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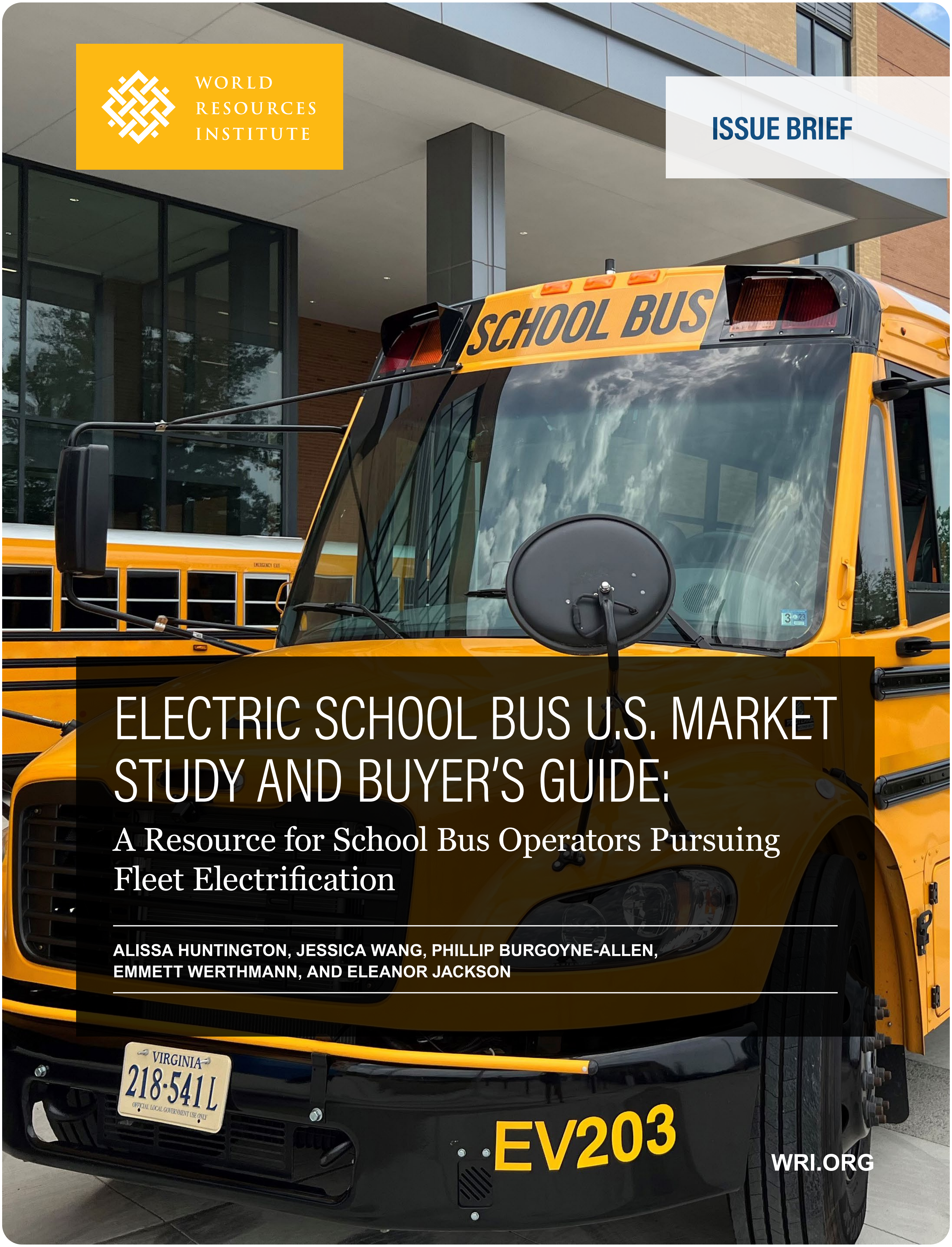

ELECTRIC SCHOOL BUS U.S. MARKET STUDY AND BUYER'S GUIDE:

A Resource for School Bus Operators Pursuing Fleet Electrification

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CONTENTS

Executive Summary 2

1. Status of the Electric School Bus Market 3

2. Electric School Bus Basics 10

3. Summary of Available Electric Bus Models 17

4. Conclusion 26

Appendix A. Key Terms and Definitions: Comparing Diesel and Electric School Buses 27

