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ISSUE BRIEF

Electric school bus US market study

A resource for school districts and other school bus operators for 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

- **Momentum for electric school buses (ESBs) continues to grow.** As of June 2024, 1,514 districts (or private operators) had committed to procuring 12,167 ESBs in 49 states. States and municipalities are setting electrification goals while manufacturers scale production.
- **Diesel exhaust pollution presents real health and development dangers to students, drivers, and communities.** ESBs have zero tailpipe emissions of harmful air pollutants and the lowest greenhouse gas emissions of any school bus type, even when accounting for emissions from the generation of electric power.
- **Although diesel-burning school buses have a lower upfront cost, record funding is available for ESBs,** and they have the potential for lower operations and maintenance costs.
- **As of June 2024, 26 models were available for Types A, C, and D buses: 20 newly manufactured models and 6 repowered models.** Each generation of buses becomes more advanced. The nameplate range of current models is between 100 and 300 miles, enough to reliably cover most routes in operation.
- **Beyond the bus, charging infrastructure and software to manage the charge are necessary components of successful electric school bus adoption and operations.** Close and early collaboration with electric utilities and charge management software companies for support is necessary.

EXECUTIVE SUMMARY

Context

Momentum around ESBs continues to grow in the United States as school districts across the country transition to a cleaner and healthier technology, bolstered by multiple federal funding programs, including US$5 billion from the Environmental Protection Agency's Clean School Bus Program. The ESB transition requires 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.

We developed this publication to provide school districts, transportation directors, and other school bus operators exploring school bus electrification (battery electric vehicles) a better understanding of the state of the ESB market, related technologies, and available offerings. In the first section, "Status of the electric school bus market," we explore the growing demand and funding opportunities for these buses and how manufacturers are positioning themselves to meet that demand. The second section, "Summary of available technology," breaks down the key components of the vehicles, charging infrastructure, and charge management software, and outlines battery chemistry, safety, and circularity. This section also highlights key trends in current ESB vehicle models, the industry, and repowers (fossil fueled buses that have been converted to electric). An accompanying publication—*Electric School Bus U.S. Buyer's Guide* (Wang and Werthmann 2024)—catalogs the 26 ESB models available as of June 2024, including vehicle specifications. Overall, school bus electrification is rapidly scaling, and the student transportation industry continues to make significant progress in this transition.

Approach and methodology

We gathered the content for this publication from a variety of sources. Information in the accompanying *Electric School Bus U.S. Buyer's Guide* (Wang and Werthmann 2024) on models available in the United States comes from publicly available vehicle specification sheets and has been confirmed through discussions with manufacturers when possible.

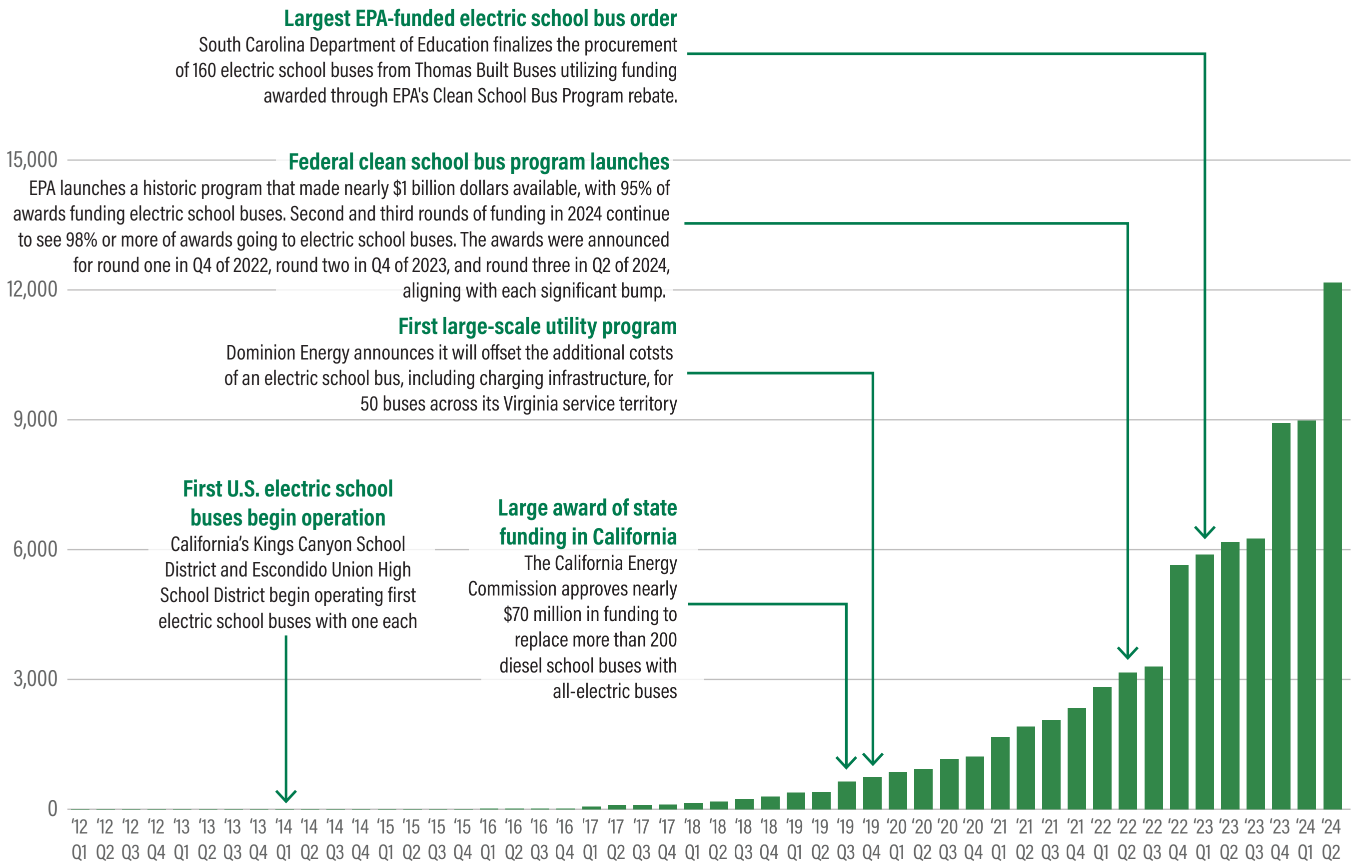
We explored school districts' experiences with ESBs representing a variety of use cases in the United States: rural, suburban, and urban; warm and cold weather; and early adopters further along in the process and those in earlier stages of procurement. We compiled recent research and reporting on school 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.

1. STATUS OF THE ELECTRIC SCHOOL BUS MARKET

The electric school bus (ESB) market was established in 2014, when three California school districts, Kings Canyon Unified School District, Escondido Union High School District, and Gilroy Unified 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 and Gilroy's at 40 miles (Adams 2014; Edelstein 2014; MPS 2014, Petray 2014).

Figure 1. **Cumulative number of electric school buses committed to by quarter in the United States (2014–2024)**

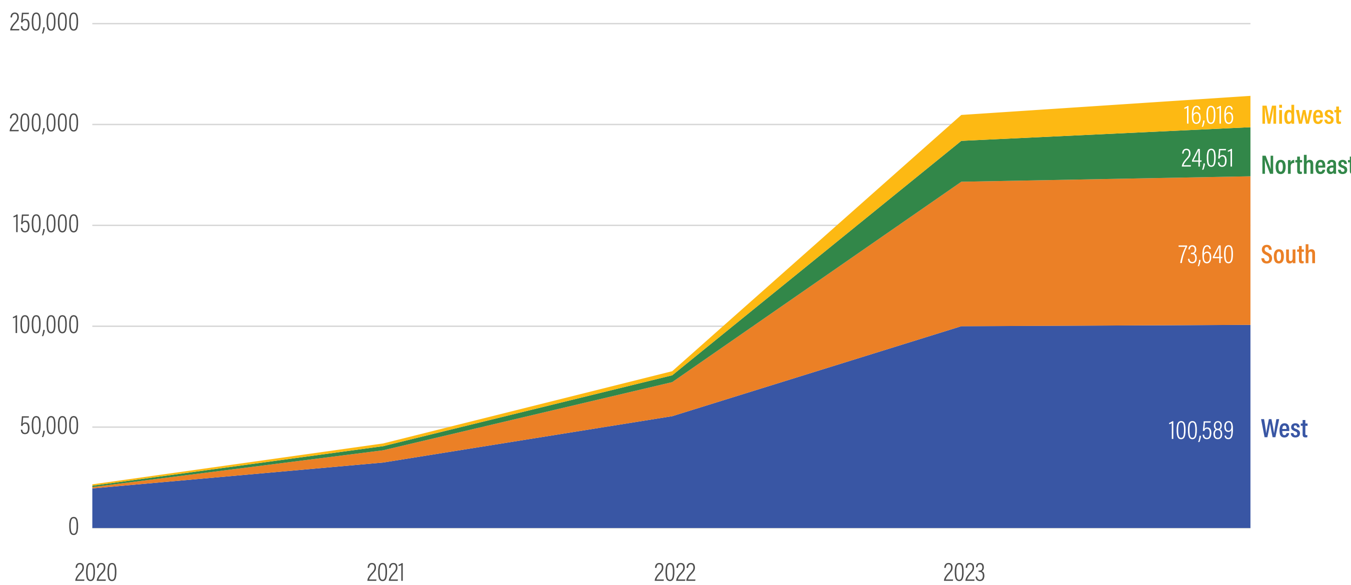


Notes: This graph depicts electric school bus (ESB) commitments at the earliest confirmed phase in the commitment process (awarded, ordered, delivered, or in operation); 131 ESBs were excluded due to unknown dates of their commitment stages. EPA = Environmental Protection Agency. ESB = electric school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

Source: Based on Freehafer and Lazer 2024.

Today, 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 (Types C and D) school buses on the road are diesel powered. However, there is growing interest in ESBs, and, as of June 2024, 49 states; Washington, DC; Puerto Rico; the US 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, had committed to procuring ESBs. There are now 12,167 ESB commitments across 1,514 districts (or private operators), representing around 2.5 percent of the current fleet size; 3,429 ESBs in 48 states have been delivered or are in operation (Lazer and Freehafer 2024). More than 180,000 students are riding ESBs (Figure 2).

