Vehicle Materials: Material Composition of Powertrain Systems

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September 2015 (revised August 2018)

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ACRONYMS

AHSS	advanced high strength steel
BEV	battery electric vehicle
BOF	basic oxygen furnace
BoP	balance of plant
CAP	criteria air pollutants
CED	cumulative energy demand
CI-ICEV	compression ignited ICEV
EAF	electric arc furnace
FCV	fuel cell vehicle
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GHG	greenhouse gas
HVAC	heating, ventilation, and air conditioning
ICEV	internal combustion engine vehicle
LCA	life cycle analysis
LCI	life cycle inventory
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle
SI-ICEV	spark ignited ICEV
USAMP	United State Automotive Materials Partnership

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1 INTRODUCTION

There are a number of key parameters required for representative determinations of vehicle Life Cycle Inventories (LCI). Included in this set are vehicle mass, powertrain type, material composition of vehicle components, fuel consumption, and lifetime driving distance. Of the mass related components in this set, the overall vehicle mass is the most significant because it impacts fuel consumption, a major component of the fuel cycle, in addition to impacting the vehicle cycle. However, vehicle material composition is also important. For example, the use of lighter weight materials on a specific vehicle will reduce its fuel consumption (liters/km). On the other hand, the use of lighter weight materials is usually accompanied by higher environmental burdens than those for conventional vehicle materials, which, in turn impacts a vehicle's environmental performance. When substituting alternative for conventional materials, the material production stage of a vehicle's life cycle is usually negatively impacted, the magnitude of which is dependent on the amount of substitution among other factors. This is because most alternative materials generally have greater production energy use and emissions than those for conventional materials. This is readily seen upon a casual comparison of material production burdens for conventional mild steel vs. those for the usual alternative materials employed in lightweight cars such as aluminum, magnesium, and glass and carbon fiber composites (Argonne 2014b).

When compared to decades past and considering weight reduction initiatives, the material composition of current vehicles is being transformed. More specifically, because of increasing concerns over climate change, vehicles are increasingly being made using alternative materials in order to reduce vehicle weight and hence improve (reduce) fuel consumption (e.g. liter/km). Further, reduced fuel consumption improves operational costs. An example of a shift in vehicle material composition is witnessed by the ever increasing use of aluminum on cars, resulting in a reduction in the amount of steel being used. This is exemplified by the recent deployment of Ford's aluminum intensive F-150 truck. However, the production of a kg of virgin aluminum has considerably higher environmental burdens than those for a kg of steel (Argonne 2014b; Dai et al 2015; Kelly et al. 2015). Nevertheless, from a functional unit point of view and over the lifetime of the vehicle, there is a net positive benefit of replacing steel with aluminum in appropriate vehicle applications (Keoleian and Sullivan 2012).

Life Cycle Analysis (LCA) is a consistent methodology for evaluating environmental performance of various product systems. The system boundary of LCA is from cradle to gate as applied to a wide range of product systems, including cars and trucks. In GREET2, a vehicle's life cycle is comprised of two aggregate life cycle stages: vehicle cycle and the fuel cycle. The former includes the life cycle stages of the production of vehicle materials, part manufacture and vehicle assembly, vehicle maintenance and repair, and end of life. The fuel cycle includes fuel production and its consumption by the vehicle.

Because many manufacturing and production processes evolve to newer more efficient systems over time, life cycle data for those systems that appear in various databases, including GREET1 and GREET2, need to be updated. For example, due to the enactment of renewable portfolio standards by many states for electric power production, renewable power from wind, photovoltaic, geothermal and other generators is displacing power from coal, gas, oil, and nuclear plants. Hence, the environmental burdens associated with the production of a unit (kWh) of grid electricity are changing, resulting in changes in key life cycle metrics that collectively represent the environmental performance of that unit of power. These metrics include criteria air pollutants (CAP), cumulative energy demand (CED) and life cycle greenhouse gas emissions (LC-GHG) per kWh of electricity and represent the energy and emission burdens associated with fuels used to make the power and the material production and construction activities required to build the power generating facilities. Recent studies have developed revised CED and LC-GHG (Sullivan et al. 2010-2014) and CAP (Cai et al. 2012) values for a kWh from a range of U.S. fossil, nuclear, and renewable generators. Those results have been used to update power production metrics in GREET1 (Argonne 2014a).