Appendix B. Additional Resources 29

Glossary 31

Endnotes 32

References 33

Acknowledgments 38

About the Authors 38

About WRI Electric School Bus Initiative 38

About WRI 39

Photo Credits 39

EXECUTIVE SUMMARY

Highlights

- School districts across the United States have started transitioning to electric school buses (ESBs). As of March 2022, 415 districts (or private fleet operators) had committed[1] to procuring 12,275 ESBs across 38 states and a range of operating conditions. States and municipalities are setting electrification goals while manufacturers scale production.
- Compared with the typical school bus that runs on diesel fuel, ESBs have the potential to lower operations and maintenance costs for fleets and have zero tailpipe emissions. Their large batteries can store and deliver energy using "vehicle-to-everything" technology, to power buildings and other devices, which can support greater resiliency, including through the integration of renewable energy. ESBs also have the potential to generate revenue by discharging energy from their batteries back onto the grid, lowering utility costs and emissions. Though this is a nascent market, technological advancements should make this widely available in the near future.
- As of January 2022, 22 ESB models were available from 12 manufacturers for Type A, C, and D buses: 14 newly manufactured vehicle models and 8 repowered vehicle models.[2] There is the largest selection of Type A models. Type C models are the most commercially ready.
- Each generation of buses is more advanced than the previous: Many manufacturers are on their second or third iteration, some even further along. Electric school buses have ranges of up to 210 miles for Type C buses; all Type A, C and D buses listed offer over 100 miles of range, enough to cover most bus routes.

Context

Momentum around electric school buses (ESBs) is growing in the United States as school districts across the country transition to this cleaner and healthier technology, bolstered by an infusion of new funding from the federal government. The ESB transition will require a coordinated effort among numerous entities, including school district leadership and staff, school bus manufacturers and contractors, utilities, policymakers, regulators, local advocacy organizations, and community members.

This publication is intended to serve as a resource primarily for school districts, transportation directors, and other school bus operators exploring school bus electrification to provide a better understanding of the state of the ESB market and available offerings. It aims to present the growing interest and investment in this sector along with key aspects of the current technology. In Section 1, we explore the growing demand for these buses and how manufacturers are positioning themselves to meet that demand through a scan of the market. Next, in Section 2, we explain key components of an ESB and discuss the charging and related infrastructure that is needed to support these buses. The core element of the publication, Section 3, presents a catalog of the 22 ESB models available as of early 2022 with detailed vehicle specifications allowing readers to compare various models and weigh important considerations. We conclude by summarizing the status of school bus electrification to date.

Approach and Methodology

The content of this publication has been gathered from a variety of sources, with information on models available in the United States from publicly available vehicle specifications sheets confirmed through discussions with bus manufacturers when possible.

We explored school district experiences with ESBs representing a variety of use cases in the United States—rural, suburban, and urban; warm and cold weather, including extreme temperatures; and early adopters further along in the process, as well as those in earlier stages of procurement. We compiled recent research and reporting on school district commitments and experiences and supplemented public information with conversations with school districts and other partners. We plan to update this publication annually as new vehicles come to market and existing models are altered.

This resource is one of many from World Resources Institute's Electric School Bus Initiative and is intended to be updated to expand upon topics like funding and financing, alternative service models, and utility engagement.[3]

1. STATUS OF THE ELECTRIC SCHOOL BUS MARKET

There are nearly half a million school buses in the United States that transport more than 20 million children to and from school (FHA 2019; SBF 2021a). More than 90 percent of school buses on the road today are diesel powered, but interest in ESBs has grown in recent years (APP 2022). There are 12,275 ESB commitments, representing around 2.5 percent of the current fleet size (Lazer and Freehafer 2022). The ESB market was established in 2014, when two California school districts, Kings Canyon School District and Escondido Union High School District, became the first school districts to operate ESBs. Kings Canyon's four early Trans Tech models carried 25 students each and were able to travel between 80 and 100 miles on a charge while Escondido's TransPower bus had a range of approximately 60 miles (MPS 2014; Edelstein 2014; Adams 2014).

Since 2014, hundreds of other school districts across the United States have begun to embrace fleet electrification, manufacturers have positioned themselves to meet growing demand, and school bus electrification has gained traction (Figure 1).

