

**SUPPORTING INFORMATION FOR:**

Kim, H.-J., C. McMillan, G. A. Keoleian, and S. J. Skerlos. 2010. Greenhouse gas emissions payback for lightweight vehicles using aluminum and high strength steel. *Journal of Industrial Ecology*.

**Summary**

This supplement contains three tables with data on life cycle greenhouse gas emissions, material substitution, and methods used in both aluminum and steel industries, as well as vehicle miles traveled (VMT) assumptions as used in the modeling.

**A. Life Cycle Greenhouse Gas Emissions for each LW scenarios using industry data**

This is the result of life cycle GHG emissions assessment for each LW scenarios using the data which both steel and aluminum industry newly provided. Their values are 2.2 kg CO<sub>2</sub> –eq/kg for the high estimate of primary steel, 2.3 kg CO<sub>2</sub> –eq/kg for the high estimate of high strength steel GHG emission factor (Opbroek 2010) for the Mid emission factors. In addition, 2.7 kg CO<sub>2</sub> –eq/kg (primary steel) and 2.8 kg CO<sub>2</sub> –eq/kg (high strength steel) are applied as the High emission factors (Table S-1). For aluminum case, 0.5 kg CO<sub>2</sub>-eq/kg is applied for the secondary aluminum production GHG emission factor (EAA 2008).

In this case, the 19% LW HSS has approximately similar performance to the 23% LW AL for the upper bound value, however, the 23% LW AL option has better performance at the lower bound. These trends are still valid, when 2.2 and 2.3 kg CO<sub>2</sub> –eq/kg are applied for high emission factors for primary and high strength steel emission factors (Table S-2).

**Table S-1.** Life cycle GHG emissions for each LW Scenario using industry-provided emission factors

LW Options	Production			Use		EOL	Total	
	Low emission factors	Mid emission factors	High emission factors	Low	High		Low	High
Baseline Vehicle	1,670	3,590	4,100	38,248	57,753	147	40,065	62,000
6% LW HSS	1,620	3,685	3,863	35,547	54,178	138	37,305	58,179
6% LW AL	911	3,750	4,350	35,547	54,178	122	36,580	58,650
11% LW AL	896	4,320	5,090	32,548	49,145	108	33,552	54,343
19% LW HSS	1,563	3,765	3,787	29,500	44,544	100	31,163	48,431
23% LW AL	870	5,720	6,540	27,945	42,197	147	28,962	48,884

**Table S-2.** Life cycle GHG emissions for each LW Scenario using industry provided emission factor

LW Options	Production			Use		EOL	Total	
	Low emission factors	Mid emission factors	High emission factors	Low	High		Low	High
Baseline Vehicle	1,670	3,590	4,100	38,248	57,753	147	40,065	62,000
6% LW HSS	1,620		3,685	35,547	54,178	138	37,305	58,001
6% LW AL	911	3,750	4,350	35,547	54,178	122	36,580	58,650
11% LW AL	896	4,320	5,090	32,548	49,145	108	33,552	54,343
19% LW HSS	1,563		3,765	29,500	44,544	100	31,163	48,409
23% LW AL	870	5,720	6,540	27,945	42,197	147	28,962	48,884

**B. Table S-3** Material substitution for lightweighting options (modified from Tessieri and Ng 1995)

(√: Substitution into the light metals)

