Updates to Lithium-Ion Battery Material Composition for Vehicles

by

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TABLES

ACRONYMS

Ah	Ampere-hour
BOM	Bill-of-Materials
$CoSO_4$	Cobalt Sulfate
EV	(Battery) Electric Vehicle
FCV	Fuel-Cell Electric Vehicle
GREET®	Greenhouse gases, Regulated Emissions, and Energy use in Technologies
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
Kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour
LCI	Life-Cycle Inventory
LDV	Light-Duty Vehicle
LFP	Lithium Iron Phosphate
Li	Lithium
LIB	Lithium-Ion Battery
LiOH	Lithium Hydroxide
$LiPF_6$	Lithium Hexafluorophosphate
LMO	Lithium Manganese Oxide ($LiFePO_4$)
MHDV	Medium- and Heavy-Duty Vehicle
$MnSO_4$	Manganese Sulfate
NaOH	Sodium Hydroxide
NCA	(Lithium) Nickel Cobalt Aluminum (Oxide) ($LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$)
NH_4OH	Ammonium Hydroxide
$NiSO_4$	Nickel Sulfate
NMC	Nickel Manganese Cobalt
NMC111	Lithium Nickel Manganese Cobalt Oxide ($LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$)
NMC532	Lithium Nickel Manganese Cobalt Oxide ($LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$)
NMC622	Lithium Nickel Manganese Cobalt Oxide ($LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$)
NMC811	Lithium Nickel Manganese Cobalt Oxide ($LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$)
NMC95	Lithium Nickel Manganese Cobalt Oxide ($LiNi_{0.95}Mn_{0.025}Co_{0.025}O_2$)
PHEV	Plug-in Hybrid Electric Vehicle

PnD	Pickup-and-Delivery
PUT	Pick-up Truck
PVDF	Polyvinylidene Fluoride
SUV	Sports Utility Vehicle
V	Volts
W	Watt
Wh	Watt-hour

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This memo discusses updates for the weight and bill-of-materials (BOMs/material composition) of lithium (Li)-ion batteries for vehicles in GREET® 2023, based on the latest version of Argonne's BatPaC (BatPaC 5.1) model. The vehicles considered for this update include three light-duty vehicles (car, sports utility vehicle or SUV, and pick-up truck or PUT), one medium-duty vehicle (Class 6 pickup-and-delivery or PnD truck), and two heavy-duty vehicles (Class 8 regional day-cab and long-haul sleeper-cab trucks). Updates are made to hybrid, plug-in hybrid, battery electric, and fuel-cell powertrains for these vehicles based on battery power or energy sizing as appropriate. We also discuss the parameters and the underlying rationale behind the battery packaging considered for all the above-mentioned vehicles in the GREET model. This update also describes the addition of the NMC95 chemistry to GREET.

1. Introduction

Lithium (Li)-ion batteries (LIBs) are critical to the decarbonization of the U.S. transportation sector (FCAB, 2021). LIB performance (in terms of specific power or energy) has shown a significant improvement over time on the back of growing technological and material advancements (Li et al., 2018). These enhancements have substantially influenced the LIB's weight and material composition, and thereby, the resultant environmental impacts stemming from their production. To account for these changes over time, we periodically update the LIB weight and bill-of-materials (BOMs) in Argonne's GREET® (Greenhouse gas, Regulated Emissions, and Energy use in Technologies) model. In addition, we also update the production inventory (material and energy inputs, and emission outputs) for the underlying materials used in LIBs (such as lithium, nickel, and cobalt).

In this memo, we discuss the updates to LIB weight and material composition in GREET 2023. Note that these updates are based on the most recent versions of two Argonne models – Autonomie (2023) data as provided in Islam et al (2023), and BatPaC (5.1) that is updated using the BatPaC 5.0 platform (Argonne, 2022; Knehr et al., 2022). Autonomie is a simulation model that computes vehicle characteristics based on multiple inputs, such as drive cycles, driving ranges, and the nature of the powertrain employed (Argonne, 2021; Islam et al., 2023, 2021). BatPaC is a battery pack tool that considers inputs from users on battery configuration and chemistry to provide relevant outputs, including battery power, energy, voltage, specific power/energy, weight, bill-of-materials, and associated manufacturing costs (Argonne, 2022; Knehr et al., 2022).

We have updated the weight and material composition of LIBs for all those vehicles in the GREET model for which vehicle-cycle inventory is provided. These include: (a) Three light-duty vehicles (LDVs): car, sports utility vehicle (SUV), and pick-up truck (PUT); and (b) Three medium- and heavy-duty vehicles (MHDVs): Class 6 pickup-and-delivery (PnD) truck, and Class 8 regional day-cab and long-haul sleeper-cab trucks. Across all vehicles, four powertrains deploy LIBs: conventional hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (EVs), and fuel-cell electric vehicles (FCVs). Batteries are sized by power for HEVs and FCVs and by energy for PHEVs and EVs. We use the battery power/energy sizing (as appropriate) from Autonomie 2023 model results – provided in Islam et al (2023) – as inputs to BatPaC 5.1 model (Argonne, 2022; Knehr et al., 2022) to determine the resultant LIB parameters for this update (weight, BOM, and specific LIB power and energy).

Our previous update on LIB weight and material composition was for GREET 2022 (Iyer and Kelly, 2022; Wang et al., 2022). There, we considered seven LIB cathode chemistries for LDVs and four chemistries for MHDVs (Iyer and Kelly, 2022). In GREET 2023, we have expanded this coverage to eight and six chemistries for LDVs and MHDVs, respectively. The chemistries covered include: (a) LMO (lithium manganese oxide) or $LiMn_2O_4$; (b) LFP (lithium iron phosphate) or $LiFePO_4$; (c) Li-NCA (lithium nickel cobalt aluminum oxide) or $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$; (d) Li-NMC (lithium nickel manganese cobalt oxide) in four forms considered in prior GREET versions – NMC111 ($LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$), NMC532 ($LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$), NMC622 ($LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$), and NMC811 ($LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$) – and one new form considered for the first time in GREET from BatPaC 5.1 model (Argonne, 2022; Knehr et al., 2022) – NMC95 ($LiNi_{0.95}Mn_{0.025}Co_{0.025}O_2$). We also discuss the inventory data for the production of NMC95 cathode, while a similar discussion for other cathodes is already provided in prior GREET-related technical reports and memos (Dai et al., 2018, 2017; Dunn et al., 2015; Winjobi et al., 2020).

The rest of this report is organized as follows. Section 2 discusses the life-cycle inventory (LCI, or material and energy inputs) for producing NMC95 – the new cathode considered in this year's GREET update. Section 3 describes the updates made to LIB parameters for LDVs, while Section 4 provides a similar update for MHDV LIBs. The corresponding sections also provide the underlying rationale used to arrive at the battery weight and material composition for these

vehicles from the BatPaC 5.1 model. The final section (Section 5) highlights the tabs to which updates have been made regarding LIB parameters.

2. Life-Cycle Inventory: NMC95 Production

Previously, Dai et al (2018) discussed the material and energy inputs provided in GREET for LIB cathode production, based on an industrial facility. We use the logic from this reference for the NMC811 cathode to inform our understanding of the material and energy inputs (or LCI) for NMC95 production, given their relative similarities in material composition compared to other NMC cathodes. Based on this logic, NMC95 is produced in two steps, as shown in Figure 1 (Dai et al., 2018). First, NMC precursor ($Ni_{0.95}Mn_{0.025}Co_{0.025}(OH)_2$) is produced by a series of reactions (mixing/dissolution, co-precipitation, filtration, washing, drying, and removal of byproducts). These reactions involve stoichiometric amounts of nickel sulfate ($NiSO_4$), manganese sulfate ($MnSO_4$), and cobalt sulfate ($CoSO_4$), as well as sodium hydroxide (NaOH) and ammonium hydroxide (NH_4OH), as material inputs. These processes involve evaporative water loss, and call for the use of steam, which is assumed to use natural gas as its energy input. The subsequent step involves calcination, where the NMC precursor is reacted with lithium hydroxide (LiOH) at high temperatures (up to 1000 °C for up to 12 hours) to produce the NMC95 cathode. The process involves the use of electricity as an energy input.

Table 1 provides the material and energy inputs for both production steps in line with the reference used (Dai et al., 2018). Note that while $NiSO_4$, $MnSO_4$, and $CoSO_4$ inputs are based on stoichiometry, all other material and energy inputs for both steps are assumed to be the same as those for NMC811 in Dai et al (2018).