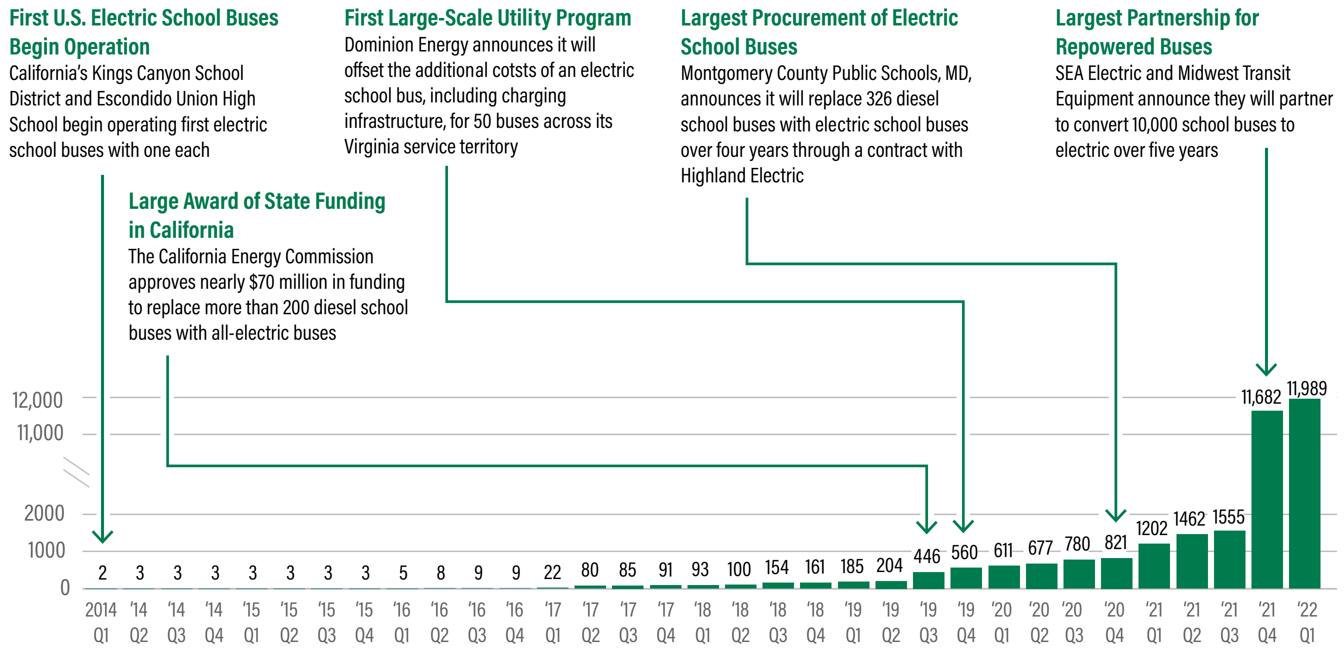
1.1 Rising Demand

A combination of factors is priming the market for ESB adoption. Compared with the typical school bus that runs on diesel fuel, ESBs have the potential to lower operations and maintenance costs for fleets and have zero tailpipe emissions (Figure 2). If equipped with bidirectional charging technology, ESBs can provide additional benefits, such as potentially acting as mobile generators in an emergency.

Influenced by these benefits, communities and policymakers are advocating for ESBs, which has resulted in commitments to electrification. Implementation of these commitments is aided by grants and incentives to bring down the upfront price of the buses (Box 6).

FIGURE 1

CUMULATIVE NUMBER OF ELECTRIC SCHOOL BUSES COMMITTED BY QUARTER IN THE UNITED STATES (2014–2022)



First U.S. Electric School Buses Begin Operation
California's Kings Canyon School District and Escondido Union High School begin operating first electric school buses with one each

First Large-Scale Utility Program
Dominion Energy announces it will offset the additional cotsts of an electric school bus, including charging infrastructure, for 50 buses across its Virginia service territory

Largest Procurement of Electric School Buses
Montgomery County Public Schools, MD, announces it will replace 326 diesel school buses with electric school buses over four years through a contract with Highland Electric

Largest Partnership for Repowered Buses
SEA Electric and Midwest Transit Equipment announce they will partner to convert 10,000 school buses to electric over five years

Large Award of State Funding in California
The California Energy Commission approves nearly $70 million in funding to replace more than 200 diesel school buses with all-electric buses

Notes: This graph depicts electric school bus (ESB) commitments at the earliest confirmed phase in the commitment process (awarded, ordered, delivered, or first operating)—286 ESBs were excluded due to unknown dates of their commitment stages. Abbreviation: Q = quarter.

Source: Based on Lazer and Freehafer 2022.

