Addition of New Conventional and Lightweight Pickup Truck Models in the GREET™ Model

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1 BACKGROUND

Advanced vehicle technologies are being promoted in order to reduce local air pollutants, greenhouse gas emissions, and the United States' dependence on oil imports. One major factor impacting these current industry trends for improving vehicle fuel economy are recently released US Environmental Protection Agency (EPA) standards for corporate average fuel economy (CAFE) requiring automakers to raise the average fuel economy of passenger vehicles to 35.5 miles per gallon gasoline equivalent (mpgge) by 2016 and to 54.5 mpgge by 2025. The required increase in the associated vehicle fuel economy can only be achieved through improvements in the efficiency with which vehicles utilize energy. This suggests that there may be a meaningful change in vehicle design and material composition.

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 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 based on mass and material composition. The data for these breakdowns is culled from a variety of reports, design tools, and expert interviews, as detailed in (Burnham, Wang, and Wu 2006; Burnham 2012). The 2012 update to GREET 2 vehicle specifications included the addition of two new vehicle types (a mid-size sport utility vehicle, and a full-size pick-up truck) in addition the previous mid-size passenger car, along with the addition of two propulsion technologies (a plug-in grid connected hybrid electric vehicle [HEV] with an SI engine, and a battery electric vehicle [EV]) to the already existing internal combustion engine vehicle (ICEV) with a spark-ignition (SI) engine, grid-independent HEV with an SI engine, and fuel cell vehicle (FCV) with a hybrid configuration. That update built upon previous versions of GREET 2 and added new data based on a wide variety of sources documented in that report (Burnham 2012). The 2014 update to GREET 2 added new ICEV models for the passenger car, cross over utility vehicle, and pickup truck model using both conventional and lightweight materials (Kelly et al. 2014). However, the pickup truck data within that report was based on a preliminary study, not on a comprehensive teardown study.

The present update to the GREET 2 pickup truck model utilizes a recently released report for lightweighting trucks and describes probable near-term mass reductions, with a focus on material composition (U.S. Environmental Protection Agency 2015). CAFE standards will cause vehicle manufacturers to lightweight their vehicles as one of many strategies to comply with fuel efficiency mandates. This can be accomplished in many ways. However, the report provides both engineering and economic analyses on a system-by-system basis, thereby ensuring that proposed lightweighting approaches are both technically and economically feasible in the near-term. The data in this U.S. EPA report has been evaluated and augmented for inclusion in this GREET 2 release.

2 VEHICLE SPECIFICATIONS

The 2015 release of the GREET 2 model includes two new pickup truck models that can be used for life-cycle analysis, especially for assessing the impacts of near-term vehicle lightweighting efforts. The release consists of a baseline pickup truck, along with a lightweight truck. These are based on data contained within a U.S. Environmental Protection Agency report, which provides detail for these vehicles' compositions (U.S. Environmental Protection Agency 2015). Table 1 contains the weights of the new vehicles, excluding the weight of the vehicle's fuel, which is consistent with previous GREET 2 releases.

TABLE 1 Total Vehicle Weight Excluding Fuel (lb)

	PUT ICEV	LW PUT ICEV
Total weight	5,228	4,029

Along with the weight of these vehicles, it is imperative to understand each vehicle's fuel economy in order to calculate its lifetime emissions during the use phase. GREET uses an approach that incorporates realistic driving conditions results simulated via Autonomie (Moawad, Sharer, and Rousseau 2013). However, for the two new vehicles the following approach was used. The combined (city/highway) fuel economy of the pickup truck was not available in the report, so the U.S. EPA's fueleconomy.gov website was used to determine the associated city and highway fuel economy, since those data are taken from official reporting by the automakers. The combined fuel economy was calculated using the weighted harmonic average of the reported city (53%) and highway (47%) fuel economies to increase fidelity versus the reported combined fuel economy values, which has an integer basis. Finally, a rule of thumb was used to determine fuel economy increase. Specifically, for each 10% reduction in weight a 7% improvement in fuel economy can be realized. Table 2 presents the fuel economy of each vehicle in the study based on the 2011 Chevrolet Silverado K15 4WD (5.3 L, 8 cyl, Automatic 6-spd) model on fueleconomy.gov.