Figure 2. **Number of children riding electric school buses by US region, 2020–23**

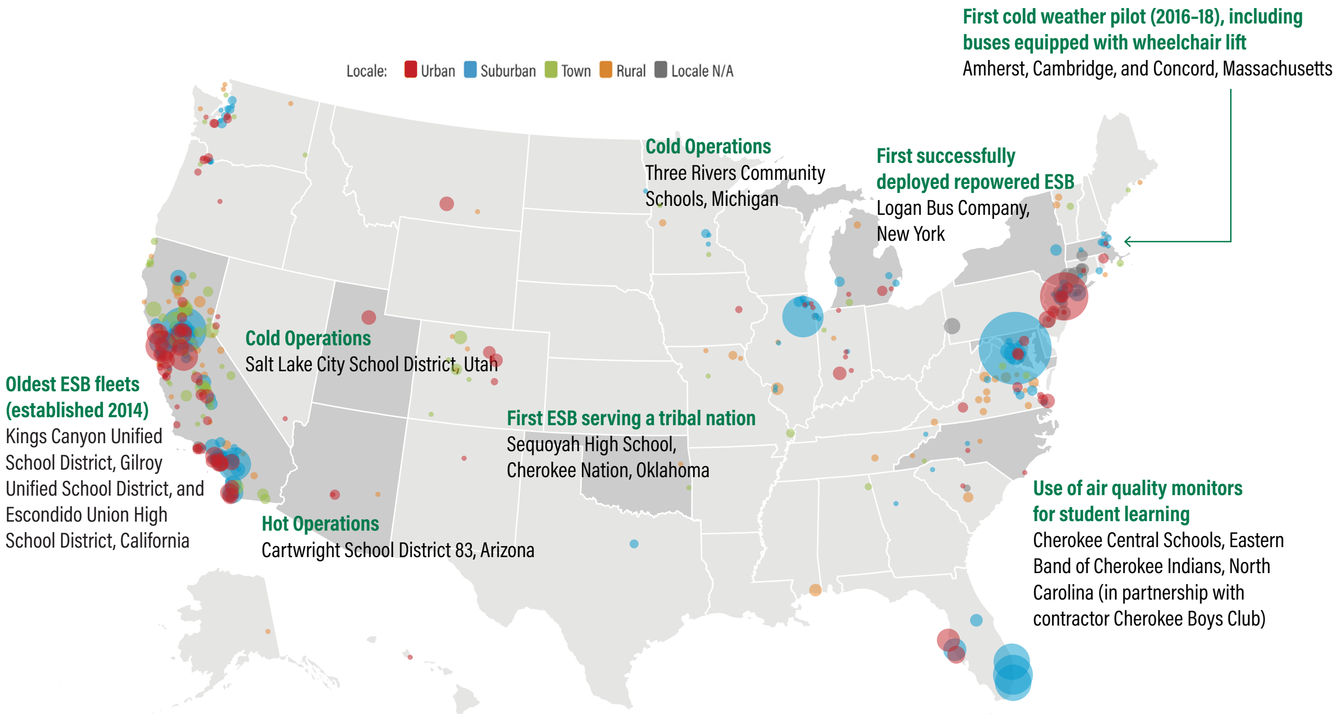


Source: WRI authors.

Before October 2022, about half of ESB commitments were concentrated in California. Today, the West, including California, represents 29 percent of ESB commitments. While there has been significant growth in ESB adoption in other states, as of June 2024, California continues to lead with over 3,100 committed electric school buses across the state, of which nearly 70 percent are delivered or operating. This is more than four times as many buses as the next leading state, New York, with 764 commitments. The remaining top five states with the most committed electric school buses include Illinois (609), Florida (466), and Pennsylvania (460) (Lazer and Freehafer 2024).

School districts and cities across the country are becoming part of the transition to ESBs, driving demand nationwide. Electric school buses have successfully been deployed in a variety of climates (Figure 3). 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" (Dumont and Burgoyne-Allen 2023). 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).

Figure 3. **Committed electric school buses in the United States operating across a wide range of settings and conditions**



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

1.1 Rising demand

A combination of factors is priming the market for ESB adoption. Compared with the typical school bus, which burns fossil fuels, ESBs have the potential to reduce operations and maintenance costs for fleets and produce zero tailpipe emissions (Figure 4). If equipped with bidirectional-charging technology, ESBs can provide additional benefits, such as supplying mobile emergency power.

Motivated by these benefits, communities and policymakers are advocating for ESBs, resulting in an increasing number of commitments to transition targets. Implementation of these commitments is aided by grants and incentives to bring down the upfront cost.

Figure 4. **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, Black students, and children with disabilities, 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.

1.2 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,[1] 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).

At the state level, Chispa's volunteers have supported legislation in Nevada and helped hold school districts to their commitments in Arizona (Schlosser 2021b). 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; student pressure at school board meetings in Miami, Florida, helped convince the district to pursue a grant for 50 ESBs; and in Williamsfield, Illinois, after a particularly bad event when the district lost power, students designed a grid resiliency microgrid project paired with their electric school buses (Casey 2021; Huntington 2022; Hosansky et al. 2024). These are just a few examples of how communities have driven demand for ESBs by advocating for children's health and safety.

1.3 State and local commitments

Policy commitments can influence the speed of adoption and provide long-term market signals to school districts and manufacturers. In 2022, four states—New York, Connecticut, Maryland, and Maine—enacted legislation that set school bus electrification targets. In 2023, two more states—California and Delaware—followed suit, and in 2024 Washington became the seventh state with a statutorily enacted transition requirement. In addition to these three legislatively enacted commitments, Colorado, Michigan, and Washington, DC, have set targets in agency-led transportation and climate action planning documents (Figures 5 and 6) (Ameer and McLaughlin 2023).

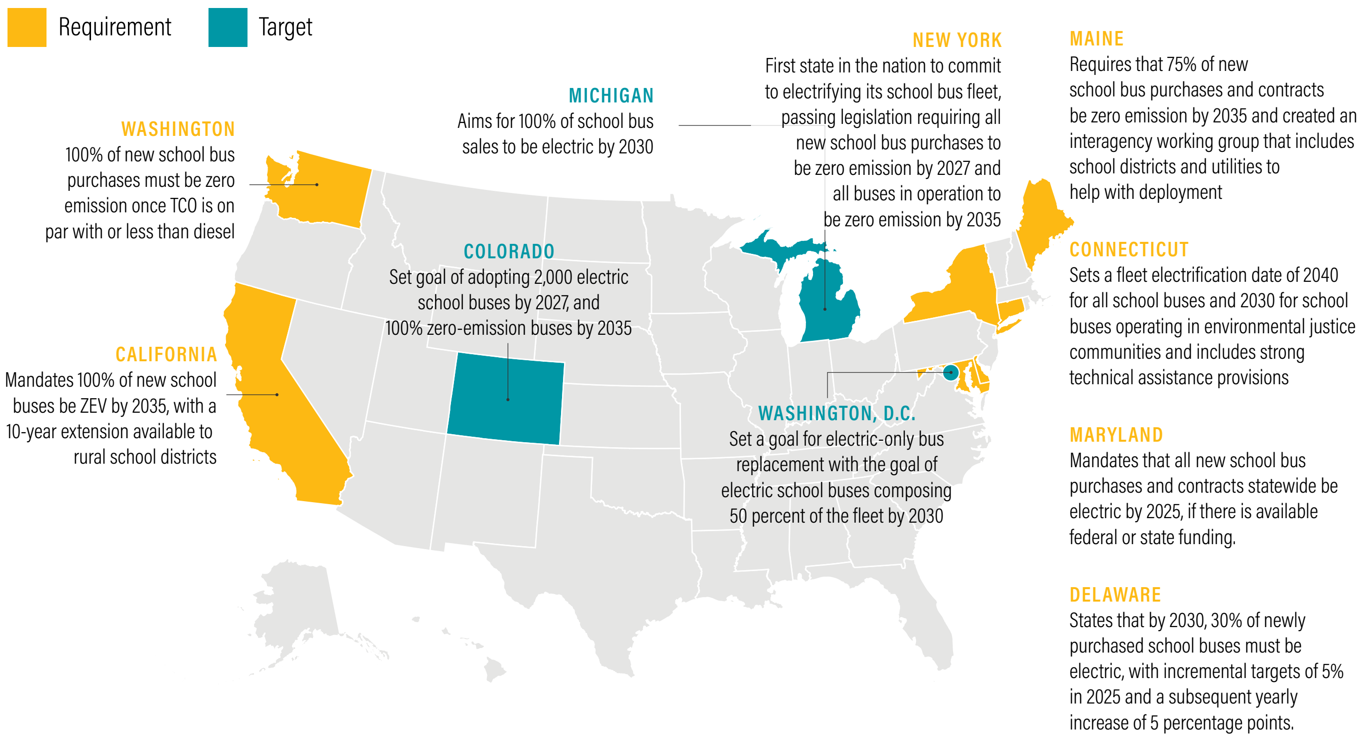
At the local level in school districts, Fairfax County Public Schools in Virginia (approximately 1,625 buses), Boston Public Schools in Massachusetts (approximately 700 buses), Austin Independent School District in Texas (approximately 500 buses), and Monroe County Community School Corporation in Indiana (approximately 85 buses) are some of the districts 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.; Johnson 2022).

Advanced Clean Trucks rule

In 2020, the California Air Resources Board (CARB) adopted the Advanced Clean Trucks (ACT) rule, which requires manufacturers to sell zero-emission vehicles as an increasing proportion of sales starting in 2024. According to CARB, "By 2035, zero-emission truck/chassis sales would need to be 55% of Class 2b–3 truck sales, 75% of class 4–8 straight truck sales, and 40% of truck tractor sales" (CARB 2021). School buses are included under the ACT rule as class 4–8 vehicles.

Under Section 177 of the Clean Air Act, other states can adopt California's standards. Ten additional states have adopted the ACT rule (Colorado, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Rhode Island, Vermont, and Washington), and three others (Connecticut, Illinois and Maine) have rulemaking processes underway. The ACT rule provides state governments the opportunity to ensure manufacturers are selling and servicing electric medium- and heavy-duty vehicles (MHDVs) in their states.