Component	Quantity per Vehicle	Total Weight as Aluminum	Total Weight as HSS	Baseline	LW 6% HSS	LW 6% Aluminum	LW 11% Aluminum	LW 19% HSS	LW 23% Aluminum
<b>(A) POWERTRAIN</b>									
<b>(1) Engine</b>									
Balance Shaft Carrier	1	2.5	4.4					√	
Belt Tensioner	1	0.8	1.4		√			√	
Brackets	1	1.2	2.1		√		√	√	√
Catalytic Converter Heat Shield	1	0.5	1.0	√		√	√		√
Chain Case	1	2.7	4.9				√		√
Cylinder Head	2	12.7	22.9	√		√	√		√
Cylinder Liner	6	2.7	4.9		√			√	
Engine Block	1	18.2	32.7					√	
Fuel Filling Rail	1	0.5	0.8		√		√	√	√
Intake Manifold	1	4.5	8.2		√			√	
Oil Filter Adapter	1	0.2	0.3				√		√
Oil Pan	1	3.2	5.7				√		√
Oil Pump Body/Cover	1	1.5	2.6		√		√	√	√
Pistons	6	3.3	5.9	√		√	√		√
Rocker/Cam Covers	1	1.6	2.9		√		√	√	√
Rocker Arm	1	0.9	1.6		√			√	
Rocker Assembly Pedestals	1	1.8	3.3		√			√	
Starter motor Nose Housing	1	0.6	1.1		√		√	√	√
Super Charger Cover/Bedring Plate	1	2.5	4.6					√	
Super Charger Housing	1	7.4	13.3					√	
Super Charger Rotor	1	3.0	5.5					√	
Throttle Body	1	0.7	1.3		√			√	
Timing Chain Cover/Front Cover	1	1.7	3.0		√		√	√	√
Turbo Intake	1	2.3	4.1		√			√	
Water Pump Assembly	1	1.4	2.5	√		√	√		√
<b>(2) Transmission</b>									
Accumulator (Housing, Bushing Cover)	1	1.2	2.1		√		√	√	√
Bedring Cup Retainer	1	0.7	1.2		√			√	
Clutch Retainer	1	2.2	4.0		√			√	
Drive Shaft	1	10.5	18.8		√			√	
Driven Sproket Support	1	1.8	3.3		√			√	
Drivetrain End Cover/Side Differential	1	3.6	6.5					√	
Extension Cover	1	0.9	1.6				√		√
Forward Servo (Piston and Cover)	1	0.3	0.6		√		√	√	√
Hydraulic Clutch	1	0.9	1.6		√			√	
Input Clutch Housing	1	1.8	3.3		√			√	
Pistons	1	1.4	2.5	√		√	√	√	√
Reverse Boost Bushing	1	0.0	0.1				√		√
Reverse Servo(Piston and Cover)	1	0.2	0.3		√			√	
Stator	1	0.7	1.2		√			√	√
Structural Side Cover	1	4.2	7.6				□	√	
Transfer Plate/Channel Plate	1	1.7	3.1		√		√	√	√
Transmission/Transfer Case	1	13.6	24.5	√		√	√	□	√
Valve Body	1	2.4	4.3		√		√	√	√
<b>(3) Steering System</b>									
Power Steering Pump Bracket	1	1.4	2.5		√			√	
Power Steering Rack & Pinion Housing	1	1.8	3.3	√		√	√		√
Steering Wheel	1	2.7	4.9		√			√	

Table S-3 continued

(√: Substitution into the light metals)