TABLE 2 Vehicle Fuel Economies (MPG)

	PUT ICEV	LW PUT ICEV
Fuel economy	17.3	20.1

2.1 DEFINITION OF VEHICLE COMPONENTS

The total weight of each vehicle is broken down into three major categories: vehicle components, battery, and fluids. The vehicle components category includes four major systems: body, powertrain, transmission, and chassis. The fluid category includes engine oil, power steering fluid, brake fluid, transmission fluid, powertrain coolant, windshield fluid, and adhesives. These categories are all consistent with previous GREET 2 versions.

When collecting data for the pickup truck, the weights and material compositions often did not correspond perfectly to GREET definitions. Therefore, we needed a more detailed breakdown of each system in order to place part and subsystem data into the right component category in GREET; parts are aggregated into subsystems, and subsystems are aggregated into systems for inclusion in GREET. In the GREET 2 model, users do not see parts or subsystems — only systems, although the details of these parts and subsystems are provided in the documentation that accompany GREET model releases. Tables 3 – 8 provide definitions, primarily based on the Automotive System Cost Model (ASCM) developed by IBIS Associates and Oak Ridge National Laboratory (Das 2004), for the major parts and subsystems in each system category (i.e., body, powertrain, transmission, chassis, battery, and fluid). These systems and subsystems are consistent with previous GREET 2 documentation, but the data sources from the reports used in this augmentation are not always consistent with these. Therefore, in some instances, component categories required modification. As components roll up to the entire body system, the system level comparisons are consistent with previous GREET 2 versions, but the component level material compositions within the body system may vary somewhat, and users should be aware of those differences.

TABLE 3 Body System

Body-in-white	Primary vehicle structure, usually a single-body assembly to which other major components are attached. Includes the cargo box for pick-up trucks
Body panels	Closure panels and hang-on panels, such as the hood, roof, tailgate, doors, quarter panels, and fenders
Front/rear bumpers	Impact bars, energy absorbers, and mounting hardware
Body hardware	Miscellaneous body components
Glass	Front windshield, rear windshield, and door windows
Paint	E-coat, priming, base coats, and clear coats
Exterior trim	Molding, ornaments, bumper cover, air deflectors, ground effects, side trim, mirror assemblies, and nameplates
Body sealers/deadeners	All rubber trim
Exterior lighting	Head lamps, fog lamps, turn signals, side markers, and tail light assemblies
Instrument panel module	Panel structure, knee bolsters and brackets, instrument cluster, exterior surface, console storage, glove box panels, glove box assembly and exterior, and top cover
Trim and insulation	Emergency brake cover, switch panels, ash trays, arm rests, cup holders, headliner assemblies, overhead console assemblies, assist handles, coat hooks, small item overhead storage, pillar trim, sun visors, carpet, padding, insulation, and accessory mats
Door module	Door insulation, trim assemblies, speaker grills, switch panels and handles (door panels are considered as part of the body panels category)
Seating and restraint system	Seat tracks, seat frames, foam, trim, restraints, anchors, head restraints, arm rests, seat belts, tensioners, clips, air bags, and sensor assemblies
Heating, ventilation, air conditioning (HVAC) module	Air flow system, heating system, and air conditioning system (which includes a condenser, fan, heater, ducting, and controls)
Interior electronics	Wiring and controls for interior lighting, instrumentation, and power accessories

TABLE 4 Powertrain System

Engine unit	Engine block, cylinder heads, fuel injection, engine air system, ignition system, alternator, and containers and pumps for the lubrication system
Engine fuel storage system	Fuel tank, tank mounting straps, tank shield, insulation, filling piping, and supply piping
Powertrain thermal system	Water pump, radiator, and fan
Exhaust system	Catalytic converter, muffler, heat shields, and exhaust piping
Powertrain electrical system	Control wiring, sensors, switches, and processors
Emission control electronics	Sensors, processors, and engine emission feedback equipment

TABLE 5 Transmission System

Transmission unit	Gearbox, torque converter, and controls
ICEV	Uses an automatic transmission and therefore a torque converter

TABLE 6 Chassis System

Cradle	Frame assembly, front rails, and underbody extensions, cab and body brackets (the cradle bolts to the BIW and supports the mounting of the engine/fuel cell)
Driveshaft/axle	A propeller shaft, halfshaft, front axle and rear axle (the propeller shaft connects the gearbox to a differential, while the halfshaft connects the wheels to a differential)
Differential	A gear set that transmits energy from the driveshaft to the axles and allows for each of the driving wheels to rotate at different speeds, while supplying them with an equal amount of torque
Corner suspension	Upper and lower control arms, ball joints, springs, shock absorbers, steering knuckle, and stabilizer shaft
Braking system	Hub, disc, bearings, splash shield, and calipers
Wheels	Four main wheels and one spare
Tires	Four main tires and one spare
Steering system	Steering wheel, column, joints, linkages, bushes, housings, and hydraulic-assist equipment
Chassis electrical system	Signals; switches; horn wiring; and the anti-lock braking system wiring, sensors, and processors

