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Vehicle-Cycle Inventory for Type C School Buses and Intracity Transit Buses

Energy Systems and Infrastructure Assessment Division

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ACRONYMS AND ABBREVIATIONS

ADR	assembly, disposal, and recycling
BatPaC	Battery Performance and Cost (model)
BIW	body-in-white
EV	electric vehicle
REET	Greenhouse gases, regulated emissions, and energy use in technologies
HVAC	heating, ventilation, and air conditioning
ICEV	internal combustion engine vehicle
LDV	light-duty vehicle
LFP	lithium iron phosphate (LiFePO_4)
LIB	lithium-ion battery
MHDV	medium- and heavy-duty vehicle
Nd(Dy)FeB	neodymium (dysprosium) iron boron (magnet)
NMC811	lithium nickel manganese cobalt oxide ($\text{LiNi}_{0.8}\text{Mn}_{0.1}\text{Co}_{0.1}\text{O}_2$)
OEM	original equipment manufacturer
PET	polyethylene terephthalate
PBT	polybutylene terephthalate
PM _{2.5}	particulate matter with a diameter $\leq 2.5 \mu\text{m}$
PM ₁₀	particulate matter with a diameter $\leq 10 \mu\text{m}$
R&D	research and development

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1 INTRODUCTION

This report documents the new inventory incorporated into the Research and Development version of Greenhouse gases, Regulated Emissions, and Energy use in Technologies (R&D GREET) 2025 model for the vehicle cycle of Type C school buses and intracity transit buses.

The transportation sector contributes significantly to the United States' energy consumption and resultant emissions (EPA, 2025a). However, public transit plays an important role in mitigating these impacts because it consumes a relatively low amount of energy per passenger (Congressional Budget Office, 2022). Public transit is widely used in the United States; more than 500,000 school buses (EPA, 2025b) and ~75,000 service buses (American Public Transportation Association, 2025) operate in the nation. These are primarily internal combustion engine vehicles (ICEVs) powered by diesel.

Original equipment manufacturers (OEMs) are making efforts to electrify U.S. bus fleets by using batteries as a propulsion system to replace internal combustion engines. Electrification can reduce tailpipe emissions, such as particulate matter (with a diameter $\leq 10 \mu\text{m}$ [PM_{10}] and with a diameter $\leq 2.5 \mu\text{m}$ [$\text{PM}_{2.5}$]) and nitrogen oxides (Jonas et al., 2025; Martinez and Samaras, 2024; EPA, 2025b; Wayne et al., 2009). Hence, any energy and emission impact analysis of public transit must consider both conventional ICEVs and upcoming electric vehicle (EV) options for the school and transit buses that dominate this landscape.

To understand the detailed environmental impact profiles of ICEV and EV school and transit buses, it is necessary to conduct a thorough analysis covering both vehicle manufacturing and vehicle use stages. The current literature lacks a detailed vehicle-cycle inventory for school and transit buses, which makes this kind of comparison difficult. To overcome this gap, we developed a comprehensive vehicle-cycle model for school and transit buses in Argonne's R&D GREET 2025 model. The model is flexible in handling user inputs for key assumptions, such as component weights and material compositions, upstream energy sources for material processing, and vehicle operating parameters, to understand their impacts on energy use and emissions for both school and transit buses.

This report is organized as follows: Section 2 provides details on the modeling approach and vehicle specifications (weights and composition of different vehicle components, and vehicle operating parameters) for both school and transit buses. Section 3 provides details on vehicle assembly, disposal, and recycling (ADR) approaches for the two buses. Section 4 includes details about their incorporation into the R&D GREET model.

2 MODELING APPROACH AND VEHICLE SPECIFICATIONS

2.1 MODELING APPROACH

The modeling approach for both school and transit buses is similar to the previously used framework for agricultural tractors in R&D GREET2 (shown in the Tractor tab). Both the vehicle cycle and the fuel cycle are considered for both kinds of buses.

2.2 VEHICLE SPECIFICATIONS

School buses are available in various sizes, ranging from Class 4 to Class 8, based on their weight rating. This work assesses a Type C conventional school bus with 78 seats, which is typical of a full-size Type C school bus (Arnold, 2025).

Intracity transit buses are also available in sizes ranging from 30 to 60 feet. This work considers a 40-foot transit bus because it is the most common size of this bus category.

Two powertrain options are considered for both school and transit buses: an ICEV and a fully battery EV.

2.3 TOTAL VEHICLE WEIGHT

The vehicle weights of both school and transit buses were obtained from Argonne’s Autonomie model (Islam et al., 2023) and are provided in Table 1. Autonomie provides details on vehicle weights for various powertrains in the Class 7 school bus and the Class 8 transit bus. In this study, we only consider ICEV and EV powertrain options for these buses. The total vehicle weight for ICEVs includes the weight of lead-acid batteries, and that for EVs includes the weights of both lead-acid batteries and lithium-ion batteries (LIBs). Two LIBs are considered for EVs: $\text{LiNi}_{0.8}\text{Mn}_{0.1}\text{Co}_{0.1}\text{O}_2$ (NMC811) and LiFePO_4 (LFP).

