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ISSUE BRIEF

Electric school bus U.S. market study

A resource for school bus operators pursuing fleet electrification

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Issue briefs focus on policy issues, and clearly draw out the implications of existing evidence for decision makers.

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HIGHLIGHTS

- **School districts across the United States are transitioning to electric school buses (ESBs), and momentum grew in 2022 due to funding from the Clean School Bus Program.** As of December 2022, 895 districts (or private operators) had committed to procuring 5,612 ESBs (1.2 percent of the current fleet) across a range of operating conditions and in all 50 states.[1] States and municipalities are setting electrification goals while manufacturers scale production.
- **Although diesel-burning school buses have lower upfront costs, ESBs offer access to record funding, have the potential for lower operations and maintenance costs, and produce zero tailpipe emissions.** Bidirectional-capable vehicles can store and deliver energy using "vehicle-to-everything" technology, which bolsters resiliency.
- **Communities that have been historically disadvantaged are disproportionately affected by air pollution and must be prioritized for access to ESBs and their benefits.**
- **As of March 2023,** 24 models **were available from nine manufacturers for Type A, C, and D buses: 18 newly manufactured models and 6 repowered models.**[2]
- **Each generation of buses becomes more advanced: Many manufacturers are on their third or fourth iteration, some further along.** The nameplate range of current models is between 75 and 210 miles, enough to reliably cover most routes in operation.

Context

Momentum around ESBs is growing in the United States, as school districts across the country transition to this cleaner and healthier technology, bolstered by US$5 billion in new federal funding from the Environmental Protection Agency's (EPA) Clean School Bus Program (CSBP). The ESB transition will require a coordinated effort among numerous entities, including school district leadership and staff, school bus and charging infrastructure manufacturers and contractors, utilities, policymakers, regulators, local advocacy organizations, and community members.

This publication was developed to provide school districts, transportation directors, and other school bus operators exploring school bus electrification a better understanding of the state of the ESB market and available offerings. In "Status of the electric school bus market," we explore the growing demand for these buses and how manufacturers are positioning themselves to meet that demand. In "Electric school bus basics," we explain key components of an ESB and the related charging infrastructure. "Summary of available electric bus models" and the accompanying *Electric School Bus Buyer's Guide* (https://electricschoolbusinitiative.org/buyers-guide) (Huntington et al. 2023) present a catalog of the 24 ESB models available as of early 2023, including vehicle specifications.

Approach and methodology

The content of this publication has been gathered from a variety of sources. Information in the accompanying *Electric School Bus Buyer's Guide* (Huntington et al. 2023) on models available in the United States comes from publicly available vehicle specifications sheets and has been confirmed through discussions with manufacturers when possible.

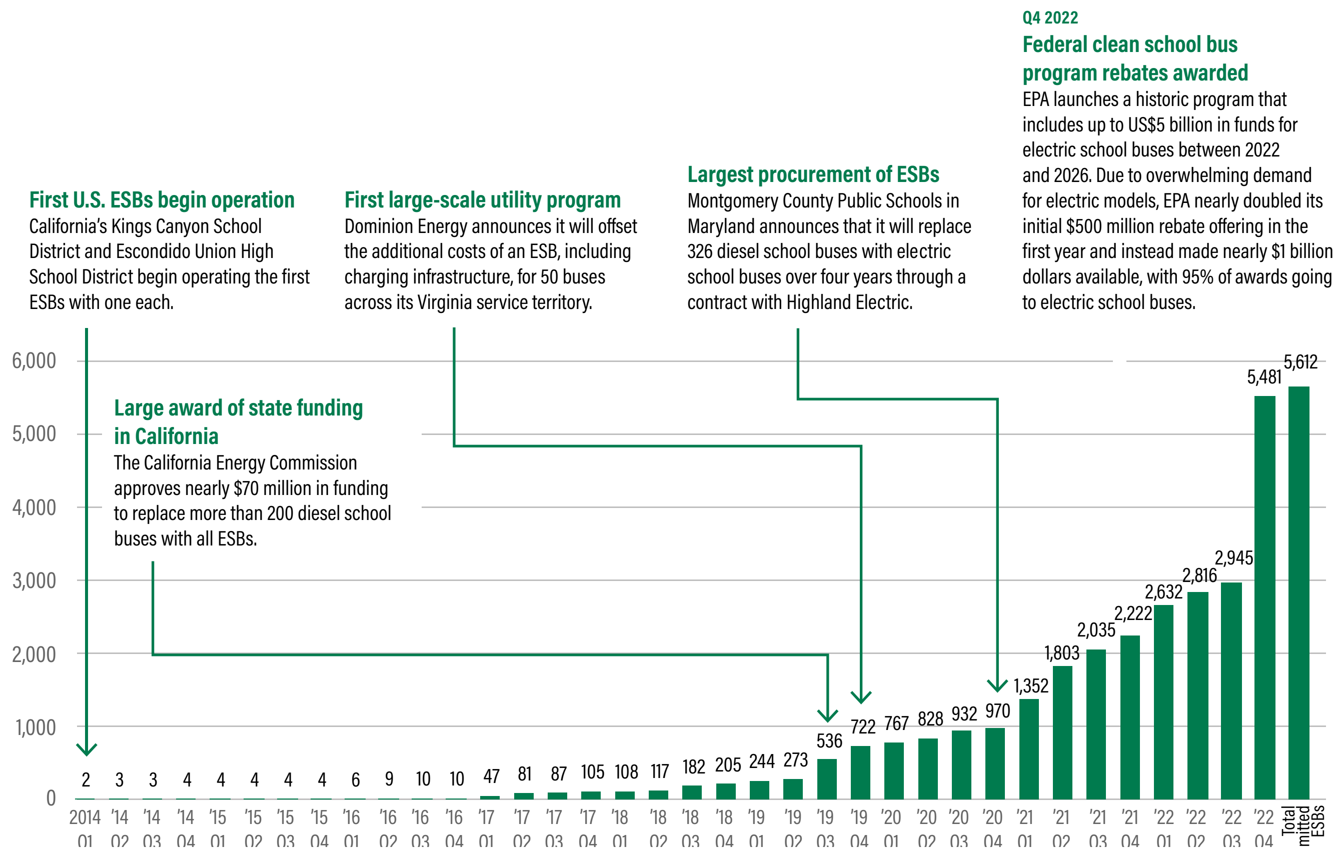
We explored school districts' experiences with ESBs representing a variety of use cases in the United States: rural, suburban, and urban; warm and cold weather; and early adopters further along in the process and those in earlier stages of procurement. We compiled recent research and reporting on school districts' commitments and experiences and supplemented public information with conversations with school districts and other partners. We plan to update this publication annually.

This resource is one of many from World Resources Institute's Electric School Bus Initiative. See Appendix B for additional resources.

STATUS OF THE ELECTRIC SCHOOL BUS MARKET

There are nearly half a million school buses in the United States that transport more than 20 million children to and from school (FHA n.d.; SBF 2021). More than 90 percent of full-size (Type C and D) school buses on the road today are diesel powered. However, interest in electric school buses (ESBs) has grown in recent years (Lazer et al. 2022) such that there are now 5,612 ESB commitments, representing around 1.2 percent of the current fleet size; 971 ESBs in 37 states have been delivered or are in operation (Freehafer and Lazer 2023). The ESB market was established in 2014, when two California school districts, Kings Canyon Unified School District and Escondido Union High School District, became the first school districts to operate ESBs. Kings Canyon's four early Trans Tech models traveled between 80 and 100 miles on a charge, while Escondido's TransPower bus had a range of approximately 60 miles (Adams 2014; Edelstein 2014; MPS 2014). Since 2014, hundreds of other school districts across the United States have begun to embrace fleet electrification, manufacturers have positioned themselves to meet growing demand, and school bus electrification has gained traction (Figure 1).

Cumulative number of electric school buses committed by quarter in the United States (2014–2022)



Notes: This graph depicts electric school bus (ESB) commitments at the earliest confirmed phase in the commitment process (awarded, ordered, delivered, or in operation); 131 ESBs were excluded due to unknown dates of their commitment stages. EPA = Environmental Protection Agency. ESB = electric school bus. Q = quarter.

Source: Based on Freehafer and Lazer 2023.

Rising demand

A combination of factors is priming the market for ESB adoption. Compared with the typical school bus that burns fossil fuels, ESBs have the potential to reduce operations and maintenance costs for fleets and produce zero tailpipe emissions (Figure 2). If equipped with bidirectional-charging technology, ESBs can provide additional benefits, such as potentially supplying mobile emergency power.

FIGURE 2

Sample of electric school bus benefits and considerations

Lower operations and maintenance costs

ESBs have lower maintenance and fuel costs over time, and our research suggests that compared with a new diesel school bus, a new ESB can save an average of $6,000 every year on operational expenditures, depending on circumstances.[a] Today, these savings alone are insufficient to cover the vehicle price differential without additional grant funding or subsidies, but experts anticipate significant price declines over the next decade as battery costs decrease, development of new battery chemistries advances, and the electric vehicle industry achieves efficiencies of scale in component markets and manufacturing.[b] Market experts anticipate that the lifetime total cost of owning an ESB will achieve cost parity with diesel-burning school buses by the middle of this decade.[c]

Health benefits

There is evidence that children are particularly susceptible to the negative health impacts of diesel exhaust, which has been linked to increased risk for asthma.[d] There is also evidence that reducing this exposure can improve not only respiratory health but also standardized test scores, especially for elementary-age students.[e] Although there has not been extensive research measuring the air quality benefits of ESBs specifically, these results strongly suggest that adopting these vehicles—which have zero tailpipe emissions—would have positive effects on students' health and academic outcomes, particularly for low-income students and Black students, who are more likely than their peers to ride a school bus.[f]

Climate benefits

For school buses, electricity emits half as many greenhouse gas emissions annually as the next-best fuel.[g] Electricity is the only viable fuel that will reduce greenhouse gas emissions over time as the grid integrates more renewables. Buses can also be paired with on-site renewable energy.

Resilience and grid potential

ESBs have the potential to serve as mobile power units for buildings during outages (V2B), for the grid during high energy demand (V2G), or for another load (V2L)—collectively identified as V2X.[h] Manufacturers are continuing to improve V2X technology and telematics and studying the impacts of the frequency and intensity of charge and discharge cycles on battery life. Charging ESBs during off-peak hours and under managed charging conditions produces grid benefits today by not charging when energy demand is highest or by charging when renewable energy is abundant.

Notes: ESB = electric school bus. V2B = vehicle-to-building. V2G = vehicle-to-grid. V2L = vehicle-to-load. V2X = vehicle-to-everything.

Sources:

a. EDF 2021; Levinson et al. 2023.

b. BloombergNEF 2021; EDF 2021.

c. Ledna et al. 2022; Watson et al. 2020.

d. Espinoza and Vemireddy 2018; Liu and Grigg 2018; Vieira et al. 2012.

e. Austin et al. 2019.

f. BTS 2021; FHA n.d.

g. ANL n.d., comparing five fuels for school buses: electric, compressed natural gas, propane, diesel, and biodiesel; utilizing various electricity mixes for electric school buses and North American natural gas for compressed natural gas; and based on 15,000 miles per bus per year.

h. Hutchinson and Kresge 2022. Motivated by these benefits, communities and policymakers are advocating for ESBs, resulting in an increasing number of commitments to school bus electrification and transition mandates. Implementation of these commitments is aided by grants and incentives to bring down the upfront costs.

Community support

Community members can drive demand for school bus electrification. Grassroots organizations and advocacy groups, which are often made up of parents and other caregivers, have been effective at advocating for school district commitments and creating policy changes. At the national level, Chispa League of Conservation Voters (LCV) has been driving the ESB conversation since 2016 by creating the "Clean Buses for Healthy Niños" campaign to push decision-makers to prioritize ESBs when spending Volkswagen settlement funds,[3] forming the Alliance for Electric School Buses, and championing the numerous benefits that ESBs bring to communities (Saez 2017; see also EPA n.d.b; McLaughlin and Balik 2022). Chispa's volunteers have supported legislation in Nevada and helped hold school districts to their commitments in Arizona (Schlosser 2021). In Virginia, Mothers Out Front helped Virginia Delegate Mark Keam's ESB bill get passed (Frisch 2021; MOF n.d., 2021). In New York, advocacy from NYLCV, Tri-State Transportation Campaign, and other groups helped push both New York City's and New York State's commitments to transition the fleet by 2035 (EarthJustice 2022; City of New York 2021; Kaye 2022; News 12 Staff 2022). Students have also been effective changemakers, especially at the school district level: in Salt Lake City, Utah, students worked with local advocates to advance an equity-centered plan that aims for carbon neutrality by 2040, while student pressure at school board meetings in Miami, Florida, helped convince the district to pursue a grant for 50 ESBs (Casey 2021; Huntington 2022). These are just a few examples of how communities have driven demand for ESBs by advocating for children's health and safety.