To conduct accurate LCAs on current and future vehicles, it is necessary to have up-to-date vehicle material compositions. The purpose of this report is to review overall changes in vehicle material composition with a focus on powertrain materials. Details on material composition of other vehicle subsystems like body, chassis, electrical and other are subjects for a future report. The vehicles most focused on are internal combustion engine vehicles (ICEV), though some limited data were found for fuel cell (FCV) and plug-in hybrid electric vehicle (PHEV) systems. First, an overall comparison is made on the average material composition of vehicles across various size classes over the last two decades. Next, changes in vehicle powertrain material composition are discussed. In regards to its impact on vehicle weight reduction, trends in power output versus vehicle mass are also discussed. Results of this study are intended to update material compositions of vehicle powertrains in the GREET2 model (Argonne 2014b).

2 METHODOLOGY

According to the structure outlined in the USAMP (1999) Generic Family Sedan life cycle study, we divide the vehicle into six systems, namely powertrain, suspension, HVAC, electrical, body, and finally interior. The powertrain systems which is the primary focus of this study is divided into 7 subsystems: exhaust, engine, transmission, air, clutch, fuel, and cooling. Our material categories are as follows: ferrous metals, aluminum alloys (henceforth denoted alloys), other metals, plastics, elastomers, fluids, fabrics, glass, and others.

The data used for this study are from several sources: USCAR data (USAMP 1999), Ford data (Sullivan 2003), some engine materials composition data from a European Car manufacturer (Sullivan 2015), extensive composition data from a confidential source, and data from the literature. The most complete and detailed data are those from the confidential source. That source provides vehicle information on a part by part basis, and in many cases the weight of the part and its material composition are given. For example, a brake pedal for one of the vehicles is listed as weighing 1.7 kg and being made of steel. However, such details do not apply to all of their part listings. For example, many parts in that dataset are listed as a combination of materials where the weight and identity of materials are given but the proportions of materials are not provided. An example is a 0.7 kg shift cable assembly listed as "metal + plastic" which in this case is made up of steel & EPDM but the relative amounts are not quantified. Due to this a number of assumptions has to be made. These assumptions are listed in Table 1. Admittedly, these assumptions are approximate but are expected to be reasonable estimates on an overall vehicle scale.

Summaries of material composition data from the confidential sources cannot be provided. However, Tables A-1 and A-2 are summaries of datasets developed during tear down studies of the Honda Accord (Singh 2012) and Toyota Venza (USEPA 2012); those tables contain material details for the powertrain only.

The USAMP data (1999) is detailed on a vehicle system level but less so on a subsystem level. Nevertheless, there is enough information in that report to provide an estimate of vehicle engine mass as well as the material composition of the powertrain and other major vehicle systems. Material compositions for both the overall vehicle and its powertrain are given in Table A-3 from the USAMP generic D-Class sedan. Also employed in this study are overall vehicle material compositions for a number of Ford vehicles of the early 2000s (Sullivan, 2003). These data are employed for comparing typical vehicle compositions between current and past model year populations.

Also employed here are material compositions for three spark ignited and two diesel engines. These material listings (Sullivan 2015) are detailed from an overall engine point of view but not on a part or subsystem basis.

Finally, we report data on a fuel cell powered vehicle (FCV) (Notter et al. 2010 & 2015). Material data for the fuel cell stack and BoP were reported by Notter et al (2015) and data for the drivetrain and glider of a BEV were taken from an earlier report (Notter et al. 2010) and used for the FCV. Because FCV and BEV are both electric vehicles, it is reasonable to use the drivetrain and glider from the BEV in this context. Also covered are some material composition data for the powertrain of a plug-in hybrid electric vehicle (PHEV). Unfortunately, these data (from a confidential source) are incomplete as the dataset from which they were derived did not have data on that system's 1.8 liter Atkinson cycle engine, an important and significant component of that powertrain. Details are in Table A-4.