Component	Quantity per Vehicle	Total Weight as Aluminum	Total Weight as HSS	Baseline	LW 6% HSS	LW 6% Aluminum	LW 11% Aluminum	LW 19% HSS	LW 23% Aluminum
<b>(B) BODY IN WHITE/CLOSURE PANEL/BUMPER</b>		0.0	0.0		√			√	
Body Shell	1	145.5	261.8			√	√	√	√
Bumper System Front	1	7.7	13.9		√			√	
Bumper System Rear	1	7.3	13.1		√			√	
Deck Lid	1	7.0	12.6		√			√	
Doors	4	29.8	53.7						√
Door Reinforcement Beams	4	7.3	13.1		√		√	√	√
Fender/Quarter Panel	2	6.8	12.3				√		√
Hood	1	8.8	15.8						√
Luggage Rack	1	2.3	4.1		√		√	√	√
Roof	1	2.3	4.1		√		√	√	√
Seat Pan	1	1.3	2.3		√		√	√	√
<b>(C) BRAKE SYSTEM</b>									
ABS Module Housing	1	1.0	1.7		√			√	
Brake Pistons	1	0.5	0.8		√			√	√
Brake Rotor Front	2	5.9	10.6		√			√	
Brake Rotor Rear	2	3.6	6.5		√			√	√
Calipers	2	6.4	11.5		√			√	√
Master Cylinder	1	0.9	1.6	√		√	√		√
<b>(D) CHASSIS AND SUSPENSION</b>									
Cross Member/Sub Frame	2	11.5	20.6	√		√	√		√
Diff Carrier	1	4.3	7.8		√			√	
Knucide Front	2	5.8	10.5			√			√
Knucide Rear	2	5.9	10.6			√		√	√
Control Arm Front Lower	1	2.6	4.7		√			√	√
Control Arm Front Upper	1	2.4	4.3		√			√	
Control Arm Rear Lower	1	2.9	5.2		√			√	
Control Arm Rear Upper	1	3.1	5.6		√			√	
Rear Assembly	1	9.1	16.4			√			√
<b>(E) CLIMATE CONTROL</b>		0.0	0.0		√			√	
A/C Compressor & Pistons	1	3.6	6.5	√		√	√		√
Accumulator/Dryer	1	0.5	0.8		√			√	
Block Valve	1	0.5	0.8	√		√	√		√
Condenser	1	3.2	5.7	√		√	√		√
Evaporator	1	1.8	3.3	√		√	√		√
Heater Core	1	0.9	1.6	√		√	√		√
Radiator	1	1.8	3.3	√		√	√		√
Receiver/Dryer	1	0.9	1.6	√		√	√		√
System Tubing/Hardware	1	5.5	9.8			√	√	√	√
<b>(F) ELECTRICAL/MECHANICAL GROUP</b>		0.0	0.0		√			√	
Alternator Case	1	0.9	1.6	√		√	√		√
EEC Module Housing	1	0.1	0.2	√		√	√		√
Radio Chassis	1	0.4	0.7		√			√	
Radio Heat Sink	1	0.1	0.2	√		√	√		√
Underhood Moodule Housing	1	1.0	1.8	√		√	√		√
Wiper Motor Housing	1	0.5	0.8	√		√	√		√
<b>(G) ALLOY WHEELS</b>		0.0	0.0		√			√	
4 Wheels	4	23.6	42.5	√		√	√		√
<b>(H) AIR BAG COMPONENTS</b>		0.0	0.0		√			√	
Air Bag Brackets	1	0.2	0.4		√			√	
Driver Air Bag	1	0.2	0.4		√			√	
Passenger Air Bag	1	0.6	1.1	√		√	√		√
<b>MISCELLANEOUS</b>		0.0	0.0		√			√	
Seat Frame	1	9.1	16.4		√		√	√	√
Sunroof Tracks	1	0.9	1.6		√			√	
Threadplate	1	3.6	6.5		√			√	

C. Table S-4 Used manufacturing methods and alloys (modified from Tessieri and Ng 1995)

(√: Substitution into the light metals)

Component	Manufacturing methods				Alloys																														
	Cast AL	Flat rolled	Extruded	Forged	319	332	339	356	357	380	383	390	A356	A357	1100	1350	3003	4043	4045	4047	5052	5182	5454	5754	6009	6061	6063	6111	7003	7021	other comp.				
<b>(A) POWERTRAIN</b>																																			
<b>(1) Engine</b>																																			
Balance Shaft Carrier	2.5	0.0	0.0	0.0				√																											
Belt Tensioner	0.8	0.0	0.0	0.0						√																									
Brackets	0.8	0.0	0.0	0.0	√					√																									
Catalytic Converter Heat Shield	0.0	0.5	0.1	0.1																		√													
Chain Case	2.7	0.0	0.0	0.0	√					√																									
Cylinder Head	12.7	0.0	0.0	0.0	√			√		√			√																						
Cylinder Liner	2.7	0.0	0.0	0.0								√																							
Engine Block	18.2	0.0	0.0	0.0	√			√		√																									
Fuel Filling Rail	0.0	0.0	0.0	0.0																							√								
Intake Manifold	0.0	0.0	0.0	0.0	√																													√	
Oil Filter Adapter	0.2	0.0	0.0	0.0						√																									
Oil Pan	3.2	0.0	0.0	0.0						√																									
Oil Pump Body/Cover	1.5	0.0	0.0	0.0						√		√																							
Pistons	3.3	0.0	0.0	0.0		√	√					√																							
Rocker/Cam Covers	1.6	0.0	0.0	0.0						√																									
Rocker Arm	0.9	0.0	0.0	0.0									√																						
Rocker Assembly Pedestals	1.8	0.0	0.0	0.0					√					√																					
Starter motor Nose Housing	0.6	0.0	0.0	0.0						√																									
Super Charger Cover/Bedring Plate	2.5	0.0	0.0	0.0						√	√																								
Super Charger Housing	7.4	0.0	0.0	0.0	√																														
Super Charger Rotor	0.0	0.0	0.0	0.0																													√		
Throttle Body	0.7	0.0	0.0	0.0						√																									
Timing Chain Cover/Front Cover	1.7	0.0	0.0	0.0	√					√																									
Turbo Intake	2.3	0.0	0.0	0.0	√					√																									
Water Pump Assembly	1.4	0.0	0.0	0.0	√					√																									