The actions of community advocates over several years set the stage for making the EPA's CSBP a reality (see Box 1 for details). The Alliance for Electric School Buses created numerous templates for advocates to help them reach out to policymakers and support the program. The Alliance also highlighted some of the work ahead for the CSBP that can be applied to many funding programs: "There is still urgent work to do to ensure this program prioritizes and reaches the communities breathing the dirtiest air and who desperately need relief: low-income communities and Black, Indigenous, and communities of color. We also urge EPA to adopt measures for subsequent funding rounds that promote the creation of high-quality, family-sustaining jobs" (AESB 2022).

State and local commitments

Policy commitments can influence speed of adoption and provide long-term market signals to school districts and manufacturers. In 2022, four states enacted legislation that set school bus electrification targets.

- New York—home to one of the nation's largest school bus fleets—made history as the first state in the nation to commit to electrifying its school bus fleet, passing legislation requiring all new school bus purchases to be zero emission by 2027 and all buses in operation to be zero emission by 2035 (WRI 2022; Lazer et al. 2022). The new law also requires the New York State Energy Research & Development Authority (NYSERDA) to offer technical assistance to school districts and publish an implementation road map.
- Connecticut set a fleet electrification date of 2040 for all school buses and 2030 for school buses operating in environmental justice communities (as previously defined in a state statute) and includes strong technical assistance provisions (Connecticut General Assembly n.d.).
- Maryland mandated that all new school bus purchases and contracts statewide will be electric by 2025, the earliest such date of targets passed this session and one contingent on available funding (Maryland General Assembly n.d.).
- Maine required that 75 percent of new school bus purchases and contracts must be zero emission by 2035 and created an interagency working group that includes school districts and utilities to help with deployment (Maine Legislature n.d.).

In addition to these four legislatively enacted commitments, two other states have set targets in agency-led transportation and climate action planning documents. In Colorado, the Clean Truck Strategy sets a nonbinding goal to "support the adoption of 2,000 electric school buses by 2027 and a longer-term goal to achieve 100% zero-emission buses on the road by 2035, with a focus on adoption in school districts in disproportionately impacted communities" (CEO et al. 2022, 19). In Michigan, the Michigan Healthy Climate Plan has aspirational language saying the state should aim for 100 percent of school bus sales in 2030 to be electric and suggests the state offer funding support and prioritization of communities with high levels of air pollution (EGLE 2022).

In Washington, DC, in 2019, the DC Council passed the Clean Energy DC Omnibus Amendment Act, which sets a goal for electric-only bus replacement with the goal of ESBs composing 50 percent of the fleet by 2030 (Council of the District of Columbia n.d.).

At the local level, Fairfax County Public Schools in Virginia (which has approximately 1,625 buses), Montgomery County Public Schools in Maryland (approximately 1,400 buses), Boston Public Schools in Massachusetts (approximately 700 buses), and Austin Independent School District in Texas (approximately 500 buses) are looking to transition their fleets to electric or zero-emission buses between 2030 and 2035 (City of Boston 2022; Environment Texas 2022; FCPS 2021; MCPS n.d.). In addition, after receiving North Carolina's first ESB in early 2022 and five additional buses in mid-2023, the Eastern Band of Cherokee Indians set a goal of becoming the first school system in the state to electrify its full fleet (Huntington and Jackson 2022; WLOS Staff 2022).

Grants and incentives

Funding at the utility, local, state, and federal levels has catalyzed adoption, with school districts leveraging dozens of funding sources to offset the high upfront costs of the buses, which can be three to four times more than the costs of diesel models (Levinson 2022; see "Electric School Bus Price Tracker—State-Level Sources" [Huntington et al. 2023]).

At the federal level, the Bipartisan Infrastructure Investment and Jobs Act, signed into law in November 2021, provides an unprecedented amount of funding—$5 billion over five years to the EPA to establish the CSBP in support of school districts and other eligible contractors or entities (Box 1 and Figure 3). The program will offer both rebate and grant programs to support the replacement of existing school buses with cleaner zero- or low-emission school buses. This funding includes $2.5 billion in dedicated funding for zero-emission ESBs and another $2.5 billion for zero- and low-emission school buses, including both electric and alternative fuel buses. These programs will prioritize projects that align with the Justice40 Initiative, which aims to deliver at least 40 percent of the overall benefits from federal climate and clean energy investments to underserved communities.

BOX 1

The Clean School Bus Program: An inflection point for electric school buses

On October 26, 2022, the EPA released a list of 2022 rebate award recipients and a waitlist for the first round of funding. Due to overwhelming demand for ESBs, EPA nearly doubled its initial US$500 million rebate offering and instead awarded $965 million for low- and zero-emission school buses, with 95 percent of awards going to ESBs based on high demand for this technology.[a] The 2022 rebate awards will help almost 400 school districts purchase more than 2,400 buses.[b] These awards mean that ESBs will arrive in many places where none were previously in use: Arkansas, Idaho, Kansas, Kentucky, Louisiana, Nebraska, New Hampshire, Ohio, South Dakota, West Virginia, Wisconsin, and Wyoming, as well as the District of Columbia, American Samoa, and Puerto Rico and four tribal nations, including the Morongo Band of Mission Indians, Mississippi Band of Choctaw Indians, Lower Brule Sioux Tribe, and Soboba Band of Luiseño Indians (Figure 3). Several states will see large jumps from current numbers: Texas will go from only 3 committed ESBs to almost 140; South Carolina will go from 8 to more than 150; and Illinois will more than double, from 89 to more than 200.

Beyond geographic distribution, the rebate prioritized school districts based on whether they were "high need," rural, tribal, or a combination of these criteria. The number of ESBs in the fourth quartile of low-income school districts—those with the highest share of low-income households—has increased significantly. Before October 2022, 25 percent of all ESBs and districts with ESBs were in the fourth quartile. Now, this quartile has 41 percent of ESBs and 34 percent of school districts.[c]

The program's second tranche of funding, to be provided via a grant program, was announced on April 24, 2023. (The application, open through August 22, 2023, can be found at https://www.epa.gov/cleanschoolbus/clean-school-bus-program-grants.)

Notes: EPA = Environmental Protection Agency. ESB = electric school bus.

Sources:

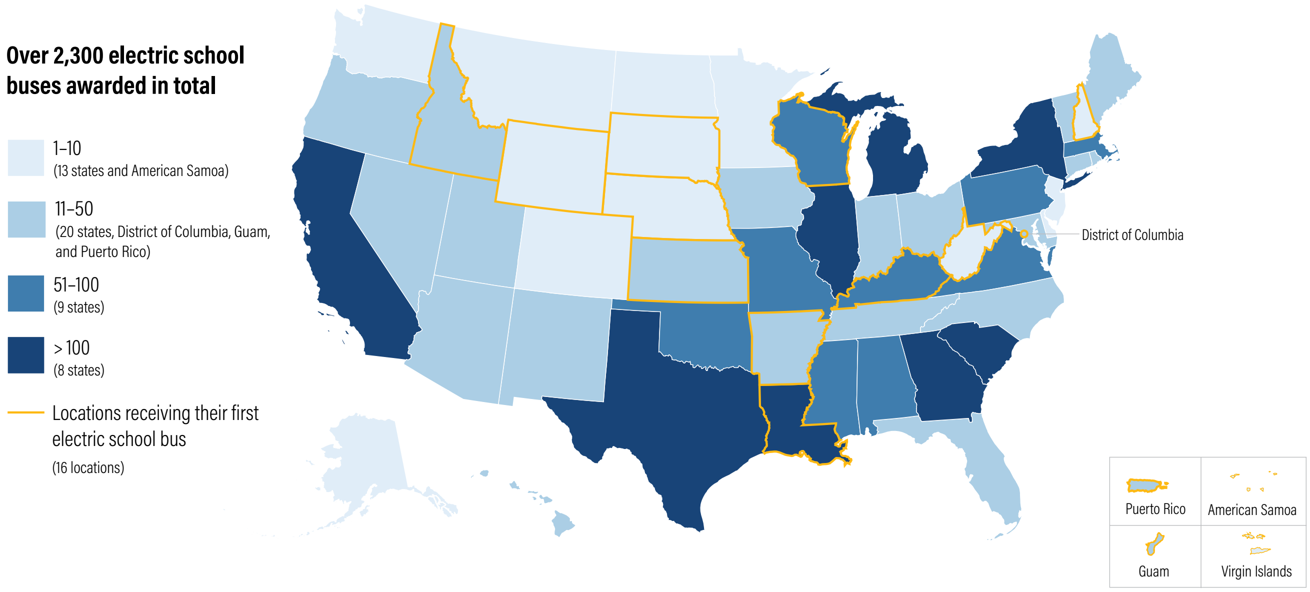
a. U.S. EPA 2022

b. Gander et al. 2022.

c. Freehafer and Lazer 2023.

FIGURE 3

Electric school buses awarded in the Clean School Bus Program 2022 rebates



Note: State awards include awards made to tribal communities within that state.

Sources: ESBI 2023b; U.S. EPA n.d.a.

Further bolstering momentum, the Inflation Reduction Act of 2022 provided additional funding and tax credits to assist schools in electrifying their school bus fleets (Akopian et al. 2022). The Inflation Reduction Act established the Clean Heavy-Duty Vehicle Program, which allocated an additional $1 billion to the EPA to replace eligible Class 6 and 7 vehicles (including school buses) with zero-emission alternatives. The Inflation Reduction Act also established tax credits of up to $40,000 per vehicle purchased through the Commercial Clean Vehicle Credit (Internal Revenue Code 45W) and up to $100,000 per charger purchased through the Alternative Fuel Vehicle Refueling Property Credit (Internal Revenue Code 30C) and allowed school districts to be eligible through "direct pay" provisions as tax-exempt entities (ESBI 2022a; ESBI 2022b).

States, too, are an important source of funding for school bus electrification. California, Massachusetts, and New York have voucher incentive projects and pilot programs (California HVIP n.d.; MDER n.d.; NYSERDA n.d.). Across the board, the state funding landscape has evolved due to the Volkswagen settlement funds, which make up more than one-third of states' public funding for ESBs allocated to date (McLaughlin and Balik 2022). States are creating dedicated funding pots for ESBs, including California ($1.5 billion), Colorado ($65 million), Connecticut ($20 million), New Jersey ($45 million), and New York ($500 million) (McLaughlin and Sedigh 2022).

Current market status

School districts and cities across the country are becoming part of the transition to ESBs, driving demand nationwide (Box 2). As of December 2022, 895 districts (or private operators) had committed to procuring 5,612 ESBs (1.2 percent of the current fleet size) (Freehafer and Lazer 2023; Figure 4). ESBs are committed in all 50 states; Washington, DC; Puerto Rico; the U.S. Virgin Islands; Guam; American Samoa; and tribal nations, including the Cherokee Nation, the Eastern Band of Cherokee Indians, the Lower Brule Sioux Tribe, the Morongo Band of Mission Indians, Mississippi Band of Choctaw Indians, the Soboba Band of Luiseño Indians, and the White Mountain Apache Tribe. Before October 2022, 59 percent of ESB commitments were in the West, including more than 50 percent in California. California now represents 39 percent of committed ESBs, only a little more than the South's 34 percent.

BOX 2

How increasing demand is leading to business model innovation

The electrification of school buses presents districts with the opportunity to assess their existing arrangement of roles, responsibilities, and financial obligations—in other words, their business models. Districts can benefit from expert project management, procurement support, and ongoing operations and maintenance services offered by third parties (structured as service contracts).

To respond to growing demand from school districts, existing contractors, who represent around 40 percent of the school bus market, are beginning to explore pathways to electrification to meet customer demand.[a] For example, National Express aims to transition its school bus fleet (Durham School Services) to zero-emission buses by 2040, while First Student has committed to convert 30,000 diesel buses to electric by 2035.[b] Midwest Transit Equipment is partnering with SEA Electric to repower 10,000 school buses to electric by 2026.[c]

Complementing these options, interest in fleet electrification has prompted the emergence of business models that specifically address the unique challenges and opportunities associated with ESBs. Two examples are Highland Electric Fleets and Levo Mobility, firms that leverage private finance, potential vehicle-to-grid revenues, public funds, and the purchasing power of multiple clients to provide bundled packages of services that enable electrification.

Note: For more information on shifting and new business models, see https://electricschoolbusinitiative.org/all-about-electric-school-bus-business-models.

