Life Cycle Energy and Greenhouse Gas (GHG) Assessments
of Automotive Material Substitution

2024 Input Data Update

for the

WorldAutoSteel/UCSB Automotive Energy and GHG Model v5.1

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Acronyms

BD	Biodiesel
BF/BOF	Blast furnace, basic oxygen furnace
CFRP	Carbon fiber reinforced composite
CIDI	Compression ignition, direct injection
CO_2e	Carbon dioxide equivalent
EAF	Electric arc furnace
EPDM	Ethylene propylene diene monomer
EtOH	Ethanol
FFV	Flex fuel vehicle
GFRP	Glass fiber reinforced composite
GHG	Greenhouse gas
GPPS	General purpose polystyrene
HDG	Hot dip galvanized
HDPE	High-density polyethylene
HIPS	High impact polystyrene
HRC	Hot rolled coil
LDPE	Low-density polyethylene
LLDPE	Linear low-density polyethylene
MJ	Mega Joule
PC	Polycarbonate
PET	Polyethylene terephthalate
PP	Polypropylene
PUR	Polyurethane
PVC	Polyvinyl chloride
RoW	Rest of World, i.e., without China
SMC	Sheet molding compound
UCSB	University of California at Santa Barbara

1 Introduction

1.1 Background

The first version of what is now called the WorldAutoSteel/UCSB Automotive Energy & GHG Model was developed and delivered in 2007 (1,2). The model calculates the life cycle energy demand and GHG emissions of user-specified light duty vehicles and has a particular emphasis on the impact of material choice in relationship to power train and other basic vehicle configurations (3,4,5). Since 2007, the model went through a variety of model and data updates. The latest update is Version 5, which was completed and delivered in 2018 (6). Version 5.0 is now six years old, and some of the input data and parameters are therefore outdated.

1.2 Project Scope

This project had the following two goals:

- Review all input data and parameters.
- Update those which are outdated and for which suitable updates are available.

The computational structure of the model is deemed current and remained unchanged.

1.3 Key Data Sources

Below are the key data sources used for data update:

- Steel production and finishing: World Steel Association (WSA) (7)
- Stainless steel production: European Steel Association (Eurofer) (8)
- Primary aluminium production: International Aluminium Institute (IAI) (9)
- Aluminium finishing: Aluminum Association (AA) (10)
- All other materials: Argonne National Laboratory, GREET 2 2023rev1 (11)
- Fuel production and combustion: Argonne National Laboratory, GREET 1 2023rev1 (11)

All new data was cross-checked and compared with other available data, including academic literature, industry reports, and proprietary LCA databases, for quality control and assurance.

Unless specified otherwise, the geographical scope of the unit processes is global, i.e., the energy and GHG intensities are meant to represent global averages. Notable exceptions are production technologies that are very specific to or dominated by certain world regions. Magnesium production via electrolysis, for example, predominantly happens in regions with an abundance of hydropower such as Canada and Norway. The magnesium smelting industry of China, on the other hand, is mainly based on the Pidgeon process. As another example, corn-based ethanol production is dominated by the USA, while the majority of ethanol made from sugarcane if from Brazil.

2 Old and New Input Data

This section shows the old and the new (updated) input data, including its sources. With a few exceptions, the only input data that it was necessary to update were the energy and greenhouse gas (GHG) intensities of all unit processes in the model.

2.1 Materials Production

	Old data (v5)			Updated data (v5.1)		
Unit process	Total energy in MJ/kg	Fossil energy in MJ/kg	GHGs in kg CO2e /kg	Total energy in MJ/kg	Fossil energy in MJ/kg	GHGs in kg CO2e /kg
Aluminum, primary ingot, RoW	154.00	109.00	10.70	169.52	121.34	12.30
Aluminum, primary ingot, GLO	191.00	163.00	16.40	191.08	161.64	16.80
Aluminum, secondary ingot	8.55	8.27	0.51	8.41	7.86	0.53
Battery (1)	266.00	244.00	19.90	172.02	154.80	11.94
CFRP	402.00	355.00	20.20	404.89	358.02	18.79
Copper	41.50	35.80	3.78	37.08	29.44	2.33
GFRP	104.00	104.00	7.26	85.66	79.75	4.64
Glass	14.80	14.10	1.13	14.95	13.91	1.23
Magnesium, electrolytic	146.00	30.00	20.50	243.60	217.46	18.11
Magnesium, Pidgeon	358.00	320.00	35.80	322.79	303.33	30.21
Magnesium, secondary (2)	11.40	11.17	3.60	3.34	3.28	6.04
Rubber	95.40	93.00	3.38	54.77	53.34	3.86
SMC	54.50	49.50	2.65	59.71	56.12	3.20
Stainless steel	60.30	56.00	4.93	64.67	60.16	4.75
Steel, BF/BOF slab	21.27	20.89	2.08	23.72	22.89	2.13
Steel, EAF slab	7.73	6.34	0.48	7.48	5.98	0.44