Table 1. Total Vehicle Weight for School and Transit Buses, Excluding Fuels

Bus Type	ICEV (lb.)	EV (lb.)	
		NMC811	LFP
Class 7 School Bus	19,441	21,396	22,087
Class 8 Transit Bus	26,418	33,472	31,698

2.4 DEFINITION OF VEHICLE COMPONENTS

School and transit buses differ in their constituent component systems, as shown in Table 2. Here, we use the same definitions for these component systems as those considered in our earlier studies for light-duty vehicles (LDVs) (Burnham, 2012; Burnham et al., 2006). ICEVs do not

include traction motors and electronic controllers. We consider a direct drive system for EVs, so the transmission system is not included for this powertrain.

Table 2. Presence of Vehicle Components

Component System	ICEV	EV
Body	Yes	Yes
Chassis	Yes	Yes
Transmission	Yes	No
Powertrain	Yes	Yes
Traction Motor	No	Yes
Electronic Controller	No	Yes
Batteries	Yes	Yes
Fluids (excluding fuel)	Yes	Yes

To maintain consistency in our analysis, we obtained the weights of these component systems from Argonne’s Autonomie model (Islam et al. 2023). However, there are differences in the component systems used in this study compared to those provided in Autonomie. Table 3 provides an overview of these differences. For example, the chassis weight in Autonomie includes the weights of the chassis, bus body, and powertrain considered in this study.

Table 3. Comparison of Component Systems: Autonomie vs. This Study

Autonomie	This Study
Chassis	<ul style="list-style-type: none"> • Chassis (includes braking systems, wheels, tires, steering system, chassis electrical system, suspension, driveshaft/axles, differential, and cradle) • Bus body • Powertrain (after-treatment technology)
Powertrain (ICEV)	Powertrain (ICEV)
Transmission	Transmission
Motor	Traction motor and electronic controller
Batteries	Batteries (lead acid and lithium ion)
Fuel Tank	Powertrain (fuel tank)

We employed both bottom-up and top-down approaches to resolve the inconsistencies in the weights of component systems and convert Autonomie-based component weights to component weights for this study. The process followed in this regard is similar to that employed in earlier work (Iyer et al., 2021). To convert the data from Autonomie-based component systems to those considered in this study, we used component system definitions adapted from prior studies (Burnham, 2012; Burnham et al., 2006). These components and systems are listed in Tables 4 through 10.

Table 4. Body System

Subsystems	Individual Parts
Body-in-white (BIW)	Primary bus structure, usually a single-body assembly to which other major components are attached
Body Panels	Closure panels and hang-on panels, such as the hood, roof, decklid, doors, quarter panels, and fenders
Front/Rear Bumpers	Impact bars, energy absorbers, and mounting hardware
Body Hardware	Miscellaneous body components, including stop arms and signs for a school bus
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 taillight assemblies
Instrument Panel	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, ashtrays, armrests, 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	Door insulation, trim assemblies, speaker grills, switch panels, and handles (door panels are considered as part of the body panels category)
Seating and Restraints	Seat tracks, seat frames, foam, trim, restraints, anchors, head restraints, arm rests, seat belts, tensioners, clips, air bags, and sensor assemblies
Heating, Ventilation, and Air Conditioning (HVAC)	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 5. Powertrain System

Subsystems	Individual Parts
Engine Unit	Engine block, cylinder heads, shafts, fuel injection, engine air system, ignition system, manifolds, alternator, containers and pumps for the lubrication system, gaskets, and seals
Engine Fuel Storage	Fuel tank, tank mounting straps, tank shield, insulation, filling piping, and supply piping
Powertrain Thermal	Water pump, radiator, and fan
Exhaust	Catalytic converter, muffler, heat shields, and exhaust piping
Powertrain Electrical	Control wiring, sensors, switches, and processors
Emission Control Electronics	Sensors, processors, and engine emission feedback equipment

Table 6. Transmission System

Powertrains	Individual Parts
ICEV Transmission Unit	Uses an automated manual transmission system (includes clutch, gearbox, final drive, and controls)
EV Transmission Unit	Uses a direct drive system, so no transmission unit

Table 7. Chassis System

Subsystems	Individual Parts
Cradle	Frame assembly, front rails and cross-members, cab and body brackets (the cradle bolts to body-in-white and supports the mounting of the engine or fuel-cell)
Driveshaft/Axles	<ul style="list-style-type: none"> • Propeller shaft that connects the gearbox to the differential • Steer and drive axles
Differential	Gear set that transmits energy from the driveshaft to the axles and allows each of the driving wheels to rotate at different speeds, while supplying them with an equal amount of torque
Suspensions	Upper and lower shock brackets, shock absorbers, springs, steering knuckle, and stabilizer shaft
Braking	Hub, disc, rotor, splash shield, and calipers
Wheels and Tires	Steer and drive axle wheels and tires
Steering	Steering wheel, column, joints, linkages, bushes, housings, and hydraulic-assist equipment
Chassis Electrical	Signals; switches; horn wiring; and the anti-lock braking system wiring, sensors, and processors