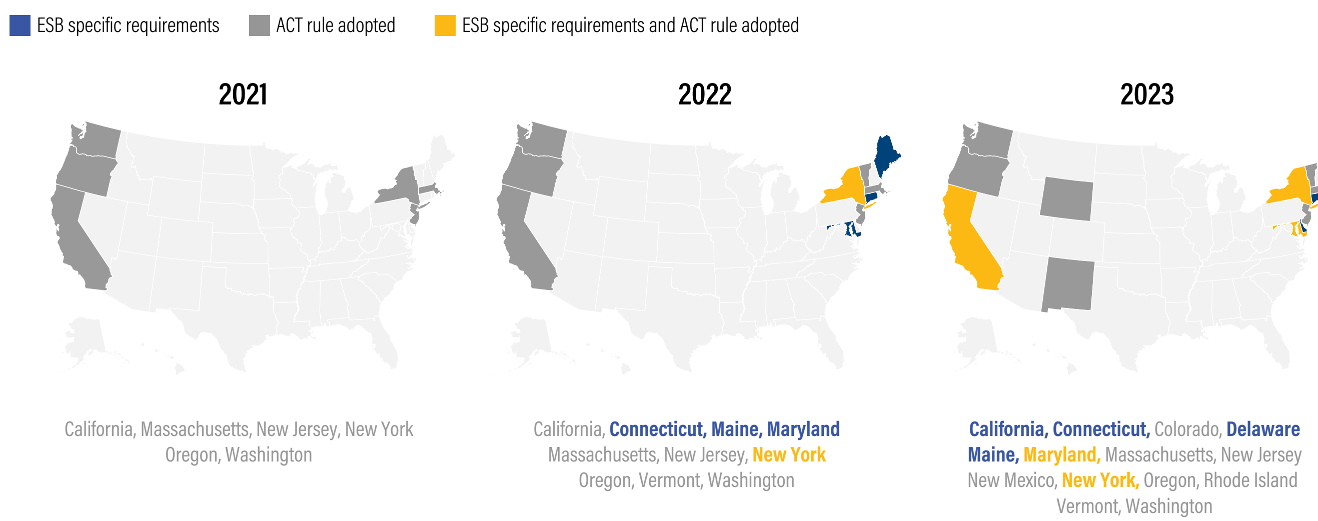
Figure 5. **Electric school bus state transition requirements and targets**



Notes: TCO = total cost of ownership. ZEV = zero-emission vehicle.

Source: WRI authors, based on publicly available information.

Figure 6. **Number of states that have a statewide transition requirement for zero-emission vehicles (inclusive of school buses) and/or school buses (2021–2023)**



Note: Two states—Colorado and Michigan in 2023—and Washington, DC, in 2021 have nonbinding zero-emission transition goals for or inclusive of school buses.

Source: WRI authors.

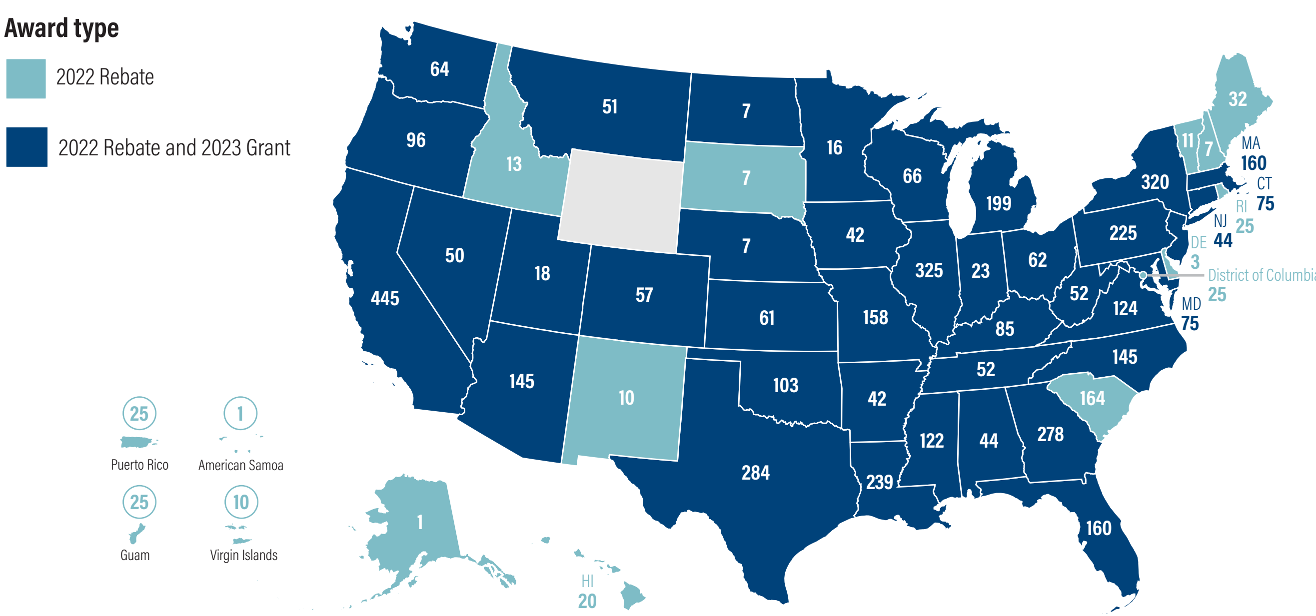
1.4 Grants and incentives

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 cost of the buses, which can be three to four times more than the cost of diesel models (Levinson 2022; see also Levinson et al. 2024).

At the federal level, the bipartisan Infrastructure Investment and Jobs Act, signed into law in November 2021, provides an unprecedented amount of funding—US$5 billion over five years (fiscal years 2022–26) to the Environmental Protection Agency (EPA) to establish the Clean School Bus Program in support of school districts and other eligible contractors or entities (Figure 7). The program offers 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 dedicated for zero-emission ESBs and another $2.5 billion for zero- and low-emission school buses, including both electric and alternativ-fuel buses. These programs 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.

Further bolstering momentum, the Inflation Reduction Act (IRA) of 2022 provided additional funding and tax credits to assist schools in electrifying their school bus fleets (Akopian et al. 2022). The IRA established the Clean Heavy-Duty Vehicles 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. A competitive grant opportunity to distribute

Figure 7. **Electric school buses awarded in the Clean School Bus Program 2022 rebates and 2023 grants**



Sources: ESBI 2024a; EPA n.d.a.

this funding opened in April 2024. The IRA 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 2024b) through December 2032.

States, too, are an important source of funding for school bus electrification. California, Colorado, Massachusetts, Michigan, New Jersey, and New York have voucher incentive projects and pilot programs (California HVIP n.d.a., n.d.b.; CDPHE n.d.; MMOR-EV n.d.; MDER n.d.; NJDEP n.d.; and NYSERDA n.d.). Across the board, the state funding landscape has evolved due to the Volkswagen settlement funds, which made up more than one-third of states' public funding for ESBs allocated in 2022 (McLaughlin and Balik 2022). As more electric school bus state funding programs come online, VW funding is now just under a quarter of total state funding (WRI analysis of Atlas Public Policy 2024). States are creating dedicated funding pots for ESBs, including California ($1.5 billion), Colorado ($65 million), Connecticut ($20 million), Michigan ($125 million), New Jersey ($45 million), and New York ($500 million) (Ameer and McLaughlin 2023).

1.5 Scaling supply

To meet the growing demand for ESBs, existing manufacturers are ramping up production, and new manufacturers continue to enter the field (Figure 8). Although initial offerings were limited in the 2010s, when ESBs were just emerging, today there are 26 ESB models available, with many manufacturers on their third, fourth, or even later generation.

Since 2021, the ESB industry has seen the construction of new manufacturing plants and expansion of existing facilities. In Drummondville, Canada, Micro Bird completed a facility expansion providing the space to produce over 1,000 ESBs per year (Schlosser 2021a). In 2022, Thomas Built Buses added 280 employees in High Point, North Carolina, to help ramp up ESB production, setting the company up for its 1,000th ESB delivery in March 2024 (TBB 2022, 2024). In Joliet, Illinois, the Lion Electric Company opened a new manufacturing plant in 2023 and has since scaled ESB production to 2,500 vehicles per year, matching the capacity of its first facility in Canada (Lion Electric 2023). In the same year, GreenPower Motor Company began producing ESBs at its new facility in Charleston, West Virginia (SBF Staff 2023). Further south, Blue Bird Corporation opened an EV Build-Up Center on its Fort Valley, Georgia, manufacturing campus. As a result, Blue Bird's electric Type C and D production capacity will eventually grow to 5,000 buses annually, a fivefold increase (Blue Bird 2023).