(1) Based on Li-Ion battery chemistry with a battery energy density of 177 Wh/kg
(2) Assumes 230 g of SF6 emissions per 1,000 kg of magnesium output

Old data source (v5)	New data source (v5.1)
RoW: Aluminium ingot mix IAI (2010) IAI	IAI 2019 Report; GREET 2 2023: Primary Aluminum: Production in Various Geographies
GLO: Aluminium Ingot mix IAI 2010	IAI 2019 Report; GREET 2 2023: Primary Aluminum: Production in Various Geographies
EU-27: Aluminium recycling 2010 EAA	GREET 2 2023: 100% Recycled Al
GLO: Lithium nickel cobalt manganese oxide cell (scaled to 100 kg battery weight) PE <p-agg>	GREET 2 2023: EV: Conventional Material, Li-Ion
DE: Carbon Fiber (CF; from PAN; standard strength) PE	GREET 2 2023: Carbon Fiber
EU-27: Copper Wire Mix DKI/ECI	GREET 2 2023: Final Copper Product - US Consumption Mix
RER: Polyamide 6 GF30 (PA 6 GF30) ELCD/PlasticsEurope <p-agg>	GREET 2 2023: Final Glass Fiber-Reinforced Plastic Product: Combined
EU-27: Float flat glass ts	GREET 2 2023: Final Flat Glass Product
NO: MAGNESIUM PIG PE	GREET 2 2023: Magnesium via Electrolytic production
CN: Magnesium ts	GREET 2 2023: Magnesium via Thermal production
Version 4	GREET 2 2023: Recycled Magnesium
DE:Styrene-Butadiene Rubber (SBR) Mix ts	GREET 2 2023: Final Average Rubber Product: Combined
DE: Sheet Moulding Compound resin mat (SMC) ts	GREET 2 2023: Final Glass Fiber-Reinforced Plastic Product: SMC
RER: stainless steel cold rolled coil (430) Eurofer ctg	Eurofer 2019: Cold rolled coil - 430 Stab. (without recycling potential)
WSA 2018	WSA 2024
WSA 2018	WSA 2024

2.2 Materials Finishing

	Old data (v5)			Updated data (v5.1)		
Unit process	Total energy in MJ/kg	Fossil energy in MJ/kg	GHGs in kg CO2e /kg	Total energy in MJ/kg	Fossil energy in MJ/kg	GHGs in kg CO2e /kg
Aluminum casting	11.81	10.87	0.74	12.66	11.26	0.68
Aluminum extrusion	14.90	12.30	0.73	13.91	12.74	0.75
Aluminum rolling	10.40	8.40	0.50	11.71	10.70	0.62
Magnesium casting (1)	15.40	13.90	0.95	12.59	11.01	6.60
Magnesium rolling	10.40	8.40	0.50	11.71	10.70	0.62
Rubber compression molding	11.18	10.40	0.81	10.28	9.24	0.63
Rubber injection molding	10.78	9.33	0.83	8.97	7.03	0.54
Stainless mill and machining	7.34	6.72	0.54	6.60	5.77	0.40
Steel casting	2.00	1.96	0.14	2.00	1.96	0.14
Steel HDG	8.24	7.57	0.62	8.89	7.78	0.46
Steel HRC	2.01	1.85	0.14	3.13	2.90	0.16
Steel long	4.61	4.04	0.15	2.89	2.79	0.19