Table 8. Electric-Drive System

Subsystems	Individual Parts
Traction Motor	Electric motor used to drive the wheels
Electronic Controller	Power controller/phase inverter system that converts power between the batteries and motor/generators for electric drive vehicles

Table 9. Battery System

Powertrains	Individual Parts
ICEV	Lead-acid battery to handle startup and accessory load
EV	Lead-acid battery to handle mainly startup load
	LIB for use in an electric drive system

Table 10. Fluid System

Powertrains	Individual Parts
ICEV	Engine oil, engine/powertrain coolant with coolant cleaner, brake fluid, windshield fluid, transmission fluid, power steering fluid, lubricant oils
EV	Powertrain coolant with coolant cleaner, power steering fluid, brake fluid, transmission fluid, windshield fluid, and lubricant oils

Vehicle-cycle analysis is dictated by two parameters: component system weights (that drive the total vehicle weight) and component material composition, which together determine the bill of materials for the vehicle (and, in turn, its vehicle-cycle impacts). Component weights obtained using the bottom-up approach were scaled to their corresponding weights obtained from Autonomie using the top-down approach.

For specific component systems, additional modifications were required to determine their respective weights. For instance:

- The powertrain weight for EVs includes powertrain thermal and electrical components.
- The motor weight from Autonomie is distributed across the traction motor and the electronic controller for R&D GREET, based on our bottom-up weight calculations. For the EV school bus, the percentage distribution was 91.4% for the traction motor and 8.6% for the electronic controller, while for the EV transit bus, the percentage distribution was 83.0% for the traction motor and 17.0% for the electronic controller.

Equations 1–11 provide details on the conversion process of component weights from Autonomie to the component weight shares used in this study in Tables 14 and 15. Table 11 explains the variables used in Equations 1–11:

$$\text{Chassis}_{\%} = \frac{\text{Chassis}_{\text{bu}}}{\text{Chassis}_{\text{bu}} + \text{Body}_{\text{bu}} + \text{Powertrain}_{\text{bu}}} \times \frac{\text{Chassis}_{\text{total_auto}}}{\text{Total_weight}_{\text{auto}}} \quad (1)^1$$

$$\text{Body}_{\%} = \frac{\text{Body}_{\text{bu}}}{\text{Chassis}_{\text{bu}} + \text{Body}_{\text{bu}} + \text{Powertrain}_{\text{bu}}} \times \frac{\text{Chassis}_{\text{total_auto}}}{\text{Total_weight}_{\text{auto}}} \quad (2)^2$$

¹ Powertrain_{bu} is only included for the EV calculation.

² Powertrain_{bu} is only included for the EV calculation.

For EVs:

$$\text{Powertrain}_{\%} = \frac{\text{Powertrain}_{bu}}{\text{Chassis}_{bu} + \text{Body}_{bu} + \text{Powertrain}_{bu}} \times \frac{\text{Chassis}_{total_auto}}{\text{Total_weight}_{auto}} \quad (3)$$

For ICEVs:

$$\text{Powertrain}_{\%} = \frac{\text{Engine}_{auto} + \text{Fuel_tank}_{auto} + \text{Generator}_{auto} + \text{Electronic_accessory}_{auto} + \text{Starter}_{auto}}{\text{Total_weight}_{auto}} \quad (4)$$

$$\text{Transmission}_{\%} = \frac{\text{Gearbox}_{auto} + \text{Mechanical_accessory}_{auto} + \text{Torquq_coupling}_{auto} + \text{Clutch}_{auto} + \text{Final_drive}_{auto}}{\text{Total_weight}_{auto}} \quad (5)^3$$

$$\text{Traction_motor}_{\%} = \frac{\text{Motor}_{auto}}{\text{Total_weight}_{auto}} \times \text{Factor}_{bu} \quad (6)$$

$$\text{Electronic_controller}_{\%} = \frac{\text{Motor}_{auto}}{\text{Total_weight}_{auto}} \times \text{Factor}_{bu} \quad (7)$$

$$\begin{aligned} \text{Powertrain}_{auto} &= \text{Engine}_{auto} + \text{Fuel_tank}_{auto} + \text{Generator}_{auto} \\ &+ \text{Electronic_accessory}_{auto} + \text{Starter}_{auto} \end{aligned} \quad (8)$$

$$\begin{aligned} \text{Transmission}_{auto} &= \text{Gearbox}_{auto} + \text{Mechanical_accessory}_{auto} + \text{Torquq_coupling}_{auto} \\ &+ \text{Clutch}_{auto} + \text{Final_drive}_{auto} \end{aligned} \quad (9)$$

$$\text{Chassis}_{total_auto} = \text{Chassis}_{auto} + \text{Wheels}_{auto} \quad (10)^4$$

$$\text{Total_weight}_{auto} = \text{Chassis}_{auto} + \text{Powertrain}_{auto} + \text{Transmission}_{auto} + \text{Motor}_{auto} \quad (11)$$

³ Transmission_% is only calculated for ICEVs. For EVs, this weight is added to Chassis_{auto}.