TABLE 7 Battery System

ICEV	Pb-Ac battery to handle the startup and accessory load

TABLE 8 Fluid System

ICEV	Engine oil, power steering fluid, brake fluid, transmission fluid, powertrain coolant, windshield fluid, and adhesives

2.2 CONVENTIONAL AND LIGHTWEIGHT PICKUP TRUCK

The conventional and lightweight pickup trucks are based on the previously mentioned US EPA report (U.S. Environmental Protection Agency 2015). That report utilized teardown data for a 2007 Chevrolet Silverado modified to be consistent with a 2011 Chevrolet Silverado to identity baseline vehicle characteristics for pickup trucks, and then developed several lightweight options for that vehicle and its components. Detailed technical analyses of the lightweight vehicle structure, and economic and technical feasibility studies provided validation of viable near-term lightweighting options for this vehicle. The study used a detailed approach in identifying, evaluating and selecting available lightweighting options for many vehicle systems, components, and parts. That report contained sufficient information to determine the mass and material composition of many parts for both the conventional and lightweight vehicles. These data were augmented with other studies as needed using studies that are consistent with those used in previous GREET 2 releases. Table 9 contains a material composition breakdown for the components within both the baseline and the lightweight pickup truck models, and Table 10 contains weights for those components. The final vehicle system mass distribution and material mass distribution within the vehicle and its constituent systems are provided in Tables 11 – 16.

TABLE 9 Material Composition of Pickup Truck Components (PUT)

Component	Conventional	Lightweight	Source(s)
Body			
Body-in-white	99.0% steel 1.0% plastic	81.7% wrought Al 12.6% steel 2.6% cast Al 1.6% AHSS 1.5% plastic	EPA 2015 and Burnham 2012
Front doors	45.0% HSS 29.0% steel 26.0% AHSS	65.0% wrought Al 35.0% AHSS	EPA 2015 and Burnham 2012
Rear doors	73.0% HSS 18.0% AHSS 9.0% steel	60.0% wrought Al 40.0% AHSS	EPA 2015 and Burnham 2012
Hood	97.0% HSS 3.0% AHSS	94.0% wrought Al 6.0% AHSS	EPA 2015 and Burnham 2012
Tailgate	100.0% AHSS	85.0% wrought Al 15.0 AHSS	EPA 2015 and Burnham 2012
Fenders	100% steel	100% wrought Al	EPA 2015and Burnham 2012
Bumpers	77.0% steel 23.0% plastic	66.0% wrought Al 34.0% plastic	EPA 2015and Burnham 2012
Glass	100% glass	100% glass	EPA 2015and Burnham 2012
Misc. (accessories, fasteners)	66.6% steel 30.2% plastic 2.6% glass 0.3% copper 0.3% cast iron	67.7% steel 31.6% plastic 0.4% copper 0.3% cast iron	EPA 2015 and Burnham 2012
Exterior			
Lighting	67.8% plastic 18.4% copper 13.8% steel	66.4% plastic 19.1% copper 14.5% steel	EPA 2015 and Burnham 2012
Wiper system	62.0% steel 38.0% plastic	62.8% steel 37.2% plastic	EPA 2015and Burnham 2012
Interior			
Instrument panel	58.0% plastic 42.0% steel	73.1% plastic 26.9% magnesium	EPA 2015 and Burnham 2012
Trim & insulation	64.5% plastic 30.9% rubber 3.3% steel 1.3% wrought Al	66.9% plastic 28.1% rubber 3.7% steel 1.4% wrought Al	EPA 2015 and Burnham 2012

TABLE 9 (Cont.)