Sources:

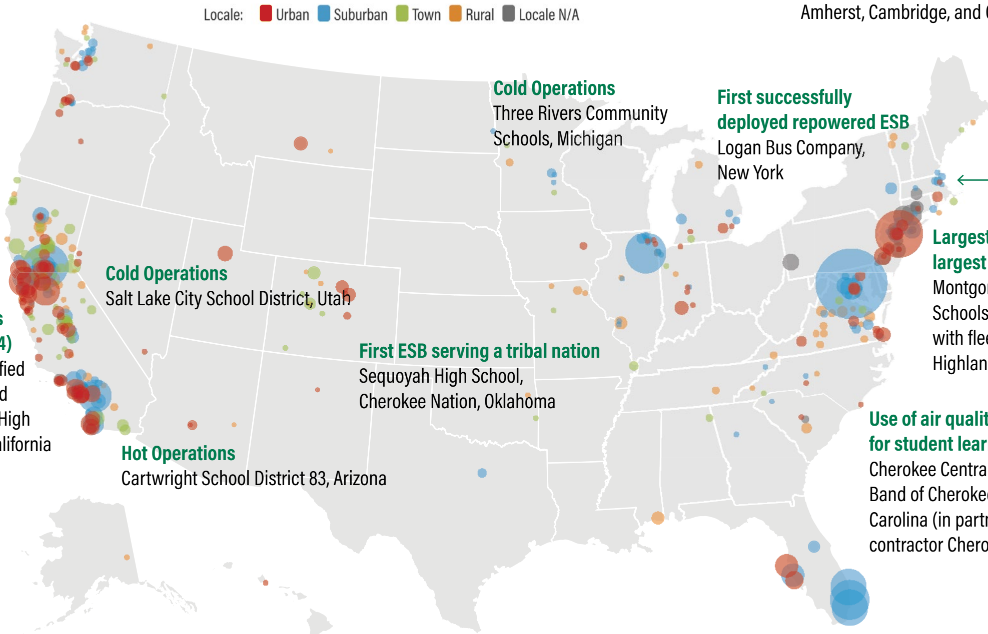
a. Gissendaner 2021b.

b. First Student n.d.; Lam 2022.

c. SEA Electric 2021.

FIGURE 4

Committed electric school buses in the United States operating across a wide range of settings and conditions



Notes: Data as of December 2022. World Resources Institute identified a total of 5,612 committed ESBs across the United States, which represents 1.2% of the entire U.S. school bus fleet. Not shown: American Samoa Department of Education (1 ESB), Guam Department of Education (25 ESBs), and Saint Thomas–Saint John School District (10 ESBs). ESB = electric school bus.

Sources: Freehafer and Lazer 2023; NCES n.d.a, n.d.b; examples gathered by authors.

Electric school buses have successfully been deployed in a variety of climates. For example, ESBs can offer unique advantages in cold weather. Unlike a diesel bus, which has weight concentrated in the front, ESBs' battery weight is distributed more evenly between the front and rear wheels, improving driving in the snow. Three Rivers Community Schools, a school district outside of Kalamazoo, Michigan, has found that its ESBs have "outperformed [their internal combustion engine] buses in cold weather" (ESBI 2022c). Although Three Rivers uses an auxiliary diesel heater, Salt Lake City School District in Utah has opted for electric heaters. Electric heaters do draw from the battery responsible for propulsion, but Salt Lake City has been able to recoup the energy used for the heater through regenerative braking. Buses have also been deployed in hot weather climates. Cartwright School District 83 outside of Phoenix, Arizona, received the state's first ESB in July 2021. The bus has an upgraded air conditioning system that is appropriate for the Arizona heat and has successfully operated in summer temperatures without major battery impacts (Ekbatani 2021). ESBs are also navigating the mountainous terrain of Cherokee, North Carolina, as well as snow-covered ski mountains for field trips and local canyons for regular routes outside of Salt Lake City (Huntington 2022; Huntington and Jackson 2022).

Scaling supply

To meet the growing demand for ESBs, existing manufacturers are ramping up production and new manufacturers continue to enter the field (Figure 5). Although initial offerings were limited in the 2010s, when ESBs were just emerging, today there are 24 ESB models available, with many manufacturers on their third or fourth generation, if not more. In addition, traditional school bus manufacturers and newer manufacturers that specialize solely in electric models are expanding production capacity to meet demand.

Between the end of 2022 and mid-2023, GreenPower Motor Company completed construction of its second ESB manufacturing facility, located in West Virginia; began production of ESBs; and conducted a series of pilot programs to observe performance across the state (GreenPower 2022). Lion Electric Company, a Canada-based group, produced its first ESB that was certified as made in America at their newly constructed facility in Illinois (Lion Electric 2022a). When it reaches its eventual full capacity of 20,000 units, the plant is poised to be the largest electric truck and bus manufacturing facility in the United States.

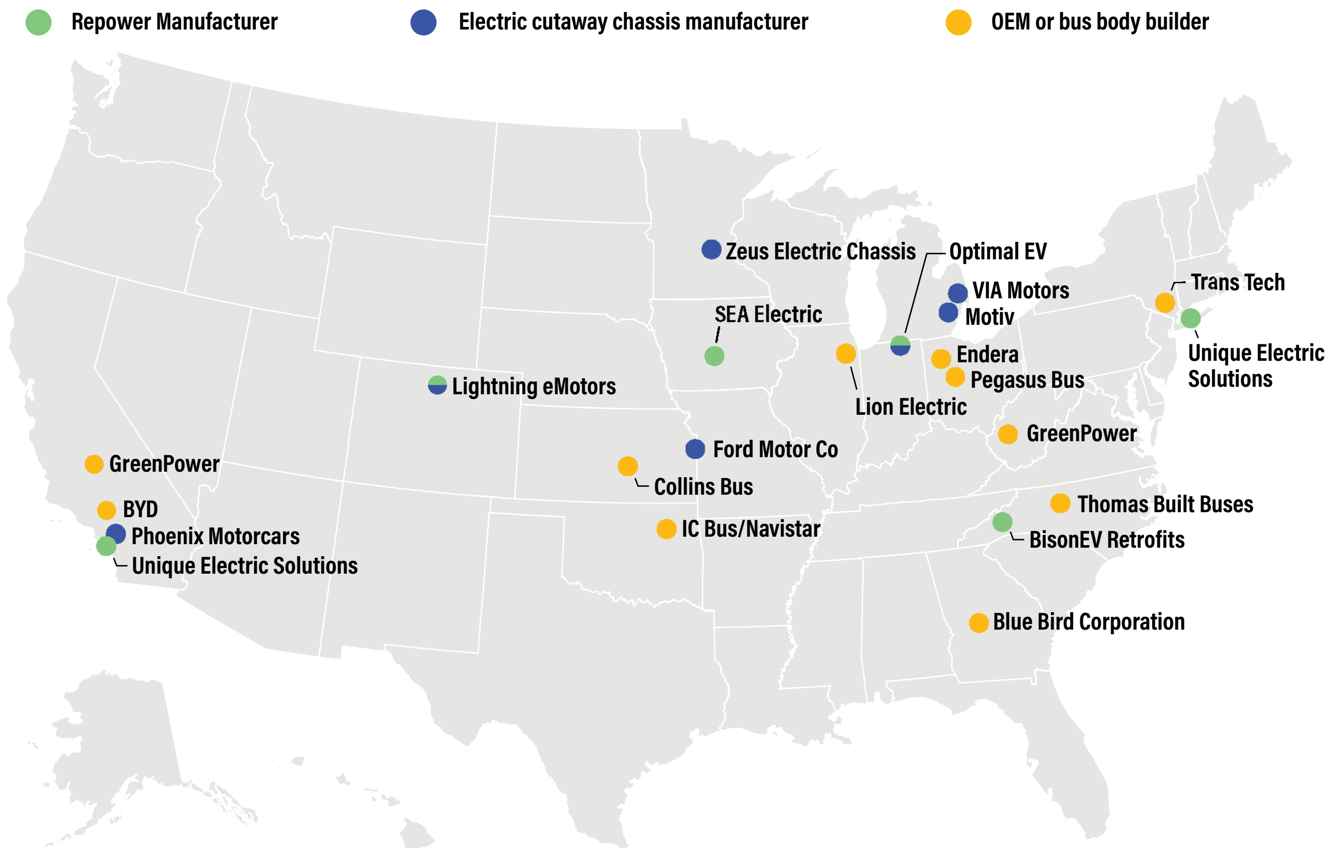
In addition to new construction, manufacturers are also expanding their existing facilities. Thomas Built Buses increased its manufacturing capacity, in part to support a ramp-up of ESB production, by adding 280 employees in North Carolina, setting the company up for its 200th ESB delivery in October 2022 (DNTA 2022; TBB 2022). Lightning eMotors, an all-electric cutaway supplier for Type A ESBs, also completed a significant expansion to meet consumer demand, doubling the footprint and production capacity of their Colorado manufacturing facility (Lightning eMotors 2022).

Manufacturers are also forging new partnerships. Collins Bus Corporation, a school bus body upfitter, and Lightning eMotors expanded their Type A ESB offerings to include both Ford and GM platforms (Lightning eMotors 2022). Pegasus Specialty Vehicles announced partnerships with three electric cutaway cab chassis suppliers—Phoenix Motor Cars, VIA Motors, and Zeus Electric Chassis—that will collectively supply Pegasus with more than 2,300 vehicles to build on (Ideanomics 2022; Phoenix Motor Inc. 2022; Zeus Electric Chassis 2022). In addition, Blue Bird Corporation announced a factory-certified repower program for existing gasoline and propane Type C buses in partnership with Lightning eMotors (Blue Bird 2022b). Thomas Built Buses also announced a partnership with Optimal-EV for an electric Type A (Optimal-EV 2023).

Looking ahead, BYD has announced its intention to construct a dedicated facility for ESB manufacturing adjacent to the existing manufacturing plant in California (CEC 2023). Pegasus also announced the company will move to a larger facility in Ohio in 2024 (Myers Cook 2023). Industry-wide, manufacturers are anticipated to more than double their existing capacity for Type C and D ESBs by the end of 2024, with longer-term expansion growing fivefold (Lee and Chard 2023).

FIGURE 5

Map of electric school bus manufacturing facilities in the United States



Notes: This map does not include electric school bus manufacturing facilities in Canada: Lion Electric Company, Micro Bird, and Ecotuned.
Source: WRI authors based on publicly available information.

School bus manufacturing is concentrated in the United States and Canada. However, ESBs are still dependent on a global supply of lithium-ion batteries, electric motors, and other electric vehicle components that have less domestic manufacturing capacity (FTA n.d.). The cost of these components, particularly batteries, directly impacts ESBs' capital cost and the industry's ability to accomplish rapid ESB adoption. Despite these challenges, even as the COVID-19 pandemic has presented unprecedented hardships for the education sector, ESBs persisted as the only fuel type to see growth in new bus sales during the pandemic, with production increasing 61 percent in 2021 from the previous year and 68 percent in 2022 (Gissendaner 2021b; Gray 2022).

As ESBs continue to gain market share, it will be crucial to advance sustainability and social equity conditions across their supply chain (Boxes 3 and 4). Some considerations could include managing diesel bus scrappage in a way that avoids displacing pollution but allows electric repowering or repurposing. Manufacturers can work to support sustainable mining practices across the supply chain that protect people and the environment. Job quality and stability are also important factors when considering the ESB transition's ultimate impact on communities, particularly given that Black individuals represent a somewhat higher share of workers in the automotive manufacturing sector than they do in the labor market as a whole, making this an important source of comparatively well-paying jobs for Black workers (Coffin and Lawrence 2020). Manufacturers should carefully evaluate what the long-term vision for electrification of their product line entails and how to prioritize sustainable environmental and social practices (Table 1). (For additional exploration of job quality in the green economy and a focus on how to ensure an equitable transition for the automotive workforce, see Jaeger et al. 2021 and Saha et al. 2023.)

BOX 3

Battery repurposing and recycling

Developing channels for battery repurposing and recycling is one important way to create sustainable systems for ESBs.[a] According to a National Renewable Energy Laboratory report, after about a decade of use, vehicle battery capacity decreases but still retains nearly 70 percent of its initial capacity. This retention of capacity could support stationary storage for renewable resources, electric vehicle charging, or resiliency for another decade after the battery is no longer fit for vehicle use.[b] After repurposing is explored, battery recycling can help capture and reuse critical mineral components. Redwood Materials plans to spend US$3.5 billion in both Nevada and South Carolina on battery recycling facilities, and Li-Cycle will soon have five facilities across North America.[c] Our survey reveals that most ESB manufacturers are still developing plans for battery end-of-life management, though a few have made public announcements (Table 1).[d] For example, Thomas Built Buses stands out because it has stated that its provider, Proterra, has built battery recycling considerations into its design and that the company works with recycling companies to recover 99 percent of precious metals. All manufacturers will ideally commit to taking responsibility for ESB batteries at the end of their useful lives and creating partnerships that enable battery circularity.

Note: ESB = electric school bus.

Sources:

a. Kothari 2023.

b. Neubauer et al. 2015.

c. Elliott 2022; Li-Cycle Corp. 2022; Redwood Materials 2022.

d. Girardin Blue Bird 2021.

