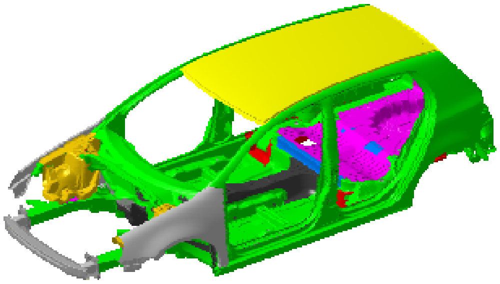


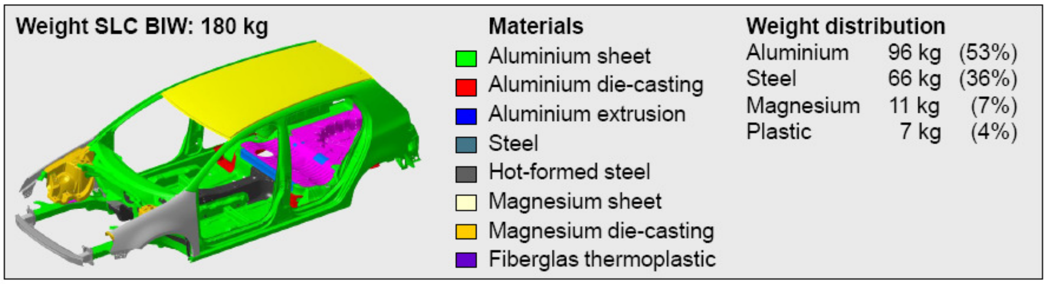
BACKGROUND

The Super LIGHT-Car (SLC) project was initiated in 2005 by a consortium of 38 leading European organizations, with Volkswagen serving as project coordinator. It was co-funded by the European Commission under the 6th Framework Programme, and was part of the European Council for Automotive Research's (EUCAR) multi-material development efforts. The primary goal of SLC was to develop a real, multi-material C-Class body structure (BIW) that achieved a 30% weight reduction, compared to the 2005 benchmark vehicles. Other goals included reduced material consumption, lightweighting costs of no more than 5 €/kg, equivalent structural performance, and the capability of being produced at a rate of 1,000 vehicles per day.

During the second year of the project, three vehicle concepts were developed, each with a different focus. The first was the Universal Light Body Concept (ULBC), which focused on all of the original project goals, but with a cost requirement (< 2.5 €/kg) even lower than the original goal set for the project. This effort resulted in a 29% mass reduction of 82 kg, at an additional cost of 2,7 €/kg. The second was the Super Light Body Concept (SLBC). The focus here was maximising weight saving, with a more generous cost requirement of < 10 €/kg savings. The results were a mass reduction of 41%, or 114 kg, with a cost increase of 2,70 €/kg. The third concept was developed by ArcelorMittal, one of the SLC partners, whose all-steel efforts focused achieving cost-effective weight reduction through the utilization of the latest grades of steel.

Blending these three designs into one, the Super LIGHT Car utilises a wide range of materials: 53% aluminium, 36% steel (in a variety of grades), 7% magnesium, and 4% composite.

Material distribution for SLC is shown below.



Weight SLC BIW: 180 kg

Materials

- 🟩 Aluminium sheet
- 🟥 Aluminium die-casting
- 🟦 Aluminium extrusion
- ▨ Steel
- ■ Hot-formed steel
- □ Magnesium sheet
- 🟨 Magnesium die-casting
- 🟪 Fiberglas thermoplastic

Weight distribution		
Aluminium	96 kg	(53%)
Steel	66 kg	(36%)
Magnesium	11 kg	(7%)
Plastic	7 kg	(4%)

Figure 1: Super LIGHT Car material distribution.

The SLC study included a cost analysis, but did not include a life cycle assessment (LCA). The analysis showed the cost to produce SLC was 112% of the reference vehicle, a Golf V. Stated differently, the cost of lightweighting in SLC was more than 7 €/kg.

Volkswagen and PE International conducted a Life Cycle Assessment (LCA) of the body structure, but appear to have apportioned use phase savings based on the weight savings from the multi-material approach. This has to the potential of greatly exaggerating use phase savings; indeed, they concluded that Use phase savings more than offset the high production emissions, and noted that "recycling credits for magnesium and aluminium were higher than the steel reference vehicle".