FIGURE 2

SAMPLE OF ELECTRIC SCHOOL BUS BENEFITS AND CONSIDERATIONS

Lower Operations and Maintenance Costs

Research suggests that after the upfront cost, electric school buses could save districts an estimated $4,000–$11,000 per school bus every year on operational expenditures like fueling and maintenance and repair costs (depending on labor costs, local electric utility rates, and the price of petroleum fuels).[a] Today, these savings alone are insufficient to cover the vehicle price differential without additional grant funding or subsidies.[b]

Health Benefits

There is increasing evidence that children are particularly susceptible to the negative health impacts of diesel exhaust, which has been linked to increased risk for asthma and pneumonia (Box 1).[c] There is also evidence that reducing this exposure can improve not just respiratory health but also standardized test scores, especially for elementary-age students.[d] While there has been little research measuring the air quality benefits of electric school buses specifically, these results strongly suggest that adopting these vehicles— which have zero tailpipe emissions— would have positive effects on students' health and academic outcomes, particularly for low-income students and Black students, who are more likely to ride the school bus than their peers.[e]

Climate Benefits

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

Resilience and Grid Potential

Electric school buses have the potential to serve as mobile generators for buildings during outages (vehicle-to-building; V2B), for the grid during high energy demand (vehicle-to-grid; V2G), or for another load (vehicle-to-another-load; V2L).[g] This technology is constantly being improved upon, and manufacturers are working actively to understand the impacts of higher charge and discharge cycles on battery life. Charging electric school buses off-peak and under managed charging offers grid benefits today by not charging when energy demand is highest or by charging when renewable energy is abundant.

Sources: [a.] Levinson 2022; Energetics Incorporated et al. 2021; Ercan et al. 2016; [b.] EDF 2021; [c.] Liu and Grigg 2018; Espinoza and Vemireddi 2018; Vieira et al. 2012; [d.] Austin et al. 2019; [e.] BTS 2021; FHA 2019; [f.] ANL 2020, 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. Based on 15,000 miles per bus per year; [g.] U.S. PIRG n.d.; [h.] Hutchinson and Kresge 2022.

BOX 1

HEALTHIER AIR FOR STUDENTS IN STOCKTON, CALIFORNIA

The residents of Stockton Unified School District (SUSD) experience some of the highest asthma rates in California, with the state ranking Stockton in the 96th percentile for pollution burden and the 100th percentile for asthma. SUSD saw the conversion to ESBs as a way to help improve air quality and protect student health.

With a host of partners, SUSD applied for the California Air Resources Board's (CARB's) Clean Mobility in Schools Project and was ultimately awarded $4.8 million from the state program. SUSD leveraged the CARB grant to secure additional sources of funding from utility, local, and state programs. In total, SUSD secured $8.3 million for 11 ESBs and charging infrastructure (a mixture of direct current fast and level 2 chargers; see Table 1 for distinction) for 24 buses in phase one of the pilot.

SUSD's pilot moved quickly despite COVID-19 budget cuts and constraints. SUSD received the initial CARB grant on January 7, 2020, had funds approved by April, broke ground on the bus charging infrastructure in September 2020, and had the charging infrastructure operational in December 2020. The district aims to eventually convert all 96 of the school district's buses.

In addition to focusing on the air quality benefits of ESBs, SUSD engages students in clean energy projects to demonstrate that the green jobs of the future are for them. "Zero-emission buses are a symbol of hope and a means of change for communities like Stockton," says Gil Rosas who was SUSD's energy education specialist during its ESB transition. "Stockton has shown how a disadvantaged community can go from design to construction to electric school buses in less than a year."

Source: Rosas 2021. Learn more about Stockton's experience by visiting Kaplan, L., and A. Huntington. 2021. "The Electric School Bus Series: Healthier Air for Students in Stockton, California." Washington, DC: World Resources Institute. https://www.wri.org/update/electric-school-bus-series-stockton-california.

Community Support

Community members can drive demand for school bus electrification. Grassroots organizations and advocacy groups, often made up of parents and other caregivers, have been effective at pushing school district commitments and creating policy changes. At the national level, Chispa LCV has been driving the ESB conversation since 2016 by creating the "Clean Buses for Healthy Niños" campaign to ask decision-makers to prioritize ESBs when spending the Volkswagen settlement funds,[4] forming the Alliance for Electric School Buses, and championing the numerous benefits ESBs bring to communities (Chispa n.d.). Its volunteers have supported legislation in Nevada and helped hold school districts to their commitments in Arizona (Schlosser 2021). In Virginia, Mothers Out Front helped get Virginia Delegate Mark Keam's ESB bill passed (MOF n.d., 2021; FCPS 2021a). In New York, advocacy from groups helped push both New York City's and New York State's commitments to transition the fleet by 2035 (News 12 Staff 2022; EarthJustice 2022; Kaye 2022; CNY 2021). Students have also been effective changemakers, especially at the school district level. For example, in Miami, student pressure at school board meetings helped convince the district to pursue a grant for 50 ESBs (Casey 2021).

These are just a few examples of how communities have driven demand for ESBs by advocating for their children's health and safety.