BOX 4

Integrating sustainability and social equity into procurement

Public entities can expand the impact of taxpayer dollars by incorporating sustainability and social equity criteria and benefits into their procurement processes, RFPs, and contracts. School districts, alongside transit agencies and cities, are increasingly leveraging their considerable buying power to achieve community co-benefits related to planned transportation projects. Portland Public Schools in Oregon issued an RFP for ESBs in 2020.[a] The district used two methods to integrate equity into the RFP:

- It highlighted its Equity in Public Purchasing and Contracting Policy, which aims to increase contracting opportunities for minority-, women-, and veteran-owned businesses and to have the district partner with contractors to provide career-learning opportunities for students.
- It considered “diversity in employment and social responsibility” as one of the 10 evaluation criteria. This criterion included certification, company demographics, and social responsibility. In the transit space, Los Angeles County Metropolitan Transit Authority (Metro Los Angeles) has used the U.S. Employment Plan since 2011, when the agency issued an RFP for the purchase of light-rail cars that awarded higher evaluation scores to companies that provided competitive hiring, training, and pay commitments in their proposals. Then, in 2022, the board adopted the Manufacturing Careers Policy to apply the U.S. Employment Plan to all agency procurements of more than US$50 million and create enforcement mechanisms (e.g., monetary penalties) to hold winning vendors to those commitments.[b] Community Benefits Agreements (CBAs) are legally enforceable agreements between private companies and coalitions of community and labor groups that agree to specific commitments to benefit the community in which manufacturing or project development is sited. CBAs can also indicate to a consumer that a manufacturer is prioritizing the creation of good jobs, integrating fair hiring practices, or investing in local communities’ infrastructure (Table 1).[c] Detroit, Michigan; St. Petersburg, Florida; and New Jersey offer examples of municipalities and states that have adopted policies to institutionalize CBAs for projects that exceed a certain financial threshold. Robust CBAs may include provisions that ensure enforceability, seek diverse community representation, and prioritize environmental sustainability and justice practices. (For more information on CBAs, see JMA 2013 or Saha et al. 2023.)

Notes: Template requests for information and proposals can be found at https://electricschoolbusinitiative.org/request-proposal-rfp-template. Section 4 of the template RFP covers race and gender equity in public purchasing and contracting. CBA = community benefits agreement. ESB = electric school bus. RFP = request for proposal.

Sources:

a. PPS 2020.

b. JMA 2022.

c. JMA 2013; Saha et al. 2023. Elliott 2022; Li-Cycle Corp. 2022; Redwood Materials 2022.

d. Girardin Blue Bird 2021.

TABLE 1

Sample environmental and social practices by original equipment manufacturer

WRI developed the following list of five characteristics to help provide school districts with a sense of how ESB manufacturers are incorporating key environmental and social practices into their current plans and operations. These are followed by data on the production levels from each company to help give some context to their practices, particularly their GHG inventories. It is important to note that all of these numbers are self-reported, and there are a number of ways to analyze these numbers.

	BLUE BIRD CORPORATION	BYD	DAIMLER TRUCK (THOMAS BUILT BUSES)	GREENPOWER MOTOR COMPANY	LIGHTNING EMOTORS	LION ELECTRIC COMPANY	MICRO BIRD	MOTIV POWER SYSTEMS	IC BUS/ NAVISTAR
Goals set for an all-electric future?	No	All-electric OEM	By 2030: 60% of sales are ZEV. By 2039: Sell exclusively CO_2-neutral vehicles in North America.[a]	All-electric OEM	All-electric powertrain supplier	All-electric OEM	No	All-electric OEM	By 2030: 50% ZEV sales.By 2040: 100% ZEV sales.[b]
Public battery reuse, repurpose, or recycling initiative?	No, but efforts are underway.	No, but efforts are underway.	Yes (Proterra design)[c]	No	No[d]	No, but efforts are underway.[e]	Yes, in Quebec (Lithion Recycling partnership[f]	Yes (in partnership with manufacturer)	No
Unionized workforce?[g]	Yes (USW)	Yes (SMART)	Yes (UAW)	No	No	No	Yes (USW)	No	Yes (UAW)
Community benefits agreement?[g]	No	Yes	No	No	No	No	No	No	No
GHG emissions inventory									
GHG emissions reported?	No	Yes (Scope 1 and 2)[h]	Yes (Scope 1 and 2)[a]	No	No	Yes (Scope 1 and 2); materiality assessment for Scope 3 underway as of 2022[e]	No	No	Yes (Scope 1 and 2); calculating Scope 3 as of 2022[i]
Type of reporting	Not disclosed	Company aggregate	Per bus	Not disclosed	Not disclosed	Company aggregate	Not disclosed	Not disclosed	Company aggregate

TABLE 1

Sample environmental and social practices by original equipment manufacturer (Cont'd)

	BLUE BIRD CORPORATION	BYD	DAIMLER TRUCK (THOMAS BUILT BUSES)	GREENPOWER MOTOR COMPANY	LIGHTNING EMOTORS	LION ELECTRIC COMPANY	MICRO BIRD	MOTIV POWER SYSTEMS	IC BUS/ NAVISTAR
Scope 1 (2021)	Not disclosed	315,610 tCO_2e	1,858 kg CO_2	Not disclosed	Not disclosed	634 tCO2e	Not disclosed	Not disclosed	64,816 tCO2e
Scope 2 (2021)		4,903,502 tCO_2e	1,037 kg CO_2			79 tCO2e			106,286 tCO2e
Production (units, or sales when production is not available; inclusive of but not limited to ESBs or United States)									
2021	6,679 units (school buses; multiple fuel types)[j]	740,131 sold (transit and school buses, trucks, and cars; all electric)[h]	455,445 sold (school and transit buses and trucks; multiple fuel types)[a]	96 units (vans, cargo, school and transit buses, and motorcoaches; all electric)	146 units (vans, shuttles, school and transit buses, trucks, and motorcoaches; all electric)	196 units (school buses and trucks; all electric)[e]	2,409 units (school and shuttle buses; multiple fuel types)	58 units (trucks, vans, shuttle buses, and school buses; all electric)	82,728 units (trucks and buses; multiple fuel types)[i]
2022	6,822 units (school buses; multiple fuel types)	1,967,043 sold (transit and school buses, trucks, and cars; all electric)	Not disclosed	185 units (vans, cargo, school and transit buses, and motorcoaches; all electric)	374 units (vans, shuttles, school and transit buses, trucks, and motorcoaches; all electric)	Not disclosed	2,161 units (school and shuttle buses; multiple fuel types)	111 units (trucks, vans, shuttle buses, and school buses; all electric)	TBD

Notes: Battery plans classified as "No, but efforts are underway" include a range of efforts such as internal coordination, partnership cultivation, or development of pilots. Community benefits agreements are legally enforceable agreements between private companies and coalitions of community and labor groups. An example of BYD's community benefits agreements can be found at https://jobstomoveamerica.org/resource/community-benefits-agreements/. GHG inventories are lists of emission sources and their associated emissions using standardized methods. More information and definitions of Scope 1, 2, and 3 emissions can be found at https://www.epa.gov/climateleadership/ghg-inventory-development-process-and-guidance. Production is offered as a reference of scale in comparison to the GHG inventory. CO_2 = carbon dioxide. ESB = electric school bus. GHG = greenhouse gas. kg = kilograms. OEM = original equipment manufacturer. SMART = International Association of Sheet Metal, Air, Rail, and Transportation Workers. TBD = to be determined. tCO2e = tonnes of carbon dioxide equivalent. UAW = United Automobile, Aerospace and Agricultural Implement Workers of America. USW = United Steelworkers. WRI = World Resources Institute. ZEV = zero-emission vehicle.

Sources: Publicly available information gathered by authors and confirmed or adjusted by the following ESB manufacturers: Blue Bird Corporation, BYD, GreenPower Motor Company, Lightning eMotors, Lion Electric Company, Micro Bird, Motiv Power Systems, IC Bus/Navistar, and Thomas Built Buses. Not listed are manufacturers that are included in the buyer's guide (Huntington et al. 2023) but whose data were not confirmed: Pegasus Bus Company, SEA Electric, and Unique Electric Solutions. Specific sources noted below.

a. Daimler Truck 2022.

b. Navistar n.d.

c. TBB n.d.

d. Lightning eMotors n.d.

e. Lion Electric 2022b.

f. Girardin Blue Bird 2021.

g. Elder 2023.

h. BYD 2022.

i. Navistar 2022.

j. Blue Bird 2022a.2 Electric school bus basics.

ELECTRIC SCHOOL BUS BASICS

In preparing for ESB adoption, project developers need to understand considerations for both the buses and the charging infrastructure to power them. This section outlines components of the ESB and its charging infrastructure (Appendix A provides additional terms and units) and offers considerations for implementation.

Electric school bus

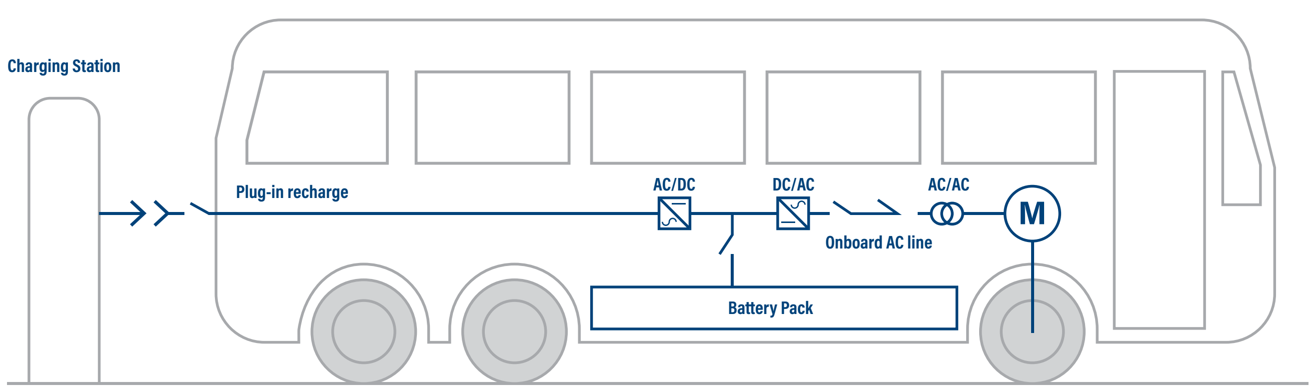
As school districts embrace ESBs, fleet managers, bus drivers, and maintenance technicians will need to familiarize themselves with elements that vary between diesel and electric (Figures 6 and 8). Although many elements of the body and cabin are similar, there are two key features of the electric model that are not present in the diesel model: the presence of high-voltage electrical systems and the absence of internal combustion-related components.

ESBs contain high-voltage systems powered by a large lithium-ion battery pack mounted to the chassis. These batteries meet rigorous safety standards and are extensively tested (ESBI 2023a). Power from the high-voltage battery is distributed to the electric motor and other systems using high-voltage cables (bright orange), alternating current/direct current (AC/DC) inverters, and DC/DC converters. The high-voltage battery pack is supported by a thermal management system that maintains battery health and longevity by keeping the batteries within an optimal temperature range regardless of external temperature (vital to ESBs' ability to operate in both cold and hot climates).

When considering the battery range, it is important to distinguish the "nameplate" battery capacity from its "usable" capacity. Many manufacturers will cite the actual battery size (kWh) or nameplate capacity of a bus, but in reality, approximately 80 to 90 percent of that capacity will be "usable." Manufacturers reserve about 10 to 20 percent of the battery capacity to maintain the battery state of health over the long run (Figure 7). Reserving some battery power also ensures that the vehicle will maintain critical functionality and not suddenly shut off. The usable range can be impacted by various factors. Managing the battery's temperature and heating or cooling the cabin in very high or low external temperatures will expend the usable range more quickly, while effective use of regenerative braking will recapture energy to add range back en route. Over the lifetime of an ESB, the battery will naturally degrade by around 20 percent after several years of use.