TABLE 1 Assumptions for components: mass provided but materials proportion not

	As listed in confidential dataset	Assumption
1	Steel + alloy	For engine: 90% alloy and 10% steel
2	Steel + alloy	For all other systems: 50% alloy and 50% steel
3	Electronic Component	50% other metal (Cu, solder) and 50% plastic
4	Metal + plastic	30% plastic and 70% steel
5	Elastomer + plastic	50% elastomer and 50%plastic
6	Metal + elastomer	30% elastomer and 70% steel
7	Several components	50% alloy and 50% plastic

3 RESULTS

Table 2 reveals changes in overall vehicle material composition over time by presenting percentage composition results on two populations of vehicles for the time periods of "1993-2002" and "2010-2014". For convenience, we denote the former as "late-90s" and the latter as "current". These results are based on data given in Appendix A for the current vehicle population and data from Sullivan (2003) for the late-90s vehicle population. Each set contains a mix of vehicles ranging from trucks, SUVs, mini-vans, to sedans. Based on average values given in Table 2, it is clear that ferrous metal content of vehicles has decreased over time by about fifteen percentage points. Associated with that decrease is an increase in aluminum alloys. The relative amounts of plastics on vehicles has also increased over this time span. The use of other metals appears unchanged; elastomer composition appears to have decreased somewhat. For the reasons stated above, these trends are expected as they positively affect fuel consumption reduction goals over the last decade.

Because none of the material composition references used herein distinguished mild conventional steels from advanced high strength steels (AHSS), it is hard to determine with certainty what the impact of the greater use of AHSS has been on overall vehicle ferrous weight. However, based on a recent study of aluminum use on vehicles (Ducker Worldwide 2014), the identification of ferrous products types (sheet: cold roll, hot roll, galvanized; forgings, bars, rods, EAF steel, BOF steel) used on vehicles (USAMP 1999), and considering that AHSS parts are primarily stamped from sheet products, an estimate of the impact of AHSS use in the last decade and a half has been developed. Assuming that AHSS are used primarily for body, chassis, and suspension, we estimate that two percentage points of the fifteen percentage point reduction between late-90s and current populations shown in Table 2 is due to AHSS applications. See Appendix B for details.

Table 3 presents material composition percentages for vehicle powertrains. Upon comparing compositions of current vehicles with the 1999 vehicle (base case), it is clear that powertrain material compositions have changed significantly since the late-90s. Ferrous metal use has decreased significantly whereas aluminum alloy and plastics use have increased considerably. Given that most powertrain metals are either castings or forgings, little AHSS is expected to be used in powertrains.

It would have been desirable to have more material compositions on late-90s powertrains. Unfortunately, none with adequate detail are at hand. The USAMP (1999) data is the most complete set at hand for that time period, though it was not broken down on a component by component basis as is the case for the data representing the current population. For the current population set on powertrains, the Honda Accord and Toyota Venza data were taken from reports cited above.

TABLE 2 Material composition for two populations of vehicle models: late-90s vs. current

Vehicle	Overall Material Percentages in Various Vehicles										
	Vehicle type	Ferrous	Alloys[a]	Other Metals[b]	Plastics[c]	Elastomers[d]	Fluids	Fabrics[e]	Glass	Other	Vehicle Mass - kg
1993 Ford Mondeo	Sedan	70.3	3.4	7.9	6.9	5.9	1.2	[f]	3.1	1.4	1,214
1993 Ford Escort	Sedan	69.6	6.0	7.3	5.9	5.0	1.3	[f]	3.3	1.6	1,102
1995 Japan Average[g]	Sedan	72.2	6.2	1.8	10.1	3.1			2.8	3.8	1,270
1998 Ranger Truck	Truck	77.9	4.5	2.0	6.8	5.2	1.7	[f]	1.2	0.6	1,354
2000 Ford Taurus	Sedan	69.9	7.3	2.5	9.5	5.8	1.3	[f]	2.2	1.5	1,439
2000 Ford Focus	Sedan	68.5	8.4	2.5	10.0	4.4	1.3	[f]	2.1	2.8	1,181
2002 Ford Explorer	Truck	66.2	11.6	1.8	9.9	4.8	1.2	[f]	2.5	1.9	1,969
Generic D-Class Sedan	Sedan	64.3	6.3	2.7	9.3	6.9	4.8	0.7	2.7	2.2	1,532
Average		69.9	6.7	3.7	8.6	5.1					
Standard Deviation		4.1	2.5	2.7	1.7	1.1					
2013 Class E	Sedan	56.3	14.7	2.5	16.9	1.6	4.0	1.2	1.7	0.6	1,910
2014 Class D	Sedan	48.8	18.7	3.9	17.7	1.2	4.8	1.0	1.8	1.7	1,750
2012 Class D	Sedan	56.3	8.7	3.0	20.6	2.8	4.3	0.6	2.6	0.9	1,580
2011	Mini-van	62.7	8.8	3.2	13.1	4.1	3.7	0.7	2.0	0.9	1,960
2013	SUV	53.2	14.8	3.4	17.9	1.8	4.4	1.0	2.3	0.8	2,220
2014 Class D	Sedan	51.7	19.8	3.5	15.5	1.2	4.7	0.4	1.8	0.8	1,790
Average		54.8	14.3	3.3	17.0	2.1					
Standard Deviation		4.8	4.7	0.5	2.5	1.1					