Policy Commitments

Policy commitments can influence speed of adoption. The New York State budget for fiscal year 2023 includes a new, nation-leading requirement for all new school bus purchases in New York State to be zero emission starting in July 2027 (Lewis 2022). All school buses in service statewide must be zero emission by 2035. The new law also requires the New York State Energy Research & Development Authority to offer technical assistance to school districts and publish an implementation roadmap. The legislation further allocates $500 million in potential state funding for school bus electrification. This new funding, part of a larger environmental bond act, is subject to voter approval in November 2022. In California, the governor's budget proposal, currently being considered in the state legislature, would allocate $1.5 billion in one-time funding, available over three years, to support school transportation programs, with a focus on greening school bus fleets (Gray 2022).

At the local level, Fairfax County Public Schools in Virginia, with 1,625 school buses, one of the largest fleets in the country, adopted a goal for full fleet electrification by 2035 (FCPS 2021b; Schlosser 2019). In addition, after receiving North Carolina's first ESB earlier this year, the Eastern Band of Cherokee Indians set a goal of becoming the first school system in the state to electrify its full fleet and has already ordered four additional ESBs that are expected to be delivered this summer (WLOS Staff 2022; Kays 2022).

Grants and Incentives

As of April 2022, about 80 percent of school districts or fleet operators with committed ESBs had only one batch of ESBs so far—20 percent (83 school districts or fleet operators) had between two and four batches.[5] Funding at the utility, local, state, and federal levels has catalyzed adoption, with school districts leveraging dozens of funding sources across the country to offset the high upfront prices of the buses, which can be three to four times more than a diesel model (Levinson 2022; Tables 2, 3, and 4).

States are an important source of funding for school bus electrification. California has awarded over $116 million for ESBs through its California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (California HVIP 2022). New York State's Truck Voucher Incentive Program and Massachusetts' Vehicle-to-Grid Electric School Bus Pilot Program are other early examples of states providing funding for ESBs (NYSERDA 2022; MDER 2022). Across the board, the state funding landscape has evolved due to the Volkswagen settlement funds, which make up over one-third of state public funding for ESBs allocated to date and are the primary source of state funding for ESBs in most states (McLaughlin and Balik 2022; Box 2).

BOX 2

A RURAL COUNTY'S EXPERIENCE WITH ELECTRIC SCHOOL BUSES—KNOX COUNTY, MISSOURI

After success with on-site solar, Knox County R-I School District—the second largest geographically in Missouri—began looking for other ways to reduce expenditures, increase revenues, and expose students to a growing field that could offer well-paying clean energy jobs within their own community. At the suggestion of Lewis County REC, the district's electric cooperative, Knox County Superintendent Andy Turgeon and his team turned their sights to an ESB.

In 2020, the district began searching for funding, ultimately securing four grants—one state, one federal, and two from utilities: Department of Natural Resources Volkswagen settlement funding ($169,126); U.S. Department of Agriculture's Community Facilities program ($116,626); Associated Electric Cooperative Inc. ($30,000); and Lewis County REC ($15,000).

The district received its ESB six months after placing an order. The school district had slight challenges with regenerative braking and the direct current to direct current (DC-DC) converter. When installing USB (universal serial bus) ports in the bus, one of the relay switches that operates the regenerative braking was knocked loose. Turgeon and his team quickly identified and fixed the issue after plugging in a laptop for remote communication and diagnostics. For the DC-DC converter, the cameras Knox County School District installed on the bus were not shutting off and were draining the onboard 12-volt battery. Once identified, the manufacturer sent a new onboard battery and the bus mechanic installed it within an hour.

Overall, Turgeon and the drivers have enjoyed the bus, noting how quiet and smooth the rides are. Looking ahead, Knox County schools believe that full electrification of their 14-bus fleet is in their future and have already applied for grants for two more buses through the state's Department of Natural Resources.

Source: Turgeon, A. 2021. Learn more about Knox's experience at Huntington, A., and L. Kaplan. 2021. "The Electric School Bus Series: Wiring Up in Knox County." Washington, DC: World Resources Institute. https://www.wri.org/update/electric-school-bus-series-knox-county.