FIGURE 6

Electric school bus diagram

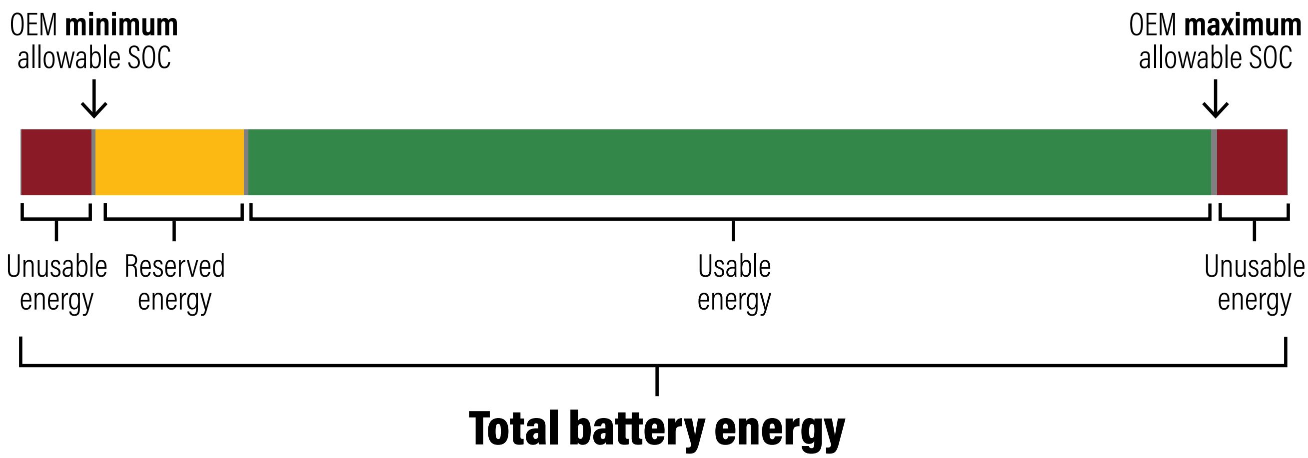


Notes: AC = alternating current; DC = direct current; M = motor.

Source: Ainsalu et al. 2018.

FIGURE 7

Total battery energy: Nameplate vs. usable range



Notes: OEM = original equipment manufacturer. SOC = state of charge.

Source: Adapted from Bigelow 2017.

With the inclusion of an electric power train, ESBs do not contain internal combustion engine components and systems (see components highlighted in red in Figure 8). Electric buses utilize motors composed of only around 20 parts, compared with 2,000 in a diesel engine; require fewer fluid changes, including elimination of engine oil; and commonly use a direct drive system, eliminating the need for a transmission. Additionally, unlike a diesel bus, which has weight concentrated in the front, ESB battery weight is distributed more evenly between the front and rear wheels.

With respect to vehicle servicing, technicians have fewer parts to maintain for ESBs than for their diesel counterparts. Moreover, many auxiliary systems in ESBs, such as braking and steering, remain similar to those of diesel buses, making them relatively easy to maintain (see components highlighted in blue in Figure 8). Additionally, like diesel buses, ESBs also have low-voltage auxiliary systems that use a lead-acid battery to support components such as the dashboard, lights, and windshield wipers. However, to operate on high-voltage systems, maintenance technicians do need specialized training. For on-site depot maintenance staff, completing this training can be both costly and time-consuming.

If qualified technicians are not readily available where the bus operates, any issues that arise with the high-voltage system must be resolved by the closest dealer or manufacturer that has trained staff. Depending on the proximity of the bus to these services, there can be delays and challenges with bus uptime. To address this issue, it is imperative that manufacturers and dealers work closely with transportation managers, technicians, and their teams to provide training in proper management of these systems and related safety considerations and to decentralize where the ability and knowledge to operate on high-voltage systems is concentrated.

FIGURE 8

Comparison of electric and internal combustion engine vehicle components

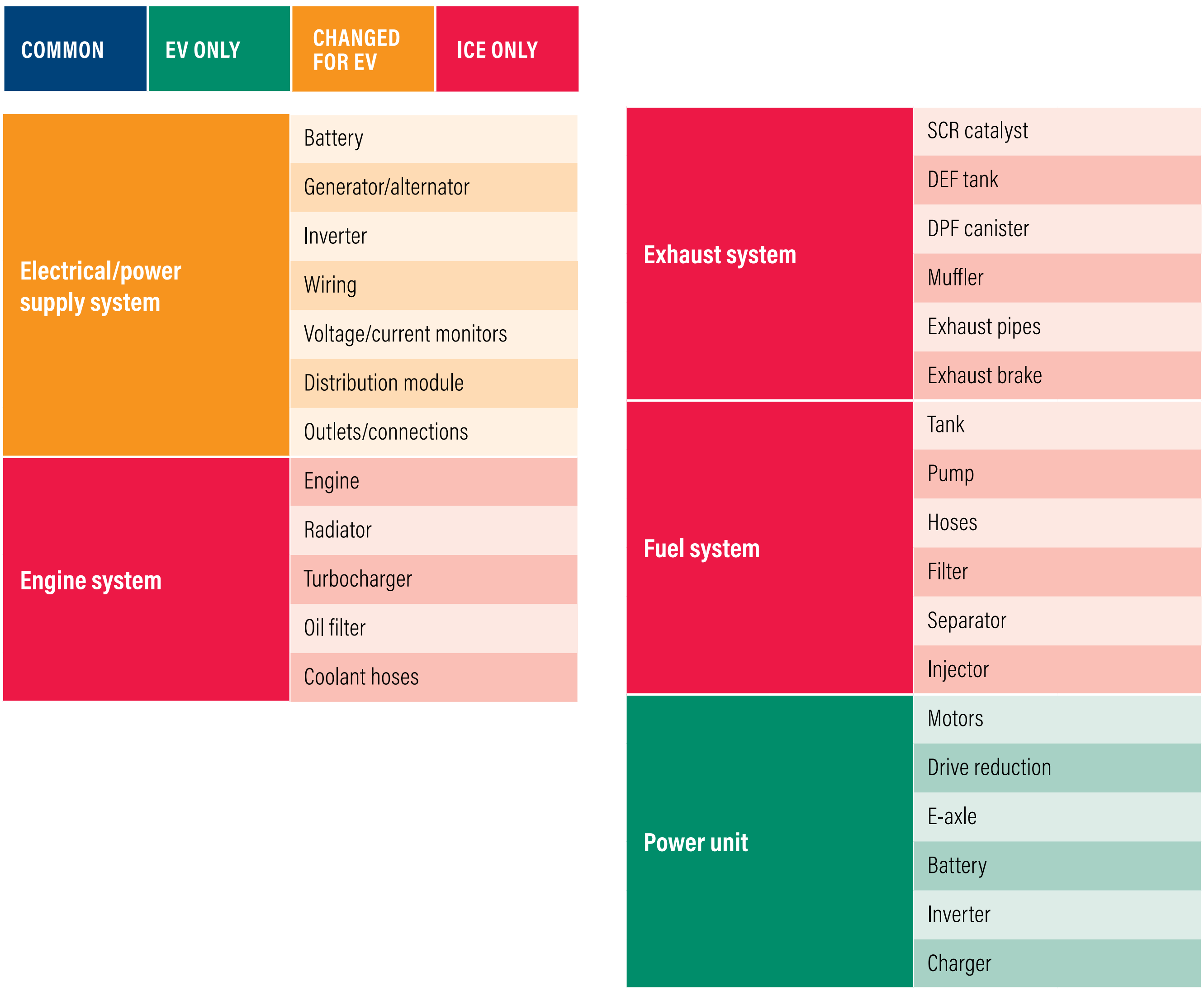
COMMON	EV ONLY	CHANGED FOR EV	ICE ONLY

System	Component
Body system	Body
	Doors
	Windows
	Head/all lights
Suspension system	Springs
	Shocks
	Air leveling
	Front axle
	Control arms
Brake system	Brake calipers
	Air compressor
	Reservoir
	Brake pedal
Steering system	Steering wheel
	Gearbox
	Power steering pump
	Steering arm
	Tie rod
	Hydraulic system
Climate control system	HVAC compressor
	Blower
	Ducts
	Vents
	Heat pump
	Burner/heater
	Controls

System	Component
Gauge and warning system	Instrument cluster
	System monitor sensor
	Display/HMI
	Alert buzzer
Communications system	Transponder
	PA system
	Tracking
Lighting system	Control panel
	Lights (interior, overhead)
Interior system	Seats
	Flooring
	Luggage storage
Public interface	Display signage
	Advertising
Chassis system	Frame
	Body mounts
	Engine mounts
	Suspension mounts
Driveline system	Transmission
	Driveshaft
	Shifter
	Rear axle(s)
	Differentials
	Wheels
	Tires

FIGURE 8

Comparison of electric and internal combustion engine vehicle components (Cont'd)



Notes: DEF = diesel exhaust fluid. DPF = diesel particulate filter. EV = electric vehicle. HMI = human-machine interface. HVAC = heating, ventilation, and air conditioning. ICE = internal combustion engine. PA = public address. SCR = selective catalytic reduction.

Source: Nair et al. 2022.

Charging infrastructure

As school districts consider procuring ESBs, they must also think about the corresponding infrastructure needed to charge these buses. Infrastructure can be broken into hardware and software components (Box 5). For charging hardware, there are three levels available today: Level 1 alternating current (AC), Level 2 AC, and Level 3 direct current (DC) (with various power ranges) (Table 2).

Bus depots can and often do have a mix of Level 2 ACs and direct current fast charger equipment (DCFC equipment) (see Box 5). With lower power demands, several buses can typically charge at the same time with multiple L2 chargers that can have two ports per charger. For DCFCs, higher power demands may restrict charging to fewer buses and only one per DCFC.

TABLE 2

Charging levels

ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE) CHARGING LEVELS AND COSTS

Level/type of current	Level 1 AC	Level 2 AC				Level 3 DC (DCFC)
Power (kW)[a]		19.2	24–30	50	70	150
Recharge time (hours)[b]	Typically for residential, personal vehicle charging; not suitable for ESBs due to low rate of charge relative to the time it takes to charge a battery	5.5–13	3.5–10.25	1.5–4.25	1.5–3.5	n/a
EVSE cost (US$/charger)		3,127–5,586[c]	21,838[d]	25,836[e]–56,802[c]	~54,300[e]	75,000[f]–87,800[c]
Maintenance cost ($/charger/year; average estimate)[g]		536	1,704	1,704	1,704	2,237
Software cost ($/station/year; average estimate)[g,h]		454–484	522	522	522	522
Customer-side construction and equipment installation costs ($/station; average estimate)[i]		6,661[g]	19,823[d]	28,009[g]	29,386[g]	60,186[g]

Notes: AC = alternating current. DC = direct current. DCFC = direct current fast charger. ESB = electric school bus. EVSE = electric vehicle supply equipment. kW = kilowatt. kWh = kilowatt-hour. n/a = not applicable.

a. The ranges for Level 2 include single- and dual-port offerings. The ranges for DC represent dual-port offerings. Dual ports increase costs.

b. Recharge time depends on vehicle battery size and can be calculated by dividing battery capacity (kWh) by power (kW). Example: Battery capacity size is 155 kWh, charger is 19.2 kW, recharge time is approximately 8 hours. Examples are based on the information in the accompanying Electric School Bus Buyer's Guide (Huntington et al. 2023w).

c. Bennett et al. 2022.

d. WRI authors, in discussions with school districts and vendors.

e. Nair et al. 2022.

f. Nelder and Rogers 2019.

g. Levinson et al. 2023.

h. Some districts may opt not to use such software, in which case this cost could be $0. Additionally, some vendors may bundle a package if there is a mix of Level 2 and DCFCs.

i. Installation costs will be site and geography dependent. Estimates do not include potential grid upgrade costs.

Hardware and software compatibility: Identifying misconnection points[4]

To successfully operate, three components must "talk" to one another or "complete a handshake (see Figure 9):" the electric school bus, the charger (firmware), and the network (software).

ESB <-> Charger: Like an appliance's plug fits into a household wall outlet, a bus's charging port must be physically compatible with the charger connector, which delivers electric current from the charger hardware to the vehicle battery. There are two connector types used for ESBs (Table 3).

For Level 2 charging, a single plug standard is used across the industry: SAE J1772. For DCFC, all school buses are equipped with the Combined Charging System (CCS). In Table 3, note that the Level 2 SAE J1772 standard is identical to the top half of the CCS. As by the first word in its name, the Combined Charging System is designed to accept both the Level 2 SAE J1772 plug and a CCS1 DCFC plug.[5] Most buses come equipped with a single CCS port, like the one shown in Table 3, that can facilitate Level 2 and DCFC charging. See the glossary for more on AC/DC charging and charger ports.

Each bus has its own power requirements, measured in kilowatts (kW). Common power levels as listed in the *Buyer's Guide* section (Huntington et al. 2023) include 13 and 19.2 kW for Level 2 and 24, 50, and 60 kW for DCFC. Some buses may have a minimum or maximum threshold for power acceptance (e.g., a bus that can only accept a maximum of 60 kW will not work with a 100 kW charger). For Salt Lake City School District, the latter issue resulted in two months of disruption, in part due to difficulties identifying which party would resolve the issue after purchasing charging infrastructure through a third-party vendor that did not include a service-level agreement or coverage for the communication link between bus and charger (Huntington 2022). Moreno Valley Unified School District in California, on the other hand, identified two vendors—one original equipment manufacturer and one charger and charge management provider—for all of their 46 ESBs and 46 chargers based on the strong relationship built between the two entities (Burleson 2023). When issues between the buses and chargers have arisen, Moreno Valley credits the charging provider with rapid, boots-on-the-ground support for quick resolution.