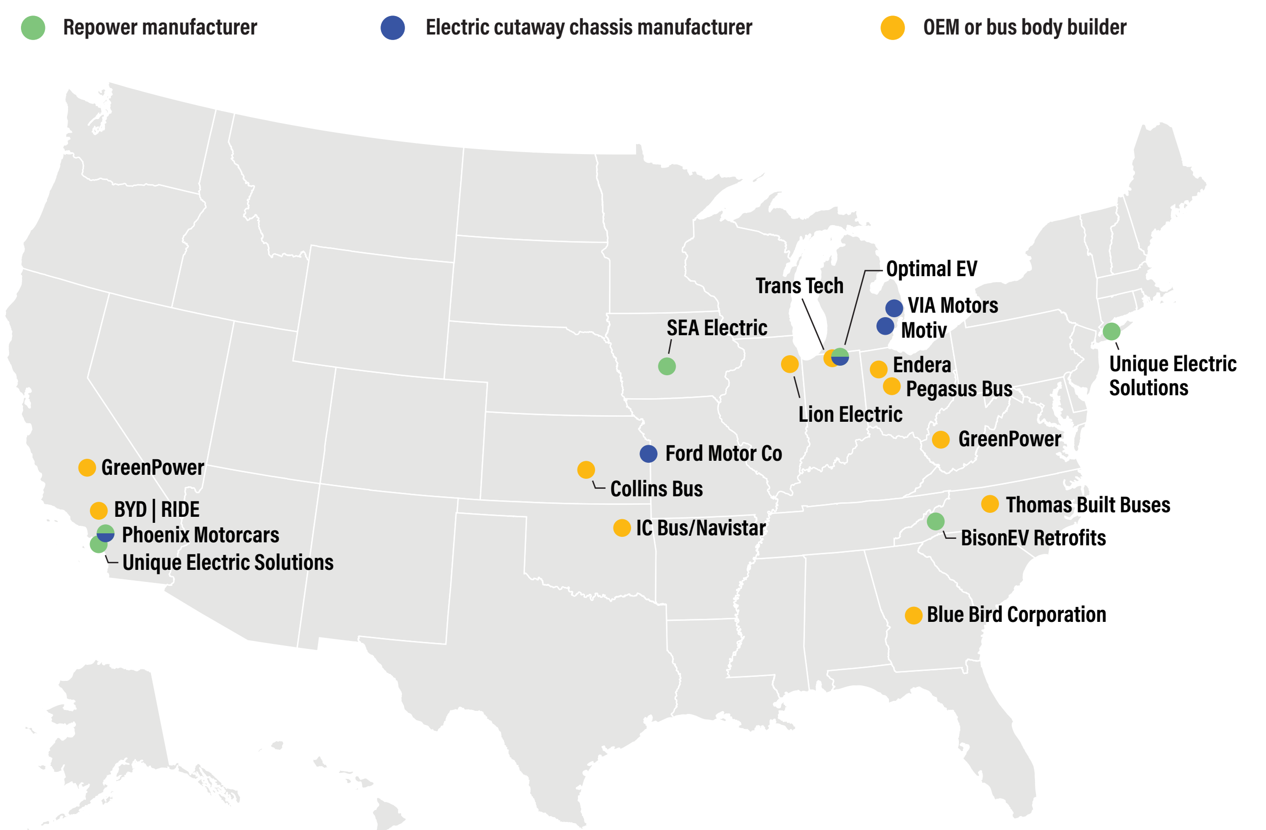
Looking ahead, BYD | RIDE is constructing an ESB facility adjacent to the company's existing electric transit bus manufacturing plant in Lancaster, California, that will build 4,000 ESBs per year (CEC 2022). Industry-wide, manufacturers are anticipated to more than double their existing capacities for Types C and D ESBs by the end of 2024, with longer-term expansion growing fivefold (Lee and Chard 2023). Blue Bird, with nearly $800 million in cost-share funding through the Domestic Manufacturing Auto Conversion Grants program, has plans to convert its prior internal combustion engine vehicle manufacturing location to a new 600,000-square-foot facility to produce electric school buses, and provide education and workforce training (DOE 2024).

In addition to new buses, ESB repowers—fossil-fueled buses converted to electric—show promise to bolster supplies; see subsection "Repowered electric school buses (Types A, C, and D)" for more on repowers. SEA Electric and Unique Electric Solutions continue to deliver buses to fleets. A handful of other companies, including BisonEV Retrofits, Optimal EV, and Phoenix Motorcars, have recently announced repower programs for school buses (Ly and Werthmann 2023).

Since the start of 2024, the ESB manufacturing industry has also experienced some noticeable consolidation. Most notably, Forest River acquired two leading producers of Type A school bus bodies: Collins Bus Corporation and Trans Tech (Ekbatani 2024; Gray 2024). On the power train side of the equation, Lightning eMotors, a leading supplier of electric cutaway chassis for the Type A ESB market, was acquired in February 2024 and has since ceased production (GILLIG 2024). For batteries, Proterra, a leading US-based supplier of battery packs to original equipment manufacturers (OEMs), was acquired by Volvo (Volvo 2024). Under Volvo, Proterra continues to produce a steady supply of batteries for the ESB industry.

As ESBs continue to gain market share, it will be crucial to advance sustainability and social equity conditions across their supply chain (Box 1). 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 responsible 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). Manufacturing workers in the school bus industry have made progress and secured benefits through union contracts. Most notably, the United Auto Workers negotiated a new contract for employees at Thomas Built Buses, and the United Steelworkers ratified a collective bargaining agreement with Blue Bird (Reuters 2024; APNews 2024).

Figure 8. **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.

Box 1. Integrating sustainability and social equity into procurement

Manufacturers' commitments to environmental justice and social welfare are key factors in ensuring an equitable transition to ESBs that not only reduces harm across the supply chain but also maximizes community benefits. Public entities—such as school districts, transit agencies, and cities—are increasingly leveraging their considerable buying power to achieve environmental and social benefits when planning transportation projects. Table 1 gathers high-level data around different OEMs' environmental and social practices to help educate districts on issues to consider when purchasing buses in line with their values. This section outlines potential strategies and tools public entities can use to evaluate manufacturers' practices and promote more sustainable and equitable actions.

School districts can expand the impact of taxpayer dollars by incorporating sustainability and social equity criteria and benefits into their procurement processes, requests for proposals (RFPs), and contracts.

Portland Public Schools in Oregon issued an RFP for ESBs in 2020.[a] The district used two methods to integrate equity into the RFP:

- 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.
- 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 Transportation Authority (LA Metro) has used the US Employment Plan policy tool to build good jobs and equity into the procurement process. In 2011, LA Metro 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 US Employment Plan to all agency procurements of more than $50 million and create enforcement mechanisms (e.g., monetary penalties) to hold winning vendors to those commitments.[b]

1. Some public entities also choose to contract with companies that demonstrate a commitment to community benefits through company policies or legally enforceable agreements. For example, bus manufacturers may have workforce policies that create good jobs or targeted hiring,[c] environmental policies that mitigate environmental and social impacts such as requiring responsible material sourcing and human rights/labor practices, or community development policies that guide meaningful engagement or invest in local communities' infrastructure (Table 1).
2. Some manufacturers may also have project labor agreements, good neighbor agreements, or community benefits agreements (CBAs) with local communities. These 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. They can indicate to a consumer that a manufacturer is prioritizing community benefits. 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, legally enforceable agreements such as CBAs often include provisions that ensure enforceability, seek diverse community representation, and prioritize environmental sustainability and justice practices.[d]
3. For school districts wondering where to start, these types of considerations, along with more specific equity criteria, can be found in World Resources Institute's (WRI's) template RFP (see ESBI 2023d).[e]

Notes and sources:

a. PPS 2020.

b. JMA 2022.

c. JMA 2013; Saha et al. 2023.

d. For more information, see JMA (2013) or Saha et al. (2023).

e. Section 4 of the template RFP covers race and gender equity in public purchasing and contracting.

Table 1 shows ways OEMs impact people and the planet, but it is not an exhaustive list. WRI developed the four characteristics in the first section of the table 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 greenhouse gas (GHG) inventories. It is important to note that all of these numbers are self-reported, and there are several ways to analyze them.

Table 1. **Sample environmental and social practices by original equipment manufacturer**

	BLUE BIRD CORPORATION	BYD | RIDE	DAIMLER TRUCK (THOMAS BUILT BUSES)	GREENPOWER MOTOR COMPANY	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 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, but efforts are underway[d]	Yes, in Quebec (Lithion Recycling partnership)[e]	Yes (in partnership with manufacturer)	No
Unionized workforce?[f]	Yes (USW)	Yes (SMART)	Yes (UAW)	No	No	Yes (USW)	No	Yes (UAW)
Community benefits agreement?[f]	No	Yes	No	No	No	No	No	No
GHG emissions inventory								
GHG emissions reported?	No	Yes (Scope 1 and 2)[g]	Yes (Scope 1 and 2)[a]	No	Yes (Scope 1 and 2); materiality assessment for Scope 3 underway as of 2022[d]	No	No	Yes (Scope 1 and 2); calculating Scope 3 as of 2022[h]
Type of reporting	Not disclosed	Company aggregate	Per bus	Not disclosed	Company aggregate	Not disclosed	Not disclosed	Company aggregate
Scope 1 (2021)	Not disclosed	315,610 tCO_2e	1,858 kg CO_2	Not disclosed	634 tCO_2e	Not disclosed	Not disclosed	64,816 tCO_2e
Scope 2 (2021)	Not disclosed	4,903,502 tCO_2e	1,037 kg CO_2	Not disclosed	79 tCO_2e	Not disclosed	Not disclosed	106,286 tCO_2e
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)[i]	740,131 sold (transit and school buses, trucks, and cars; all electric)[g]	455,445 sold (school and transit buses and trucks; multiple fuel types)	96 units (vans, cargo, school and transit buses, and motorcoaches; all electric)	196 units (school buses and trucks; all electric)[d]	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)[h]
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)	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 a community benefits agreement with BYD|RIDE can be found at https://jobstomoveamerica.org/resource/community-benefits-agreements/ (see "Our CBA with Electric Bus Builder BYD"). 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 on the Environmental Protection Agency's website: 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 = kilogram. OEM = original equipment manufacturer. SMART = International Association of Sheet Metal, Air, Rail, and Transportation Workers. TBD = to be determined. tCO_2e = 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|RIDE, GreenPower Motor Company, Lion Electric Company, Micro Bird, Motiv Power Systems, IC Bus/Navistar, and Thomas Built Buses. Not listed are manufacturers that are included in ***The Electric School Bus U.S. Buyer's Guide*** (Wang and Werthmann 2024) 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. Lion Electric 2022.

e. GBB 2021.

f. Elder 2023.

g. BYD 2022.

h. Navistar 2022.

i. Blue Bird 2022.