Table S-4 continued

(√: Substitution into the light metals)

Component	Manufacturing methods				Alloys																												
	Cast AL	Flat rolled	Extruded	Forged	319	332	339	356	357	380	383	390	A356	A357	1100	1350	3003	4043	4045	4047	5052	5182	5454	5754	6009	6061	6063	6111	7003	7021	other comp.		
<b>(2) Transmission</b>	0.0	0.0	0.0	0.0																													
Accumulator (Housing, Bushing Cover)	1.2	0.0	0.0	0.0						√																							
Bedring Cup Retainer	0.4	0.0	0.0	0.0								√																					
Clutch Retainer	1.1	0.0	0.0	0.0						√		√																					
Drive Shaft	0.0	0.0	0.0	0.0																							√						
Driven Sproket Support	1.8	0.0	0.0	0.0						√																							
Drivetrain End Cover/Side Differential	3.6	0.0	0.0	0.0						√																							
Extension Cover	0.9	0.0	0.0	0.0						√																							
Forward Servo (Piston and Cover)	0.3	0.0	0.0	0.0						√																							
Hydraulic Clutch	0.9	0.0	0.0	0.0						√																							
Input Clutch Housing	1.8	0.0	0.0	0.0						√																							
Pistons	1.4	0.0	0.0	0.0						√																							
Reverse Boost Bushing	0.0	0.0	0.0	0.0						√																							
Reverse Servo(Piston and Cover)	0.2	0.0	0.0	0.0						√																							
Stator	0.7	0.0	0.0	0.0						√																							
Structural Side Cover	4.2	0.0	0.0	0.0						√																							
Transfer Plate/Channel Plate	1.7	0.0	0.0	0.0						√																							
Transmission/Transfer Case	13.6	0.0	0.0	0.0						√																							
Valve Body	2.4	0.0	0.0	0.0						√																							
<b>(3) Steering System</b>	0.0	0.0	0.0	0.0																													
Power Steering Pump Bracket	1.4	0.0	0.0	0.0						√																							
Power Steering Rack & Pinion Housing	1.8	0.0	0.0	0.0						√																							
Steering Wheel	0.8	0.0	0.0	0.0								√																					

Table S-4 continued

(√: Substitution into the light metals)