FIGURE 9

Communication among bus, charger, and network

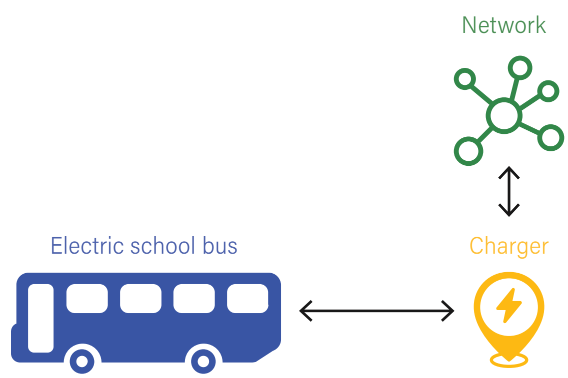
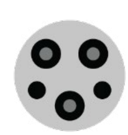
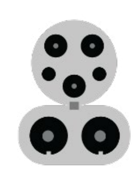


TABLE 3

Charging plug types

	Level 2	Direct current fast charger
PLUG TYPE	SAE J1772	Combined charging system
IMAGE		

Source: AFDC n.d..

Charger <-> Network (Hill-Cristol 2023): Potential partners that could help manage the charger-to-network interaction could include the charger manufacturer, the charger vendor, and a charge management service provider (e.g., network provider, charge point operator); some vendors may only be responsible for one element, while others might encompass all. When it comes to the charger-to-network interface, Open Charge Point Protocol (OCPP) is a communication standard that allows managed charging stations to connect with a central, often cloud-based network to operate the charger.[6] Full implementation of the latest version of OCPP and the right software allows for sophisticated load management. The first step for compatibility is to confirm that a charger is OCPP compliant. Then, during operation, just as a phone receives updates for apps, chargers' firmware also needs to update. To ensure there is not a service interruption between the charger and the network during these instances, the following best practices should be applied:

- Ensure that the various vendors and dealers involved for the three elements are communicating with one another on system requirements and timelines. Each charger manufacturer and networking company may implement OCPP differently and will require its own configuration, which can take weeks or months to accomplish.
- Execute a service-level agreement (SLA) to cover operations, maintenance, and warranty of the charging equipment to avoid getting stuck in the middle between the charge management provider and the charger manufacturer. To mitigate this challenge, school districts may assign the overall charging operations responsibilities to the network provider so that issues are resolved in a timely manner.[7]
- Include a requirement in the SLA to use a local contractor who has direct electric vehicle charger installation, maintenance, and repair experience.
- Require parties to give prior notice when they plan to issue firmware or software updates.
- Request that software updates are tested before launching, occur during business hours to receive prompt customer service, and take place when student transportation is not needed.

BOX 5

Charging infrastructure[a]

Charging infrastructure will be a new frontier for almost all districts.[b] When evaluating charger assortment, districts should keep in mind questions such as the following:

1. **Where will chargers be located?** Conduct a preliminary site assessment that allows you to identify elements such as traffic flow, parking, and the most economical spot for a new service drop from the utility.
2. **Will electric utility upgrades be needed?** Confirm available power with your electric utility, as there may be site limitations. Finalize the location of a new service drop. You should begin conversations with your electric utility as soon as possible and engage them on a regular basis throughout the process.
3. **What are your electric utility tariffs?** Electric utilities use tariffs to send price signals to customers when using electricity is more or less expensive. Tariffs will depend on your region and electric utility—for instance, midday charging may be cheaper or more costly depending on your utility's tariff structure. Similarly, utilities may offer lower "off-peak" prices for most of the night, making overnight, lower power charging an effective solution. Some utilities may even offer "super-off-peak" prices for a few hours during some periods, allowing a DCFC to take advantage of a short supersaver period if programmed (this approach requires a network-connected charger to begin and end charging at the appropriate times). Given this variation, understanding your utility's tariff structure is critical to making your charging as cost-effective as possible and maximizing your electricity savings.
4. **How do your routes operate?** Conduct a route analysis to select and match the bus battery pack size with the appropriate power charging station. Factors include weather (and how much air conditioning or heat is used), terrain, total miles, and schedules (including dwell time between routes, early release schedules, and field trips), among other variables. Buses running longer routes (i.e., those that reduce the state of charge below the level needed to complete both morning and afternoon routes) may need to charge after their morning route and before their afternoon route (likely with a DCFC), but others may be able to complete their entire daily route without a midday charge.[c] Your district may decide to hire an external consultant to run a charging analysis or contract charging out entirely through a "charging as a service" firm.[d]
5. **Have you evaluated managed charging?** Assess software offerings that may take advantage of cheaper energy during off-peak hours.[e] "Smart chargers" (those equipped with charge management software) can be programmed to begin and end charging at the appropriate times to take advantage of the cheapest electricity rates. In addition, managed charging can allow you to control your electricity use (demand) and expand the number of buses your facility can support by staggering charging times or distributing charging across multiple chargers and vehicles.

Notes and Sources:

a. Hawkins 2023.

b. More information on charger offerings can be found at https://www.energiize.org/infrastructure?section=infrastructure.more-details.technology or https://www.epri.com/pages/sa/EVSE-Qualification-Working-Group.

c. CTE 2023.

d. More information on electric as a service, which includes charging as a service, can be found at https://electricschoolbusinitiative.org/school-bus-electric-service-eaas-directory.

e. ESBI 2022d.

Early and frequent engagement with the school district's electric utility is crucial. This engagement is necessary for evaluating the existing power supply and identifying required system upgrades. Once charging infrastructure is in place, which can take approximately 12 to 24 months, bus operators can take advantage of time-of-use rates (if available) and managed smart charging to help realize greater energy savings. For example, a 2015–18 ESB pilot program in three Massachusetts school districts found that unmanaged bus charging and high parasitic loads during charging (e.g., bus heaters, fans, lights) contributed to ESB electricity costs being 63 percent higher than necessary (VEIC 2018). To avoid excess energy consumption, the report authors recommended using managed charging.

Beyond the hardware, managed charging uses software designed to help fleet operators optimize charging schedules, costs, and bus performance. This software, often provided by charging software developers, can allow for scheduling charging times for when electricity prices are lowest or for turning off charging to preserve battery life without manual adjustments, even if the bus is plugged in continuously. Chargers equipped with this software will likely be somewhat more expensive upfront and incur ongoing subscription or service fees.

With the right hardware and software, school districts can take advantage of bidirectional charging, where the vehicle can receive electricity to charge as well as discharge to a different load or onto the grid. If equipped with this functionality, a bus can serve as a backup battery for a building and provide emergency mobile power (vehicle-to-building; V2B) or for another load (vehicle-to-load; V2L). Energy stored in bus batteries can later be discharged onto the grid to reduce districts' utility costs (vehicle-to-grid; V2G). Since the first ESB vehicle-to-grid deployment in 2014 in three California school districts, at least 15 utilities across 14 states have committed to pilot ESB V2G programs (Hutchinson and Kresge 2022; PCA 2014). Through V2G programs, buses also have the potential to generate financial benefits by discharging energy from their batteries to the grid as part of a distributed energy resource; this is a nascent market, but technological advancements and new program opportunities should make this option widely available in the near future. Although these bidirectional concepts have been deployed by only a handful of school districts so far, they offer the potential for increasing resilience, generating financial benefits, and reducing costs (Proterra 2019).

Electric bus adoption can also be paired with new or existing on-site solar (Ellis 2020; ENGIE Impact n.d.; Farley 2021; Soneji et al. 2020). This approach could further decrease energy costs while providing a power source for charging during service disruptions. Installing on-site solar also helps districts contribute to wider school district, city, or state emissions reductions or sustainability goals and directly offsets fossil fuel consumption.

SUMMARY OF AVAILABLE ELECTRIC BUS MODELS

As of March 2023, there were 24 models of ESBs available for purchase in the United States, and established manufacturers were expanding their offerings based on the potential growth of the ESB market. Electric models are available for Types A, C, and D school buses. Among the available electric models, the Type C offerings have seen the greatest level of development to date and represent the majority of commitments (Freehafer and Lazer 2023).

Manufacturers gauge commercial maturity as they move from preproduction assembly to full production, a process that achieves modest volumes and means a vehicle model is available for retail sale. Moreover, ESB models that enter commercial production will have undergone multiple testing iterations prior to factory line assembly and are more mature as later-generation products. Finally, a test of maturity can be applied to a supportive supply chain where manufacturers and their dealers establish formal maintenance networks to service ESBs after delivery.

See the *Electric School Bus Buyer's Guide* (https://electricschoolbusinitiative.org/buyers-guide) (Huntington et al. 2023).

Type A

Type A buses are small, typically accommodating fewer than 36 passengers. There can be multiple entities involved in the construction of a Type A bus, with different manufacturers responsible for different elements (e.g., the chassis, the power train, the body).

Type C

Type C buses, with passenger capacities between 40 and 83 and a curved hood that increases front visibility, make up 70 percent of the overall school bus fleet (Matthews 2021).

Type D

Type D buses—the largest of school buses, seating up to 90 students—make up approximately 20 percent of the market (Matthews 2021).

Newly manufactured electric school buses

A newly manufactured bus is one that has been designed and built to operate with an electric power train from the ground up, with one exception being some electric Type A cutaway buses. Although the purchase price of newly manufactured ESBs is currently around three to four times that of diesel buses—as batteries are more expensive than internal combustion engines and the market has yet to achieve economies of scale—the costs associated with operations and maintenance of ESBs are substantially lower. Research suggests that compared with a new diesel school bus, a new ESB can save an average of $6,000 every year on operational expenditures, depending on circumstances (Levinson et al. 2023). When considering models, school districts should keep in mind the difference between a newly manufactured ESB and a repowered bus.

Repowered electric school buses (Types A, C, and D)

An electric repower—sometimes referred to as an electric conversion or retrofit—involves removing a vehicle's internal combustion engine that runs on a fossil fuel such as diesel, gasoline, propane, or natural gas and replacing it with an electric drive system (or repower kit), transforming the vehicle to one that is fully battery-electric with no tailpipe emissions. Repowered school buses are typically built with a similar electric drive system to new ESBs and often use the same suppliers for battery packs and other components. The key difference is that repowers do not use a brand-new chassis and body and instead take advantage of an existing bus from a fleet or dealer. Repowered and newly manufactured buses utilize the exact same charging infrastructure and can complement each other within a fleet electrification strategy.

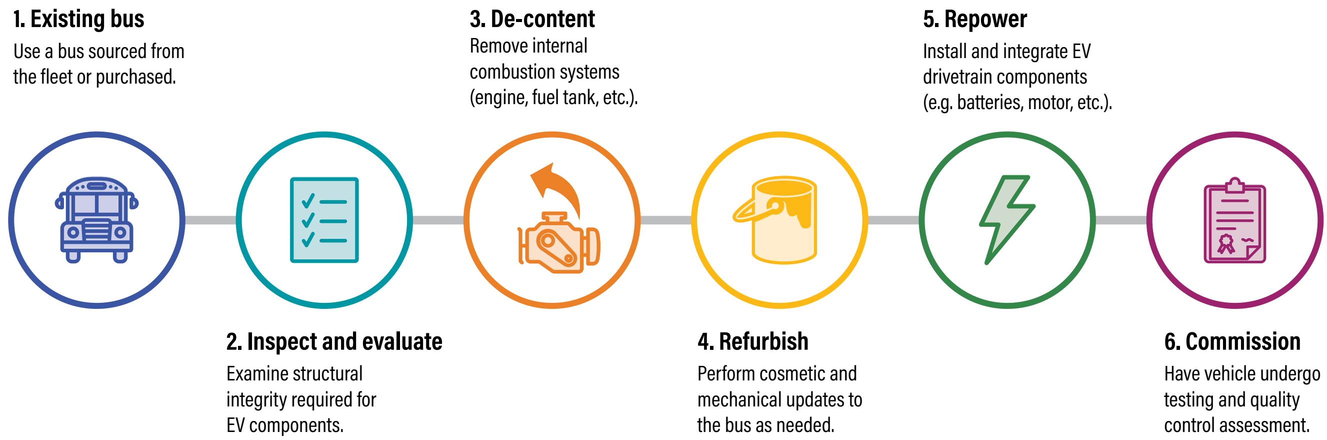
Although brand-new buses typically cost more than $300,000, repowered school buses can cost substantially less, usually between $110,000 and $180,000 (Ly and Werthmann 2023). Repowering offers several other potential benefits. Repowering can prevent a bus from continuing to pollute in another state or country, avoid scrappage and reduce waste (Figure 10), limit manufacturing emissions, and help avoid susceptibility to supply chain delays for body and chassis components. As repowering grows in popularity and availability, repower kits could be used by dealers and other postproduction service providers to repower buses nationwide.

