Vehicle Materials: Fuel Cell Vehicle Material Composition Update

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ACRONYMS

BoP	balance of plant
CAP	criteria air pollutants
CARB	California Air Resources Board
EPA	US Environmental Protection Agency
EV	battery electric vehicle
FCV	fuel cell vehicle
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
GHG	greenhouse gas
HEV	hybrid electric vehicle
ICEV	internal combustion engine vehicle
LW	light weight

NHTSA	National Highway Safety Administration

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1 INTRODUCTION

Numerous efforts at both the national and regional level are in place to reduce both the greenhouse gas (GHG) and criteria air pollutant (CAP) emissions associated with vehicles. These include regulations stemming primarily from the US Environmental Protection Agency (EPA), the National Highway Safety Administration (NHTSA) and the California Air Resources Board (CARB). One outcome of these regulations has been the continued advancement of vehicle powertrain technologies. One such powertrain technology is the fuel cell, which converts hydrogen and oxygen into electricity on-board to propel the vehicle. Fuel cell vehicles (FCV) have efficiency advantages and lower in-use emissions than conventional vehicles.

The GREET® (**G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation) model was originally developed to evaluate fuel-cycle (or well-to-wheels) energy use and emissions of various transportation technologies (Wang 1999). In 2006, the GREET vehicle-cycle model (GREET 2) was released to examine energy use and emissions of vehicle production, assembly and disposal processes (Burnham, Wang, and Wu 2006). Along with providing detailed environmental impacts for numerous materials and manufacturing processes, the GREET 2 model breaks down vehicles into their constituent systems, components and parts and provides corresponding mass and material composition. The data for these breakdowns is culled from a variety of reports, design tools, and expert interviews, as detailed in previous GREET publications (Burnham, Wang, and Wu 2006; Burnham 2012). GREET 2 has vehicle specifications for mid-size passenger cars, mid-size sport utility vehicles (SUV), and full-size pick-up trucks (PUT). In addition, GREET 2 has several propulsion technologies: internal combustion engine vehicle (ICEV) with a spark-ignition (SI) engine; grid-independent hybrid electric vehicle (HEV) with an SI engine; a (grid-connected) plug-in hybrid electric vehicle (PHEV) with an SI engine; battery electric vehicle (BEV); FCV with a hybrid configuration.

This update describes how new FCV powertrain material composition data was obtained and integrated within 2016 GREET 2. Several technology advances have occurred since the original FCV powertrains were devised for GREET 2, and this present update will address the new composition.

2 MATERIAL UPDATES

The materials for the fuel cell stack and the fuel cell balance of plant (BoP), along with hydrogen storage tank (and its peripherals), have been updated based on recent studies from Argonne National Laboratory (Ahluwalia et al. 2010; Hua et al. 2011; Elgowainy, Reddi, and Wang 2012; Ahluwalia et al. 2011; Ahluwalia, Wang, and Steinbach 2016; R. K. Ahluwalia, X. Wang, and J-K Peng 2015; James 2015). Previous versions of GREET identified the FCV powertrain and storage across systems called the fuel cell stack (which was within Powertrain Systems) and fuel cell auxiliaries (BoP and hydrogen storage). The present update -places the fuel cell stack and BoP into the “Powertrain System (including BOP)” category, while placing hydrogen storage system into the “Fuel Cell Onboard Storage” category (see Table 1 for a breakdown). Therefore, direct comparisons cannot be made between these updates and previous GREET versions on a system-by-system basis, but one could compare the total fuel cell system masses across old and new version of GREET.

Table 1 Major parts and subsystems in each updated fuel cell system

Component	Source(s)
Powertrain System (including BOP)	Membrane electrode assembly, bipolar plates, gaskets, current collector, insulator, outer wrap, tie bolts membrane humidifier, compressor/expander/motor, controller, sensors, air handling, mounting, wiring, HTL and LTL systems
Fuel Cell Onboard Storage	Pressure vessel, vacuum shell, insulation, brackets, and balance of plant (valves, piping, heat exchanger, instruments, etc.)

In addition to published data, the authors of (James 2015) shared the bill of materials for a designed fuel cell power system for the present analysis. That system had a design net power of 80 kW (88.2 kW gross), it was also scaled to a per kW basis. The results of the composition analysis are available in Table 2, and these values will be integrated within GREET 2016. The previous ANL report describes a fuel cell system with a 70 kW stack coupled with a 33 kW battery for the midsize passenger car (Burnham, Wang, and Wu 2006; Burnham 2012). However, an updated analysis from ANL’s Autonomie group provides information for fuel cell and battery power ratios, and onboard hydrogen storage needs (Moawad et al. 2016). Fuel cell stack size, battery size in battery power, and weight of onboard hydrogen storage in GREET, are therefore updated with the Autonomie data to represent the state-of-art of FCV designs. This data is also the basis of a recent Cradle-to-Grave report, which is used as a basis for harmonizing all vehicles within GREET (Elgowainy et al. 2016).