⁴ Also includes Powertrain_{auto} and Transmission_{auto} for EVs.

Table 11. Variables Used in Equations 1–11

Variable	Description
Total_weight _{auto}	Total weight of the vehicle provided in Autonomie
Chassis _{auto}	Weight of chassis provided in Autonomie
Chassis _{total_auto}	Weight of chassis including wheels provided in Autonomie (EVs also include transmission and powertrain in the chassis)
Powertrain _{auto}	Weight of powertrain obtained from Autonomie
Transmission _{auto}	Weight of transmission obtained from Autonomie
Engine _{auto}	Weight of engine provided in Autonomie
Fuel_tank _{auto}	Weight of fuel tank provided in Autonomie
Gearbox _{auto}	Weight of gearbox provided in Autonomie
Generator _{auto}	Weight of generator provided in Autonomie
Motor _{auto}	Weight of traction motor provided in Autonomie
Electronic_accessory _{auto}	Weight of electronic accessory provided in Autonomie
Mechanical_accessory _{auto}	Weight of mechanical accessory provided in Autonomie
Starter _{auto}	Weight of starter provided in Autonomie
Torque_coupling _{auto}	Weight of torque coupling provided in Autonomie
Clutch _{auto}	Weight of clutch provided in Autonomie
Wheels _{auto}	Weight of wheels provided in Autonomie
Final_drive _{auto}	Weight of final drive provided in Autonomie
Chassis _{bu}	Chassis weight percentage in total vehicle weight obtained from bottom-up approach
Body _{bu}	Body weight percentage in total vehicle weight obtained from bottom-up approach
Powertrain _{bu}	Powertrain weight percentage in total vehicle weight obtained from bottom-up approach for EVs only
Chassis _%	Chassis weight percentage used in this study
Body _%	Body weight percentage used in this study
Transmission _%	Transmission weight percentage used in this study
Traction_motor _%	Traction motor weight percentage used in this study
Electronic_controller _%	Electronic controller weight percentage used in this study
Powertrain _%	Powertrain weight percentage used in this study
Factor _{bu}	Weight distribution percentage between traction motor and electronic controller obtained from bottom-up approach

auto: refers to data obtained from Autonomie; bu: refers to data obtained from the bottom-up approach

2.5 VEHICLE COMPONENTS: MATERIAL COMPOSITION AND WEIGHT

In addition to component weights, the material compositions of component systems are also needed to analyze the vehicle cycle of any vehicle. The literature review conducted for this study did not identify any prior studies on the material composition of school and/or transit bus components. To overcome this lacuna, we relied on details obtained from the bottom-up data collection from multiple data sources, as provided in Tables 12 and 13. The data sources used include company product catalogs for major components (such as engines, transmissions,

HVAC, axles, suspensions, traction motors, and electronic controllers); customer quotations for part details; and various websites. Material compositions of both types of bus bodies are based on the dimensions and material information provided in reports and other information found on websites, and using material densities. A similar approach was employed to determine the weight and material composition of the chassis cradle for each bus.

Table 12. Data Sources for School Bus Component System Weights and Material Compositions

Component System	Key References
Bus Body	75chromeshop (2025); Amazon (2025a); B-Quiet (2025); Carolina Thomas (2016); Carpenter Bus Parts (2025); DTNA Parts (2025); Etsy.com (2025); IC Bus (2025a,b; 2013a,b); MidWest Bus Parts (2025); SchoolBusFleet (2011); Tepkos (2025a,b); Thomas Built Buses, Inc. (2025); Thomas Built Buses, Inc. (2017); Thomas Built Buses, Inc. (2024)
Chassis	Amazon (2025b,c); BuyTruckWheels.com (2025); Dana (2025a,b); DonBrown (2025); FleetPride (2025a,b); Fort Wayne Clutch (2025); Haldex (2025a); IC Bus (2025c; 2013a,b); Meritor Parts Xpress (2025); Mobile Climate Control Reference Manual (2025); SimpleTire (2025); Thomas Built Buses, Inc. (2024); TruckPro (2025)
Powertrain	Amazon (2025d); Cummins (2025a,b); Ford Motor Company (2025a,b)
Electric-Drive Components	Blue Bird (2025)
Transmission	Amazon (2025e); Copeland International (2025)

Table 13. Data Sources for Transit Bus Component System Weights and Material Compositions

Component System	Key References
Bus Body	Bus Parts Factory (2025); Gillig (2013); Kiel-Seating (2025); Middle Market Growth (2017); Proterra (2021); Seattle Transit Blog (2013); Spheros (2025; The International Council on Clean Transportation (2021); Thermo King (2025); Vapor Bus Door System (2025)
Chassis	Alcoa Wheels (2025); Big Rig Chrome Shop (2025); DuraBrake (2025); Eaton Vickers (2025); Gillig (2013); Haldex (2025b); International CE (2025); Michelin Tires (2025); Middle Market Growth (2017); MR Steering Specialist (2025); Navistar International (2025a); United Pacific (2025); ZF Friedrichshafen AG (2025a,b)
Powertrain	American Bus, Inc. (2025); AutoZone (2025); CEN (2025); Cummins (2021, 2017); Dale’s Super Store (2025); Modine EV (2025); Navistar International (2025b)
Electric-Drive Components	Accelera by Cummins (2025a,b); Littelfuse (2025); Parker (2025); Vanner, Inc. (2025)
Transmission	Voith (2020)

The weight distribution between different *component systems*, calculated based on the description in Section 2.4, is given in Tables 14 and 15.