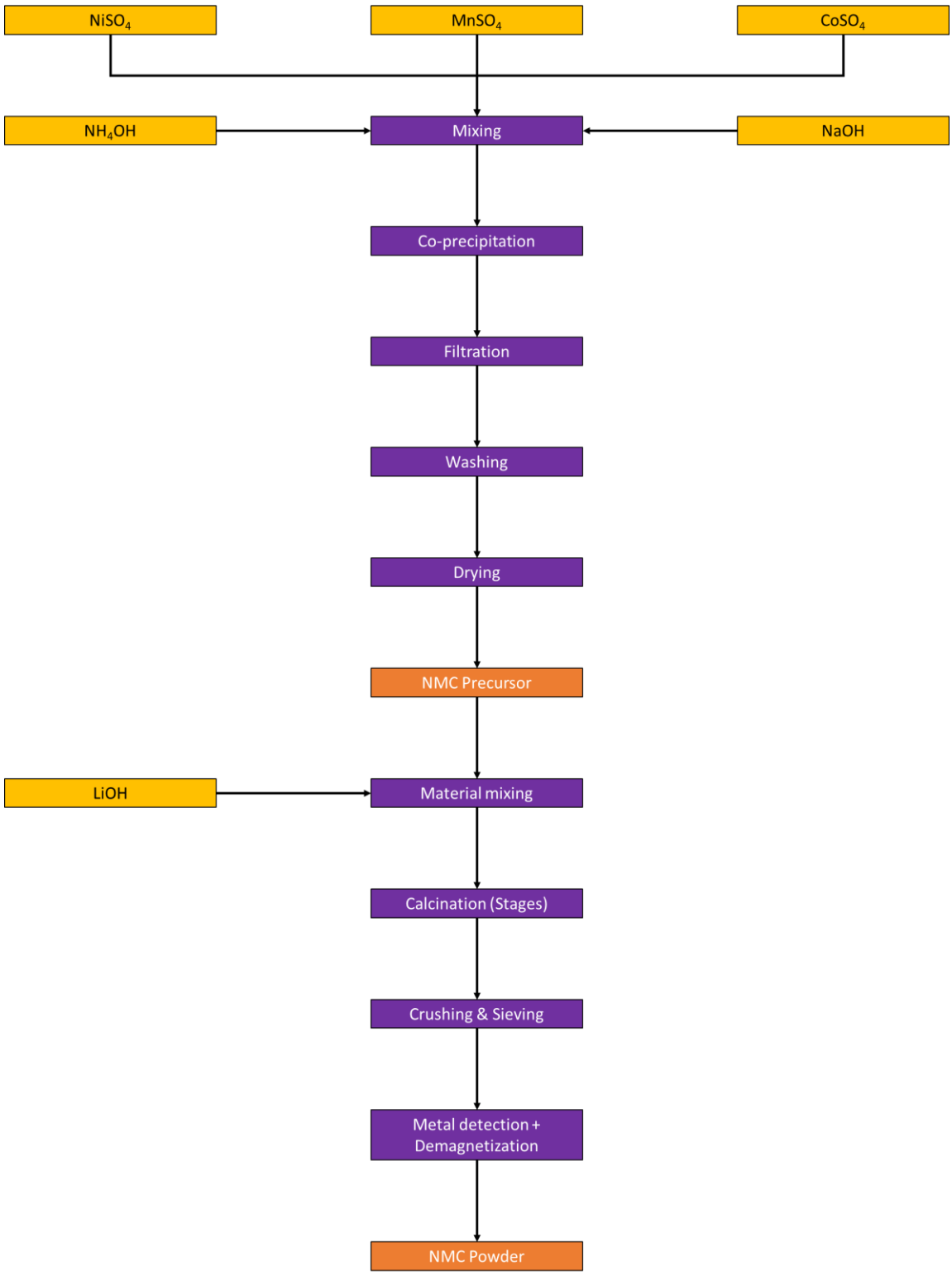

Figure 1: Schematic for NMC95 production

Table 1: Material and energy inputs for NMC95 production steps

Inputs	NMC95 Precursor Production	NMC95 Production
Material inputs (ton/ton of output)		
Nickel Sulfate ($NiSO_4$)	1.587	
Cobalt Sulfate ($CoSO_4$)	0.042	
Manganese Sulfate ($MnSO_4$)	0.041	
Sodium Hydroxide (NaOH)	0.890	
Ammonium Hydroxide (NH_4OH)	0.124	
Lithium Hydroxide (LiOH)		0.246
$Ni_{0.95}Co_{0.025}Mn_{0.025}(OH)_2$		0.950
Energy Inputs (mmBtu/ton of output)		
Natural gas	38.618	
Electricity		24.765

3. LIB Updates for Light-Duty Vehicles (LDVs)

3.1. Vehicles, Powertrains, and Batteries Considered

The GREET model considers three LDVs as mentioned earlier: car, SUV, and PUT. For each of these LDVs, the GREET model analyzes four powertrains that employ LIBs: HEV, PHEV, EV, and FCV. Autonomie considers two battery-related driving ranges for PHEVs (35-mile and 50-mile) and four driving ranges for EVs (150-mile, 200-mile, 300-mile, and 400-mile) across all three LDVs (Islam et al., 2023). We have included all these LDV categories in the GREET 2023 updates. Regarding LIBs, we have considered all eight cathode chemistries for LDVs (LMO, LFP, NMC111, NMC532, NMC622, NMC811, NMC95, and NCA).

3.2. Rationale for LIB Configuration

As mentioned earlier, we have used battery power/energy sizing from Autonomie (Islam et al., 2023) as inputs to BatPaC 5.1 model (Argonne, 2022; Knehr et al., 2022) to determine the corresponding LIB weight and material composition for all vehicles. Note that these LIB parameters are highly influenced by the battery configuration used for different vehicles (type, powertrain, and driving range). Hence, we designed the LIB configurations for all vehicles based on extensive discussions with Argonne's BatPaC team. Here, we present a brief summary of key aspects from our discussions that influence the LIB parameters updated in GREET 2023.

Battery configurations are primarily influenced by two parameters – cell capacity (measured in Ampere-hour or Ah) and battery pack voltage (measured in volts or V). These are complemented by other parameters, such as specific battery pack power/energy and battery production costs. Further, both parameters are heavily influenced by the LIB cathode chemistry for the same battery configuration. Based on their internal studies, the BatPaC team has determined cell capacities in the range of 0-20 Ah for HEVs and 40-65 Ah for EVs. This is because of the focus on sizing batteries by power for HEVs and energy for FCVs. Note that the BatPaC model considers pouch cells for EVs. Pack voltages are assumed to be in the range of 250-600 V for EVs and 70-100 V for HEVs. We have considered these cell capacity and pack voltage ranges for the default LIB cathode in GREET (NMC111) in determining our battery pack configuration. Further, we have assumed the cell capacities and pack voltages of FCVs and PHEVs to be in line with those for HEVs and EVs, respectively. This is due to the respective similarity in nature of the corresponding powertrains (HEV with FCV and PHEV with EV). We have also assumed a maximum energy capacity of 150 kWh per battery pack, meaning that any vehicle that requires more than 150 kWh of pack energy (per the Autonomie model) uses more than 1 LIB pack (after discussions with the BatPaC team). Based on this assumption, all LDVs use only 1 LIB pack except for the 400-mile PUT.

3.3. Battery Sizing Details

Table 2 provides the battery sizing details (by power for HEVs and FCVs and by energy for PHEVs and EVs) for all three LDVs.

Table 2: Battery sizing details for LDVs

LDV Type	Battery power (kW)		Battery energy (kWh)					
			PHEV		EV			
	HEV	FCV	35-mile	50-mile	150-mile	200-mile	300-mile	400-mile
Car	32	38	8	15	84	84	84	84
SUV	45	45	11	19	109	109	109	109
PUT	53	51	13	24	135	135	135	135

3.4. Battery Specific Power and Energy

Table 3 provides the specific power of LIBs across different cathode chemistries for HEV and FCV LDVs, while Tables 4 and 5 respectively provide the specific energy of LIBs for PHEV and EV LDVs.

Table 3: Specific power of LIBs for HEV and FCV LDVs

LIB Cathode Chemistry	Specific power (W/kg)					
	Car		SUV		PUT	
	HEV	FCV	HEV	FCV	HEV	FCV
LMO	2,221	2,517	2,050	1,890	2,295	2,050
LFP	1,982	2,227	2,221	2,342	2,395	2,523
NMC111	2,378	2,708	2,378	2,513	2,572	2,715
NMC532	2,419	2,759	2,419	2,558	2,619	2,767
NMC622	2,421	2,761	2,421	2,565	2,622	2,774
NMC811	2,484	2,839	2,484	2,635	2,694	2,853
NMC95	2,527	2,893	2,527	2,677	2,744	2,904
NCA	2,438	2,788	2,438	2,584	2,646	2,796

Table 4: Specific energy of LIBs for PHEV LDVs

LIB Cathode Chemistry	Specific energy (Wh/kg)					
	Car		SUV		PUT	
	35-mile	50-mile	35-mile	50-mile	35-mile	50-mile
LMO	135.6	145.2	140.8	144.0	143.0	148.5
LFP	131.5	141.5	136.7	140.5	139.1	145.1
NMC111	157.0	171.3	165.0	173.9	172.2	175.3
NMC532	161.8	177.9	171.3	180.7	178.9	182.1
NMC622	163.1	179.4	172.6	182.2	180.3	183.6
NMC811	177.6	188.9	181.0	191.9	189.9	193.4
NMC95	182.6	195.4	186.7	198.6	195.2	200.2
NCA	165.9	185.0	177.3	188.0	186.0	189.5

Table 5: Specific energy of LIBs for EV LDVs

LDV Type	LIB Cathode Chemistry	Specific energy (Wh/kg)			
		150-mile	200-mile	300-mile	400-mile
Car	LMO	130.9	136.7	147.7	152.0
	LFP	127.4	133.8	144.0	148.4
	NMC111	152.3	160.3	176.7	182.3
	NMC532	158.1	166.7	183.8	190.9
	NMC622	159.1	167.8	186.1	192.3
	NMC811	167.5	176.9	196.4	203.3
	NMC95	172.3	182.2	202.9	211.3
	NCA	163.6	172.7	191.6	198.2
SUV	LMO	133.4	138.5	147.8	154.8
	LFP	130.4	135.5	144.2	150.7
	NMC111	156.5	163.1	176.9	187.4
	NMC532	162.6	169.6	184.9	195.9
	NMC622	163.6	170.7	186.2	197.5
	NMC811	172.3	180.1	196.5	209.5
	NMC95	177.4	185.6	203.9	217.0
	NCA	168.3	175.8	191.7	204.0
PUT	LMO	138.8	143.3	152.0	149.3
	LFP	135.1	140.2	148.3	145.6
	NMC111	163.3	170.0	182.3	179.0
	NMC532	169.8	177.7	190.0	186.3
	NMC622	170.9	178.8	192.3	188.6
	NMC811	180.2	188.8	203.4	199.1
	NMC95	185.7	194.8	211.3	206.7
	NCA	175.9	184.1	198.2	194.2

3.5. Battery Material Composition

Tables 6-29 provide the material composition of LIBs with various cathode chemistries for the three LDVs (car, SUV, and PUT) across different powertrains, as obtained using the BatPaC 5.1 model.