2. SUMMARY OF AVAILABLE TECHNOLOGY: VEHICLES, CHARGING INFRASTRUCTURE, AND CHARGE MANAGEMENT SOFTWARE

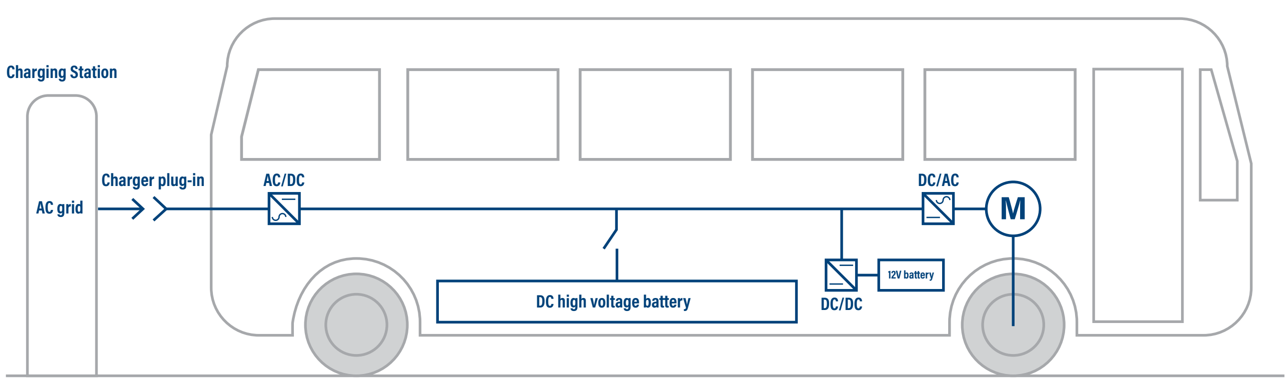
In preparing for ESB adoption, project developers need to understand considerations for both the buses and the charging infrastructure to power them. This section outlines components of the ESB and its charging infrastructure (Appendix A provides additional terms and units) and offers considerations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

2.1 Electric school buses

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 9 and 11). Although many elements of the body and cabin are similar, there are two key features of the electric model that differ from 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 2023c). 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

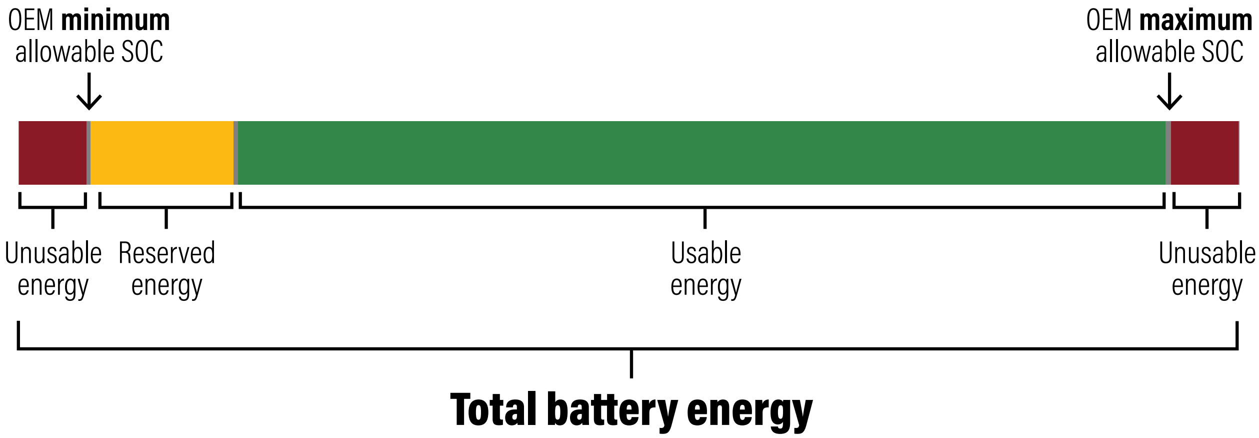
Figure 9. **Electric school bus diagram**



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

Source: Adapted from Ainsalu et al. 2018.

Figure 10. **Total battery energy: Nameplate versus usable range**



Notes: OEM = original equipment manufacturer. SOC = state of charge.
Source: Adapted from Bigelow 2017.

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 (in kilowatt-hours; kWh) or nameplate capacity of a bus, but only 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 10). Reserving some battery power also ensures that the vehicle will sustain critical functionality and not suddenly shut off. Various factors, such as the local weather, the route terrain, and the types of chargers buses use, can impact the usable range. 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.

With the inclusion of an electric power train, ESBs do not contain internal combustion engine components and systems (components highlighted in red in Figure 11). Electric buses utilize motors composed of only around 20 parts, compared with 2,000 in a diesel engine; require fewer fluid changes, and don't use engine oil; and commonly use a direct drive system, eliminating the need for a transmission. It is also important to consider ground clearance of vehicles per state requirements.

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 service (components highlighted in blue in Figure 11). Additionally, like fossil fuel powered 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, technicians will need specialized training to perform maintenance on high voltage systems.

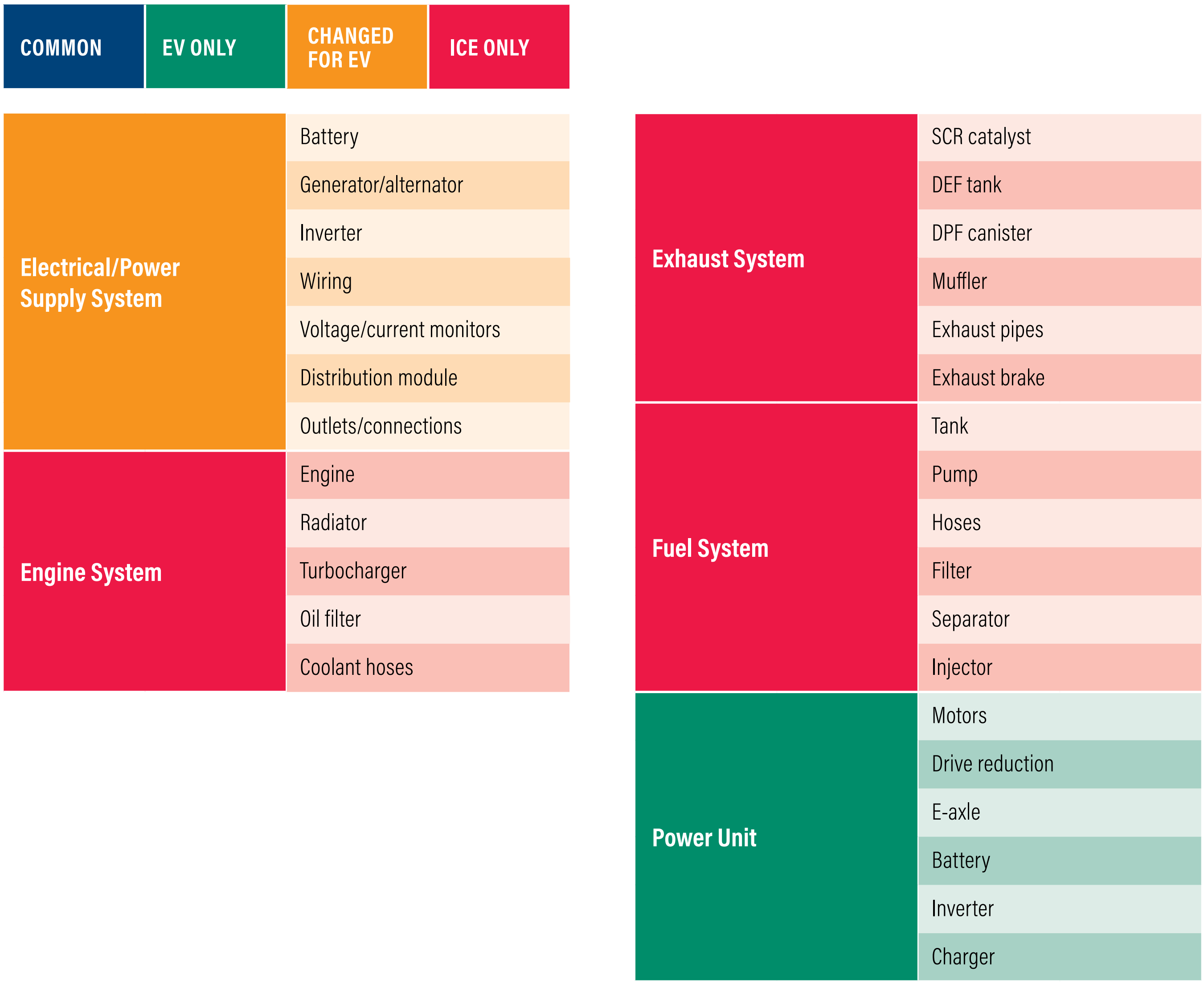
If qualified technicians are not readily available where the bus operates, any issues that arise with the high-voltage system should be resolved by the closest dealer or manufacturer that has trained staff. Proximity of these services can impact response times and bus uptime. To address this issue, it is imperative that manufacturers and dealers work closely with transportation managers, technicians, and their teams to provide training on 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. Establishing a service-level agreement between a customer and vendor that covers product operations and maintenance is a recommended best practice to ensure reliable operations. For more information, see ESBI (2023b).

Figure 11. **Comparison of electric and internal combustion engine vehicle components**

COMMON | EV ONLY | CHANGED FOR EV | ICE ONLY

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
Gauge & 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 11. **Comparison of electric and internal combustion engine vehicle components (Cont'd)**



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

Source: Nair et al. 2022.

2.2 Available electric bus models

As of June 2024, there were 26 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 (Lazer and Freehafer 2024).

See the *Electric School Bus U.S. Buyer's Guide* for more information about Types A, C, and D (Wang and Werthmann 2024).

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).

2.3 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). And with unprecedented state and federal funding for ESBs, their final upfront cost is often at parity or lower than diesel equivalents. When considering models, school districts should keep in mind the difference between a newly manufactured ESB and a repowered bus.

See the *Electric School Bus Price Tracker—State-Level Sources* for more information on electric school bus prices (Levinson, Burgoyne-Allen, and Hosansky 2024)

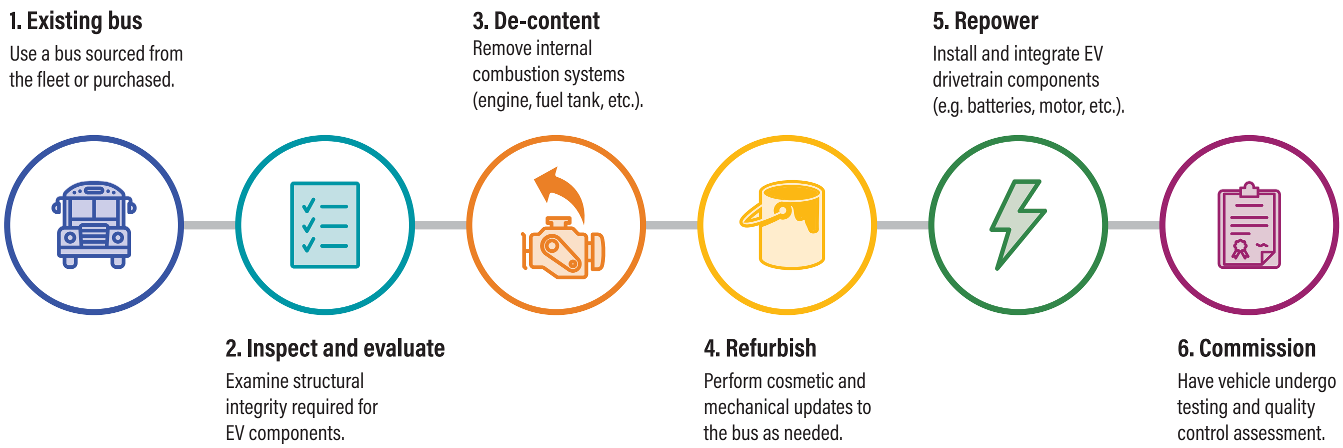
2.4 Repowered electric school buses (Types A, C, and D)

An electric repower—sometimes referred to as an electric conversion or retrofit—involves removing a vehicle's internal combustion engine, which 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 use 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 12), 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 regulations. Repower companies often prefer to focus on buses from a specific

Figure 12. **Vehicle repower process**



Note: EV = electric vehicle.
Source: Ly and Werthmann 2023, adapted from ABC Companies.