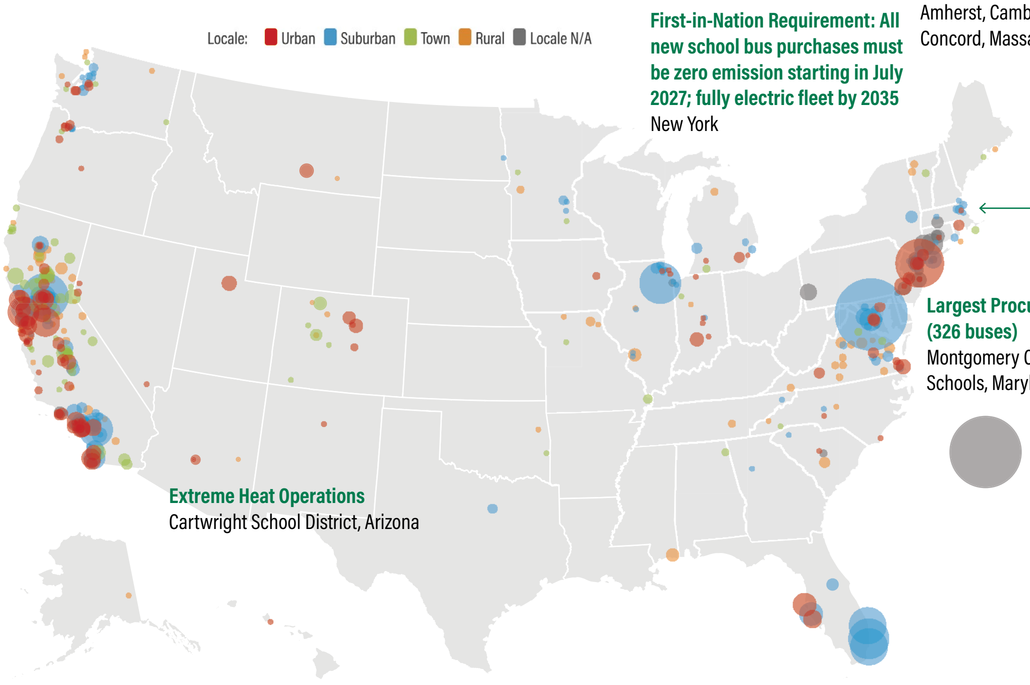
In addition to state and local funding, the bipartisan Infrastructure Investment and Jobs Act, signed into law in November 2021, will provide an unprecedented amount of funding—$5 billion over five years to the U.S. Environmental Protection Agency to establish the Clean School Bus Program—to school districts and other eligible contractors or entities starting in mid-2022. The program will offer both rebate and grant programs to support the replacement of existing school buses with cleaner zero- or low-emission school buses, which should help bring down the upfront price school districts pay for electric models. This funding includes $2.5 billion in dedicated funding for ESBs and another $2.5 billion for zero- and low-emission school buses, including both electric and alternative fuel buses. These programs will prioritize projects that align with the Justice40 initiative, which aims to deliver at least 40 percent of overall benefits from federal climate and clean energy investments to underserved communities.

Current Market Status

School districts and cities across the country are becoming part of the transition to ESBs, driving up demand nationwide. As of March 2022, 415 districts (or, in some cases, private fleet operators) had committed to procuring 12,275 ESBs (Lazer and Freehafer 2022; Figure 3). ESBs are committed in 38 states, the Cherokee Nation, and the White Mountain Apache Tribe. Most are located in California, which features robust and long-standing state funding programs (Box 3).

FIGURE 3

ELECTRIC SCHOOL BUSES IN THE UNITED STATES



First Cold Weather Pilot (2016–18)
Amherst, Cambridge, and Concord, Massachusetts

First-in-Nation Requirement: All new school bus purchases must be zero emission starting in July 2027; fully electric fleet by 2035
New York

Largest Electric School Bus Fleet (50 buses)
Twin Rivers Unified School District, California (Box 3)

Oldest Electric School Bus Fleets (Est. 2014)
Kings Canyon Unified School District and Escondido Union High School District, California

Largest Procurement (326 buses)
Montgomery County Public Schools, Maryland

Extreme Heat Operations
Cartwright School District, Arizona

Extreme Cold Operations
Alaska Gateway School District, Alaska

Notes: Data as of March 2022. Midwest Transit Equipment and SEA Electric have not yet announced the location of their 10,000 repowered electric school buses (grey circle).

Sources: Lazer and Freehafer 2022; NCES 2018, 2020; examples gathered by authors.

BOX 3

BUILDING INTERNAL CAPACITY WITH ELECTRIC SCHOOL BUSES IN TWIN RIVERS, CALIFORNIA

Twin Rivers Unified School District began operating its first ESBs in 2017. Currently, the school district operates the largest ESB fleet in the nation with 50 electric Type A, C, and D buses from a variety of manufacturers (Lion, Trans Tech, Blue Bird, and Collins with orders placed for Micro Bird and Thomas Built Buses). All are newly manufactured models; none are repowered models.