Table 14. Weight Breakdown of School Bus (values in wt.%)

Component System	ICEV	EV
Body (including BIW, interior, exterior, and glass)	55.6	57.2
Chassis	38.0	39.2
Transmission	2.4	—
Powertrain	4.1	0.6
Traction Motor	—	2.7
Electronic Controller	—	0.3

Table 15. Weight Breakdown of Transit Bus (values in wt.%)

Component System	ICEV	EV
Body (including BIW, interior, exterior, and glass)	56.7	58.4
Chassis	38.1	38.3
Transmission	1.9	—
Powertrain	3.4	0.8
Traction Motor	—	2.1
Electronic Controller	—	0.4

Bus bodies and chassis are assumed to be similar between ICEV and EV powertrains for each bus type (school and transit buses). The material compositions of different component systems are provided in Tables 16 through 21.

Table 16. Material Composition of Component Systems in ICEV School Bus (values in wt.%)

Material	Body	Powertrain	Transmission	Chassis
Steel	72.4	45.3	69.0	77.1
Cast Iron	0.1	42.3	24.0	7.9
Cast Aluminum	0.0	4.6	6.0	0.2
Aluminum Sheet (Automotive)	1.0	3.3	0.0	0.0
Aluminum Extrusion (Automotive)	0.1	1.5	0.0	0.0
Copper/Brass/Bronze	0.5	0.1	0.0	0.9
Rubber	3.5	0.2	0.0	12.3
Average Plastic	10.7	1.5	0.0	1.0
Glass	3.4	0.0	0.0	0.0
Zinc	0.3	0.0	0.0	0.2
Others	8.1	1.1	1.0	0.5

Table 17. Material Composition of Component Systems in EV School Bus (values in wt.%)

Material	Body	Powertrain	Chassis	Traction Motor	Electronic Controller
Steel	72.4	4.2	77.4	54.0	2.7
Stainless Steel	0.0	0.0	0.0	0.7	0.0
Cast Iron	0.1	0.0	7.7	0.0	0.0
Cast Aluminum	0.0	0.0	0.2	31.6	52.9
Aluminum Sheet (Automotive)	1.0	8.4	0.0	0.0	0.0
Aluminum Extrusion (Automotive)	0.1	18.9	0.0	0.0	0.0
Copper/Brass/Bronze	0.5	0.0	0.8	8.6	27.1
Magnet (Nd(Dy)FeB)	0.0	0.0	0.0	2.9	0.0
Nickel	0.0	0.0	0.0	0.0	0.0
Rubber	3.5	0.9	12.2	0.0	1.1
Average Plastic	10.7	67.6	1.0	0.0	11.3
Nylon	0.0	0.0	0.0	0.0	0.0
PET	0.0	0.0	0.0	0.3	0.0
Fiberglass	0.0	0.0	0.0	0.0	0.0
Glass	3.4	0.0	0.0	0.0	0.0
Phenolic Resin	0.0	0.0	0.0	0.1	0.0
Enamel	0.0	0.0	0.0	0.4	0.0
PBT	0.0	0.0	0.0	0.2	0.0
Mica	0.0	0.0	0.0	0.0	0.0
Silicone	0.0	0.0	0.0	0.0	0.0
Epoxy Resin	0.0	0.0	0.0	0.8	0.0
Methacrylate Ester Resin	0.0	0.0	0.0	0.1	0.0
Paint/Varnish	0.0	0.0	0.0	0.3	0.0
Zinc	0.3	0.0	0.1	0.0	1.1
Others	8.1	0.0	0.5	0.0	3.8

Table 18. Material Composition of School Bus, Aggregate of All Component Systems (values in wt.%)

Material	ICEV	EV
Steel	73.0	73.2
Stainless Steel	0.0	0.0
Cast Iron	5.4	3.1
Cast Aluminum	0.4	1.1
Aluminum Sheet (Automotive)	0.7	0.6
Aluminum Extrusion (Automotive)	0.1	0.2
Copper/Brass/Bronze	0.6	0.9
Magnet (Nd(Dy)FeB)	0.0	0.1
Nickel	0.0	0.0
Rubber	6.6	6.8

Material	ICEV	EV
Average Plastic	6.4	6.9
Nylon	0.0	0.0
PET	0.0	0.0
Fiberglass	0.0	0.0
Glass	1.9	1.9
Phenolic Resin	0.0	0.0
Enamel	0.0	0.0
PBT	0.0	0.0
Mica	0.0	0.0
Silicone	0.0	0.0
Epoxy Resin	0.0	0.0
Methacrylate Ester Resin	0.0	0.0
Paint/Varnish	0.0	0.0
Zinc	0.2	0.2
Others	4.7	4.8