(1) Assumes 230 g of SF6 emissions per 1,000 kg of magnesium output

Old data source (v5)	New data source (v5.1)
DE: Aluminium die-cast part ts <u-so>, US: Electricity grid mix ts, US: Thermal energy from natural gas ts	AA (North America), Life Cycle Assessment Report (January 2022): Die casting
EU-27: Aluminium extrusion profile ts <p-agg>	AA (North America), Life Cycle Assessment Report (January 2022): Automotive extrusion
EU-27: Aluminium sheet ts <p-agg>	AA (North America), Life Cycle Assessment Report (January 2022): Automotive sheet
DE: Magnesium die-cast part PE <u-so>, US: Electricity grid mix ts (excludes cover gas)	GREET 2 2023: Magnesium Casting and Molding
EU-27: Aluminium sheet ts <p-agg>	AA (North America), Life Cycle Assessment Report (January 2022): Automotive sheet
GREET 2 2012	GREET 2 2023: Rubber Compression Molding
GREET 2 2012	GREET 2 2023: Rubber Injection Molding
GREET 2 2012	GREET 2 2023: Stainless Steel Rod and Bar Mill, Machining
WSA 2010	WSA 2010
WSA 2018	WSA 2022
WSA 2018	WSA 2022
WSA 2018	WSA 2022

2.3 Plastics Production

	Old data (v5)			Updated data (v5.1)		
Unit process	Total energy in MJ/kg	Fossil energy in MJ/kg	GHGs in kg CO2e /kg	Total energy in MJ/kg	Fossil energy in MJ/kg	GHGs in kg CO2e /kg
ABS Resin	91.00	90.80	3.88	90.55	88.65	3.35
EPDM Resin	73.40	71.30	1.89	73.62	73.22	1.79
Liquid Epoxy Resin	130.00	129.00	8.55	126.00	122.49	6.19
GPPS Resin	76.60	76.00	2.24	84.74	83.78	3.08
HDPE Resin	72.10	71.50	1.96	65.68	65.14	1.29
HIPS Resin	80.40	79.90	2.45	85.10	84.13	3.06
LDPE Resin	73.50	72.50	2.14	71.99	70.86	1.62
LLDPE Resin	68.70	68.40	1.88	68.39	67.84	2.07
Nylon 6 Resin	121.00	121.00	9.05	110.68	108.46	8.79
Nylon 66 Resin	132.00	132.00	8.12	124.49	120.74	6.53
PC Resin	96.80	96.10	4.17	97.69	94.57	4.31
PET Resin	75.70	75.70	3.33	62.46	60.63	1.75
PP Resin	69.70	69.40	2.00	61.55	61.05	1.12
PUR Flexible Foam	92.70	91.80	4.80	74.37	71.92	3.37
PUR Rigid Foam	94.90	94.30	4.30	71.02	68.81	3.16
PVC Resin	56.10	55.20	2.78	51.08	49.71	2.21

Old data source (v5)	New data source (v5.1)
RER: acrylonite-butadiene-styrene granulate (ABS) ELCD/PlasticsEurope	GREET 2 2023: ABS Resin
DE: PP/EPDM, TPE-O Mix ts	GREET 2 2023: EPDM Resin
Epoxy resin PlasticsEurope	GREET 2 2023: Liquid Epoxy Resin
EU-27: GPPS Plasticseurope	GREET 2 2023: GPPS Resin
RER: PE-HD Plastics Europe	GREET 2 2023: HDPE Resin
EU-27: HIPS PlasticsEurope	GREET 2 2023: HIPS Resin
RER: PE-LD PlasticsEurope	GREET 2 2023: LDPE Resin
RER: PE-LLD Plastics Europe	GREET 2 2023: LLDPE Resin
RER: PA 6 Plastics Europe	GREET 2 2023: Nylon 6 Resin
RER: PA 6.6 Plastics Europe	GREET 2 2023: Nylon 66 Resin
EU-25: PC Plastics Europe	GREET 2 2023: PC Resin
RER: PET amorph Plastics Europe	GREET 2 2023: PET Resin
RER: PP PlasticsEurope	GREET 2 2023: PP Resin
RER: PU flexible foam Plastics Europe	GREET 2 2023: PUR Flexible Foam
RER: PU rigid foam PlasticsEurope	GREET 2 2023: PUR Rigid Foam
RER: suspension, S-PVC Plastics Europe	GREET 2 2023: PVC Resin