Reflecting on his district's journey, Twin Rivers Transportation Director Tim Shannon encourages fleets to "think big" at the outset, as doing multiple upgrades for infrastructure can be burdensome and costly. Depot upgrades include underground work, trenching, and laying pipe. Fleets can minimize facility disruption by planning early on to accommodate a larger electric fleet. While total infrastructure costs depend on several factors, the size of the fleet and the available power source are two of the greatest. To make nationwide electrification possible, Twin Rivers highlighted the need for broader investments in public infrastructure so that school districts can use their electric buses for longer field trips or activities, which has proved difficult to date.

Twin Rivers has experienced some operational issues, primarily problems with converters/inverters and battery replacements in three of its eight first-generation buses. These replacements were covered by the eight-year warranties offered by the manufacturer. Twin Rivers has not experienced this challenge in later-generation buses and has found that manufacturers and dealers have been responsive regarding both immediate needs and longer-term modifications to their offerings. While Raymond Manalo, Twin Rivers' vehicle maintenance manager, emphasizes that forging strong partnerships with manufacturers and dealers is essential, he also cautions against relying too heavily on those parties: Effectively training technicians to resolve issues internally can address simpler issues and reduce downtime. A school district can build internal capacity for its maintenance technicians by receiving manufacturer or dealer training, which can be built into purchase contracts or requests for proposals. Twin Rivers has also leveraged its network of local school districts operating electric buses as a form of mutual aid when schools encounter issues or need parts.

Source: Shannon and Manalo 2021.

Electric school buses have successfully been deployed in a variety of climates. For example, Tok Transportation began operating Alaska's only ESB, a Type C with a 138-mile range, in October 2020 and has since been able to operate in temperatures as low as -38 degrees Fahrenheit (°F) (O'Hare 2021). In such extreme conditions, the bus's efficiency is halved—a more substantial decrease in efficiency than that of buses operating in areas with less severe winters regardless of fuel type (Henning et al. 2019). However, Tok Transportation can manage this drop in efficiency as its average route length is just 30 miles. 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 (Hannon 2021).

1.2 Scaling Supply

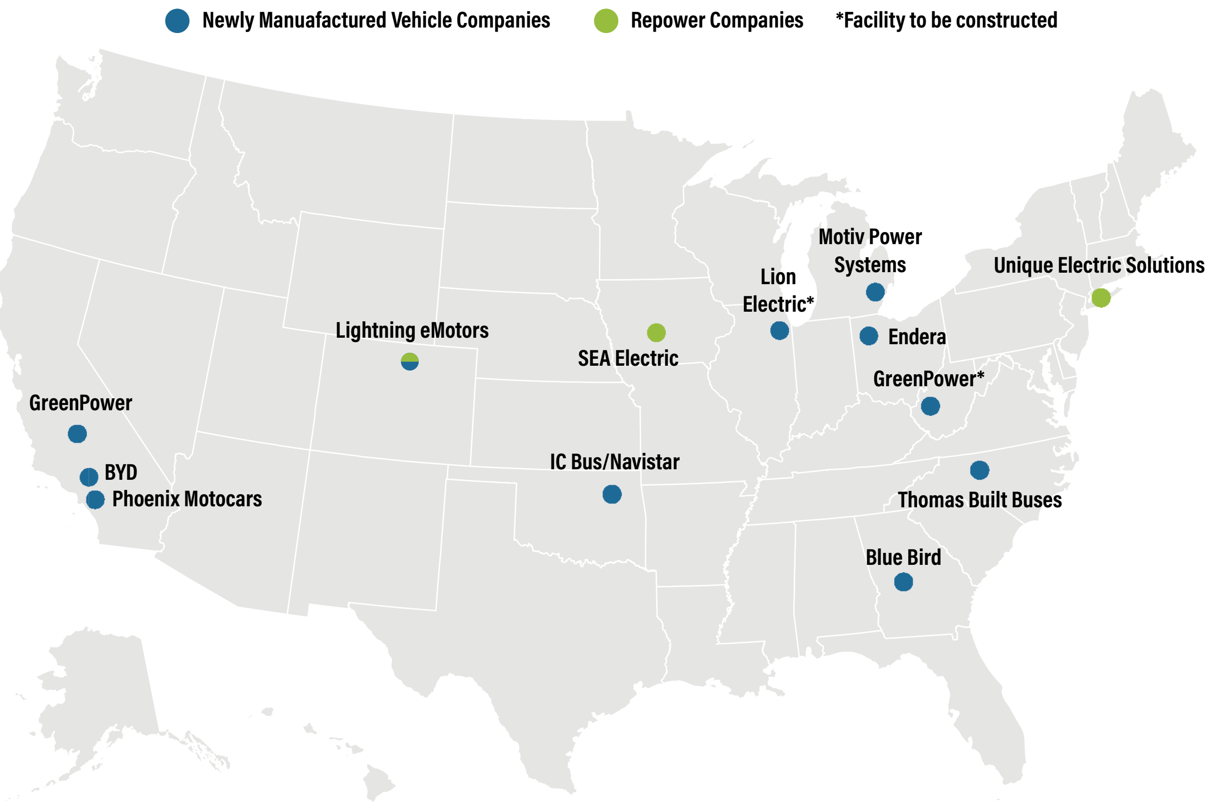
To meet the growing demand for ESBs, existing manufacturers are ramping up production, and new manufacturers continue to enter the field (Figure 4). While initial offerings were limited, today many manufacturers are on their second or third ESB model iteration, some more, and are expanding their production capacity to meet demand. For example, after expanding its production capacity sixfold in late 2020 due to a sales increase of 250 percent compared with the previous year, Blue Bird became the first manufacturer to achieve 800 electric-powered school buses either delivered or on order (Blue Bird 2020; STN 2021c). The company reported a backlog of over 380 buses on order last year and will again increase production capacity in 2022 (Blue Bird 2021a, 2021b). Lion Electric, a Canada-based group, announced it would expand its footprint by constructing a U.S. manufacturing facility in Joliet, Illinois, that will have an annual production capacity of up to 20,000 all-electric buses and trucks (Lion Electric 2021). In response to the favorable market outlook due to the federal government's Infrastructure Investment and Jobs Act, GreenPower announced it would double its ESB production capacity in 2021; the manufacturer said it would lease or purchase a manufacturing facility in West Virginia (GreenPower 2021; Justice 2022). Providers are also forging partnerships: Lightning eMotors, an all-electric powertrain manufacturer, and Collins Bus, a school bus body upfitter, have partnered to deliver more than 100 electric Type A buses by 2023 (Lightning eMotors 2021).