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 June 2024, 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.

2.5 Batteries

Batteries that power electric school buses are getting more advanced, more reliable, and safer with each generation. ESB buyers should pay more attention to bus batteries as they can make up to 15–40 percent of the total bus price. The chemistry of a battery has a direct impact on vehicle range, battery price, safety, and circularity.

Chemistry

There are two kinds of cathode chemistries that dominate school bus batteries: nickel-manganese-cobalt (NMC) and lithium-iron-phosphate (LFP). Due to concentrated availability, high environmental impacts, and human rights issues associated with mining cobalt and nickel, there is a concerted effort to shift away from NMC batteries. High dependency on limited sources of battery materials can create significant risk to the battery supply chain. There is growing regulatory pressure on vehicle manufacturers to transparently trace their battery minerals up the supply chain through a digital identifier, like a Battery Passport.[2] LFP batteries eliminate the negative impacts mentioned above due to the abundance of iron and phosphorus. LFP also offers additional benefits like higher stability, domestic sourcing potentially at lower cost, and even extended use of the battery beyond the bus. Newer chemistries such as lithium-manganese-iron-phosphate, sodium-ion, solid-state, and zinc-ion batteries are not used in ESBs today.

Range

Current electric school bus battery capacity for all Type A, C, and D buses offers over 100 miles or more of range. Cold weather does reduce an ESB's range by slowing reactions within the battery and because more energy is needed to maintain the cabin temperature and the temperature of the batteries themselves. The battery management system can help control the temperature of the battery during storage and charging.

Charging habits also affect range. There is an assumption that prolonged use of DC fast charging can accelerate battery degradation, which in turn could reduce battery life and vehicle range. However, recent data show this impact to be minimal versus Level 2 (L2) charging for new vehicles, with a caveat that accelerated range loss may still happen later (Witt 2024). Therefore, a best practice here is to use L2 charging (capped at 19.2 kW) whenever possible and reserve fast charging for when limited downtime is available. While vehicle manufacturers have built in additional battery capacity for safe operations (see Figure 10), as a precautionary measure, it is beneficial to the health of the battery to maintain a battery state of charge above 20 percent. This can be an important consideration during route planning.

Prices

With nearly $150 billion invested to set up battery supply chains in the United States and elsewhere, we are seeing a steady decline in NMC and LFP battery prices (IEA 2024a, 2024b). However, this benefit has not yet been passed on to the school bus buyer. Because diesel school bus prices are increasing too, potentially higher prices of bus components common to electric buses could be one reason why this benefit has been negated in the near term.

Safety

All school buses, including electric, are designed to be safer than any other passenger vehicle type and are the most regulated vehicles on the road, required to meet more Federal Motor Vehicle Safety Standards than any other vehicle. When it comes to the batteries inside ESBs, there are a few key things to know:

- ESB batteries are designed and built to be safe
- ESB batteries are extensively tested
- ESB batteries have rigorous safety mechanisms built in
- ESB safety training for technicians and first responders is always a good idea

Due to extensive safety standards, school bus fires are very rare. Bus fires, including school buses of any fuel type, accounted for only 1 percent of all vehicle fires in 2021, none of which involved ESBs. And there were zero bus-fire-related deaths reported to the National Fire Incident Reporting System as of 2023. While extremely rare, school bus fires are possible with any fuel type. But the batteries in ESBs are less likely to catch fire than the internal combustion engines used in diesel-burning and propane-burning school buses (Jones 2023).

Despite the safety measures, there remains a small risk of fire and electrical shock while working with high-voltage components. Electric vehicles are new to many first responders and technicians, and precautions and knowledge on risks including arcing, ejected metal, and conductive soot must be adequately covered in training. Good case practices include adequate technician training and making sure local fire departments have emergency response guides for the specific bus model.

Circularity

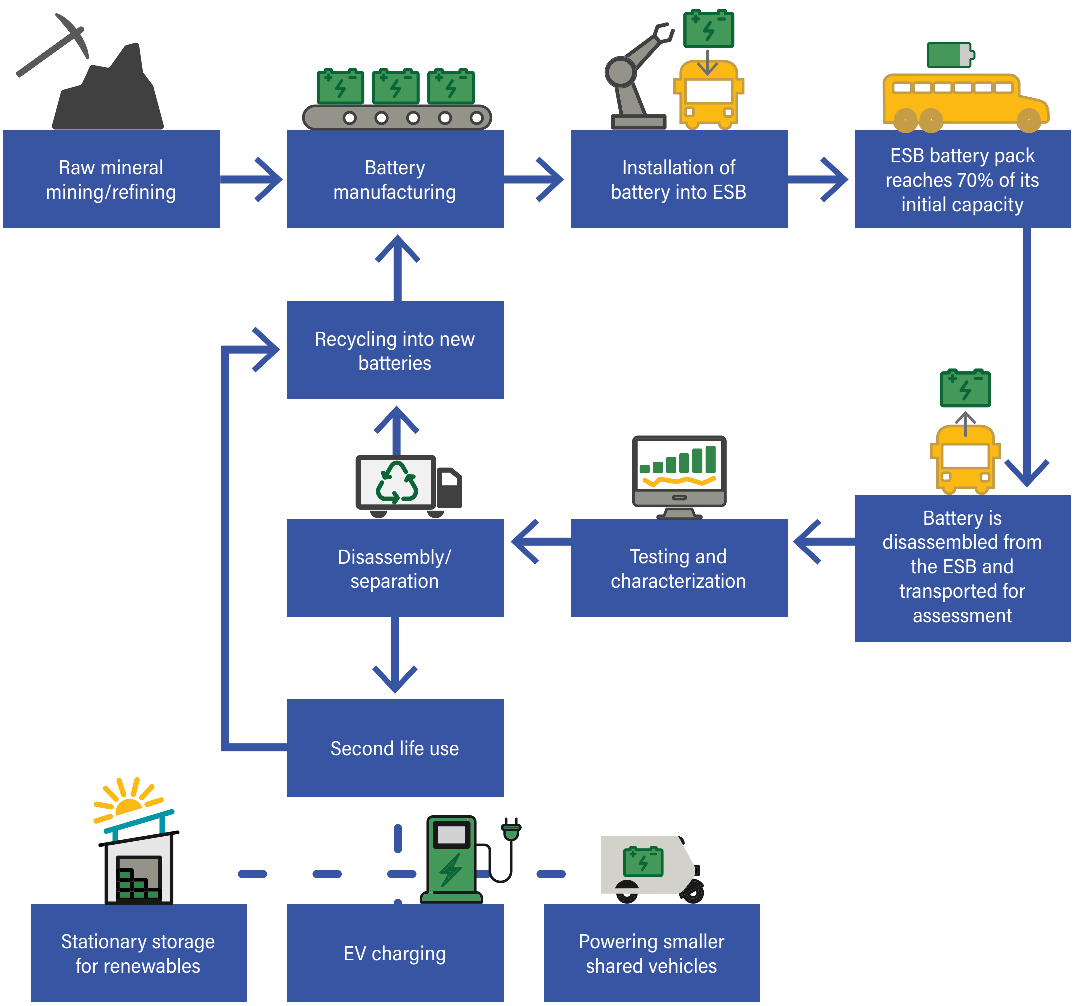
Even with all the measures taken to limit battery degradation, eventually it will reach a point where it is no longer fit to be used for transportation. Vehicle manufacturers generally offer an 8-to-10-year warranty, extendable to 12 years. Once an ESB battery's capacity or state of health drops to 70–80 percent, the battery is no longer deemed fit for the vehicle and must be replaced. These used batteries can be reused and then recycled into new batteries to avoid ending up in a landfill. Landfills can leach toxic chemicals that contaminate soil and water (Siddiqua et al. 2022). Landfills can also leak gases, causing respiratory issues in the surrounding community. Since landfills are disproportionately sited in communities of color, those communities bear an inequitable portion of the negative impacts (Mohai and Saha 2015).

To minimize costs and maximize resource utility, second-life use should be considered before recycling. The large pack size of ESB batteries and favorable attributes like high safety, low thermal risk, and predictable charging patterns make them ideal for second-life use for an estimated 7–10 additional years in a low-demand application (NREL 2015). A popular second-life application for bus batteries is stationary storage (en:former 2023).

Recycling batteries breaks them down into component materials (e.g., plastics, metals, minerals) and processes them to manufacture new batteries. Battery recycling can use 80 percent less energy, generate 70 percent less carbon dioxide emissions, and require 80 percent less water compared with the impacts from battery manufacturing using mined minerals (Machala et al. 2023). Critically, using recycled materials avoids the significant human rights and health concerns associated with mineral mining (Murray 2022; Schwartz et al. 2021). Battery recycling economics currently hinge on the quantity of valuable nickel and cobalt in a battery. This is why NMC batteries can be economically recycled today whereas recycling LFP batteries is not yet commercially viable. Figure 13 illustrates a circular value chain for electric school bus batteries.

It is beneficial for school districts to use their procurement opportunities to seek an end-of-life plan for their batteries from the vehicle manufacturers. Sample language can be found in WRI's RFP template (see ESBI 2023d).