Table 19. Material Composition of Component Systems in ICEV Transit Bus (values in wt.%)

Material	Body	Powertrain	Transmission	Chassis
Steel	56.1	42.2	69.0	75.7
Cast Iron	0.2	44.4	24.0	5.8
Cast Aluminum	0.0	4.9	6.0	4.0
Aluminum Sheet (Automotive)	5.7	4.2	0.0	0.8
Aluminum Extrusion (Automotive)	0.0	1.6	0.0	0.0
Copper/Brass/Bronze	1.6	0.1	0.0	0.6
Rubber	3.7	0.0	0.0	12.2
Average Plastic	9.6	1.7	0.0	0.7
Glass Fiber-Reinforced Plastic	15.3	0.0	0.0	0.0
Glass	2.2	0.0	0.0	0.0
Zinc	0.0	0.0	0.0	0.0
Others	5.5	1.0	1.0	0.1

Table 20. Material Composition of Component Systems in EV Transit Bus (values in wt.%)

Material	Body	Powertrain	Chassis	Traction Motor	Electronic Controller
Steel	56.0	29.9	76.3	54.0	2.7
Stainless Steel	0.0	0.0	0.0	0.7	0.0
Cast Iron	0.2	4.8	6.0	0.0	0.0
Cast aluminum	0.0	0.0	4.1	31.6	52.9
Aluminum Sheet (Automotive)	5.9	40.1	0.8	0.0	0.0
Copper/Brass/Bronze	1.7	21.5	0.1	8.6	27.1
Magnet (Nd(Dy)FeB)	0.0	0.0	0.0	2.9	0.0
Nickel	0.0	0.0	0.0	0.0	0.0
Rubber	3.7	0.0	12.4	0.0	1.1
Average Plastic	9.6	3.7	0.1	0.0	11.3
Nylon	0.0	0.0	0.0	0.0	0.0
PET	0.0	0.0	0.0	0.3	0.0
Glass Fiber-Reinforced Plastic	15.3	0.0	0.0	0.0	0.0
Fiberglass	0.0	0.0	0.0	0.0	0.0
Glass	2.2	0.0	0.0	0.0	0.0
Phenolic Resin	0.0	0.0	0.0	0.1	0.0
Enamel	0.0	0.0	0.0	0.4	0.0
PBT	0.0	0.0	0.0	0.2	0.0
Mica	0.0	0.0	0.0	0.0	0.0
Silicone	0.0	0.0	0.0	0.0	0.0
Epoxy Resin	0.0	0.0	0.0	0.8	0.0
Methacrylate Ester Resin	0.0	0.0	0.0	0.1	0.0
Paint/Varnish	0.0	0.0	0.0	0.3	0.0
Zinc	0.0	0.0	0.0	0.0	1.1
Others	5.5	0.0	0.1	0.0	3.8

Table 21. Material Composition of Transit Bus, Aggregate of All Component Systems (values in wt.%)

Material	ICEV	EV
Steel	63.4	63.3
Stainless Steel	0.0	0.0
Cast Iron	4.3	2.5
Cast Aluminum	1.8	2.5
Aluminum Sheet (Automotive)	3.7	4.1
Aluminum Extrusion (Automotive)	0.1	0.0
Copper/Brass/Bronze	1.1	1.5
Magnet (Nd(Dy)FeB)	0.0	0.1
Nickel	0.0	0.0
Rubber	6.7	6.9
Average Plastic	5.8	5.7
Nylon	0.0	0.0
PET	0.0	0.0
Glass Fiber-Reinforced Plastic	8.7	8.9
Fiberglass	0.0	0.0
Glass	1.3	1.3
Phenolic Resin	0.0	0.0
Enamel	0.0	0.0
PBT	0.0	0.0
Mica	0.0	0.0
Silicone	0.0	0.0
Epoxy Resin	0.0	0.0
Methacrylate Ester Resin	0.0	0.0
Paint/Varnish	0.0	0.0
Zinc	0.0	0.0
Others	3.2	3.3

2.6 BATTERIES: SIZING, WEIGHT AND MATERIAL COMPOSITION

Battery capacity for both school and transit buses was obtained from the Autonomie model, as reported in Islam et al. (2023). We assume that lead-acid battery requirements for school buses are similar to those of Class 6 pickup-and-delivery trucks, while those for transit buses are similar to the lead-acid battery requirements for Class 8 regional day-cab trucks (Iyer et al., 2021). The material compositions of lead-acid batteries are taken from Burnham (2012). LIB weights, capacities, and material compositions are obtained by inputting battery energy/power capacities from Islam et. al (2023) into Argonne’s Battery Performance and Cost (BatPaC) model (Knehr et al., 2022). We only consider NMC811 and LFP cathode chemistries for these two buses. Tables 22 through 28 provide details about batteries used in school and transit buses.