2.4 Plastics Forming

	Old data (v5)			Updated data (v5.1)		
Unit process	Total energy in MJ/kg	Fossil energy in MJ/kg	GHGs in kg CO2e /kg	Total energy in MJ/kg	Fossil energy in MJ/kg	GHGs in kg CO2e /kg
Blow Molding (HDPE)	15.03	13.01	1.16	12.50	9.80	0.75
Calendaring (PVC)	5.10	4.41	0.39	4.24	3.32	0.26
Compression Molding	11.18	10.40	0.81	10.28	9.24	0.63
Extrusion (HDPE)	4.81	4.16	0.37	4.00	3.13	0.24
Extrusion (PP)	6.15	5.32	0.47	5.11	4.01	0.31
Extrusion (PVC)	4.63	4.01	0.36	3.85	3.02	0.23
Injection Molding (HDPE)	17.54	15.17	1.35	14.58	11.43	0.88
Injection Molding (PP)	7.02	6.07	0.54	5.83	4.57	0.35
Injection Molding (PVC)	10.78	9.33	0.83	8.97	7.03	0.54

Old data source (v5)	New data source (v5.1)
GREET 2 2012	GREET 2 2023: Blow Molding (HPDE)
GREET 2 2012	GREET 2 2023: Calendaring (PVC)
GREET 2 2012	GREET 2 2023: Compression Molding
GREET 2 2012	GREET 2 2023: Extrusion (HDPE)
GREET 2 2012	GREET 2 2023: Extrusion (PVC)
GREET 2 2012	GREET 2 2023: Extrusion (PP)
GREET 2 2012	GREET 2 2023: Injection Molding (HDPE)
GREET 2 2012	GREET 2 2023: Injection Molding (PP)
GREET 2 2012	GREET 2 2023: Injection Molding (PVC)

2.5 Fluids Production

	Old data (v5)			Updated data (v5.1)		
Unit process	Total energy in MJ/kg	Fossil energy in MJ/kg	GHGs in kg CO2e /kg	Total energy in MJ/kg	Fossil energy in MJ/kg	GHGs in kg CO2e /kg
Brake Fluid	52.90	52.40	1.08	53.32	53.03	0.84
Powertrain Coolant	45.30	44.00	1.57	23.12	22.79	0.60
Engine Oil	52.90	52.40	1.08	53.32	53.03	0.84
Transmission Fluid	52.90	52.40	1.08	53.32	53.03	0.84
Windshield Fluid	12.50	11.30	0.39	15.42	15.23	0.24

Old data source (v5)	New data source (v5.1)
EU-27: Lubricants at Refinery ts	GREET 2 2023: Brake Fluid
EU-27: Ethylene glycol Plastics Europe and EU-27: Water (desalinated, deionized)	GREET 2 2023: Powertrain Coolant
EU-27: Lubricants at Refinery ts	GREET 2 2023: Engine Oil
EU-27: Lubricants at Refinery ts	GREET 2 2023: Transmission Fluid
EU-27: Ethylene glycol Plastics Europe, DE: Butylglycol PE, and EU-27: Water (desalinated, deionized)	GREET 2 2023: Windshield Fluid

2.6 Assembly

	Old data (v5)			Updated data (v5.1)		
Unit process	Total energy in MJ/car	Fossil energy in MJ/car	GHGs in kg CO2e /car	Total energy in MJ/car	Fossil energy in MJ/car	GHGs in kg CO2e /car
Paint Production	738.50	638.28	56.99	613.89	481.02	36.97
Painting	3844.42	3684.06	277.32	3679.36	3465.76	232.05
VAC and Lighting	2546.77	2202.84	196.58	2117.61	1659.27	127.52
Heating	3456.18	3454.07	235.03	3498.71	3496.68	217.77
Material Handling	527.50	455.76	40.71	438.49	343.59	26.41
Welding	702.63	607.68	54.21	583.95	457.56	35.16
Compressed Air	1051.84	910.47	81.21	874.85	685.50	52.68

Old data source (v5)	New data source (v5.1)
GREET 2 2012	GREET 2 2023: Paint Production
GREET 2 2012	GREET 2 2023: Vehicle Assembly - Painting
GREET 2 2012	GREET 2 2023: Vehicle Assembly - HVAC & Lighting
GREET 2 2012	GREET 2 2023: Vehicle Assembly - Heating
GREET 2 2012	GREET 2 2023: Vehicle Assembly - Material Handling
GREET 2 2012	GREET 2 2023: Vehicle Assembly - Welding
GREET 2 2012	GREET 2 2023: Vehicle Assembly - Compressed Air