[a] Alloys of aluminum; [b] Included where listed representing copper (in wiring), brass, lead, etc.; [c] Includes polyethylene, polypropylene, nylon, thermoplastics, thermosets, ABS, PVC, others; [d] Includes natural rubber, SBR, urethane elastomers, EPDM, [e] Includes carpeting; [f] In earlier vehicle tear down data, these materials were identified only by their polymer class; [g] Average passenger car in Japan-see Kobayashi, 1997.

TABLE 3 Comparison of material composition percentages for powertrains

Vehicle	Ferrous	Alloys[a]	Other Metals[b]	Plastics[c]	Elastomers[d]
2014 Class D Sedan	57.6	31.5	3.6	7.1	0.2
2014 Class D Sedan	59.2	30.5	5.2	3.8	1.3
2012 Class D Sedan	49.9	29.3	6.5	12.1	2.1
2013 Class E Sedan	58.9	27.0	4.3	8.9	1.0
2011 Mini Van	53.4	32.3	3.6	7.4	3.4
2013 SUV	63.3	22.2	5.1	8.5	0.9
2011Honda Accord (NHTSA study)	55.0	32.2	4.9	7.9	0.0
2010 Venza (NHTSA study)	63.4	23.6	6.2	5.6	0.0
Average	57.6	28.6	4.9	7.7	1.1
USAMP Generic Sedan (1999)	72.8	20.4	3.4	1.9	1.5

Table 4 presents material composition data for a set of different vehicle powerplants including a PHEV, FCV, spark ignited ICEV (SI-ICEV), and compression ignited ICEV (CI-ICEV). The data for the ICEVs were provided by an OEM (Sullivan 2015). The PHEV material composition data (from a confidential source) are the best available but unfortunately as discussed above are incomplete. Material composition data for the fuel cell stack and BoP (Notter et al. 2015) for our assumed FCV are also listed in Table 4. An inspection of the table clearly shows that, with one exception (1.6 liter SI), ferrous metals are the majority material in all of these powertrains. However, in all cases shown a substantial amount of aluminum alloys are also employed. Some OEMs are limiting the amount of aluminum alloys used in powertrains due to better noise suppression by iron and steel engines (Sullivan 2015).

TABLE 4 Material composition data (%) for a PHEV, FC, and SI and CI engines

Powerplant type		Ferrous	Alloys[a]	Other metals[b]	Plastic[c]	Elastomer[d]	Other	Mass – (kg) Subsystem	Mass – (kg) vehicle
PHEV[g]	Battery, electrical, HVAC & cooling	47	23	4	25			[e]	
	Transmission	63	12	6	19			[e]	
	Total	54	18	3	20	0.0	4	194	1,420
Fuel Cell	Stack and BoP	85.8	12.7	1.4	0.0	0.2	3.9[f]	68.6	-
	Engine only								
SI	1 liter	72.4	19.6	2.0	4.7	1.3	4.4	102	-
SI	1.6 liter	43.3	48.4	1.2	5.8	1.1	0.3	96	-
SI	2.5 liter	48.3	39.1	5.9	5.4	1.2	0.4	101	-
CIDI	1.6 liter	60.0	36.0	0.6	2.9	0.6	0.6	121.7	-
CIDI	2.0 liter	77.2	18.7	0.9	2.3	0.8	0.5	202.1	-