LIFE CYCLE ASSESSMENT PARAMETERS

A vehicle Life Cycle Assessment (LCA) was conducted by WorldAutoSteel comparing the SLC to a Volkswagen Golf V as the baseline vehicle, and a simulated Golf V manufactured from AHSS. We used the UCSB Phase 2 GHG Materials Comparison Model (June 30, 2010), featuring the most up-to-date LCI's for steel (worldsteel, 2010) and aluminium (IAI, 2005). Our vehicle analysis included an estimated lifetime mileage of 200,000 km and fuel consumption ratings of 7.2 L/100km or 32.7 mpg, Golf V performance with a 1.6 liter gasoline ICE. All evaluations were conducted with a recycling treatment consistent with end-of-life methodology, the prescription adopted by the metals industry (alpha value = 0.1). This treatment favours materials with high manufacturing emissions. The modelling parameters are shown in Table 1.

Table 1: UCSB Model Parameters for Super LIGHT Car

Golf V	AHSS	Super LIGHT Car
Vehicle Curb Weight – 1320 kg	1247 kg	1189 kg
Body Structure Mass - 281 kg	225 kg	180 kg
Body Structure Mass Reduction	56 kg	101 kg
Powertrain – ICE-g 410.4 kg		
Powertrain Resizing?	Yes – 356 kg	Yes – 356 kg
Secondary Mass Reduction	30 %	30 %
Total Mass Reduction	73 kg	131 kg
Fuel Consumption – 7.2 liters/100 km		
Driving Cycle	NEDC	NEDC
Lifetime Driving Distance	200,000 km / 124,321 miles	200,000 km / 124,321 miles
Steel Composition	75% hot-dip galvanized, 25% CR	75% hot-dip galvanized, 25% CR
Recycling Treatment – alpha value	Alpha = 0.1	Alpha = 0.1
SRI Recycling Rates:		
Steel (conv. and AHSS)	97% collection, 98% shredder efficiency, 95% collection	97% collection, 98% shredder efficiency, 95% collection
Aluminium	97% collection, 90% shredder efficiency, 90% collection	97% collection, 90% shredder efficiency, 90% collection
Magnesium	97% collection, 90% shredder efficiency, 90% collection	97% collection, 90% shredder efficiency, 90% collection
Manufacturing Yields:		
Steel (conv. and AHSS)	60% stamping	60% stamping
Aluminium	55% stamping, 80% extrusion and casting	55% stamping, 80% extrusion and casting
Magnesium	55% casting, 96% sheet	55% casting, 96% sheet
Composites	50%	50%

AHSS Mass Reduction Potential. The UltraLight Family of Research (www.worldautosteel.org), as well as industry practice, shows that a 25% mass reduction can be achieved with AHSS compared to conventional mild steel. Optimisation techniques have yielded light weighting potential beyond 35% for specific sub-systems. In our AHSS-intensive Golf V concept we've estimated mass reduction potential of 20% compared to the baseline vehicle, recognizing the potential of optimisation and the reality of a body structure already utilising some AHSS products.

Table 2 (below) shows the results of the UCSB modelling.

Table 2: UCSB GHG Materials Comparison Model Results for Super LIGHT Car

Vehicle Description	Mass (kg)	Body Structure Materials	Production GHG's (kg)	Use Phase GHGs (kg)	Recycling Credit (kg)	Life Cycle GHGs (kg)
Baseline – 2008 Golf V	1310 kg	Steel	3,019	41,249	(1,288)	42,980
AHSS-Intensive Golf V	1428 kg	AHSS	2,721	39,868	(1,144)	41,445
Super LIGHT Car	1210 kg	Multi-Material	4,478	38,770	(2,220)	41,028

CONCLUSIONS

1. Multi-material vehicles have distinct emissions advantages in the use phase, but distinct disadvantages in the production phase. Figure 2 shows, however, that with optimal recycling behavior, Super LIGHT Car achieves slightly lower life cycle emissions compared to the AHSS-intensive concept.