Table 6: LIB material composition for HEV cars

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	15.20	12.36	11.40	10.59	10.42	9.46	8.89	9.97
Graphite	6.53	6.82	6.88	6.95	6.97	7.04	7.09	7.03
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.44	0.39	0.37	0.36	0.35	0.34	0.33	0.35
Copper	17.34	19.93	19.89	20.30	20.40	20.83	21.05	20.70
Aluminum Sheet	15.41	16.15	16.04	16.17	16.20	16.35	16.44	16.28
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	0.90	0.96	0.83	0.82	0.81	0.80	0.79	0.80
Ethylene Carbonate	2.52	2.68	2.31	2.28	2.27	2.23	2.20	2.24
Dimethyl Carbonate	2.52	2.68	2.31	2.28	2.27	2.23	2.20	2.24
Polypropylene	1.82	2.05	1.98	2.00	2.01	2.03	2.04	2.03
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.29	0.30	0.28	0.27	0.27	0.27	0.27	0.27
Steel	18.38	17.98	18.49	18.58	18.61	18.74	18.83	18.62
Stainless Steel	7.61	7.41	7.67	7.71	7.73	7.78	7.82	7.74
Rubber	0.27	0.29	0.31	0.32	0.32	0.32	0.33	0.32
Thermal Insulation	0.55	0.54	0.56	0.57	0.57	0.57	0.58	0.57
Glycol	4.50	4.35	4.55	4.57	4.57	4.61	4.64	4.57
Electronic Parts	5.72	5.11	6.13	6.23	6.23	6.40	6.50	6.27
*Assumed to be the same as average plastic in GREET model								

Table 7: LIB material composition for 35-mile PHEV cars

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	29.06	25.40	24.87	23.53	23.23	22.57	21.43	22.38
Graphite	11.47	13.05	14.00	14.43	14.52	15.74	16.08	14.79
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.83	0.78	0.79	0.77	0.77	0.78	0.77	0.76
Copper	8.00	8.72	7.70	7.89	7.97	8.55	8.71	8.18
Aluminum Sheet	11.66	12.11	11.70	11.86	11.91	12.65	12.80	12.01
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	0.98	1.07	0.93	0.93	0.93	0.97	0.96	0.92
Ethylene Carbonate	2.74	2.98	2.60	2.59	2.60	2.70	2.68	2.57
Dimethyl Carbonate	2.74	2.98	2.60	2.59	2.60	2.70	2.68	2.57
Polypropylene	1.57	1.63	1.50	1.52	1.53	1.63	1.65	1.55
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Polyethylene Terephthalate	0.26	0.28	0.26	0.26	0.26	0.28	0.28	0.26
Steel	17.06	17.30	18.20	18.49	18.50	15.15	15.36	18.67
Stainless Steel	6.04	6.15	6.36	6.45	6.44	6.86	6.96	6.49
Rubber	0.06	0.07	0.07	0.07	0.07	0.08	0.08	0.07
Thermal Insulation	0.35	0.36	0.38	0.38	0.38	0.41	0.42	0.39
Glycol	2.77	2.83	2.94	2.98	2.99	3.19	3.23	3.01
Electronic Parts	4.38	4.26	5.07	5.23	5.27	5.71	5.88	5.35
*Assumed to be the same as average plastic in GREET model								

Table 8: LIB material composition for 50-mile PHEV cars

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	31.12	27.34	27.15	25.91	25.60	24.07	23.01	25.01
Graphite	12.26	14.03	15.25	15.86	15.98	16.76	17.24	16.50
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.89	0.84	0.87	0.85	0.85	0.83	0.82	0.85
Copper	7.95	8.38	7.03	6.94	6.92	6.79	6.71	6.79
Aluminum Sheet	11.55	12.04	11.51	11.58	11.59	11.68	11.73	11.57
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.05	1.15	1.01	1.00	1.00	0.99	0.99	0.99
Ethylene Carbonate	2.93	3.21	2.81	2.79	2.79	2.77	2.75	2.76
Dimethyl Carbonate	2.93	3.21	2.81	2.79	2.79	2.77	2.75	2.76
Polypropylene	1.64	1.72	1.53	1.51	1.51	1.49	1.48	1.49
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.28	0.30	0.28	0.28	0.28	0.28	0.28	0.28
Steel	15.45	15.72	16.65	17.04	17.17	17.61	17.96	17.29
Stainless Steel	5.75	5.89	6.11	6.24	6.28	6.41	6.52	6.30
Rubber	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.04
Thermal Insulation	0.33	0.34	0.36	0.37	0.37	0.38	0.39	0.37
Glycol	2.49	2.55	2.67	2.72	2.73	2.80	2.84	2.76
Electronic Parts	3.33	3.21	3.90	4.06	4.08	4.30	4.46	4.22
*Assumed to be the same as average plastic in GREET model								

Table 9: LIB material composition for 150-mile EV cars

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	28.03	24.61	24.13	23.02	22.70	21.33	20.29	22.12
Graphite	11.17	12.76	13.73	14.27	14.35	15.05	15.40	14.78
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.80	0.76	0.77	0.76	0.76	0.74	0.73	0.75
Copper	8.90	9.21	8.15	8.09	8.08	8.02	8.00	8.00
Aluminum Sheet	12.78	13.17	12.81	12.90	12.93	13.02	13.12	12.93
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	0.96	1.05	0.90	0.90	0.89	0.89	0.88	0.88
Ethylene Carbonate	2.68	2.92	2.52	2.50	2.49	2.47	2.44	2.46
Dimethyl Carbonate	2.68	2.92	2.52	2.50	2.49	2.47	2.44	2.46
Polypropylene	1.77	1.83	1.62	1.61	1.61	1.59	1.58	1.58
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Polyethylene Terephthalate	0.25	0.27	0.25	0.25	0.25	0.26	0.26	0.25
Steel	18.31	18.61	20.03	20.41	20.58	21.00	21.48	20.78
Stainless Steel	6.95	7.15	7.38	7.49	7.53	7.64	7.76	7.57
Rubber	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Thermal Insulation	0.38	0.39	0.42	0.43	0.43	0.44	0.45	0.43
Glycol	2.54	2.61	2.69	2.74	2.75	2.80	2.84	2.77
Electronic Parts	1.76	1.69	2.04	2.09	2.12	2.23	2.28	2.19
*Assumed to be the same as average plastic in GREET model								

Table 10: LIB material composition for 200-mile EV cars

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	29.27	25.84	25.41	24.27	23.93	22.53	21.46	23.35
Graphite	11.65	13.38	14.43	15.02	15.11	15.87	16.26	15.58
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.84	0.80	0.81	0.80	0.80	0.78	0.77	0.79
Copper	8.78	9.06	7.86	7.78	7.77	7.68	7.64	7.66
Aluminum Sheet	12.69	13.08	12.71	12.80	12.84	12.94	13.04	12.83
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.01	1.10	0.95	0.94	0.94	0.93	0.93	0.93
Ethylene Carbonate	2.81	3.07	2.65	2.63	2.62	2.61	2.58	2.60
Dimethyl Carbonate	2.81	3.07	2.65	2.63	2.62	2.61	2.58	2.60
Polypropylene	1.83	1.89	1.67	1.66	1.66	1.64	1.63	1.64
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Polyethylene Terephthalate	0.26	0.28	0.26	0.26	0.26	0.26	0.26	0.26
Steel	17.18	17.34	18.85	19.24	19.41	19.83	20.31	19.61
Stainless Steel	6.76	6.92	7.20	7.31	7.36	7.48	7.61	7.41
Rubber	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Thermal Insulation	0.37	0.38	0.41	0.41	0.42	0.43	0.44	0.42
Glycol	2.39	2.45	2.54	2.58	2.59	2.64	2.68	2.61
Electronic Parts	1.31	1.30	1.56	1.63	1.63	1.73	1.77	1.67
*Assumed to be the same as average plastic in GREET model								

Table 11: LIB material composition for 300-mile EV cars

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	31.62	27.80	28.00	26.76	26.55	25.02	23.89	25.90
Graphite	12.51	14.32	15.80	16.46	16.65	17.51	17.98	17.17
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.90	0.86	0.89	0.88	0.88	0.87	0.85	0.88
Copper	9.39	9.77	8.10	7.94	7.91	7.74	7.70	7.74
Aluminum Sheet	12.19	12.63	12.03	12.10	12.11	12.20	12.30	12.09
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.10	1.20	1.05	1.04	1.04	1.03	1.03	1.03
Ethylene Carbonate	3.07	3.35	2.92	2.90	2.90	2.89	2.86	2.87
Dimethyl Carbonate	3.07	3.35	2.92	2.90	2.90	2.89	2.86	2.87
Polypropylene	1.90	1.98	1.70	1.68	1.67	1.64	1.63	1.64
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.26	0.28	0.26	0.26	0.27	0.27	0.27	0.26
Steel	14.59	14.83	16.10	16.59	16.61	17.13	17.58	16.89
Stainless Steel	6.06	6.23	6.51	6.66	6.67	6.83	6.97	6.75
Rubber	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Thermal Insulation	0.33	0.33	0.36	0.37	0.37	0.38	0.39	0.37
Glycol	2.11	2.17	2.26	2.31	2.32	2.38	2.42	2.34
Electronic Parts	0.86	0.86	1.07	1.12	1.12	1.19	1.24	1.17
*Assumed to be the same as average plastic in GREET model								

