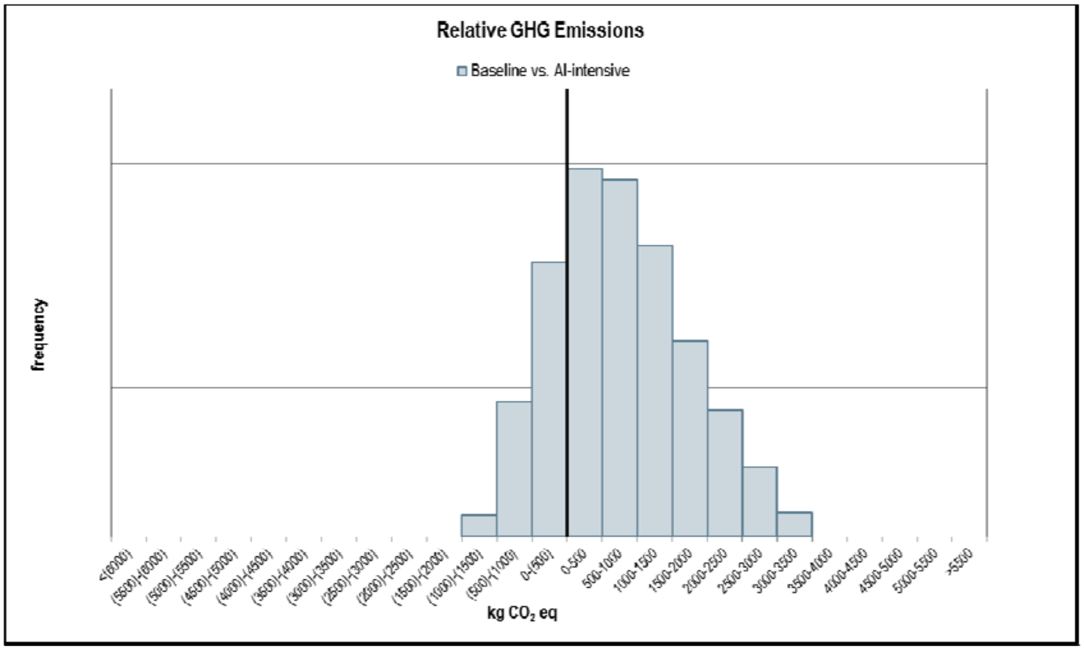


Figure 5 – Distribution of Relative Results: Baseline vs. Al-Intensive

Figure 6 shows the difference between the AHSS-intensive and Al-intensive designs. This time, a positive difference indicates that the AHSS-intensive design has higher emissions; a negative difference indicates that the Al-intensive design has higher emission. Clearly, in all parameter scenarios covered in this study, the AHSS-intensive design results in lower GHG emissions than the Al-intensive design.

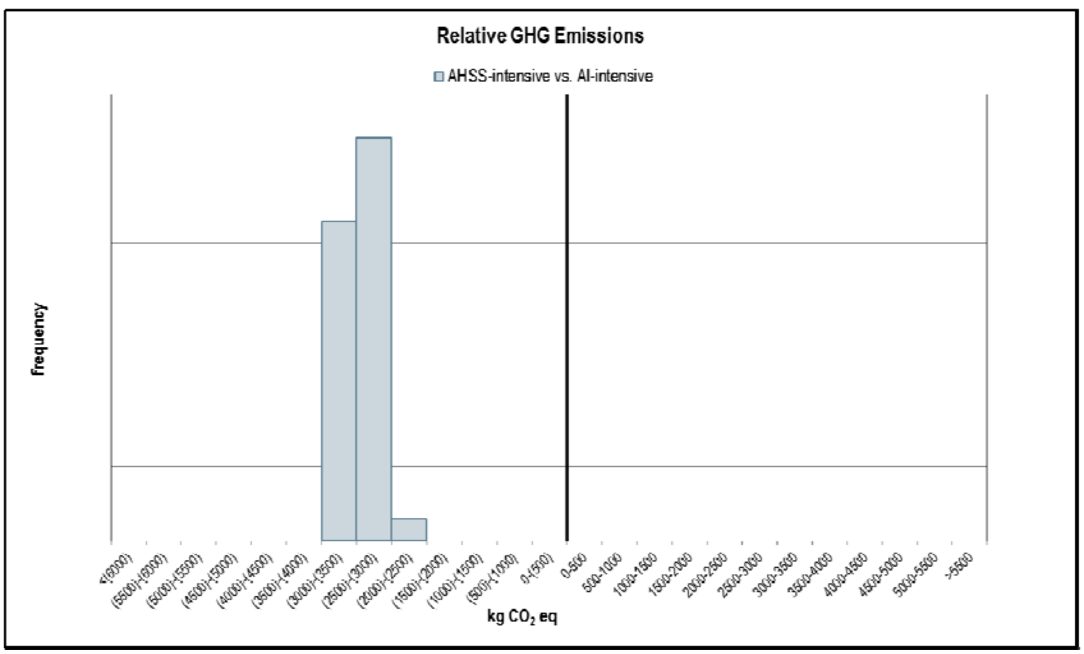


Figure 6 – Distribution of Relative Results: AHSS-Intensive vs. Al-Intensive

Expected vs. Actual Emissions – The Hole in the Tailpipe

As referenced in Background previously, current vehicle emissions regulations account only for emissions coming from the tailpipe. In addition to underestimating the total emissions of a vehicle, this approach can overestimate the emissions savings from technologies that may lower tailpipe emissions, but increase emissions in other phases of the vehicles life. Setting emissions reduction goals based on these technologies without a thorough understanding of their life cycle impact makes it impossible to know whether or not the goals are being met.