2.7 Use

	Old data (v5)			Updated data (v5.1)		
Unit process	Total energy in MJ/MJ	Fossil energy in MJ/MJ	GHGs in g CO2e /MJ	Total energy in MJ/MJ	Fossil energy in MJ/MJ	GHGs in g CO2e /MJ
Fuel production						
Biodiesel, rapeseed (EU)	0.52	0.40	-42.30	0.48	0.30	-45.11
Biodiesel, soybean (US)	0.73	0.28	-24.30	0.49	0.23	-44.78
Diesel	0.19	0.12	12.00	0.18	0.17	15.28
Bioethanol, cellulose (US)	1.25	0.12	-61.00	2.22	0.10	-48.40
Bioethanol, corn (US)	1.52	1.13	-2.88	0.71	0.67	-16.65
Bioethanol, sugar (Brazil)	1.42	-0.21	-66.20	2.69	0.24	-34.43
Gasoline	0.22	0.16	15.70	0.27	0.24	16.98
Compressed hydrogen	0.65	0.64	93.00	1.93	1.9	109.10
Electricity, China	3.09	2.83	269.00	2.43	1.98	194.21
Electricity, coal	3.00	3.00	290.00	3.11	3.11	309.01
Electricity, Europe	2.88	2.25	130.00	2.06	1.20	99.94
Electricity, India	4.45	4.07	387.00	2.61	2.30	224.53
Electricity, Japan	2.70	2.43	184.00	2.52	2.07	166.97
Electricity, USA	2.80	2.53	172.00	2.03	1.59	122.09
Fuel combustion						
Biodiesel combustion	1.00	0.00	77.00	1.00	0.00	76.00
Diesel combustion	1.00	1.00	77.00	1.00	1.00	76.00
Bioethanol combustion	1.00	0.00	72.00	1.00	0.00	70.00
Gasoline combustion	1.00	1.00	72.00	1.00	1.00	73.00
Hydrogen use	1.00	1.00	0.00	1.00	1.00	0.00

Old data source (v5)	New data source (v5.1)
Fuel production	
DE: Rapeseed methyl ester (RME) ts	GREET 1 2023: CIDI Vehicle: Canola-based BD100
US: Soy methylester (SME) by-product Glycerine (price, C mass allocated, estimation) PE	GREET 1 2023: CIDI Vehicle: Soybean-based BD100
EU-27: Diesel mix at refinery ts	GREET 1 2023: Conv. Diesel
Version 4 (Farrell et al. 2006a, 2006b, Wang 2005)	GREET 1: EtOH FFV: E100, Switchgrass
US: Ethanol (from corn) (DDGS) PE <p-agg>	GREET 1 2023: EtOH FFV: E100, Corn
BR: Ethanol from sugar cane PE	GREET 1 2023: EtOH FFV: E100, Sugarcane
EU-27: Gasoline mix (regular) at refinery ts	GREET 1 2023: Gasoline
EU-27: Hydrogen PE steam reforming - natural gas (uncompressed)	GREET 1 2023: Electricity Mix for Hydrogen Pathways
CN: Electricity grid mix PE	GREET 1 2023: China Average
US: Electricity from hard coal ts	GREET 1 2023: Coal-Fired Power Plant
EU-27: Electricity grid mix ts	GREET 1 2023: Europe Average
IN: Electricity grid mix ts	GREET 1 2023: India Average
JP: Electricity grid mix ts	GREET 1 2023: Japan Average
US: Electricity grid mix ts	GREET 1 2023: Stationary Use: U.S. Mix
Fuel combustion	
Combustion - BioDiesel <u-so>	GREET 1 2023: CIDI Vehicle: Soybean-based BD100
Combustion - Diesel <u-so>	GREET 1 2023: CIDI Vehicle: Conventional and LS Diesel
Combustion - Ethanol (as gasoline) <u-so>	GREET 1 2023: EtOH FFV: E100, Corn
Combustion - Gasoline <u-so>	GREET 1 2023: Gasoline Vehicle: Gasoline
N/A	N/A

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