Table 12: LIB material composition for 400-mile EV cars

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	32.54	28.64	28.88	27.78	27.43	25.90	24.88	26.79
Graphite	12.86	14.74	16.28	17.07	17.19	18.11	18.71	17.75
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.93	0.89	0.92	0.92	0.91	0.90	0.89	0.91
Copper	9.27	9.64	7.82	7.63	7.59	7.38	7.25	7.39
Aluminum Sheet	12.24	12.72	12.08	12.13	12.16	12.26	12.33	12.15
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.14	1.24	1.08	1.08	1.08	1.07	1.07	1.07
Ethylene Carbonate	3.17	3.46	3.02	3.02	3.01	2.99	2.98	2.98
Dimethyl Carbonate	3.17	3.46	3.02	3.02	3.01	2.99	2.98	2.98
Polypropylene	1.98	2.07	1.77	1.74	1.74	1.71	1.69	1.71
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.28	0.29	0.28	0.28	0.28	0.28	0.29	0.28
Steel	13.62	13.82	15.21	15.51	15.70	16.22	16.56	15.98
Stainless Steel	5.88	6.05	6.38	6.49	6.55	6.71	6.82	6.63
Rubber	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Thermal Insulation	0.32	0.32	0.35	0.36	0.36	0.37	0.38	0.37
Glycol	1.99	2.05	2.14	2.18	2.20	2.25	2.29	2.22
Electronic Parts	0.59	0.58	0.74	0.76	0.76	0.83	0.85	0.76
*Assumed to be the same as average plastic in GREET model								

Table 13: LIB material composition for FCV cars

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	17.22	13.89	12.98	12.08	11.89	10.82	10.17	11.40
Graphite	7.36	7.63	7.79	7.87	7.90	7.99	8.07	7.98
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.50	0.44	0.42	0.41	0.40	0.38	0.37	0.40
Copper	18.48	21.33	21.33	21.80	21.91	22.40	22.66	22.21
Aluminum Sheet	15.22	16.09	15.96	16.12	16.14	16.32	16.43	16.24
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.02	1.08	0.94	0.93	0.93	0.91	0.90	0.92
Ethylene Carbonate	2.86	3.03	2.63	2.60	2.59	2.55	2.52	2.57
Dimethyl Carbonate	2.86	3.03	2.63	2.60	2.59	2.55	2.52	2.57
Polypropylene	1.95	2.22	2.14	2.17	2.18	2.21	2.22	2.20
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.31	0.31	0.30	0.29	0.29	0.29	0.29	0.29
Steel	16.48	16.07	16.63	16.72	16.75	16.89	16.99	16.74
Stainless Steel	6.95	6.73	7.03	7.08	7.09	7.16	7.20	7.09
Rubber	0.26	0.27	0.30	0.30	0.30	0.31	0.31	0.31
Thermal Insulation	0.50	0.48	0.51	0.51	0.51	0.52	0.52	0.51
Glycol	3.85	3.71	3.91	3.93	3.93	3.97	4.00	3.94
Electronic Parts	4.18	3.69	4.50	4.59	4.60	4.73	4.83	4.63
*Assumed to be the same as average plastic in GREET model								

Table 14: LIB material composition for HEV SUVs

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	15.20	12.36	11.40	10.59	10.42	9.46	8.89	9.97
Graphite	6.53	6.82	6.88	6.95	6.97	7.04	7.09	7.03
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.44	0.39	0.37	0.36	0.35	0.34	0.33	0.35
Copper	17.34	19.93	19.89	20.30	20.40	20.83	21.05	20.70
Aluminum Sheet	15.41	16.15	16.04	16.17	16.20	16.35	16.44	16.28
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	0.90	0.96	0.83	0.82	0.81	0.80	0.79	0.80
Ethylene Carbonate	2.52	2.68	2.31	2.28	2.27	2.23	2.20	2.24
Dimethyl Carbonate	2.52	2.68	2.31	2.28	2.27	2.23	2.20	2.24
Polypropylene	1.82	2.05	1.98	2.00	2.01	2.03	2.04	2.03
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.29	0.30	0.28	0.27	0.27	0.27	0.27	0.27
Steel	18.38	17.98	18.49	18.58	18.61	18.74	18.83	18.62
Stainless Steel	7.61	7.41	7.67	7.71	7.73	7.78	7.82	7.74
Rubber	0.27	0.29	0.31	0.32	0.32	0.32	0.33	0.32
Thermal Insulation	0.55	0.54	0.56	0.57	0.57	0.57	0.58	0.57
Glycol	4.50	4.35	4.55	4.57	4.57	4.61	4.64	4.57
Electronic Parts	5.72	5.11	6.13	6.23	6.23	6.40	6.50	6.27
*Assumed to be the same as average plastic in GREET model								

Table 15: LIB material composition for 35-mile PHEV SUVs

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	30.16	26.41	26.16	24.94	24.63	23.05	21.96	23.97
Graphite	11.90	13.56	14.71	15.28	15.40	16.08	16.46	15.83
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.86	0.82	0.83	0.82	0.82	0.80	0.78	0.81
Copper	7.80	8.47	7.14	7.06	7.05	7.04	7.17	7.04
Aluminum Sheet	11.63	12.10	11.58	11.64	11.65	11.78	11.91	11.68
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.02	1.11	0.97	0.96	0.96	0.95	0.95	0.95
Ethylene Carbonate	2.85	3.10	2.71	2.69	2.68	2.67	2.66	2.66
Dimethyl Carbonate	2.85	3.10	2.71	2.69	2.68	2.67	2.66	2.66
Polypropylene	1.62	1.68	1.50	1.48	1.48	1.48	1.49	1.47
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.27	0.29	0.27	0.27	0.27	0.27	0.28	0.27
Steel	16.28	16.52	17.44	17.83	17.95	18.38	18.58	18.06
Stainless Steel	5.92	6.03	6.25	6.37	6.41	6.54	6.59	6.43
Rubber	0.04	0.05	0.05	0.05	0.05	0.06	0.06	0.06
Thermal Insulation	0.35	0.35	0.37	0.38	0.38	0.39	0.39	0.38
Glycol	2.63	2.69	2.81	2.86	2.87	2.93	2.97	2.89
Electronic Parts	3.79	3.69	4.47	4.66	4.70	4.89	5.07	4.82
*Assumed to be the same as average plastic in GREET model								

Table 16: LIB material composition for 50-mile PHEV SUVs

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	30.85	27.14	27.57	26.31	26.00	24.46	23.39	25.42
Graphite	12.16	13.93	15.49	16.11	16.24	17.04	17.53	16.77
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.88	0.84	0.88	0.87	0.86	0.85	0.84	0.86
Copper	7.62	8.00	6.82	6.71	6.69	6.55	6.46	6.55
Aluminum Sheet	12.15	12.66	12.48	12.57	12.59	12.71	12.79	12.58
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.04	1.14	1.02	1.02	1.01	1.01	1.00	1.01
Ethylene Carbonate	2.91	3.18	2.85	2.84	2.83	2.81	2.80	2.81
Dimethyl Carbonate	2.91	3.18	2.85	2.84	2.83	2.81	2.80	2.81
Polypropylene	1.64	1.72	1.56	1.55	1.55	1.53	1.52	1.52
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.27	0.30	0.28	0.28	0.28	0.28	0.28	0.28
Steel	16.61	16.82	15.92	16.32	16.44	16.88	17.23	16.56
Stainless Steel	5.53	5.66	6.03	6.15	6.19	6.33	6.44	6.22
Rubber	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Thermal Insulation	0.32	0.33	0.35	0.36	0.37	0.38	0.38	0.37
Glycol	2.30	2.36	2.52	2.57	2.58	2.64	2.69	2.60
Electronic Parts	2.77	2.69	3.33	3.45	3.49	3.67	3.80	3.59
*Assumed to be the same as average plastic in GREET model								

Table 17: LIB material composition for 150-mile EV SUVs

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	28.56	25.17	24.79	23.66	23.34	21.95	20.89	22.75
Graphite	11.37	13.04	14.09	14.65	14.74	15.47	15.84	15.19
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.81	0.78	0.79	0.78	0.78	0.76	0.75	0.77
Copper	9.29	9.65	8.38	8.32	8.31	8.26	8.24	8.23
Aluminum Sheet	12.73	13.11	12.70	12.78	12.82	12.91	13.02	12.81
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	0.98	1.08	0.93	0.92	0.92	0.91	0.90	0.91
Ethylene Carbonate	2.75	3.00	2.58	2.57	2.56	2.54	2.52	2.53
Dimethyl Carbonate	2.75	3.00	2.58	2.57	2.56	2.54	2.52	2.53
Polypropylene	1.81	1.88	1.64	1.63	1.63	1.61	1.60	1.61
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Polyethylene Terephthalate	0.25	0.27	0.25	0.26	0.26	0.26	0.26	0.26
Steel	17.57	17.70	19.26	19.64	19.81	20.23	20.70	20.01
Stainless Steel	6.81	6.96	7.25	7.35	7.40	7.51	7.64	7.44
Rubber	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Thermal Insulation	0.38	0.38	0.41	0.42	0.42	0.43	0.44	0.42
Glycol	2.44	2.50	2.59	2.63	2.64	2.70	2.73	2.66
Electronic Parts	1.45	1.43	1.71	1.76	1.75	1.86	1.89	1.82
*Assumed to be the same as average plastic in GREET model								