Lightweighting with energy-intensive materials can be just such a case. By examining both the expected (use phase only) emissions and the actual (life cycle) emissions, it becomes clear that tailpipe-only regulations will not achieve the emissions reduction goals for which they are intended. Table 2 and Figure 7 show both the expected and actual emissions for both the minimum and maximum scenarios, as well as the savings over the Baseline design.

For the Al-intensive design, it is clear that the expected emissions benefit, which reflects only the use-phase savings, is much greater than the actual benefit, which includes the added production phase burden of the aluminium production. Emissions reduction goals based on the benefits of this degree of lightweighting with aluminium will clearly fall well short.

An examination of the expected and actual emissions of the AHSS-intensive design, also shows the advantage of an LCA-based approach to regulation. In this case, because lightweighting with AHSS reduces emissions in both the production and use phases, the emissions savings is greater than expected. However it is still clear that taking into account all of the phases of the vehicle's life gives a more accurate picture of the emissions.

Table 1 - Expected and Actual Emissions Savings

		Baseline		**AHSS-intensive**		**Al- intensive**	
		Expected	**Actual**	**Expected**	**Actual**	**Expected**	**Actual**
Production	Minimum		13,743		12,968		22,852
	Maximum		13,865		13,089		22,973
Use	Minimum	36,891	36,891	33,752	33,752	32,842	32,842
	Maximum	61,486	61,486	58,613	58,613	57,779	57,779
End of Life	Minimum		(4,111)		(3,793)		(9,794)
	Maximum		(4,111)		(3,793)		(9,794)
Total	Minimum	36,891	**46,524**	33,752	**42,927**	32,842	**45,899**
	Maximum	61,486	**71,239**	58,613	**67,909**	57,779	**70,958**
Savings Over Baseline	Minimum	--	**--**	3,139	3,596	4,050	624
	Maximum	--	**--**	2,873	3,330	3,707	281

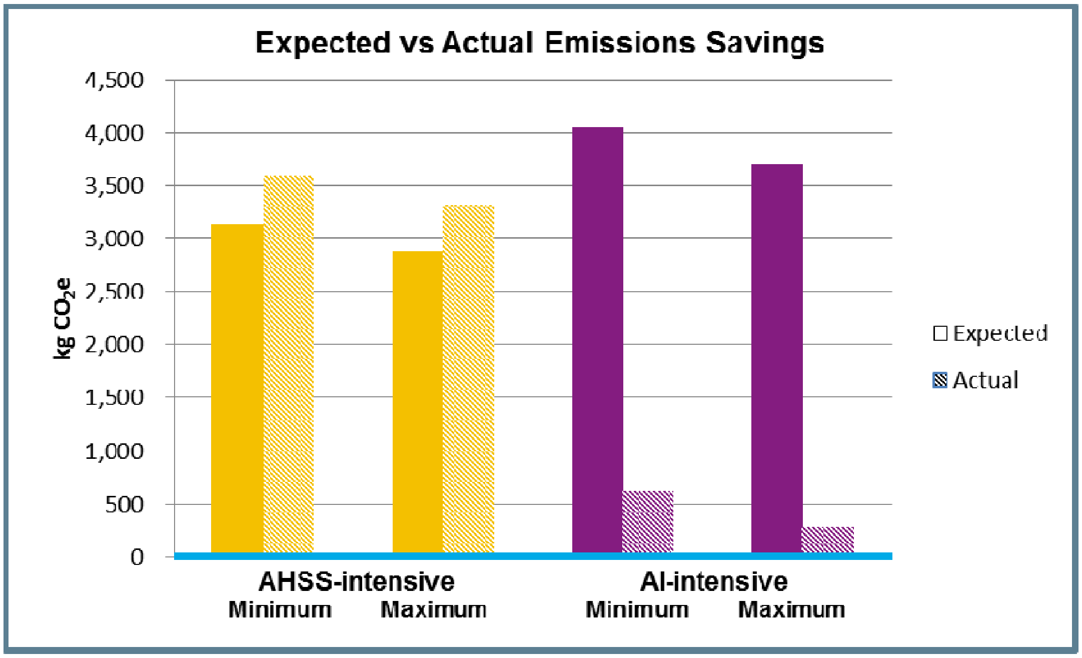


Figure 7 – Expected and Actual Emissions Savings

An examination of the expected and actual emissions of the AHSS-intensive design, as shown in Figure 8, also shows the advantage of an LCA-based approach to regulation. In this case, because lightweighting with AHSS reduces emissions in both the production and use phases, the reduction of emissions is greater than expected. However, it is still clear that taking into account all of the phases of the vehicle's life gives a more accurate picture of the emissions.

Conclusions

1. The AHSS-intensive design shows lower life cycle GHG emissions in all parameter scenarios investigated, while the Al-intensive design shows the possibility of unintended consequences in approximately 23% of the parameter scenarios.

2. Plotting both the expected and actual emissions for each material scenario clearly shows the inadequacy of tailpipe-only vehicle emissions regulations and the need to include LCA in future regulations.

ANNOTATIONS

[1] AISI, et al., *Declaration by the Metals Industry on Recycling Principles*, International Journal of Life Cycle Assessment, 2006

[2] fka, Wohlecker, Roland, et al., *Determination of Weight Elasticity of Fuel Economy for Conventional ICE Vehicles, Hybrid Vehicles and Fuel Cell Vehicles*, fka, Report 55510, June 2007.