ESB repowering is not without its own set of challenges, primarily linked to the age of the bus being repowered and existing safety compliance and regulation. Repower companies often prefer to focus on buses from a specific original equipment manufacturer, produced within a limited range of model years to reliably repower buses with similar chassis specifications and documented wiring diagrams. Similarly, repower companies generally prefer to repower "younger" buses that have experienced less wear and tear, usually requiring fewer mechanical and cosmetic improvements (Ly and Werthmann 2023). On the regulatory side, school buses fall into specific safety and compliance regulations at the federal, state, and sometimes local levels. Whether a repowered bus meets those specifications will vary based on the bus and the regulatory approach present for a given deployment.

As of March 2023, repowers remain an emerging solution that can offer dramatic cost savings, but they have not yet experienced scaled deployment. As this solution matures, it is expected that repowers will play an important role in supporting the full electrification of school bus fleets.

FIGURE 10

Vehicle repower process



Note: EV = electric vehicle.

Source: Ly and Werthmann 2023, adapted from ABC Companies.

CONCLUSION

Although school bus electrification is still in its early stages, the student transportation industry has made considerable progress since the first ESBs were deployed in 2014. In particular, the ESB model range has grown, increasing from a range of 60 to 100 miles during Kings Canyon's and Escondido's 2014 deployments to a range of 75 to 210 miles today, depending on bus type and model. These vehicles were once limited to a handful of pilot programs, but by December 2022, the number of school districts procuring electric models and integrating them into their fleets had grown to 895—more than double the number of districts with committed buses at the beginning of 2022 thanks to the Clean School Bus Program, which has transformed the market. At the same time, the number of ESB manufacturers and their production capacity have grown substantially, and vehicle features such as range and bidirectional charging have improved considerably. As of March 2023, manufacturers offered 24 models of ESBs across Type A, C, and D school buses, with more expected to enter the market. Like any new technology, there are still barriers to adopting these buses, such as high upfront bus costs and new infrastructure needs, reliability issues with older bus models, and insufficient access to specialized maintenance and technical support. However, ESBs provide a number of benefits, such as reduced operations and maintenance costs, reduced pollution and emissions, the potential to improve students' health and academic outcomes, and the potential to bolster resilience. As school districts navigate this growing market, we hope this publication and future updates will serve as valuable resource for school transportation providers interested in adopting electric school buses.

APPENDIX A. KEY TERMS AND DEFINITIONS: COMPARING DIESEL AND ELECTRIC SCHOOL BUSES

The following tables provide key terms, units, definitions, and parallels to diesel operations, where applicable, for electric school buses (ESBs). Table A-1 defines terms and Table A-2 defines units.

TABLE A1

Electric school bus key terms, definitions, and parallels to diesel operations

TERM	DEFINITION	PARALLEL TO DIESEL (IF APPLICABLE)	REFERENCE OR EXAMPLE
State of charge (SOC)	For buses: the charge level of the battery	Fuel-tank level (full/half/empty)	SOC refers to the level of charge left in the battery, which ranges from 0% to 100% or empty to full on the dashboard.
State of health (SOH)	For buses: battery health and useful life	No exact diesel parallel; however, similarities to general wear and tear	SOH refers to the difference between the health of a new battery and the health of a used battery. It is typically represented as a percentage of its initial capacity.
Alternating current (AC)	For chargers: a type of electrical current associated with the charger	Refueling—a diesel pump and hose equate to a charger and connector cable	AC is used to describe the electrical current coming from the grid into a charger. It typically takes longer to charge a bus (8 hours) using AC and likely requires overnight charging, but using AC is cheaper than fast chargers with regard to hardware, installation, and utility upgrades.
Direct current (DC)	For chargers: a type of electrical current associated with the charger	Refueling—a diesel pump and hose equate to a charger and connector cable	DC is used to describe the electrical current coming from a charger into the bus. Unlike AC chargers, DCFCs deliver DC current directly to the battery so they can charge school buses at faster rates (1.5–4 hours). Fast charging is approximately 8–10 times the cost of L2 charging for the hardware and may incur additional demand charges for electricity. Fast charging may have more of a detrimental effect on battery life and longevity.
Bidirectional charging capability	For buses and chargers: allows vehicles to both receive and deliver energy externally (V2G, V2B, V2L—collectively V2X)	Unique to electric vehicles	V2G: Stored energy in the vehicle is delivered back through facility infrastructure (reverse power flow) to the grid. V2B: Stored energy in the vehicle is delivered to a facility or building, covering some of the building's power requirements. V2L: V2L allows the bus to serve as a mobile charging source to power another load.

Note: DCFC = direct current fast charger. L2 = Level 2. V2B = vehicle-to-building. V2G = vehicle-to-grid. V2L = vehicle-to-load. V2X = vehicle-to-everything.

Sources: WRI authors; Aamodt et al. 2021; CTE 2020; Dunn 2022; KCM 2020..

TABLE A2

Electric school bus key units, definitions, and parallels to diesel operations

UNIT	DEFINITION	PARALLEL TO DIESEL (IF APPLICABLE)	REFERENCE OR EXAMPLE
kilowatt (kW)	For buses: measure of power	Horsepower (HP)	Manufacturers specify a bus motor's power in kW. For example, a typical electric motor can provide 230 kW (308 HP).
	For chargers: measure of power	No diesel parallel	Different vehicle chargers can deliver electricity at different power levels.
Kilowatt-hour (kWh)	For buses: measure of battery pack energy capacity either as rated (advertised total battery capacity for vehicle), usable (actual accessible battery capacity for operating), or passively consumed (while bus is not driving but still powered on). Can be used to measure range in miles	Fuel tank capacity (gallons)	Manufacturers specify an electric bus's range in kWh. For example, a typical ESB uses a 150 kWh battery pack with a range of 80 to 120 miles (depending on conditions), and a typical diesel bus has a 60-gallon diesel tank with a 450-mile range. This equates to approximately 1.3 kWh per mile for an ESB and 7.5 miles per gallon for a diesel bus.
	For chargers: kilowatts multiplied by total hours, which is a measure of energy	Gallon or liter of fuel	kWh are measured by a utility and charged to customers on their electricity bills.
kWh per mile (kWh/mile)	For buses: the battery capacity (kWh) used for every mile driven Can be used to measure efficiency	Miles per gallon	Efficiency can be calculated by dividing the battery pack size by the range. For a typical 150 kWh battery pack with a stated range of 100 miles, the bus would have an efficiency of 1.5 kWh per mile (150 kWh/100 miles = 1.5 kWh/mile). Models described in this report range between 0.78 and 1.61 kWh per mile. However, efficiency depends on route and climate and is impacted by use of air conditioning, heat, or other factors. The greater the efficiency, the lower the energy cost per mile. Efficiency can also be improved by efficient driving.
Amperes (amps)	For buses and chargers: measure of electrical current	Both diesel and electric buses have components that are measured in amps—some applications vary.	Amps are an important unit for measuring utility capacity to support chargers. For example, each L2 charger requires approximately 40–60 amps and each DC fast charger requires a minimum of 120 amps.
Volts (V)	For buses and chargers: measure of electric potential or electromotive force	Both diesel and electric buses have components that are measured in volts—some applications vary.	Voltage varies by battery size and state of charge. For example, both diesel and electric buses have a 12 V battery to power low-voltage components like the radio, clocks, and lights. This battery also provides the starter motor and spark plugs with the energy needed to start an internal combustion engine. With regard to charging, L2 chargers typically use a 208 or 240 V AC power, and DC fast chargers can use 200–600 V DC power.
Acceptance rate	For buses: the power the bus can receive from the charger	No diesel parallel	For example, if the acceptance rate is 9.6 kW, the maximum power the vehicle can draw is 9.6 kW.
Delivery rate	For chargers: the power the charging station can deliver to the vehicle	No diesel parallel	For example, if the delivery rate is 9.6 kW, the maximum power the charging station can deliver is 9.6 kW, even though the vehicle might be able to accommodate higher-level charging.

Note: AC = alternating current. DC = direct current. ESB = electric school bus. L2 = Level 2.
Sources: WRI authors; Aamodt et al. 2021; CTE 2020; KCM 2020.

APPENDIX B. ADDITIONAL RESOURCES

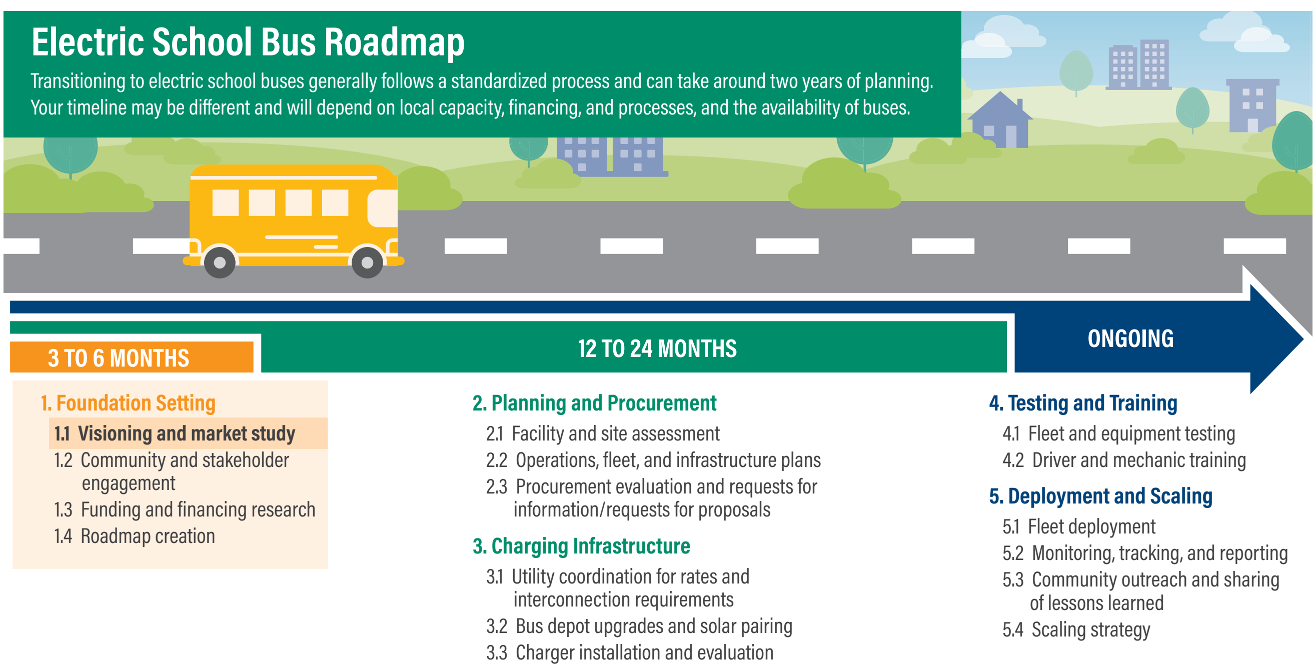
This appendix shares additional resources from the Electric School Bus Initiative.

Electric School Bus Initiative: https://electricschoolbusinitiative.org/. See the Resource Library for an extensive list of World Resources Institute and external resources.

- School district project planning and management:
  - *Step-by-Step Guide for School Bus Electrification*: https://electricschoolbusinitiative.org/step-step-guide-school-bus-electrification
  - *School Bus Electrification Template Roadmap* (an Excel-based tool): https://electricschoolbusinitiative.org/school-bus-electrification-template-roadmap. This tool identifies common steps for electrifying a school bus fleet and how to center equity in that process.
  - *Request for Proposal (RFP)* Template: https://electricschoolbusinitiative.org/request-proposal-rfp-template. This document provides school districts with an easily modifiable electric school bus and charger RFP template for electric school buses.
- Funding and financing
  - Clearinghouse: Electric School Bus Funding and Financing Opportunities: https://electricschoolbusinitiative.org/clearinghouse-electric-school-bus-funding-and-financing-opportunities. This resource is a compilation of the many available options in a single file, which contains information regarding type of funding, program eligibility, funding levels, and more.
  - *Electric School Bus Business Models Guide*: https://electricschoolbusinitiative.org/electric-school-bus-business-models-guide. The guide and the accompanying blog define key electric school bus roles and present benefits and considerations that districts can weigh when assigning responsibility for each role. The directory lists the firms that offer services that can aid school districts with the transition to electric fleets.
    - "All About Electric School Bus Business Models" blog post: https://electricschoolbusinitiative.org/all-about-electric-school-bus-business-models

FIGURE B1

Electric school bus road map



Sources: WRI authors, based on technical assistance from the Electric School Bus Initiative.

- "School Bus Electric-as-a-Service (EaaS) Directory": https://electricschoolbusinitiative.org/school-bus-electric-service-eaas-directory.