Table 18: LIB material composition for 200-mile EV SUVs

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	29.65	26.17	25.84	24.69	24.35	22.94	21.85	23.76
Graphite	11.79	13.54	14.67	15.27	15.36	16.15	16.55	15.84
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.85	0.81	0.83	0.82	0.81	0.80	0.78	0.81
Copper	9.25	9.56	8.29	8.22	8.21	8.14	8.12	8.12
Aluminum Sheet	12.62	13.01	12.60	12.69	12.72	12.82	12.93	12.72
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.02	1.12	0.96	0.96	0.96	0.95	0.94	0.95
Ethylene Carbonate	2.85	3.12	2.69	2.68	2.67	2.66	2.63	2.64
Dimethyl Carbonate	2.85	3.12	2.69	2.68	2.67	2.66	2.63	2.64
Polypropylene	1.86	1.93	1.69	1.68	1.67	1.66	1.65	1.65
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.26	0.28	0.26	0.26	0.26	0.27	0.27	0.26
Steel	16.57	16.70	18.21	18.58	18.76	19.16	19.64	18.95
Stainless Steel	6.63	6.79	7.08	7.19	7.24	7.36	7.49	7.29
Rubber	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Thermal Insulation	0.37	0.37	0.40	0.41	0.41	0.42	0.43	0.42
Glycol	2.30	2.36	2.45	2.49	2.50	2.55	2.58	2.52
Electronic Parts	1.10	1.08	1.31	1.35	1.38	1.43	1.48	1.40
*Assumed to be the same as average plastic in GREET model								

Table 19: LIB material composition for 300-mile EV SUVs

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	31.64	27.83	28.02	26.92	26.56	25.03	24.01	25.91
Graphite	12.52	14.34	15.82	16.56	16.67	17.53	18.08	17.19
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.90	0.86	0.89	0.89	0.88	0.87	0.86	0.88
Copper	9.35	9.74	7.99	7.81	7.78	7.59	7.48	7.59
Aluminum Sheet	12.29	12.75	12.15	12.20	12.23	12.33	12.41	12.22
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.10	1.20	1.05	1.05	1.04	1.04	1.03	1.03
Ethylene Carbonate	3.08	3.36	2.93	2.92	2.91	2.89	2.88	2.88
Dimethyl Carbonate	3.08	3.36	2.93	2.92	2.91	2.89	2.88	2.88
Polypropylene	1.94	2.02	1.73	1.71	1.70	1.67	1.66	1.67
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Polyethylene Terephthalate	0.26	0.28	0.26	0.27	0.27	0.27	0.27	0.27
Steel	14.45	14.66	16.03	16.36	16.56	17.12	17.47	16.86
Stainless Steel	6.14	6.32	6.62	6.73	6.79	6.96	7.07	6.87
Rubber	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Thermal Insulation	0.33	0.33	0.36	0.37	0.37	0.39	0.39	0.38
Glycol	2.07	2.14	2.23	2.27	2.28	2.34	2.38	2.31
Electronic Parts	0.81	0.77	0.95	0.98	1.01	1.04	1.09	1.02
*Assumed to be the same as average plastic in GREET model								

Table 20: LIB material composition for 400-mile EV SUVs

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	33.14	29.08	29.69	28.50	28.16	26.68	25.55	27.57
Graphite	13.06	14.93	16.69	17.46	17.60	18.60	19.16	18.21
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.94	0.90	0.95	0.94	0.93	0.92	0.91	0.93
Copper	9.96	10.39	8.26	8.08	8.04	7.83	7.71	7.83
Aluminum Sheet	12.24	12.76	12.04	12.10	12.11	12.19	12.26	12.08
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.16	1.27	1.12	1.11	1.11	1.11	1.10	1.10
Ethylene Carbonate	3.24	3.53	3.12	3.11	3.10	3.09	3.07	3.07
Dimethyl Carbonate	3.24	3.53	3.12	3.11	3.10	3.09	3.07	3.07
Polypropylene	2.00	2.10	1.80	1.77	1.76	1.73	1.72	1.73
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.31	0.33	0.31	0.31	0.31	0.32	0.32	0.31
Steel	12.39	12.63	13.81	14.19	14.37	14.78	15.25	14.57
Stainless Steel	5.57	5.74	6.05	6.18	6.24	6.38	6.53	6.30
Rubber	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Thermal Insulation	0.29	0.30	0.32	0.33	0.33	0.34	0.35	0.34
Glycol	1.88	1.93	2.03	2.08	2.09	2.14	2.19	2.12
Electronic Parts	0.54	0.54	0.66	0.70	0.72	0.77	0.78	0.74
*Assumed to be the same as average plastic in GREET model								

Table 21: LIB material composition for FCV SUVs

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	16.03	12.99	12.05	11.20	11.04	10.04	9.42	10.56
Graphite	6.86	7.15	7.25	7.32	7.35	7.43	7.48	7.42
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.47	0.41	0.39	0.38	0.38	0.36	0.34	0.37
Copper	18.01	20.69	20.72	21.16	21.23	21.69	21.96	21.55
Aluminum Sheet	15.21	16.03	15.88	16.02	16.06	16.22	16.31	16.14
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	0.95	1.01	0.87	0.86	0.86	0.85	0.84	0.85
Ethylene Carbonate	2.66	2.83	2.44	2.41	2.41	2.37	2.34	2.38
Dimethyl Carbonate	2.66	2.83	2.44	2.41	2.41	2.37	2.34	2.38
Polypropylene	1.85	2.10	2.02	2.05	2.05	2.08	2.09	2.07
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.29	0.30	0.28	0.28	0.28	0.28	0.27	0.28
Steel	17.64	17.23	17.74	17.83	17.83	17.96	18.07	17.84
Stainless Steel	7.27	7.04	7.34	7.38	7.38	7.44	7.49	7.39
Rubber	0.29	0.30	0.33	0.34	0.34	0.34	0.35	0.34
Thermal Insulation	0.53	0.51	0.53	0.54	0.54	0.54	0.55	0.54
Glycol	4.27	4.12	4.32	4.35	4.36	4.40	4.42	4.36
Electronic Parts	5.01	4.46	5.40	5.47	5.48	5.63	5.73	5.53
*Assumed to be the same as average plastic in GREET model								

Table 22: LIB material composition for HEV PUTs

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	16.39	13.24	12.33	11.47	11.29	10.27	9.65	10.82
Graphite	7.01	7.27	7.40	7.48	7.50	7.59	7.65	7.58
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.48	0.42	0.40	0.39	0.38	0.36	0.35	0.38
Copper	18.29	21.07	21.07	21.52	21.63	22.11	22.35	21.92
Aluminum Sheet	15.14	15.96	15.82	15.96	15.99	16.15	16.25	16.08
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	0.97	1.03	0.90	0.88	0.88	0.87	0.86	0.87
Ethylene Carbonate	2.72	2.88	2.50	2.47	2.46	2.42	2.39	2.44
Dimethyl Carbonate	2.72	2.88	2.50	2.47	2.46	2.42	2.39	2.44
Polypropylene	1.87	2.12	2.04	2.07	2.07	2.10	2.12	2.09
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.29	0.30	0.28	0.28	0.28	0.28	0.28	0.28
Steel	17.30	16.92	17.40	17.49	17.51	17.64	17.73	17.50
Stainless Steel	7.11	6.89	7.18	7.22	7.24	7.30	7.34	7.23
Rubber	0.29	0.31	0.34	0.34	0.34	0.35	0.36	0.35
Thermal Insulation	0.51	0.49	0.52	0.52	0.53	0.53	0.53	0.53
Glycol	4.17	4.02	4.23	4.25	4.25	4.29	4.32	4.26
Electronic Parts	4.74	4.20	5.09	5.19	5.19	5.32	5.43	5.23
*Assumed to be the same as average plastic in GREET model								

Table 23: LIB material composition for 35-mile PHEV PUTs

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	30.64	26.88	27.30	26.04	25.73	24.19	22.97	25.15
Graphite	12.09	13.81	15.35	15.96	16.09	16.88	17.23	16.61
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.87	0.83	0.87	0.86	0.85	0.84	0.82	0.85
Copper	7.65	8.28	7.11	7.02	7.00	6.88	7.01	6.87
Aluminum Sheet	11.40	11.88	11.65	11.72	11.74	11.83	11.98	11.72
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.04	1.13	1.01	1.01	1.00	1.00	0.99	1.00
Ethylene Carbonate	2.89	3.15	2.83	2.81	2.80	2.79	2.77	2.78
Dimethyl Carbonate	2.89	3.15	2.83	2.81	2.80	2.79	2.77	2.78
Polypropylene	1.66	1.73	1.58	1.57	1.56	1.54	1.57	1.54
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.28	0.30	0.28	0.28	0.28	0.29	0.28	0.29
Steel	17.23	17.38	16.45	16.86	16.99	17.43	17.79	17.09
Stainless Steel	5.70	5.81	6.19	6.32	6.36	6.50	6.61	6.38
Rubber	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Thermal Insulation	0.33	0.34	0.37	0.37	0.38	0.39	0.39	0.38
Glycol	2.37	2.42	2.59	2.64	2.65	2.71	2.75	2.68
Electronic Parts	2.91	2.85	3.53	3.67	3.71	3.88	4.01	3.82
*Assumed to be the same as average plastic in GREET model								

Table 24: LIB material composition for 50-mile PHEV PUTs

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	31.81	28.03	27.80	26.52	26.20	24.65	23.57	25.63
Graphite	12.54	14.39	15.62	16.24	16.36	17.18	17.67	16.91
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.91	0.87	0.89	0.87	0.87	0.85	0.84	0.87
Copper	7.72	8.10	6.71	6.60	6.57	6.42	6.33	6.42
Aluminum Sheet	12.17	12.68	12.20	12.28	12.31	12.42	12.50	12.29
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.08	1.18	1.03	1.02	1.02	1.02	1.01	1.01
Ethylene Carbonate	3.00	3.29	2.88	2.86	2.85	2.84	2.82	2.83
Dimethyl Carbonate	3.00	3.29	2.88	2.86	2.85	2.84	2.82	2.83
Polypropylene	1.70	1.78	1.59	1.57	1.57	1.55	1.54	1.55
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Polyethylene Terephthalate	0.28	0.31	0.29	0.29	0.28	0.29	0.29	0.29
Steel	15.64	15.81	17.06	17.53	17.69	18.19	18.61	17.82
Stainless Steel	5.48	5.61	5.84	5.96	6.00	6.13	6.24	6.02
Rubber	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Thermal Insulation	0.32	0.32	0.34	0.35	0.35	0.36	0.37	0.36
Glycol	2.15	2.20	2.30	2.34	2.35	2.41	2.45	2.37
Electronic Parts	2.17	2.10	2.54	2.68	2.70	2.82	2.91	2.77
*Assumed to be the same as average plastic in GREET model								