Figure 13. **Circular value chain for electric school bus batteries**



Note: ESB = electric school bus. EV = electric vehicle.

Source: ESBI 2023a.

2.6 Charging infrastructure

As school districts consider procuring ESBs, they must also think about the corresponding infrastructure needed to charge these buses (see Box 2). Infrastructure can be broken into hardware and software components. For charging hardware, there are three levels available today: Level 1 alternating current (AC), Level 2 AC, and Level 3 direct current with various power ranges from low-powered DC (24–30 kW) to fast-powered DC–DCFC (direct current fast charger) (50+ kW).

Bus depots can and often do have a mix of L2 AC chargers and Level 3 DC chargers. Chargers can be installed in phases beginning with L2 chargers using existing power at the site along with energy efficiency improvements while planning for a larger installation that may include L3 DC fast charging. There is a trade-off between charger costs and charging speeds. As the charger power increases and allows for faster charging, so do the costs. L2 chargers typically can be purchased for under $5,000 per unit whereas L3 DCFCs can be five times that or more (Levinson et al. 2023). If charging is done overnight, L2 chargers may be sufficient, with L3 DCFC used when batteries are running low and there may be an immediate need to recharge quickly. Lower-powered Level 3 DC chargers are available in the market and are three to four times the cost of an L2 charger (Table 2).

Early and frequent engagement with the school district's electric utility is crucial, and it is incumbent on utilities to provide resources to ameliorate the transition to electric fleets as part of their obligation to serve customers electricity. This engagement is necessary for evaluating existing power supply and identifying required system upgrades. Charging infrastructure and installation can take approximately 12 to 24 months depending on the scope of upgrades needed.

Table 2. **Charging levels and costs**

ELECTRIC VEHICLE SUPPLY EQUIPMENT CHARGING LEVELS AND COSTS						
Level/type of current	**Level 1 AC**	**Level 2 AC**	**Level 3 DC (DCFC for 50+)**			
Power (kW)[a]	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	19.2	24–30	50	70	150
Recharge time (hours)[b]		5.5–13	3.5–10.25	1.5–4.25	1.5–3.5	N/A
EVSE cost (US$/charger)		$4,700–5,300[c]	$14,300[d]	$28,259[e]–62,130[c]	$54,500[e]	$96,700[g]
Maintenance cost ($/charger/year; average estimate)[g]		$600	$1,600	$2,500	$2,500	$3,100
Software cost ($/station/year; average estimate)[g,h]		$600	$600	$600	$600	$600
Customer-side construction and equipment installation costs ($/station; average estimate)[i]		$7,900[g]	$13,422[d]	$32,900[g]	$34,100[g]	$70,100[g]

Notes: Costs are subject to change and are averages. We encourage each operator to request customized quotes. For 2024, we updated the electric vehicle supply equipment (EVSE) cost values to 2024 prices to reflect inflation. We did this using the methodology and data from the Bureau of Labor Statistics' Consumer Price Index (CPI) Inflation Calculator. We used the CPI Index for All Urban Consumers from February 2012 to February 2024 to find inflationary rates and apply them to the original prices.

AC = alternating current. DC = direct current. DCFC = direct current fast charger. ESB = electric school bus. 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 eight hours. Examples are based on the information in the accompanying *Electric School Bus U.S. Buyer's Guide* (Wang and Werthmann 2024).

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.

Box 2. **Charging infrastructure**

Charging infrastructure will be a new frontier for almost all districts.[a] When evaluating charger assortment,[b] 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, ideal bus port location (e.g., nose or driver's side rear), and the most economical spot for a new service drop from the utility.
2. **Will electric utility upgrades be needed?** Confirm available power (open capacity) from your building infrastructure as well as available capacity from 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 and your school district's electrical engineer as soon as possible. Engage them on a regular basis throughout the process.
3. **What utility demand charges and tariffs will you pay?** Utility demand charges can increase significantly with usage and electric vehicle charging can result in raised demand charges if charging infrastructure is not properly planned. Electric utilities also use time-variant 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). Some utilities may also offer specific rates for electric vehicles (EVs). 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. **Consider if you will be using an existing utility meter or installing a new service.** Connecting behind an existing meter can foster the discharge of electricity to electrical panels installed behind the same meter (e.g., vehicle-to-building, vehicle-to-load). Strategic service meter usage can also help keep utility demand charges low.
5. **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]
6. **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.
7. **What about pairing ESBs with solar?** Electric bus adoption can also be paired with new or existing on-site solar.[f] 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.

Notes and sources:

a. Hawkins 2023.

b. More information on charger offerings can be found in the "Technology Catalog" on EnergIIZE's website at https://www.energiize.org/infrastructure?section=infrastructure.more-details.technology or on the Electric Power Research Institute's website regarding the Electric Vehicle Supply Equipment (EVSE) Working Group at 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 on the Electric School Bus Initiative's website at https://electricschoolbusinitiative.org/school-bus-electric-service-eaas-directory.

e. ESBI 2022.

f. Ellis 2020; ENGIE Impact n.d.; Farley 2021; Soneji et al. 2020.

2.7 Managed charging and operations software

Fleet management software plays an important role in planning electric school bus operations and charging infrastructure. There is a suite of software available for school bus fleet operations, not restricted to electric school buses. It can be quite cumbersome for a fleet manager to deal with a wide variety of software solutions that may or may not share data and insights with each other. To make things easier, software such as GPS telematics, route planning, fuel management, and operational considerations like maintenance and driver behavior should all be integrated for streamlined decision-making.

The right combination of fleet management software solutions will differ from fleet to fleet. There are several considerations before purchasing or subscribing to any software, such as cost, reliability, compatibility with the vehicle, and customer service offered. To ensure the proper combination of features and pricing, it is important to request quotes and trials from software providers to test integrations and suitability.

Charge management software (CMS) is just one example of available software that can be integrated into electric school bus operations and helps save time and money when charging. Managed charging is the process in which the time and power level of charging are controlled (often via software) to optimize charging schedules, costs, and bus performance while taking into consideration the electric grid. Using CMS to manage charging can provide reduced electricity bills for the fleet and lower overall operational costs. It allows for scheduling charging times for when electricity prices are lowest or for turning off charging to preserve battery life and the power level without making manual adjustments, even if the bus is plugged in continuously. For this reason, managed or smart charging can help realize and cost 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. These benefits can be seen for both small and large fleets and is a scalable solution across large operations.

Moreover, managed charging can reduce the infrastructure upgrades needed, and therefore the capital cost of installing more charging infrastructure, and speed up timelines for infrastructure deployment. For example, site capacity upgrades are often necessary to meet the charging demand of new electric vehicles. While capacity upgrades can be costly and time-consuming, using managed charging can utilize the site's existing capacity to smartly charge the fleet's EVs and reduce needed upgrades.

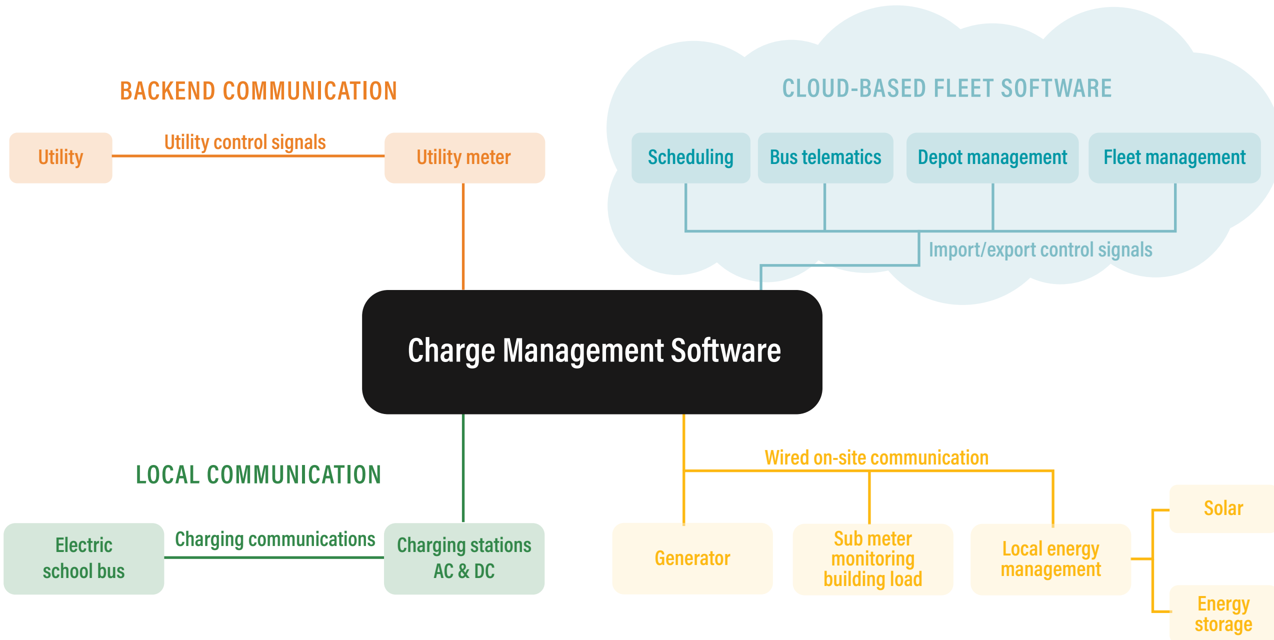
There are at least a dozen CMS providers whose software is proven to be compatible with electric school bus charging infrastructure. There are a few charging infrastructure providers that may even offer their own CMS.

See the Electric School Bus Initiative's *Charge Management Software Catalog* for more information about CMS options for school bus fleets, including information on compatibility, cost, data accessibility, and renewables integration (ESBI 2023e).

2.8 Hardware and software compatibility: Identifying misconnection points

To successfully operate, three components must "talk" to one another, or "complete a handshake": the electric school bus, the charger (firmware), and the network (software) (see Figure 14 and Glossary). Charge management software coordinates energy use, import, and production at a site. It can receive signals from the utility or cloud-based applications and adjust power flow throughout the local system. This gives managers control over when and how electricity is used (e.g., charging buses off-peak, keeping demand below a given threshold, or using local solar generation to power vehicles).