Component	Conventional	Lightweight	Source(s)
Interiors (cont.)			
Front seats	75.0% steel 25.0% plastic	68.9% plastic 23.3% GFRP 7.8% magnesium	EPA 2015and Burnham 2012
Rear seats	55.0% steel 45.0% plastic	75.0% plastic 22.0% magnesium 3.0% cast Al	EPA 2015and Burnham 2012
Safety systems	48.8% plastic 48.6% steel 2.6% copper	62.2% plastic 35.0% steel 2.8% copper	EPA 2015 and Burnham 2012
HVAC	41.1% plastic 32.8% wrought Al 15.3% copper 10.0% rubber 0.7% steel	36.3% wrought Al 35.0% plastic 16.8% copper 11.1% rubber 0.7% steel	EPA 2015 and Burnham 2012
Powertrain			
Engine	48.9% cast Al 22.9% steel 19.8% cast iron 5.3% plastic 2.5% wrought Al 0.4% copper 0.3% rubber	42.6% cast Al 21.3% cast iron 18.8% steel 8.1% plastic 3.4% magnesium 2.5% wrought Al 1.9% AHSS 0.6% GFRP 0.5% copper 0.3% rubber	EPA 2015 and Burnham 2012
Engine fuel storage system	82.8% plastic 17.2% steel	82.4% plastic 17.6% steel	EPA 2015 and Burnham 2012
Powertrain thermal	80.0% cast Al 15.0% steel 5.0% plastic	80.0% cast Al 15.0% steel 5.0% plastic	EPA 2015 and Burnham 2012
Exhaust	64.5% steel 24.1% cast iron 7.6% stainless steel 2.3% wrought Al 1.5% rubber 0.021% platinum	74.3% steel 21.8% stainless steel 2.3% wrought Al 1.5% rubber 0.026% platinum	EPA 2015 and Burnham 2012
Powertrain electrical	34.0% Copper 33.0% plastic 32.0% GFRP 1.0% steel	40.0% GFRP 34.0% plastic 18.0% wrought Al 8.0% copper	EPA 2015 and Burnham 2012

TABLE 9 (Cont.)

Component	Conventional	Lightweight	Source(s)
Transmission			
Transmission	53.7% steel 25.4% cast Al 11.1% HSS 4.3% plastic 3.2% cast iron 1.9% copper 0.4% rubber	45.5% steel 24.0% magnesium 11.6% cast Al 10.2% HSS 4.6% plastic 2.6% copper 0.9% CFRP 0.5% rubber 0.1% other	EPA 2015 and Burnham 2012
Chassis			
Cradle	100% steel	78.0% HSS 19.0% AHSS 3.0% wrought Al	EPA 2015 and Burnham 2012
Front suspension	50.5% cast iron 45.5% steel 4.0% rubber	41.0% steel 40.1% cast Al 12.8% HSS 3.2% magnesium 3.0% plastic	EPA 2015 and Burnham 2012
Rear suspension	90.4% steel 5.0% rubber 4.6% cast iron	67.0% GFRP 15.5% steel 8.4% magnesium 4.2% plastic 4.2% wrought Al 0.8% rubber	EPA 2015 and Burnham 2012
Tires and Wheels	49.7% rubber 31.3% cast Al 18.9% steel	51.4% rubber 39.6% cast Al 9.0% steel	EPA 2015 and Burnham 2012
Braking system	62.6% cast iron 35.0% steel 1.2% plastic 0.7% cast Al 0.6% rubber	49.0% cast Al 20.1% steel 16.7% magnesium 12.1% plastic 1.4% GFRP 0.8% other	EPA 2015 and Burnham 2012
Steering system	74.8% steel 10.7% cast Al 8.4% cast iron 5.5% magnesium 0.7% plastic	67.4% steel 22.3% cast Al 7.3% plastic 2.9% magnesium	EPA 2015 and Burnham 2012
Drive shaft (no axles)	89.3% steel 5.3% cast iron 3.9% wrought Al 1.5% rubber	86.6% steel 9.0% wrought Al 2.8% cast Al 1.6% rubber	EPA 2015 and Burnham 2012

TABLE 10 Pickup Truck Component Weights (lb)

Component	Conventional	Lightweight
Body		
BIW	820.43	553.23
Front Door	127.65	82.89
Rear Door	97.44	66.14
Hood	50.04	25.79
Tailgate	41.45	22.49
Fenders	63.71	31.75
Bumpers	106.70	70.55
Glass	87.30	77.53
Misc	89.28	83.39
Exterior		
Lighting	21.08	20.23
Wipers	12.36	12.20
Interior		
Instrument Panel	67.98	52.94
Trim & Insulation	195.48	178.36
Front Seat	171.05	148.44
Rear Seat	95.03	75.40
Safety Systems	43.31	40.53
HVAC	44.77	40.50
Powertrain		
Engine	448.55	394.22
Powertrain Electrical	74.06	55.39
Exhaust	111.41	88.54
Fuel System	58.07	52.89
Powertrain Thermal	53.62	45.31
Transmission	320.28	233.54
Chassis		
Cradle	533.52	481.27
Front Suspension	163.65	95.56
Rear Suspension	150.77	66.16
Tires and Wheels	348.35	268.75
Brakes	213.65	112.47
Steering	71.68	53.04
Drive Shaft	405.25	360.24