[a] Alloys of aluminum; [b] Included where listed representing copper (in wiring), brass, lead, etc.; [c] Includes polyethylene, polypropylene, nylon, thermoplastics, thermosets, ABS, PVC, others; [d] Includes natural rubber, SBR, urethane elastomers, EPDM; [e] These values are not shared due to proprietary nature of data; [f] The is comprised of 2.49 kg of PTFE, 1.58 kg of carbon black and multi-walled carbon nanotubes, 1.36 kg of PEM and 0.014 kg of platinum; [g] Due to rounding, not all systems or systems total 100

It was pointed out above that the ferrous metal content of vehicle powertrains and vehicles overall is decreasing over time. However, is the reduction in ferrous metal content of the overall vehicle mainly due to powertrain ferrous metal reductions? The answer to this question is evident in Table 5, where it is shown that the ferrous percentage content for both vehicle populations (late-90s and current) is highest in the powertrain, though less so for the current population. When compared to the late-90s population, the ferrous percentage content of the current population is lower across the vehicle and vehicle systems. Because material composition data for vehicles and associated systems are sparse for the late-90s time frame, we represent the late-90s vehicle population using data from the USAMP (1999) Generic Family Sedan. This vehicle represents an average of three D-class sedans, one from each of the three OEMs (Ford, General Motors, and Chrysler) participating in the study. The merit of the USAMP data was discussed above.

TABLE 5 Iron and steel percentages in vehicles and vehicle systems over time

Vehicle Set	Time frame	% of total vehicle	% of powertrain	% of rest of vehicle
Generic D-Class	Late-90s	64.3	72.8	61.8
Recent models	2011-2014	54.8	57.0	54.2

Though our results show that the relative amount of ferrous metal on cars is decreasing and is being replaced by lightweight materials, many of the newer vehicles are being equipped with Eco-boost and turbo-charged systems. These powertrains operate more fuel efficiently and still have greater power than their counterparts of a decade or more ago. As seen in Figure 1 there is a correlation between vehicle horsepower and powertrain mass, at least for current SI-ICEV sedans, SUVs and vans. The question at hand is whether reductions in vehicle weight across the vehicle are being offset by heavier powertrains. Sufficient data to answer this question needs to be developed.

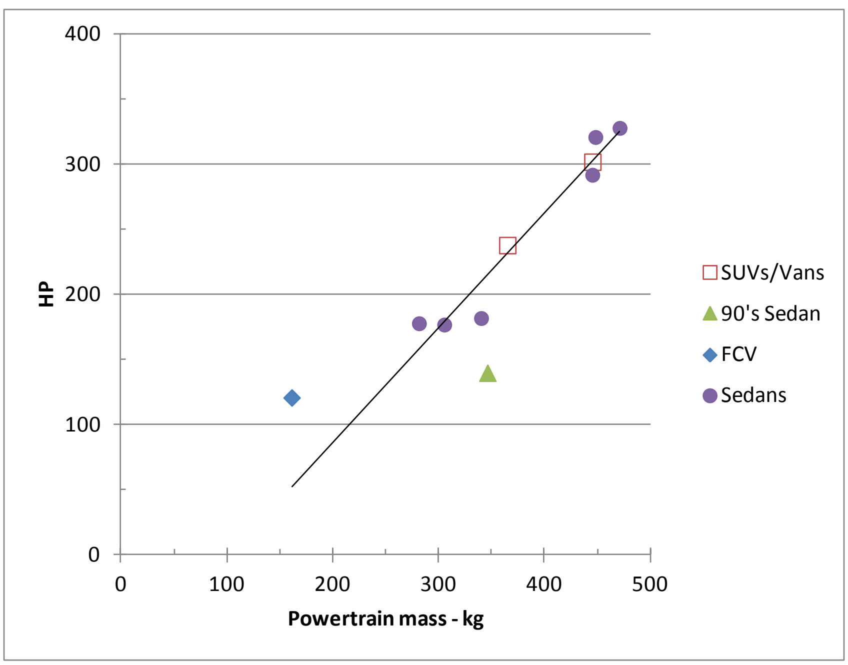

FIGURE 1 Vehicle power vs. powertrain weight for current ICEVs, a late-90s ICEV and a FCV.