Table 25: LIB material composition for 150-mile EV PUTs

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	29.71	26.09	25.88	24.72	24.39	22.96	21.87	23.79
Graphite	11.80	13.48	14.67	15.26	15.36	16.14	16.53	15.83
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.85	0.81	0.83	0.82	0.81	0.80	0.78	0.81
Copper	9.96	10.40	9.11	9.07	9.07	9.05	9.07	9.01
Aluminum Sheet	12.39	12.79	12.31	12.39	12.42	12.51	12.61	12.41
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.02	1.12	0.96	0.96	0.96	0.95	0.94	0.95
Ethylene Carbonate	2.86	3.11	2.69	2.68	2.67	2.66	2.63	2.64
Dimethyl Carbonate	2.86	3.11	2.69	2.68	2.67	2.66	2.63	2.64
Polypropylene	1.82	1.89	1.64	1.63	1.63	1.61	1.60	1.60
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Polyethylene Terephthalate	0.26	0.27	0.26	0.26	0.26	0.26	0.26	0.26
Steel	16.08	16.32	17.73	18.10	18.26	18.65	19.10	18.44
Stainless Steel	6.53	6.72	6.98	7.09	7.14	7.25	7.37	7.18
Rubber	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Thermal Insulation	0.35	0.36	0.39	0.39	0.40	0.40	0.41	0.40
Glycol	2.27	2.33	2.42	2.45	2.47	2.51	2.55	2.48
Electronic Parts	1.18	1.14	1.39	1.45	1.44	1.54	1.60	1.51
*Assumed to be the same as average plastic in GREET model								

Table 26: LIB material composition for 200-mile EV PUTs

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	30.68	27.07	26.94	25.86	25.51	24.05	22.93	24.89
Graphite	12.17	13.98	15.25	15.95	16.05	16.89	17.32	16.56
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.87	0.84	0.86	0.85	0.85	0.84	0.82	0.85
Copper	9.41	9.78	8.26	8.11	8.09	7.99	7.95	7.96
Aluminum Sheet	12.47	12.88	12.38	12.44	12.48	12.58	12.69	12.47
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.06	1.16	1.01	1.00	1.00	1.00	0.99	0.99
Ethylene Carbonate	2.97	3.25	2.81	2.80	2.79	2.78	2.75	2.76
Dimethyl Carbonate	2.97	3.25	2.81	2.80	2.79	2.78	2.75	2.76
Polypropylene	1.90	1.98	1.71	1.69	1.69	1.67	1.66	1.66
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Polyethylene Terephthalate	0.26	0.28	0.26	0.27	0.27	0.27	0.27	0.27
Steel	15.38	15.49	17.02	17.34	17.54	17.97	18.44	17.76
Stainless Steel	6.42	6.57	6.89	6.99	7.05	7.18	7.31	7.10
Rubber	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
Thermal Insulation	0.35	0.35	0.38	0.39	0.39	0.40	0.41	0.40
Glycol	2.16	2.22	2.31	2.35	2.37	2.41	2.45	2.39
Electronic Parts	0.89	0.86	1.06	1.11	1.08	1.14	1.21	1.13
*Assumed to be the same as average plastic in GREET model								

Table 27: LIB material composition for 300-mile EV PUTs

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	32.54	28.63	28.89	27.65	27.44	25.90	24.88	26.80
Graphite	12.86	14.73	16.28	16.99	17.19	18.11	18.71	17.75
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.93	0.88	0.92	0.91	0.91	0.90	0.89	0.91
Copper	9.45	9.85	8.04	7.86	7.83	7.63	7.51	7.63
Aluminum Sheet	12.20	12.67	12.03	12.10	12.11	12.20	12.27	12.09
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.14	1.24	1.08	1.08	1.08	1.07	1.07	1.07
Ethylene Carbonate	3.17	3.46	3.02	3.00	3.01	2.99	2.98	2.98
Dimethyl Carbonate	3.17	3.46	3.02	3.00	3.01	2.99	2.98	2.98
Polypropylene	1.97	2.06	1.76	1.74	1.73	1.70	1.69	1.70
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.27	0.29	0.28	0.28	0.28	0.28	0.29	0.28
Steel	13.48	13.66	15.04	15.51	15.53	16.04	16.37	15.80
Stainless Steel	5.90	6.06	6.39	6.54	6.55	6.72	6.83	6.63
Rubber	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Thermal Insulation	0.31	0.32	0.35	0.36	0.36	0.37	0.38	0.36
Glycol	1.97	2.03	2.12	2.17	2.18	2.23	2.27	2.20
Electronic Parts	0.61	0.62	0.75	0.78	0.76	0.84	0.85	0.79
*Assumed to be the same as average plastic in GREET model								

Table 28: LIB material composition for 400-mile EV PUTs

Materials	**Weight share (wt.%)**							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	31.96	28.11	28.36	27.12	26.90	25.36	24.33	26.26
Graphite	12.64	14.47	16.00	16.67	16.86	17.74	18.31	17.40
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.91	0.87	0.91	0.89	0.89	0.88	0.87	0.89
Copper	9.38	9.77	7.95	7.77	7.73	7.52	7.40	7.53
Aluminum Sheet	12.24	12.70	12.07	12.15	12.15	12.25	12.32	12.14
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.12	1.22	1.06	1.06	1.06	1.05	1.05	1.05
Ethylene Carbonate	3.12	3.40	2.97	2.95	2.95	2.93	2.92	2.92
Dimethyl Carbonate	3.12	3.40	2.97	2.95	2.95	2.93	2.92	2.92
Polypropylene	1.95	2.03	1.73	1.71	1.70	1.68	1.66	1.67
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Polyethylene Terephthalate	0.26	0.28	0.27	0.27	0.27	0.27	0.27	0.27
Steel	14.10	14.31	15.68	16.18	16.21	16.77	17.14	16.51
Stainless Steel	6.04	6.21	6.52	6.68	6.69	6.86	6.98	6.77
Rubber	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Thermal Insulation	0.32	0.33	0.35	0.37	0.37	0.38	0.39	0.37
Glycol	2.04	2.10	2.20	2.25	2.26	2.31	2.35	2.28
Electronic Parts	0.76	0.76	0.92	0.94	0.97	1.03	1.05	0.98
*Assumed to be the same as average plastic in GREET model								

Table 29: LIB material composition for FCV PUTs

Materials	Weight share (wt.%)							
	LMO	**LFP**	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**	**NCA**
Active Material	17.26	13.86	13.02	12.12	11.94	10.87	10.21	11.43
Graphite	7.36	7.59	7.78	7.87	7.90	8.00	8.07	7.98
Silicon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.50	0.44	0.42	0.41	0.40	0.39	0.37	0.40
Copper	19.07	21.98	22.01	22.49	22.57	23.08	23.39	22.92
Aluminum Sheet	14.93	15.83	15.65	15.80	15.85	16.02	16.11	15.93
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.03	1.09	0.95	0.94	0.94	0.92	0.91	0.92
Ethylene Carbonate	2.87	3.03	2.65	2.61	2.61	2.57	2.54	2.58
Dimethyl Carbonate	2.87	3.03	2.65	2.61	2.61	2.57	2.54	2.58
Polypropylene	1.90	2.17	2.08	2.12	2.12	2.15	2.17	2.15
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.29	0.31	0.29	0.28	0.29	0.28	0.28	0.28
Steel	16.47	16.10	16.55	16.63	16.64	16.77	16.86	16.64
Stainless Steel	6.70	6.47	6.78	6.82	6.82	6.88	6.94	6.83
Rubber	0.31	0.32	0.36	0.36	0.36	0.37	0.38	0.37
Thermal Insulation	0.48	0.46	0.49	0.49	0.49	0.50	0.50	0.49
Glycol	3.91	3.75	3.97	3.99	4.00	4.04	4.06	4.00
Electronic Parts	4.05	3.57	4.35	4.46	4.46	4.59	4.67	4.50
*Assumed to be the same as average plastic in GREET model								

4. LIB Updates for Medium- & Heavy-Duty Vehicles (MHDVs)

4.1. Vehicles, Powertrains, and Batteries Considered

The GREET model considers three MHDVs as mentioned earlier: Class 6 PnD truck, and Class 8 regional day-cab and long-haul sleeper-cab trucks. For all three MHDVs, the GREET model analyzes two LIB-employing powertrains: EV and FCV. Additionally, GREET also considers the HEV powertrain for Class 6 PnD truck. Since Autonomie provides battery sizing for all these vehicle-powertrain combinations (Islam et al., 2023), we have included them all in LIB updates for GREET 2023. Unlike LDVs, we consider only six cathode chemistries for MHDVs (NMC111, NMC532, NMC622, NMC811, NMC95, and LFP).

4.2. Rationale for LIB Configuration

Like for LDVs, MHDV LIB configurations too are determined by cell capacity and pack voltage. Both these parameters are influenced strongly by the larger battery energy/power sizing needs for MHDVs. Since Autonomie provides differing values for LIB power needs of HEV and FCV MHDVs (see Section 4.3), their pack voltages and cell capacities are somewhat different. Based on discussions with the BatPaC team, we have considered cell capacities of 10-15 Ah for HEV, 15-20 Ah for FCV, and 55-65 Ah for EV MHDVs with the default LIB chemistry (NMC622). The corresponding pack voltages are 180-300 V for HEV and FCV, and 450-600 V for EV MHDVs. We also applied the 150 kWh/LIB pack limit to determine the number of LIB packs used for different MHDVs. This leads to a major variation in the number of battery packs used, which are discussed in Section 4.3.