Figure 14. **Communication among bus, charger, and network**

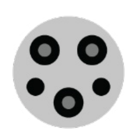
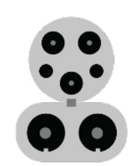


Note: AC = alternating current. DC = direct current.
Source: Hill-Cristol 2024.

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). While the light-duty vehicle market is moving toward the J3400/NACS (North American Charging Standard) for charging, this change has not proliferated into the medium- and heavy-duty vehicle market. ESBs remain largely powered by CCS or J1772 connections.

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 signified 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.[3] 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.

Table 3. **Charging plug types**

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

Source: AFDC n.d..

Each bus has its own power requirements, measured in kilowatts. Common power levels as listed in the *Electric School Bus U.S. Buyer's Guide* (Wang and Werthmann 2024) include 13 and 19.2 kW for Level 2 AC and 24, 50, and 60 kW for Level 3 DC. Some buses may have a minimum or maximum threshold for power acceptance (e.g., a bus that can accept a maximum of 60 kW will not work with a 100 kW charger). For the 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 its 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.

Charger <-> network: 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 be responsible for only 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.[4] 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.[5]
- Include a requirement in the SLA to use a local contractor that 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 be tested before launching, occur during business hours to receive prompt customer service, and take place when student transportation is not needed.

2.9 Vehicle-to-Everything

With the right hardware and software, school districts can take advantage of bidirectional charging, or vehicle-to-everything (V2X), 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 future. In 2024, ComEd (in Illinois) is launching a School Bus to Grid pilot and Ameren, IL, has plans for a School Bus Virtual Power Plant pilot.

Because V2X activities may increase the number or frequency of charge and discharge cycles in a battery, they could accelerate battery degradation. School districts should inquire with their dealers/OEMs about expected impacts from V2X services on their ESB batteries. V2X pilots using ESBs and other vehicle types are underway nationwide and may shed light on the impacts of V2X services on battery aging.

3. CONCLUSION

School bus electrification is rapidly scaling, and 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 40 to 100 miles during King Canyon's, Escondido's, and Gilroy's 2014 deployments deployments to a range of 100 to 300 miles today, depending on bus type and model. These vehicles were once limited to a handful of pilot programs, but by June 2024, the number of school districts procuring electric models and integrating them into their fleets had grown to 1,514 largely due to the Clean School Bus Program, which has transformed the market. At the same time, the number of ESB manufacturers, and their production capacities, has grown substantially, and vehicle features such as range and bidirectional charging have improved considerably.

As of June 2024, manufacturers offered 26 models of ESBs across Types 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 a high upfront bus cost and new infrastructure needs, reliability issues with older bus models, and limited specialized maintenance and workforce training support. However, ESBs provide a number of benefits, such as reduced operations and maintenance costs; lower pollution and emissions; the potential to improve driver, technician, and student health outcomes; and improved resilience. As school districts navigate this growing market, we hope this publication and future updates will serve as valuable resources 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 electric school bus key terms, units, definitions, and parallels to diesel operations, where applicable. Table A-1 defines terms and Table A-2 defines units.

Table A-1. **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 and can therefore charge school buses at faster rates (1.5–4 hours) (see Glossary for more information). 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 A-2. **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	Kilowatt-hours 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.

Table A-2. **Electric school bus key units, definitions, and parallels to diesel operations (Cont'd)**

UNIT	DEFINITION	PARALLEL TO DIESEL (IF APPLICABLE)	REFERENCE OR EXAMPLE
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 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.

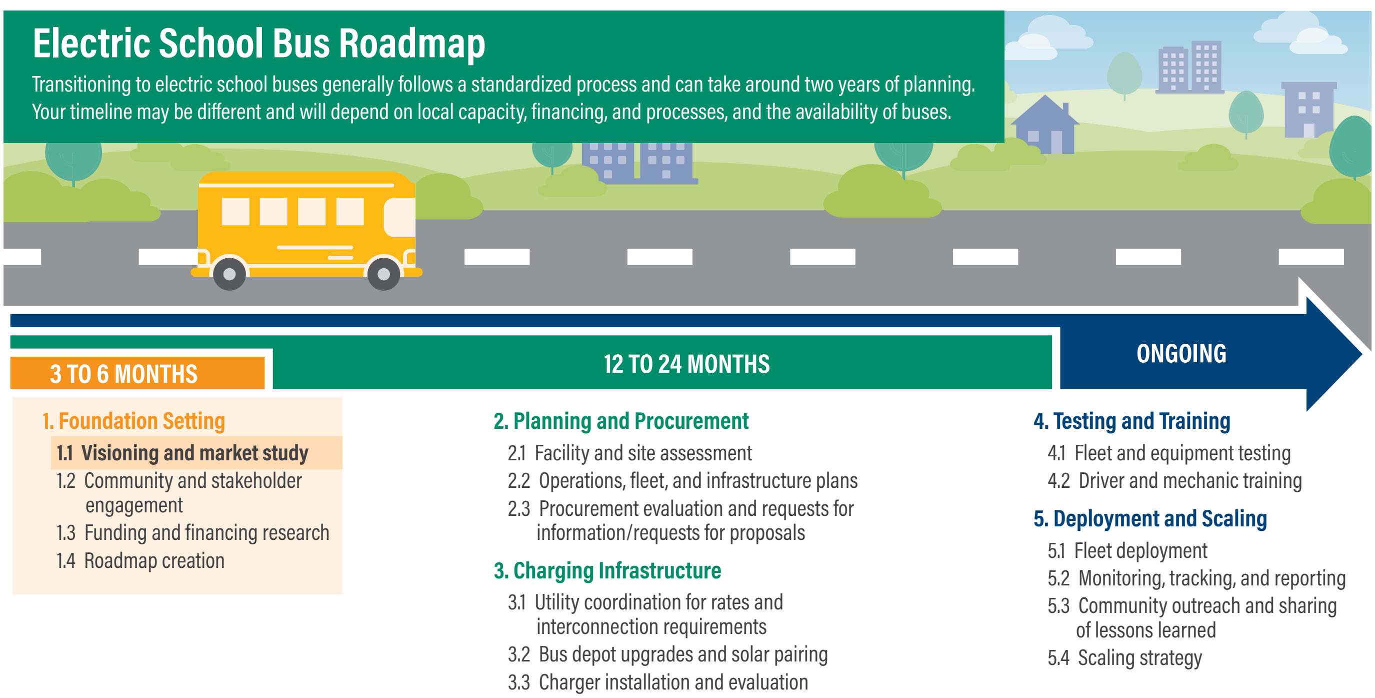
Note: AC = alternating current. DC = direct current. ESB = electric school bus. L2 = Level 2.
Sources: WRI authors; Aamodt et al. 2021; CTE 2020; KCM 2020.

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 (see Figure B-1).
- 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 Financial Solutions Guide:* https://electricschoolbusinitiative.org/electric-school-bus-financial-solutions-guide. Learn about all the ways school districts and fleet operators can use financing to bring clean rides to their students. School districts and fleet operators can use a number of mechanisms, tailoring them to their own risk tolerance and operational requirements.
  - *Electric School Bus Business Models Guide*: https://electricschoolbusinitiative.org/electric-school-bus-business-models-guide. The guide and 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 B-1. **Electric school bus roadmap**



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/sites/default/files/2023-12/ESB%20Power%20Planner%20Guide_Dec2023_0.pdf. This resource 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
  - "How School Districts Can Include Equity When Choosing Where to Deploy Electric School Buses First": https://electricschoolbusinitiative.org/equitable-deployment. This article covers ways school districts can bring the benefits of zero-tailpipe-emissions school buses to underserved communities that need them most through school bus route planning and deployment.
  - "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.
  - "For Students with Disabilities, Electric School Buses Could Transform the School Commute": https://electricschoolbusinitiative.org/students-disabilities-electric-school-buses-could-transform-school-commute. This piece covers disability rights and disability justice. The electric school bus revolution currently underway in the U.S. offers a chance to right historical wrongs and provide better, safer routes to school for multi-marginalized children across America.

- ESB adoption stories
  - *The 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:

- 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 other related topics.
- *School Transportation News*. 2024. *2024 Buyers Guide*. Redondo Beach, CA: *School Transportation News*. https://stnonline.com/digital-editions/buyers-guide-2024/. This bus

buyer's guide includes, but is not limited to, electric variants, with contact information for manufacturers and dealers.

- US 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 | RIDE: 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
- Lion Electric Company: https://thelionelectric.com/en/products/electric
- Micro Bird: https://www.microbird.com/our-buses/G5-Electric https://www.microbird.com/our-buses/G5-Electric
- Motiv Power Systems: https://www.motivps.com/application/electric-school-bus/
- Optimal-EV: https://www.optimal-ev.com/
- 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 charging: Buses that use Level 2 chargers powered by alternating current (AC) input require an onboard charger built into the bus. This charger converts the AC to direct current (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.

Battery thermal management: Vehicles have a cooling and heating system to maintain a specific battery pack temperature range during operation and charging based on the manufacturer's design. This helps the batteries operate safely and maintain peak performance.

Brakes (air/hydraulic): The vehicle braking system uses either air or brake fluid (hydraulic) to compress the brakes. This impacts the required skills needed to maintain the vehicles. Air brakes require the use of an air compressor, which draws from the battery and may impact advertised range. Vehicles with air brakes require a specialized license to operate.

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.

Firmware: A type of software that is embedded in hardware devices to control their functionality.

Heat type (electric/diesel): The heating of the vehicle can be either electric powered or fuel (diesel) powered for driver and/or cabin heat. The manufacturer should be consulted on whether heat pumps should be used to achieve the desired results.

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 using 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 rates: Through time-of-use (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.

Transmission (direct drive/2-speed): Transmission refers to the transmission of power from the motor to the wheels. Options include direct drive (short drive shaft) and multi-speed transmission.

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 (in kilowatt-hours) or nameplate capacity of a bus, but only 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. Various factors can affect the usable range.

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. 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 was required to 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.

2. WRI's Electric School Bus Initiative is supporting the Global Battery Alliance in the development of standardized metrics for disclosure of environmental and social impacts of battery supply chains.

3. 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 charge with only a DCFC unit.

4. More information on the OCPP standard can be found on the Open Charge Alliance's website: https://www.openchargealliance.org/.

5. For more information on SLAs, see ESBI (2023b).

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