Table 22. EV LIB Energy Requirements from Autonomie

Type of Bus	Energy Requirement (kWh)
School	197.6
Transit	491.5

Table 23. Specific Energy of LIBs

Type of Bus	LIB Chemistry	EV Battery Specific Energy (Wh/kg)
School	NMC811	173.4
	LFP	136.0
Transit	NMC811	180.3
	LFP	139.2

Table 24. Material Composition of EV School Bus LIBs (values in wt.%)

Material	Material Composition (wt.%)	
	NMC811	LFP
Active Material	21.7	26.2
Graphite/Carbon	15.0	13.4
Silicon	0.0	0.0
Binder	0.8	0.8
Copper	14.9	13.9
Aluminum Sheet	14.5	13.9
LiPF ₆	1.2	1.3
Ethylene Carbonate	3.3	3.7
Dimethyl Carbonate	3.3	3.7
Polypropylene	0.1	0.1
Polyethylene	1.7	1.6
Plastic (Average)	0.5	0.5
Polyethylene Terephthalate	0.2	0.2
Steel	12.6	11.3
Stainless Steel	5.6	5.2
Rubber	0.1	0.1
Thermal Insulation	0.3	0.3
Coolant	3.7	3.5
Electronic Parts	0.6	0.5

Table 25. Material Composition of EV Transit Bus LIBs (values in wt.%)

Material	Material Composition (wt.%)	
	NMC811	LFP
Active Material	22.5	26.9
Graphite/Carbon	15.5	13.7
Silicon	0.0	0.0
Binder	0.8	0.8
Copper	15.1	14.1
Average Aluminum Sheet (Automotive)	15.1	14.7
Cast Aluminum	0.0	0.0
Electrolyte: LiPF ₆	1.2	1.4
Electrolyte: Ethylene Carbonate	3.4	3.8
Electrolyte: Dimethyl Carbonate	3.4	3.8
Plastic: Polypropylene	0.1	0.1
Plastic: Polyethylene	1.8	1.8
Plastic: Polymer	0.5	0.5
Plastic: Polyethylene Terephthalate	0.3	0.3
Steel	11.0	9.9
Stainless Steel	5.0	4.6
Rubber	0.1	0.0
Thermal Insulation	0.3	0.2
Coolant: Glycol	3.4	3.1
Electronic Parts	0.4	0.3

Table 26. Lead-Acid Batteries in Different Powertrains

Type of Bus	No. of Batteries	
	ICEV	EV
School	2	1
Transit	3	1

Table 27. Material Composition of Lead-Acid Batteries in Buses (values in wt.%)

Material	Material Composition (wt.%)
Polypropylene	6.1
Lead	69.0
Sulfuric Acid	7.9
Fiberglass	2.1
Water	14.1
Others	0.8

Table 28. Bus Battery Weight (in lb.)

Type of Bus	Battery Type and Chemistry	ICEV	EV
School	Lead-acid	138	69
	LIB, NMC811	—	2,513
	LIB, LFP	—	3,204
Transit	Lead-acid	207	69
	LIB, NMC811	—	6,011
	LIB, LFP	—	7,784

2.7 BATTERY REPLACEMENT AND RECYCLING

Battery replacement values are from an earlier work on MHDVs, where Class 7 school buses are treated similarly to Class 6 pickup-and-delivery trucks, while Class 8 transit buses are similar to Class 8 day-cab trucks (Iyer et al., 2021). Details about the number of times batteries are replaced for each school and transit buses are provided in Table 29.

Table 29. Battery Replacement and Recycling

Type of Bus	Type of Battery	
	Lead-acid	LIB
School	6	0
Transit	3	1

2.8 REPLACEMENTS OF COMPONENTS: TIRES, FLUIDS, AND OTHERS

The average vehicle lifetime of a school bus is usually 350,000 miles or 12 years (Kay et al., 2011). Based on the annual mileage of 14,084 miles (Alternative Fuels Data Center, 2024), the operating year is the limiting factor in our calculation for the school bus. Therefore, we multiplied the annual miles of the school bus by its lifetime (12 years) to determine its total lifetime miles. Similarly, for a transit bus, vehicle lifetime is around 500,000 miles (Kay et al., 2011). A school bus travels fewer miles on average than a transit bus (14,084 miles vs. 42,940 miles) (Alternative Fuels Data Center, 2024). We assume that a tire will travel an average of 50,000 miles in its lifetime (School Bus Fleet, 2022). Both school buses and transit buses use two front tires and four rear tires. Table 30 lists the average lifetime of these tires.

Table 30. Lifetime of Bus Tires

Type of Bus	No. of Tires		No. of Replacements	
	Front Tires	Rear Tires	Front Tires	Rear Tires
School	2	4	3	3
Transit	2	4	9	9

Similar to batteries, the vehicle fluid data for these two buses are similar to the corresponding MHDVs (i.e., Class 6 pickup-and-delivery truck for the school bus and Class 8 day-cab truck for the transit bus). Table 31 provides the lifetime number of fluid replacements for each bus, while Tables 32 and 33 provide the fluid amount for different bus powertrains.