Component	Manufacturing methods				Alloys																															
	Cast AL	Flat rolled	Extruded	Forged	319	332	339	356	357	380	383	390	A356	A357	1100	1350	3003	4043	4045	4047	5052	5182	5454	5754	6009	6061	6063	6111	7003	7021	other comp.					
<b>(B) BODY IN WHITE/CLOSURE</b>																																				
Body Shell	0.0	145	30.0	13.6																			√		√							√				
Bumper System Front	0.0	2.6	0.5	0.2																													√		√	
Bumper System Rear	0.0	2.3	0.5	0.2																													√		√	
Deck Lid	0.0	7.0	1.4	0.7																														√		
Doors	0.0	30	6.2	2.8																														√		
Door Reinforcement Beams	0.0	0.0	0.0	0.0																														√		
Fender/Quarter Panel	0.0	6.8	1.4	0.6																														√		
Hood	0.0	8.8	1.8	0.8																															√	
Roof	0.0	2.3	0.5	0.2																															√	
Seat Pan	0.0	1.3	0.3	0.1																				√												
<b>(C) BRAKE SYSTEM</b>	0.0	0.0	0.0	0.0																																
ABS Module Housing	0.7	0.0	0.3	0.0					√																									√		
Brake Pistons	0.5	0.0	0.0	0.0						√																										
Brake Rotor Front	5.9	0.0	0.0	0.0		√																														√
Brake Rotor Rear	3.6	0.0	0.0	0.0		√																														√
Calipers	6.4	0.0	0.0	0.0										√																						
Master Cylinder	0.9	0.0	0.0	0.0					√																											
<b>(D) CHASSIS AND SUSPENSION</b>	0.0	0.0	0.0	0.0																																
Cross Member/Sub Frame	9.2	2.3	0.5	0.2									√														√									
Diff Carrier	4.3	0.0	0.0	0.0		√				√																										
Knucide Front	5.8	0.0	0.0	0.0									√																							
Knucide Rear	5.9	0.0	0.0	0.0									√																							
Control Arm Front Lower	2.2	0.0	0.0	0.5									√	√																				√		
Control Arm Front Upper	1.9	0.0	0.0	0.5									√	√																				√		
Control Arm Rear Lower	2.4	0.0	0.0	0.5									√	√																				√		
Control Arm Rear Upper	2.7	0.0	0.0	0.5									√	√																				√		

Table S-4 continued

(√: Substitution into the light metals)

Component	Manufacturing methods				Alloys																													
	Cast AL	Fiat rolled	Extruded	Forged	319	332	339	356	357	380	383	390	A356	A357	1100	1350	3003	4043	4045	4047	5052	5182	5454	5754	6009	6061	6063	6111	7003	7021	other comp.			
<b>(E) CLIMATE CONTROL</b>																																		
A/C Compressor & Pistons	3.6	0.0	0.0	0.0																														
Accumulator/Dryer	0.0	0.0	0.0	0.0					√			√																√						
Block Valve	0.0	0.0	0.0	0.0																							√							
Condenser	0.0	3.2	0.7	0.3													√	√																
Evaporator	0.0	1.8	0.4	0.2											√	√					√													
Heater Core	0.0	0.9	0.2	0.1											√		√		√															
Radiator	0.0	1.8	0.4	0.2											√		√	√	√	√														
Receiver/Dryer	0.0	0.1	0.0	0.0																							√							
System Tubing/Hardware	0.0	0.0	5.5	0.0											√		√																	
<b>(F)ELEC/MECHANICAL GROUP</b>		0.0																																
Alternator Case	0.9	0.0	0.0	0.0						√																								
EEC Module Housing	0.0	0.1	0.0	0.0																		√												
Radio Chassis	0.4	0.0	0.0	0.0						√																								
Radio Heat Sink	0.0	0.1	0.0	0.0																											√			
Underhood Moodule Housing	1.0	0.0	0.0	0.0						√																								
Wiper Motor Housing	0.5	0.0	0.0	0.0						√																								
<b>(G) ALLOY WHEELS</b>	0.0	0.0	0.0	0.0																														
4 Wheels	0.0	0.0	0.0	0.0																														
<b>(H) AIR BAG COMPONENTS</b>	0.0	0.0	0.0	0.0																														
Air Bag Brackets	0.0	0.0	0.2	0.0																							√							
Driver Air Bag	0.0	0.0	0.0	0.2																							√							
Passenger Air Bag	0.0	0.0	0.0	0.0																							√							
<b>MISCELLANEOUS</b>	0.0	0.0	0.0	0.0																														
Seat Frame	0.0	0.0	9.1	0.0																						√								
Sunroof Tracks	0.0	0.0	0.0	0.0																						√								
Threadplate	0.0	0.0	0.0	0.0														√																





**D. Table S-5 Model from (Das, 2000) Resulting in VMT Assumption of 181,195 Miles**

Vehicle age (Years)	Annual miles driven
0	15220
1	14250
2~5	12560
6~10	9780
11~17	9780

### References

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