4.3. Battery Sizing Details

Table 30 provides the LIB sizing details for various MHDVs – peak power (kW) for HEVs and FCVs and peak energy (kWh) for EVs. Table 31 provides details on the number of LIB configurations used for different vehicle-powertrain combinations.

Table 30: Battery sizing parameters for MHDVs with LIBs

MHDV types	Peak power (kW)		Peak energy storage (kWh)
	HEV	FCV	EV
Class 6 PnD	81	84	212
Class 8 day-cab		339	720
Class 8 sleeper-cab		339	1,359

Table 31: Number of LIB packs used in different MHDVs

MHDV types	HEV	FCV	EV
Class 6 PnD	1	1	2
Class 8 day-cab	1	1	5
Class 8 sleeper-cab	1	1	10

4.4. Battery Specific Power and Energy

Table 32 provides the specific power of LIBs with different cathode chemistries for HEV and FCV MHDVs, while Table 33 lists the specific energy of LIBs for EV MHDVs.

Table 32: Specific power of LIBs for HEV and FCV MHDVs

LIB Cathode Chemistry	Specific power (W/kg)					
	Class 6 PnD		Class 8 day-cab		Class 8 sleeper-cab	
	HEV	FCV	HEV	FCV	HEV	FCV
LFP	1,666	1,823	1,589	1,805	1,610	1,805
NMC111	2,002	2,217	2,067	2,178	2,092	2,178
NMC532	2,041	2,267	2,108	2,224	2,134	2,224
NMC622	2,051	2,277	2,118	2,235	2,145	2,235
NMC811	2,112	2,353	2,183	2,306	2,211	2,306
NMC95	2,155	2,405	2,228	2,355	2,257	2,355

Table 33: Specific energy of LIBs for EV MHDVs

LIB Cathode Chemistry	Specific energy (Wh/kg)		
	Class 6 PnD	Class 8 day-cab	Class 8 sleeper-cab
LFP	135.7	144.4	143.0
NMC111	158.5	170.2	168.4
NMC532	162.7	175.3	173.4
NMC622	163.5	176.1	174.2
NMC811	168.4	181.4	179.7
NMC95	170.5	184.2	182.5

4.5. Battery Material Composition

Tables 34-42 provide the material composition (wt.%) for the three MHDVs across all powertrains, as determined using the BatPaC 5.1 model.

Table 34: LIB material composition for Class 6 PnD HEVs

Materials	**Weight share (wt.%)**					
	LFP	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**
Active Material	16.79	15.52	14.45	14.28	13.01	12.25
Graphite	9.34	9.45	9.56	9.63	9.77	9.87
Silicon	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.53	0.51	0.49	0.49	0.46	0.45
Copper	17.21	17.61	18.05	18.13	18.63	18.91
Aluminum Sheet	16.38	16.51	16.70	16.74	16.97	17.11
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.18	1.01	1.00	1.00	0.98	0.97
Ethylene Carbonate	3.29	2.83	2.78	2.78	2.73	2.70
Dimethyl Carbonate	3.29	2.83	2.78	2.78	2.73	2.70
Polypropylene	2.22	2.17	2.20	2.21	2.24	2.26
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.38	0.36	0.35	0.35	0.35	0.35
Steel	16.12	17.12	17.37	17.35	17.64	17.81
Stainless Steel	7.74	8.04	8.13	8.12	8.22	8.28
Rubber	0.06	0.07	0.07	0.07	0.07	0.07
Thermal Insulation	0.56	0.60	0.61	0.60	0.62	0.62
Glycol	2.98	3.08	3.10	3.10	3.13	3.15
Electronic Parts	1.92	2.31	2.36	2.37	2.44	2.49
*Assumed to be the same as average plastic in GREET model						

Table 35: LIB material composition for Class 6 PnD EVs

Materials	Weight share (wt.%)					
	LFP	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**
Active Material	26.16	25.01	23.57	23.21	21.32	19.93
Graphite	13.46	14.09	14.47	14.53	14.89	14.96
Silicon	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.81	0.80	0.78	0.77	0.74	0.71
Copper	13.32	13.49	13.84	14.01	14.73	15.44
Aluminum Sheet	13.12	13.17	13.41	13.48	13.85	14.17
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.20	1.06	1.06	1.06	1.06	1.06
Ethylene Carbonate	3.34	2.97	2.96	2.96	2.96	2.95
Dimethyl Carbonate	3.34	2.97	2.96	2.96	2.96	2.95
Polypropylene	2.25	2.22	2.26	2.29	2.38	2.47
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.03	0.03	0.03	0.03	0.03
Polyethylene Terephthalate	0.27	0.26	0.26	0.26	0.26	0.26
Steel	13.64	14.54	14.86	14.88	15.13	15.28
Stainless Steel	6.05	6.22	6.32	6.33	6.41	6.46
Rubber	0.02	0.03	0.03	0.03	0.03	0.03
Thermal Insulation	0.32	0.33	0.34	0.34	0.35	0.35
Glycol	2.00	2.05	2.08	2.08	2.11	2.12
Electronic Parts	0.65	0.76	0.78	0.78	0.80	0.81
*Assumed to be the same as average plastic in GREET model						

Table 36: LIB material composition for Class 6 PnD FCVs

Materials	Weight share (wt.%)					
	LFP	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**
Active Material	18.37	17.19	16.05	15.85	14.50	13.67
Graphite	10.14	10.38	10.53	10.60	10.79	10.92
Silicon	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.58	0.56	0.54	0.54	0.52	0.50
Copper	15.36	15.44	15.87	15.95	16.41	16.67
Aluminum Sheet	16.16	16.27	16.48	16.53	16.78	16.94
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.29	1.12	1.10	1.10	1.09	1.08
Ethylene Carbonate	3.60	3.12	3.08	3.08	3.03	3.01
Dimethyl Carbonate	3.60	3.12	3.08	3.08	3.03	3.01
Polypropylene	2.24	2.20	2.24	2.24	2.28	2.31
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.38	0.36	0.36	0.36	0.36	0.36
Steel	15.22	16.19	16.43	16.42	16.71	16.88
Stainless Steel	7.29	7.63	7.73	7.73	7.84	7.91
Rubber	0.05	0.05	0.05	0.05	0.05	0.05
Thermal Insulation	0.51	0.55	0.56	0.56	0.57	0.58
Glycol	2.99	3.12	3.15	3.16	3.20	3.22
Electronic Parts	2.20	2.68	2.74	2.75	2.84	2.90
*Assumed to be the same as average plastic in GREET model						

Table 37: LIB material composition for Class 8 day-cab HEVs

Materials	**Weight share (wt.%)**					
	LFP	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**
Active Material	16.02	16.02	14.92	14.74	13.45	12.67
Graphite	8.91	9.75	9.88	9.94	10.09	10.20
Silicon	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.51	0.53	0.51	0.50	0.48	0.47
Copper	16.06	17.75	18.21	18.29	18.81	19.09
Aluminum Sheet	15.27	16.64	16.84	16.88	17.12	17.27
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.13	1.05	1.03	1.03	1.01	1.00
Ethylene Carbonate	3.14	2.92	2.87	2.88	2.82	2.79
Dimethyl Carbonate	3.14	2.92	2.87	2.88	2.82	2.79
Polypropylene	2.11	2.24	2.27	2.28	2.31	2.33
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.36	0.37	0.36	0.37	0.36	0.36
Steel	21.86	16.71	16.97	16.94	17.25	17.43
Stainless Steel	7.12	7.99	8.08	8.07	8.18	8.24
Rubber	0.04	0.05	0.05	0.05	0.05	0.05
Thermal Insulation	0.51	0.59	0.60	0.60	0.61	0.62
Glycol	2.55	2.83	2.85	2.85	2.88	2.90
Electronic Parts	1.28	1.66	1.69	1.70	1.75	1.79
*Assumed to be the same as average plastic in GREET model						

Table 38: LIB material composition for Class 8 day-cab EVs

Materials	Weight share (wt.%)					
	LFP	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**
Active Material	27.83	26.86	25.39	25.00	22.96	21.53
Graphite	14.26	15.06	15.51	15.57	15.95	16.07
Silicon	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.86	0.86	0.83	0.83	0.79	0.77
Copper	13.26	13.20	13.56	13.73	14.47	15.20
Aluminum Sheet	13.06	13.08	13.31	13.39	13.77	14.11
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.27	1.14	1.14	1.14	1.14	1.14
Ethylene Carbonate	3.56	3.19	3.19	3.19	3.19	3.20
Dimethyl Carbonate	3.56	3.19	3.19	3.19	3.19	3.20
Polypropylene	2.30	2.30	2.35	2.38	2.48	2.58
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.32	0.30	0.31	0.31	0.30	0.31
Steel	11.69	12.45	12.70	12.74	13.05	13.13
Stainless Steel	5.39	5.57	5.66	5.67	5.78	5.81
Rubber	0.02	0.02	0.02	0.02	0.02	0.03
Thermal Insulation	0.27	0.29	0.30	0.30	0.30	0.31
Glycol	1.82	1.88	1.91	1.91	1.94	1.96
Electronic Parts	0.50	0.58	0.60	0.60	0.62	0.63
*Assumed to be the same as average plastic in GREET model						