Table 31. Lifetime Number of Bus Fluid Replacements

Fluid	Type of Bus	
	School	Transit
Engine Oil	9	19
Steer Axle Lubricant	11	39
Drive Axle Lubricant	0	1
Inter-Axle Shaft/Driveshaft Lubricant	11	7
Lubricant: Wheel Ends at Steer Axle	0	1
Lubricant: Wheel Ends at Drive Axle	0	1
Transmission	3	1
Engine/Powertrain Coolant	1	1
Coolant Cleaner	1	1
Windshield Washer	52	32

Table 32. Amount of Fluid per Use Cycle, School Bus

Fluid	Weight of Fluid Used (lb.)	
	ICEV	EV
Engine Oil	33.7	0.0
Steer Axle Lubricant	15.4	15.4
Drive Axle Lubricant	12.9	12.9
Inter-Axle Shaft/Driveshaft Lubricant	30.9	30.9
Lubricant: Wheel Ends at Steer Axle	19.0	19.0
Lubricant: Wheel Ends at Drive Axle	19.0	19.0
Power Steering	0.0	0.0
Brake	0.0	0.0
Transmission	16.9	5.2
Engine/Powertrain Coolant	54.1	37.1
Coolant Cleaner	55.1	37.8
Windshield Washer	15.9	15.9

Table 33. Amount of Fluid per Use Cycle, Transit Bus

Fluid	Weight of Fluid Used (lb.)	
	ICEV	EV
Engine Oil	92.2	0.0
Steer Axle Lubricant	15.4	15.4
Drive Axle Lubricant	45.2	45.2
Inter-Axle Shaft/Driveshaft Lubricant	30.9	30.9
Lubricant: Wheel Ends at Steer Axle	19.0	19.0
Lubricant: Wheel Ends at Drive Axle	38.0	38.0
Power Steering	0.0	0.0
Brake	0.0	0.0
Transmission	14.1	2.2
Engine/Powertrain Coolant	121.1	83.0
Coolant Cleaner	55.1	37.8
Windshield Washer	15.9	15.9

2.9 LIMITATIONS

There is no detailed inventory for both school and transit buses from a single source. Therefore, we employed a bottom-up approach to collect data from multiple sources, which may lead to some inconsistencies in this study. We also extended the datasets for energy use and emissions associated with vehicle fluids from MHDVs to both school and transit buses. Material compositions of the traction motor, batteries, electronic controller, and several other components are assumed to be similar to the corresponding components in LDVs and MHDVs. We assume plastics to be average plastic (as defined in the “Vehi_Plastics” tab of R&D GREET2), unless otherwise specified. Materials whose inventory is not available in R&D GREET, such as wood and some metals, are included in “Others.” We assume these have no contributions to energy and emission impacts. The weight contributions of these materials are small compared to those of materials covered within R&D GREET, and hence, their impacts are expected to be minimal.

3 VEHICLE ASSEMBLY, DISPOSAL, AND RECYCLING

We assume that the data for vehicle ADR processes are similar to those used for LDVs and MHDVs in R&D GREET (Burnham, 2012; Burnham et al., 2006; Wang et al., 2024). For vehicle disposal and recycling, energy consumed is scaled based on the weight of the buses. We assume that energy use associated with lead-acid battery assembly is similar to the amounts used for LDVs and MHDVs (Burnham, 2012; Burnham et al., 2006; Wang et al., 2024). LIB assembly energy is taken from a recent update on battery assembly energy (Pandey et al., 2025). The details of ADR energy consumption are given in Table 34.

Table 34. Energy Use Associated with Vehicle and Battery ADR

Constituent Process	Energy Consumed
Paint Production	0.287 mmBtu/vehicle
Painting	2.759 mmBtu/vehicle
HVAC and Lighting	0.99 mmBtu/vehicle
Heating	2.982 mmBtu/vehicle
Material Handling	0.205 mmBtu/vehicle
Welding	0.273 mmBtu/vehicle
Compressed Air	0.409 mmBtu/vehicle
Disposal/Recycling	0.00047 mmBtu/vehicle × Weight ^a
Lead-acid Battery Assembly	2.300 mmBtu/lb.
LIB Assembly (NMC811)	0.130 mmBtu/kWh
LIB Assembly (LFP)	0.155 mmBtu/kWh

^a Weight = weight of bus, excluding fuel.

4 R&D GREET2 MODEL STRUCTURE EXPANSION FOR SCHOOL AND TRANSIT BUSES

Two new tabs are introduced in the R&D GREET2 2025 version—"Class_7_School_Bus" and "Class_8_Transit_Bus"—to incorporate the respective vehicle-cycle modeling of the two buses. Both tabs are designed to include both vehicle- and fuel-cycle information about these buses (fuel-cycle information is obtained from R&D GREET1). All required inputs and assumptions are also included within the appropriate tabs. Each tab includes a total of 20 sections. Users have the option to select the LIB cathode chemistry in Section 3.1 in each tab of R&D GREET2.

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