The composition of the hydrogen storage tank and its peripherals are based on analysis for a 700 bar storage tank and are consistent with ANL analysis based on multiple sources (Ahluwalia et al. 2010; Hua et al. 2011; Elgowainy, Reddi, and Wang 2012). The components include a polyethylene liner, a high pressure type IV tank made of carbon fiber reinforced plastic (CFRP), and various fittings, valves, and controls equipment. Table 2 presents the updated composition of the Fuel Cell Onboard Storage, and these values will be integrated within GREET 2016.

Fuel cell stack size and battery size are generally interdependent design parameters for a FCV. If users want to change the stack power, they will likely also want to change the battery power. For the conventional and lightweight(LW) FCVs, the default fuel cell stack power and battery power were determined from (Moawad et al. 2016). The mass of the fuel cell stack is also updated. The previous weight-to-power ratio for the fuel cell stack and auxiliaries was 3.23 lb/kW, and 7.8 lb/kW, respectively. In this update, a ratio of 2.81 lb/kW is used for the powertrain system (including BoP) (i.e. the stack and BoP), this is derived from data provided by the authors of James (2015), described above. For the hydrogen storage tank, it was deemed inappropriate to size it based on power requirements. In the updated version, the size of each vehicle's hydrogen tank is a fixed value based on ANL's Autonomie information for the defined vehicles (Moawad et al. 2016). Each vehicle's storage tank was determined independently, and do not change automatically with power changes, or weight changes in GREET. Minor variations in vehicle mass will not vastly impact hydrogen storage requirements.

Table 2 Updated material composition for fuel cell components

Component	Conventional and Lightweight	Source(s)
Powertrain System (including BOP)	31.3% stainless steel 18.7% steel 16.8% wrought aluminum 16.6% average plastic 6.5% rubber 2.6% glass fiber composite 2.6% PTFE 2.1% carbon paper 1.7% copper 0.6% PFSA 0.3% carbon 0.08% cast iron 0.05% silicon 0.02% platinum 0.002% nickel	ANL, DOE
Fuel Cell Onboard Storage	65.6% carbon fiber composite 9.2% steel 8.1% stainless steel 7.8% average plastics 4.5% glass fiber composite 1.0% silicon 3.9% others	ANL, DOE

These changes to material composition and component weight induce changes to the FCV vehicle system weight composition. Using the previous version of GREET and sizing an appropriate FCV within those vehicle's component compositions (and power parameters) allows us to determine an appropriate component composition to be comparable with other GREET vehicles (within class). We carry those new compositions forward, and present them in Table 3.

Table 3 System Weight Breakdown (%)

System	Car FCV	LW Car FCV	SUV FCV	LW SUV FCV	PUT FCV	LW PUT FCV
Powertrain System (including BOP)	8.6%	7.0%	8.3%	6.8%	8.2%	7.6%
Transmission System	2.8%	3.2%	2.9%	3.3%	2.9%	3.2%
Chassis (w/o battery)	25.0%	27.3%	29.9%	33.3%	30.6%	36.6%
Traction Motor	4.2%	4.5%	4.5%	5.0%	4.4%	5.4%
Generator	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Electronic Controller	3.7%	3.9%	3.9%	4.4%	3.8%	4.7%
Fuel Cell Onboard Storage	9.0%	7.4%	9.3%	7.3%	9.2%	8.4%
Body	46.7%	46.8%	41.2%	40.0%	40.9%	34.0%

3 VEHICLE UPDATES

All vehicles, including FCV, have been updated for the 2016 GREET release to be consistent with recent ANL Autonomie results (Moawad et al. 2016; Elgowainy et al. 2016). Although weight and power demands are not consistent with past GREET versions, all vehicles within the same classification in GREET 2015 and GREET 2016, have comparable performance characteristics. The lightweight (LW) version of each vehicle is based on the “high technology progression” scenario from (Elgowainy et al. 2016).

The updated information for each fuel cell vehicle’s total vehicle weight, hydrogen storage tank weight, fuel cell stack power and fuel cell battery power are shown in Table 4. For the stack power it is assumed here to be the net power, so the parasitic losses in the fuel cell system, such as pumping, are already accounted for. It should be noted that the fuel cell stack power determine the FCV powertrain (including BOP) weight according to the description above, and that the battery power determines battery mass through battery specific power. Users can still modify any of the fuel cell stack and battery parameters to fit their modeling needs.

Table 4 Updated FCV Properties

Vehicle Type	Vehicle Weight (lbs)	FC Stack (kW)	FC Battery (kW)	H_2 Storage (lbs)
Car FCV	3,147	102	38	300
Car LW FCV	2,682	66	34	196
SUV FCV	3,829	121	45	377
SUV LW FCV	3,298	80	38	241
PUT FCV	4,437	141	51	443
PUT LW FCV	3,834	106	44	327

All updates presented here are incorporated within GREET and GREET.net.

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