Table 39: LIB material composition for Class 8 day-cab FCVs

Materials	Weight share (wt.%)					
	LFP	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**
Active Material	18.20	16.89	15.75	15.56	14.21	13.39
Graphite	10.04	10.18	10.32	10.39	10.56	10.68
Silicon	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.58	0.55	0.53	0.53	0.51	0.49
Copper	15.11	15.17	15.55	15.64	16.07	16.32
Aluminum Sheet	15.09	15.00	15.18	15.22	15.43	15.56
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.28	1.10	1.08	1.08	1.06	1.05
Ethylene Carbonate	3.57	3.07	3.02	3.02	2.97	2.94
Dimethyl Carbonate	3.57	3.07	3.02	3.02	2.97	2.94
Polypropylene	2.19	2.13	2.16	2.17	2.20	2.22
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.38	0.35	0.35	0.35	0.35	0.34
Steel	18.83	20.62	21.00	20.98	21.43	21.71
Stainless Steel	6.56	6.82	6.90	6.89	6.98	7.04
Rubber	0.05	0.05	0.05	0.05	0.06	0.06
Thermal Insulation	0.39	0.42	0.43	0.43	0.43	0.44
Glycol	2.41	2.48	2.50	2.50	2.53	2.55
Electronic Parts	1.75	2.11	2.16	2.17	2.24	2.29
*Assumed to be the same as average plastic in GREET model						

Table 40: LIB material composition for Class 8 sleeper-cab HEVs

Materials	Weight share (wt.%)					
	LFP	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**
Active Material	16.23	16.22	15.11	14.93	13.62	12.83
Graphite	9.02	9.86	9.99	10.06	10.21	10.33
Silicon	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.52	0.53	0.51	0.51	0.49	0.47
Copper	16.13	17.79	18.25	18.33	18.85	19.14
Aluminum Sheet	15.24	16.57	16.77	16.81	17.06	17.20
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.14	1.06	1.04	1.04	1.02	1.01
Ethylene Carbonate	3.18	2.95	2.91	2.91	2.86	2.83
Dimethyl Carbonate	3.18	2.95	2.91	2.91	2.86	2.83
Polypropylene	2.12	2.24	2.27	2.28	2.32	2.34
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.36	0.37	0.36	0.37	0.36	0.36
Steel	21.51	16.49	16.75	16.72	17.03	17.21
Stainless Steel	7.05	7.91	8.00	8.00	8.10	8.17
Rubber	0.04	0.05	0.05	0.05	0.05	0.05
Thermal Insulation	0.50	0.58	0.59	0.59	0.60	0.61
Glycol	2.53	2.81	2.83	2.83	2.86	2.88
Electronic Parts	1.25	1.62	1.65	1.66	1.71	1.75
*Assumed to be the same as average plastic in GREET model						

Table 41: LIB material composition for Class 8 sleeper-cab EVs

Materials	Weight share (wt.%)					
	LFP	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**
Active Material	27.56	26.57	25.12	24.73	22.75	21.34
Graphite	14.14	14.91	15.35	15.41	15.82	15.94
Silicon	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.85	0.85	0.83	0.82	0.79	0.76
Copper	13.15	13.08	13.44	13.61	14.34	15.06
Aluminum Sheet	13.11	13.15	13.37	13.46	13.84	14.17
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.26	1.13	1.13	1.13	1.13	1.13
Ethylene Carbonate	3.51	3.15	3.15	3.15	3.15	3.16
Dimethyl Carbonate	3.51	3.15	3.15	3.15	3.15	3.16
Polypropylene	2.29	2.29	2.34	2.36	2.46	2.56
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.03	0.02	0.02	0.02	0.02	0.02
Polyethylene Terephthalate	0.32	0.30	0.30	0.30	0.31	0.31
Steel	12.06	12.84	13.10	13.14	13.38	13.46
Stainless Steel	5.52	5.70	5.79	5.80	5.89	5.92
Rubber	0.02	0.02	0.02	0.02	0.02	0.03
Thermal Insulation	0.28	0.30	0.30	0.31	0.31	0.31
Glycol	1.86	1.92	1.95	1.95	1.98	1.99
Electronic Parts	0.52	0.61	0.63	0.63	0.65	0.66
*Assumed to be the same as average plastic in GREET model						

Table 42: LIB material composition for Class 8 sleeper-cab FCVs

Materials	Weight share (wt.%)					
	LFP	**NMC111**	**NMC532**	**NMC622**	**NMC811**	**NMC95**
Active Material	18.20	16.89	15.75	15.56	14.21	13.39
Graphite	10.04	10.18	10.32	10.39	10.56	10.68
Silicon	0.00	0.00	0.00	0.00	0.00	0.00
PVDF	0.58	0.55	0.53	0.53	0.51	0.49
Copper	15.11	15.17	15.55	15.64	16.07	16.32
Aluminum Sheet	15.09	15.00	15.18	15.22	15.43	15.56
Cast Aluminum	0.00	0.00	0.00	0.00	0.00	0.00
$LiPF_6$	1.28	1.10	1.08	1.08	1.06	1.05
Ethylene Carbonate	3.57	3.07	3.02	3.02	2.97	2.94
Dimethyl Carbonate	3.57	3.07	3.02	3.02	2.97	2.94
Polypropylene	2.19	2.13	2.16	2.17	2.20	2.22
Polyethylene	0.00	0.00	0.00	0.00	0.00	0.00
Polymer*	0.00	0.00	0.00	0.00	0.00	0.00
Polyethylene Terephthalate	0.38	0.35	0.35	0.35	0.35	0.34
Steel	18.83	20.62	21.00	20.98	21.43	21.71
Stainless Steel	6.56	6.82	6.90	6.89	6.98	7.04
Rubber	0.05	0.05	0.05	0.05	0.06	0.06
Thermal Insulation	0.39	0.42	0.43	0.43	0.43	0.44
Glycol	2.41	2.48	2.50	2.50	2.53	2.55
Electronic Parts	1.75	2.11	2.16	2.17	2.24	2.29
*Assumed to be the same as average plastic in GREET model						

5. Tabs Updated in GREET Excel

All battery-related updates are implemented in GREET2. NMC95-related inventory and impact calculations are made in the *Other_Cathodes* tab. For LDVs, battery-related updates are made in the *Car*, *SUV*, *PUT*, *Mat_Inputs*, *Vehi_Inputs*, and *Battery_Sum* tabs. Battery-related updates for MHDVs are made in the *MHDV_Inputs*, *MHDV_Mat_Parameters*, *Class 6 PnD Trucks*, *Class 8 Day-cab Trucks*, *Class 8 Sleeper-cab Trucks*, and *MHDV_Battery_Sum* tabs.

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REFERENCES

Argonne, 2022. BatPaC: A Lithium-Ion Battery Performance and Cost Model for Electric-Drive Vehicles (version 5.0) [WWW Document]. URL http://www.cse.anl.gov/batpac (accessed 6.17.22).

Argonne, 2021. Autonomie [WWW Document]. URL https://www.autonomie.net/index.html (accessed 6.17.21).

Dai, Q., Dunn, J.B., Kelly, J.C., Elgowainy, A., 2017. Update of Life Cycle Analysis of Lithium-ion Batteries in the GREET Model. Argonne, IL.

Dai, Q., Kelly, J.C., Dunn, J.B., Benavides, P.T., 2018. Update of bill-of-materials and cathode materials production for lithium-ion batteries in the GREET® model. Argonne, IL.

Dunn, J.B., James, C., Gaines, L.L., Gallaghar, K., Dai, Q., Kelly, J.C., Gallagher, K.G., Dai, Q., Kelly, J.C., 2015. Material and Energy Flows in the Production of Cathode and Anode Materials for Lithium Ion Batteries (No. ANL/ESD-14/10 Rev). Argonne, IL. https://doi.org/10.2172/1224963

FCAB, 2021. National Blueprint for Lithium Batteries 2021-2030. Washington D.C.

Islam, E.S., Nieto Prada, D., Vijayagopal, R., Rousseau, A., 2023. Detailed Simulation Study to Evaluate Future Transportation Decarbonization Potential (No. ANL/TAPS-23/3). Lemont.

Islam, E.S., Vijayagopal, R., Kim, N., Moawad, A., Dupont, B., Nieto Prada, D., Rousseau, A., 2021. A Detailed Vehicle Modeling & Simulation Study Quantifying Energy Consumption and Cost Reduction of Advanced Vehicle Technologies Through 2050. Lemont.

Iyer, R.K., Kelly, J.C., 2022. Updates to Vehicle-Cycle Inventory for Select Components of Light-Duty, Medium-Duty, and Heavy-Duty Vehicles. Argonne.

Knehr, K.W., Kubal, J.J., Nelson, P.A., Ahmed, S., 2022. Battery Performance and Cost Modeling for Electric-Drive Vehicles (A Manual for BatPaC v5.0). Argonne, IL (United States). https://doi.org/10.2172/1877590

Li, M., Lu, J., Chen, Z., Amine, K., 2018. 30 Years of Lithium-Ion Batteries. Adv. Mater. 30, 1800561.

Wang, M., Elgowainy, A., Lee, U., Baek, K.H., Bafana, A., Benavides, P.T., Burnham, A., Cai, H., Cappello, V., Chen, P., Gan, Y., Gracida-Alvarez, U.R., Hawkins, T.R., Iyer, R.K., Kelly, J.C., Kim, T., Kumar, S., Kwon, H., Lee, K., Liu, X., Lu, Z., Masum, F.H., Ng, C., Ou, L., Reddi, K., Siddique, N., Sun, P., Vyawahare, P., Xu, H., Zaimes, G.G., 2022. Summary of Expansions and Updates in GREET® 2022 (No. ANL/ESIA-22/1). Argonne, IL (United States). https://doi.org/10.2172/1891644

Winjobi, O., Dai, Q., Kelly, J.C., 2020. Update of Bill-of-Materials and Cathode chemistry addition for Lithium-ion Batteries in the GREET® Model. Argonne, IL.