TABLE 11 Component Weight Breakdown (%)

Component	PUT ICEV	LW PUT ICEV
Body	42.0%	40.7%
Powertrain	14.7%	16.4%
Transmission	6.3%	6.0%
Chassis	37.1%	37.0%

TABLE 12 Aggregated Material Composition of Vehicle (%)

Material	PUT ICEV	LW PUT ICEV
Steel	64.5%	37.1%
Stainless Steel	0.2%	0.5%
Cast Iron	7.4%	2.2%
Wrought Aluminum	0.9%	19.4%
Cast Aluminum	9.1%	12.1%
Copper/Brass	0.9%	0.6%
Zinc	0.0%	0.0%
Magnesium	0.1%	3.6%
Glass	1.8%	2.0%
Average Plastic	9.5%	14.5%
Rubber	5.2%	5.2%
CFRP	0.0%	0.1%
GFRP	0.5%	2.7%
Nickel	0.0%	0.0%
Platinum	0.0005%	0.0006%
Others	0.0%	0.0%

TABLE 13 Material Composition of Body (%)

Material	PUT ICEV	LW PUT ICEV
Steel	74.1%	14.3%
Wrought Aluminum	0.8%	43.3%
Cast Aluminum	0.0%	1.1%
Copper/Brass	0.6%	0.8%
Zinc	0.0%	0.0%
Magnesium	0.0%	2.7%
GFRP	0.0%	2.2%
Glass	4.2%	4.9%
CFRP	0.0%	0.0%
Average Plastic	17.3%	27.3%
Rubber	3.0%	3.4%
Others	0.0%	0.0%

TABLE 14 Material Composition of Chassis (%)

Material	PUT ICEV	LW PUT ICEV
Steel	68.9%	64.2%
Cast Iron	13.3%	0.0%
Wrought Aluminum	0.8%	3.4%
Cast Aluminum	6.3%	15.4%
Copper/Brass	0.0%	0.0%
Zinc	0.0%	0.0%
Magnesium	0.2%	2.0%
GFRP	0.0%	3.2%
Average Plastic	0.2%	1.6%
Rubber	10.3%	10.0%
Others	0.0%	0.1%

TABLE 15 Material Composition of Powertrain (%)

Material	PUT ICEV	LW PUT ICEV
Steel	25.9%	25.7%
Stainless Steel	1.1%	3.0%
Cast Iron	15.5%	13.2%
Wrought Aluminum	1.8%	3.5%
Cast Aluminum	35.2%	32.1%
Copper/Brass	3.6%	1.0%
Magnesium	0.0%	2.1%
GFRP	3.2%	3.9%
Average Plastic	13.3%	15.2%
Rubber	0.4%	0.4%

TABLE 16 Material Composition of Transmission (%)

Material	PUT ICEV	LW PUT ICEV
Steel	64.8%	55.7%
Copper/Brass	1.9%	2.6%
Cast Iron	3.2%	0.0%
Magnesium	0.0%	24.0%
Wrought Aluminum	0.0%	0.0%
Cast Aluminum	25.4%	11.6%
CFRP	0.0%	0.9%
Average Plastic	4.3%	4.6%
Rubber	0.4%	0.5%
Others	0.0%	0.1%

3 IMPLEMENTATION DETAILS

Within the 2015 release of GREET 2, the user can select either previous versions of GREET PUT model (not including the 2014 truck model, which was based on approximate data and has been removed), or they can select the truck described in this document. In selecting the previous GREET PUT, the user will be presented with versions of these vehicles that include ICEV, HEV, PHEV, EV and FCV powertrains. Those powertrains have been studied and developed in detail, and are described in prior GREET documentation. The new PUT included in this update only have ICEV powertrains and, by default, the other powertrains will return null values when these updated vehicles are selected.

The associated fuel economies for these trucks, Table 2, are valid for the vehicle weights provided within GREET. Past GREET vehicle fuel economies (and hence fuel consumption results over the vehicle's lifetime) were based on extensive simulation in the Autonomie vehicle modeling software. Those relationships have been correlated with the newly added vehicles such that modifying the vehicle's weight will cause a change in the associated fuel economy. However, users that opt to change the weight of these new vehicles should be cautious with the results as this correlation has not been rigorously evaluated for these new vehicles.

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