4 CONCLUSIONS

This study was conducted to quantify changes in vehicle material composition over the previous decade or two, especially for vehicle powertrains. Several sources of vehicle material composition were identified from which composition estimates were made for SI-ICEV, CI-ICEV, PHEV, and FC powertrains. Some data sources provided information on the material composition of vehicle systems, some on a part-by-part basis and others on subsystem wide basis. The confidential material composition data is the most valuable as it includes data for not only the vehicle overall but also on a system, subsystem, and part basis. From information derived from all of the data sources, a number of conclusion can be made.

The results presented herein show that the relative ferrous metal content of vehicles is decreasing and is being replaced by aluminum, plastic based materials and AHSS. In the case of powertrains, the reduction is primarily due to increased use of aluminum and plastics. AHSS is expected to have at best minor impact on powertrain system, but significantly more impact on body, and suspension components. Despite the decrease, ferrous metal remains a significant component of PHEVs, SI-ICEVs, CI-ICEVs, and FCVs vehicles and their powertrains.

For the life cycle analyst to explore a greater range of vehicle weight reduction scenarios, the analyses presented above also need to be extended to the other five major vehicle systems (suspension, HVAC, electrical, body, and interior) and their corresponding subsystems. More data needs to be collected on weight changes within vehicle classes, especially considering the greater presence of turbocharged models in the vehicle marketplace.

A significant challenge will be establishing the amount of AHSS on vehicles being sold both now and in the future. Because it is expected to increase significantly, AHSS penetration on vehicle compositions needs to be quantified. It is unlikely that vehicle disassemblers are equipped to distinguish mild from AHSS steels. Such information is probably best obtained from the manufacturers.

APPENDIX A

TABLE A-1 Material amounts (kg) for 2011 Honda Accord

Vehicle	2011 Honda Accord – 2.4 liter engine, 177 hp, 119 ft^3 interior space										
	Ferrous	Alloys[a]	Other Metals[b]	Plastics[c]	Elastomers[d]	Fluids	Carpet	Glass	Other[e]	Mass - kg	
Powertrain Subsystems										Accounted for	Listed
Exhaust	19.7	1.0								20.7	
Engine	85.6	64.8	15.1							166	
Transmission	62.5	29.8								92.3	
Air										0	
Clutch										0	
Fuel				12						12	
Cooling		2.6		12.1						14.7	
Powertrain Total	167.8	98.2	15.1	24.1						305	306
Vehicle Total											1,488

[a] Alloys of aluminum; [b] Included where listed representing copper (in wiring), brass, lead, etc.; [c] Includes polyethylene, polypropylene, nylon, thermoplastics, thermosets, ABS, PVC, others; [d] Includes natural rubber, SBR, urethane elastomers, EPDM, [e] This includes leather, fabrics, insulation, and fibers [f] Accounted for from the original listing (e.g. datasets).

TABLE A-2 Material amounts (kg) for 2010 Toyota Venza

Vehicle	2010 Toyota Venza-2.7 liter engine, 138.7 ft^3 interior volume, 182 hp										
	Ferrous	Alloys[a]	Other Metals[b]	Plastics[c]	Elastomers[d]	Fluids	Carpet	Glass	Other[e]	Mass - kg	
Powertrain Subsystems										Accounted for	Listed
Exhaust	34									34	
Engine	79.8	60.1	20.5	15.0						175	
Transmission	65.0	24.6	0.50	1.76						91.9	
Air										0	
Clutch										0	
Fuel	22.6			1.6						24.2	
Cooling		11.3		2.8						14.1	
Powertrain Total	201.4	96	21	21.16						340	340
Vehicle Total											1,709

[a] Alloys of aluminum; [b] Included where listed representing copper (in wiring), brass, lead, etc.; [c] Includes polyethylene, polypropylene, nylon, thermoplastics, thermosets, ABS, PVC, others; [d] Includes natural rubber, SBR, urethane elastomers, EPDM, [e] This includes leather, fabrics, insulation, and fibers [f] Accounted for from the original listing (e.g. datasets).