- Utility engagement
  - *Working with Your Utility to Electrify Your School Bus Fleet*: https://electricschoolbusinitiative.org/sites/default/files/2022-10/Working%20With%20Your%20Utility-Digital-10.4.pdf. This guide provides an introduction to electric utilities.
  - *Power Planner for Electric School Bus Deployment*: https://electricschoolbusinitiative.org/all-about-working-your-electric-utility. This resources includes questions to ask your electric utility as you prepare for ESBs.
  - *Electric School Bus Facility Assessment Guide*: https://electricschoolbusinitiative.org/sites/default/files/2022-10/ESB%20Facilities%20Assessment%20Guide-Digital-10.4.pdf. This guide provides support to conduct a site walk-through and considerations for operations.
  - *All about Charging Infrastructure* video series: https://electricschoolbusinitiative.org/all-about-charging-infrastructure. These videos walk through the basics of ESB charging infrastructure.
  - *Electric Vehicle (EV) Make-Ready Programs*: https://electricschoolbusinitiative.org/sites/default/files/2022-12/Electric%20Vehicle%20%28EV%29%20Make%20Ready%20Programs.pdf. This guide provides a landscape of utility investment programs to support electric vehicle supply equipment installations.

- Community engagement and equity integration
  - "The Transition to Electric School Buses Must Center Equity. Here's Why": https://electricschoolbusinitiative.org/transition-electric-school-buses-must-center-equity-heres-why. This article discusses how centering equity in the ESB transition impacts long-standing discrimination and exclusion.

- ESB adoption stories
  - *Electric School Bus Series* https://electricschoolbusinitiative.org/engage#section-84: This series shares information about districts that have adopted electric vehicles, such as those in Stockton, California; Prince Edward Island, Canada; Knox County, Missouri; the Eastern Band of Cherokee Indians, North Carolina; Salt Lake City, Utah; and Fairfax County, Virginia.

Here are additional resources that can provide information on ESBs:

- CALSTART. 2021. *Zeroing in on Electric School Buses: The Advanced Technology School Bus Index: A U.S. ESB Inventory Report*. Pasadena, CA: CALSTART. https://calstart.org/wp-content/uploads/2022/01/ZIO-Electric-School-Buses-2021-Edition.pdf. This report offers an inventory of the number of ESBs currently present within the United States.
- CALSTART. 2021. *Electric School Bus Market Study: A Synthesis of Current Technologies, Costs, Demonstrations, and Funding.* Pasadena, CA: CALSTART. https://calstart.org/wp-content/uploads/2021/12/Electric-School-Bus-Market-Report-2021.pdf. This report includes vehicle design and model availability, cost considerations, demonstration case studies, and funding opportunities.
- Electrification Coalition. n.d. "Dashboard for Rapid Vehicle Electrification (DRVE Tool)." https://www.electrificationcoalition.org/resource/drve/. This Microsoft Excel–based tool can help stakeholders evaluate a variety of procurement ownership structures, vehicle types, electric vehicle charging configurations, and other scenarios.
- Jobs to Move America. 2022. *Driving the Future: How to Electrify Our School Buses and Center Kids, Communities, and Workers in the Transition*. Los Angeles, CA: Jobs to Move America. https://jobstomoveamerica.org/resource/driving-the-future-how-to-electrify-our-school-buses-and-center-kids-communities-and-workers-in-the-transition/. This report offers insights from conversations with school districts, private fleet operators, utilities, worker organizations, and others and provides an overview of the state of ESB technology, workforce impacts, and opportunities and policy implications.

- Oregon Department of Energy. 2022. *Guide to School Bus Electrification*. Salem, OR: Oregon Department of Energy. https://www.oregon.gov/energy/energy-oregon/Documents/2022-Jan-14-School-Bus-Electrification-Guidebook.pdf. This guide for school districts covers the benefits and challenges of electric buses, how to get started, how to select a manufacturer, and more related topics.
- *School Transportation News*. 2023. *2023 Buyers Guide*. Redondo Beach, CA: School Transportation News. https://stnonline.com/digital-editions/buyers-guide-2023/. This bus buyer's guide includes, but is not limited to, electric variants, with contact information for manufacturers and dealers.
- U.S. PIRG and Environment America. 2021. *Accelerating the Transition to Electric School Buses.* https://environmentamericacenter.org/sites/environment/files/reports/US_EL%20buses%202021%20Final.pdf. This report discusses how schools, lawmakers, and utilities can work together to speed the transition to zero-emission buses.

Electric school bus manufacturer websites

- Blue Bird Corporation: https://www.blue-bird.com/buses/electric-school-buses
- BYD: https://en.byd.com/bus/school-bus/
- Endera: https://enderamotors.com/
- GreenPower Motor Company: https://greenpowermotor.com/gp-products/beast-school-bus/
- IC Bus/Navistar: https://www.icbus.com/electric
- Lightning eMotors: https://lightningemotors.com/e-450-school-bus/
- Lion Electric Company: https://thelionelectric.com/en/products/electric
- Micro Bird: https://www.microbird.com/our-buses/G5-Electric
- Motiv Power Systems: https://www.motivps.com/application/electric-school-bus/
- Phoenix Motorcars: https://www.phoenixmotorcars.com/products/
- SEA Electric: https://www.sea-electric.com/products/industries-applications/
- Thomas Built Buses: https://thomasbuiltbuses.com/electric-school-buses/electric-bus/
- Unique Electric Solutions : http://uesmfg.com/electric-school-bus-conversions/

GLOSSARY

Alternating current/direct current (AC/DC) charging: Buses that use Level 2 chargers powered by AC input require an onboard charger built into the bus. This charger converts the AC to DC before the current reaches the battery. Buses using DC fast chargers do not require an onboard charger, as the external charger can charge the battery directly.

Battery capacity: Battery capacity, measured in kilowatt-hours (kWh), defines the amount of power in the vehicle battery. Battery capacity can be defined in two ways: rated capacity and usable capacity. Rated capacity is the advertised total capacity of the vehicle's battery. Usable capacity is the actual battery capacity available for vehicle operation (i.e., some manufacturers may reserve 10 percent of the battery for critical vehicle functions). For example, if a school bus is advertised as having 150 kWh of battery capacity, only 90 percent (135 kW) may be accessible for driving.

Capable of bidirectional charging: Buses that are designed for bidirectional charging, also known as vehicle-to-everything (V2X), are capable of two-way energy flow in which their batteries can be charged and later discharged using a bidirectional charger. V2X includes vehicle-to-grid (V2G), vehicle-to-building (V2B), and vehicle-to-load (V2L), all of which can produce energy cost savings depending on time of charge and discharge.

Charger port: The charger port delivers electric current from the charging hardware into the vehicle. The charger cable connection type is specific to the vehicle. It is best for fleets to use the same charger connector for all vehicles. SAE J1772 is the industry standard for Level 2 (L2) alternating current (AC) charger connectors. For direct current (DC) fast chargers, electric school buses typically use the Combined Charging System (CCS) connector. The CCS port is designed to accept both the SAE J1772 standard for L2 AC charging and the CCS standard for DC fast charging. Therefore, buses equipped with the CCS standard can facilitate both L2 and DC fast charging through a single CCS port, unless otherwise specified by the bus manufacturer.

Managed charging: Managed charging refers to any form of control over when vehicles are charging, integrated either into the charger itself or through some outside switch, which allows the site owner to remotely control activation and deactivation of the charger. Proper application of managed charging not only enables the site owner to take advantage of potentially cheaper energy but also may allow for planned fleet management where higher-priority vehicles are charged first. Networked and controlled charging may also offer the ability to distribute charging across the chargers in use: as more vehicles plug in, the total available energy can be distributed at a lower level to more vehicles. This scenario can work well for overnight charging where vehicles sit for long periods without use. Overall, managed charging offers site owners and fleet managers many more options to optimize fleets than chargers without controls.

Park out: In some circumstances, for operational efficiency or convenience, some school bus operators allow buses to be parked in remote locations between shifts or overnight. This scenario could include a bus being parked at or near a driver's home. These operating conditions need to be considered when planning for charging infrastructure. Solutions could include utilizing public charging or installing chargers at other sites, such as schools or drivers' homes.

Regenerative braking: Regenerative braking is a braking system unique to vehicles with electric motors that converts the vehicle's kinetic energy during braking directly into electrical energy that can be used to recharge the battery pack. It allows electric vehicles to recoup some of the energy that would otherwise be wasted as the vehicle decelerates, improving a vehicle's overall efficiency and range.

Time-of-use (TOU) rates: Through TOU rates, utilities charge a customer on total energy consumed based on the time of day the energy is used. Utilities send price signals to customers to shift consumption from when electricity demand is high to times of day when energy supply is the least expensive to produce or most abundant from specific resources. Customers can save money if they align consumption with off-peak times. TOU rates often are designed specifically to support programs such as electric vehicle charging or encourage the use of abundant renewable energy. TOU rates vary by region and utility, and not all utilities offer TOU rates.

Vehicle range: Vehicle range is determined largely by the battery capacity. When considering a vehicle's range, it is important to distinguish the "nameplate" battery capacity from its "usable" capacity. Many manufacturers will cite the actual battery size (kWh) or nameplate capacity of a bus, but in reality, approximately 80–90 percent of that capacity will be "usable." Manufacturers reserve approximately 10–20 percent of the battery capacity to maintain the battery's state of health for the long run. Reserving some battery power also ensures that the vehicle will maintain critical functionality and not suddenly shut off. The usable range can be affected by various factors.

Managing the battery's temperature and heating or cooling the cabin in very high or low external temperatures will expend the usable range more quickly, while effective use of regenerative braking will recapture energy to add range back en route. Over the lifetime of an electric school bus, the battery will naturally degrade by approximately 20 percent after several years of use.

ENDNOTES

1. An electric school bus is considered "committed" starting from the point when a school district or fleet operator has been awarded funding to purchase it or has made a formal agreement to purchase it from a manufacturer or dealer. We would not consider an ESB committed if a school district or other fleet operator only expressed interest in ESBs or stated that they plan to acquire ESBs without awarded funding or an agreement with a third party. Previously, counts of committed buses included in its definition of "committed" buses the contract for SEA Electric to provide Midwest Transit Equipment, with 10,000 buses repowered to electric over the course of five years. We have since determined that this contract is a unique arrangement that does not fit into our definition of the "awarded" subcategory of "committed," as it does not include a school district or fleet operator to date, or into any of the other three categories (ordered, delivered, or operating; see "Sheet 2: Bus-level data" in Lazer and Freehafer [2023] for more information about these stages). Therefore, the repowered buses from this contract are no longer included in our definition of a "committed" electric school bus. More information can be found in Lazer and Freehafer (2023).

2. Compared with newly manufactured school buses that are built as electric from the start, a repowered bus removes a vehicle's existing engine and replaces it with a new engine or power source (e.g., an electric drive system). See "Repowered electric school buses: Types A, C, and D section" for greater detail on repowered buses.

3. As part of the settlement between Volkswagen and the federal government following allegations that Volkswagen violated the Clean Air Act by selling vehicles equipped with "defeat devices" (i.e., computer software designed to cheat on federal emissions tests), Volkswagen will contribute to an Environmental Mitigation Trust to provide states, territories, and tribes funding to mitigate sources of nitrogen oxides. Each state designated a lead implementing agency, conducted stakeholder meetings, and submitted a state action plan (also known as a Beneficiary Mitigation Plan, or BMP) for use of the funds. One of the eligible mitigation actions was the replacement of school buses. To date, Volkswagen settlement funds have been a critical source of state funding for transportation electrification.

4. The 2023 buyer's guide (Huntington et al. 2023) attempts to clarify hardware compatibility by asking manufacturers for their preferred chargers as well as known compatible and incompatible chargers. However, conducting interoperability testing can be challenging and costly, so not all interconnections are known, but testing efforts are ongoing. More information on charger offerings can be found at https://www.energiize.org/infrastructure?section=infrastructure.more-details.technology or https://www.epri.com/pages/sa/EVSE-Qualification-Working-Group/evse. Please also look for results of ongoing EV-EVSE interoperability testing activities in North America through CharIN (Charging Interface Initiative) at https://www.charin.global. An example of CharIN testing efforts can be found at https://www.youtube.com/watch?v=zGDGZ5gHleA&t=11s.

5. The only model the authors are aware of for which this is not the case is Thomas Built Buses' Type C Jouley: although it uses a CCS1 port, it can only charge with a DC charger.

6. More information on the OCPP standard can be found at https://www.openchargealliance.org/.

7. For more information on SLAs, see https://electricschoolbusinitiative.org/all-about-service-level-agreements-slas-electric-school-buses-and-chargers.

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Our challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach

COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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In collaboration with partners and communities, the Electric School Bus Initiative aims to build unstoppable momentum toward an equitable transition of the U.S. school bus fleet to electric by 2030, bringing health, climate, and economic benefits to children and families across the country and normalizing electric mobility for an entire generation. We work with key stakeholders at all levels and across areas, including school districts, private fleet operators, electric utilities, public and private lenders, manufacturers , policymakers, equity and environmental advocacy groups, program administrators, and community members and community-based organizations.

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