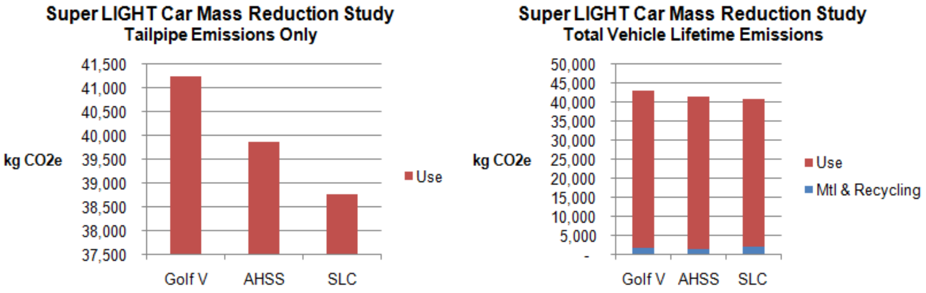


Figure 2: Tailpipe vs. Total Life Cycle Emissions for Super LIGHT Car.

2. Contrary to the misperception that material production emissions are insignificant, Super LIGHT Car's production emissions account for ~12% of its lifetime emissions, and thus cannot be ignored when considering environmental impacts. As the use of advanced powertrains (such as hybrids) and improved driving cycles (such as the implementation of timed lights and roundabouts) accelerate, dramatic reductions in use phase GHG emissions occur, and **material production emissions will become a key determinant of total life cycle emissions.**

3. The AHSS-intensive Golf V concept is the only material / design solution that results in mass, cost *and* emission savings in all life cycle phases, compared to the baseline design.

4. Super LIGHT Car (or multi-material vehicle), results in 65% greater production emissions compared to the AHSS-intensive concept vehicle. Accumulative emissions are thus significantly greater until recycling occurs at vehicle end-of-life. Due to concerns regarding the infrastructure for recycled content of GHG-intensive materials, the benefits from recycling of these materials is at minimum one vehicle life cycle, or 12 years, into the future. It's important to note that a high percentage of recycling is a fundamental requirement of energy-intensive materials (magnesium and aluminium), in order to offset their production emissions. Small changes in their recycling rates will have a large impact on GHG emissions.

5. A more realistic comparison of emissions performance for these vehicles would be to discount recycling credits altogether, until these vehicles actually demonstrate recycling behaviour that match recycling assumptions. In this scenario, Super LIGHT Car shows 650 kg **greater** CO2e per vehicle compared to the AHSS-intensive concept. With an assumption of 15 million vehicle production by 2015, this accounts for ~10 million additional tons of CO2e annual emissions.

6. Research studies argue that upfront emissions cause greater damage to the environment due to Cumulative Radiative Forcing (CRF) and propose the application of a Time Correction Factor (TCF) to account for such temporal effects. AISI and UC-Davis are collaborating on a study that will provide data to legislators, emphasizing the need for LCA and CRF cumulative effects to prevent tailpipe emissions legislation that cause unintended consequences. To demonstrate the effect, Figure 3 is a chart with TCF's applied to the material production and recycling phases of the

total vehicle life cycle. The results demonstrate the difficulty in recovering from the harmful emissions associated with environmentally unfriendly materials.

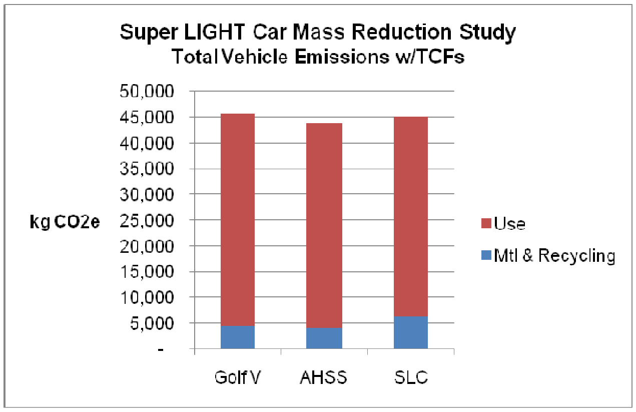


Figure 3: The Application of Time Correction Factors to Production Emissions

7. Present literature describing emissions allocated to the Body Structure (BIW) leads to an overestimation of the fuel consumption impact of vehicle mass reduction, and “is just plain wrong” (Dr. Geyer, UCSB Bren School of Environmental Science).