TABLE A-3 Material amounts (kg) for the USAMP Generic Family Sedan - a D-class vehicle; weights for powertrain materials were estimated from materials used tables in USAMP report (Tables 38 -42) and typical production efficiencies

Vehicle	**USAMP – Generic D-Class Sedan---3.0 liter V6 140hp –FE 20/29**										
	Ferrous	Alloys[a]	Other Metals[b]	Plastics[c]	Elastomer[d]	Fluids	Fabrics[e]	Glass	Other	Mass - kg Captured	Mass - kg Listed
Powertrain Total	252	70.7	11.7	6.5	5.1						346
Vehicle Total	985	96.3	41.7	143	105	74	11	42	34		1,532

[a] Alloys of aluminum; [b] Included where listed representing copper (in wiring), brass, lead, etc.; [c] Includes polyethylene, polypropylene, nylon, thermoplastics, thermosets, ABS, PVC, others; [d] Includes natural rubber, SBR, urethane elastomers, EPDM, [e] Includes carpeting.

TABLE A-4 Material amounts (kg) for a FCV low temperature PEM cell system

Vehicle	**Modeled PEM Fuel Cell Vehicle Based on Notter et al. (2010, 2015), 121 hp**										
	Ferrous	Alloys[a]	Other Metals[b]	Plastics[c]	Elastomers[d]	Fluids	Carpet	Glass	Other[e]	Mass - kg	
Powertrain Subsystems										Accounted for[f]	Listed
Stack & BoP	54.2	8.01	0.87		0.13				5.4[I]	68.6	
Drivetrain	39	32.7	19	2						92.7	
Powertrain Total	93.2	40.7	19.9	2	0.13	0	0	0	5.4	161	
Glider	531	7.8	9.2	127	41	6		30	22.2	774	
Vehicle Total	624.2	48.5	29.1	129	41.1	6	0	30	27.6	936	

[a] Alloys of aluminum; [b] Included where listed representing copper (in wiring), brass, lead, etc.; [c] Includes polyethylene, polypropylene, nylon, thermoplastics, thermosets, ABS, PVC, others; [d] Includes natural rubber, SBR, urethane elastomers, EPDM, [e] Unless otherwise specified, this includes leather, fabrics, insulation, and fibers, [f] Accounted for from the original listing (e.g. dataset), [g] this includes 2.5 kg of PTFE, 1.6 kg of carbon black and multiwalled carbon nanotubes, 1.4 kg of PEM, and 0.014 kg of platinum.

APPENDIX B

This exercise attempts to estimate the impact of advanced high strength steels (AHSS) on the relative weight composition of ferrous metals on vehicles. The comparison is between a late-90s vehicle and current vehicle models. Representing the base case late-90s vehicle is the USAMP (1999) generic family sedan, a D-class vehicle, on which considerable material composition data was developed. It is assumed that all applications for AHSS are in body, chassis, and suspension systems. Data for these systems are shown in Table B-1.

TABLE B-1 Sheet steel, ferrous content and system weights for listed vehicle systems

Vehicle System	kg of sheet steel	kg of Ferrous	Total System mass - kg
Body	417[a]	460[a]	566[b]
Suspension	82[a]	218[a]	291[b]
Total	499	678	857

[a] Assumed Production efficiencies: 60% for stamping, 90% for casting and extrusions; [b] See Table 58 of USAMP 1999.

For the calculations, the AHSS/mild steel substitution ratio is 0.8. Total vehicle weight is 1532 kg, total ferrous for the base case is 985 kg for a mix of steel sheets, rods, bars, castings and iron castings. Based on Ducker Worldwide (2014), it was estimated that the AHSS/mild steel mass ratio for a 2012 vehicle to be about 0.2. Applying this ratio to the sheet steel portion shown in Table B-1, we find that 499 kg of sheet mild steel becomes 479 kg of sheet steel, of which 80 kg is AHSS. Therefore total vehicle ferrous content goes from 985 kg to 965 kg, which is a 2% reduction is the ferrous content of the USAMP D-Class sedan.

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