School bus manufacturing is concentrated in the United States, supported by federal Buy America regulations, and in Canada. However, ESBs are still dependent on a global supply of lithium-ion batteries, electric motors, and other electric vehicle components that have less domestic manufacturing capacity (FTA n.d.). The cost of these components, particularly batteries, will directly impact ESB capital cost and the industry's ability to see rapid ESB adoption. Despite these challenges, even as the COVID-19 pandemic has presented unprecedented hardships for the education sector, ESBs have persisted as the only fuel type to see growth in new bus sales during the pandemic with sales increasing 61 percent (STN 2021b). As ESBs continue to gain market share, it will be crucial to also manage diesel bus scrappage in a way that limits used vehicle flows to international markets, permits repowering by not cutting frame rails, and allows fleet managers to hold on to buses long enough to become acclimated to ESB replacements in their fleets.

To meet demand, existing contractors and emerging third-party services are looking for ways to support school districts in this transition. Contractors, who represent around 40 percent of the school bus market,

FIGURE 4

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 and Micro Bird both have facilities in Quebec.

Source: WRI authors based on publicly available information.

are beginning to explore pathways to electrification to meet customer demand (Gissendaner 2021). For example, Student Transportation of America, a private fleet operator servicing school districts across the United States and Canada, launched an Electric School Bus Pilot Program in 2021, and Midwest Transit Equipment is partnering with SEA Electric to repower 10,000 school buses to electric through 2026 (SBF 2021b; SEA Electric 2021). New service providers are employing alternative business models to lower the upfront cost barrier and reduce new technology risks for school districts (Box 4).

BOX 4

TURNKEY ASSET MANAGEMENT AND OTHER AS-A-SERVICE MODELS

Structured as service contracts, districts can benefit from expert project management, procurement support, and ongoing operations and maintenance services. Services can span from bus ownership to site energy management, with different combinations of service solutions depending on the specific needs and context of each customer.

Two examples are Highland Electric and Levo Mobility, firms that leverage private finance, potential vehicle-to-grid revenues, public funds, and the purchasing power of multiple clients to provide bundled packages of services that enable electrification. Montgomery County Public Schools in Maryland is partnering with Highland Electric on the largest procurement of ESBs in North America. The school district announced in 2021 it would convert 326 buses to electric by 2025 on a path to full electrification of its 1,400-bus fleet.[a] Building on this progress, Highland signed a letter of intent with school bus manufacturer Thomas Built Buses in March 2022, which will allow Highland to provide ESB subscriptions through 2025 at prices that put them at cost parity with diesel.[b] In Illinois, Levo Mobility will use its turnkey electrification solution to help Troy Community Consolidated School District 30-C convert its 64-school bus fleet to zero emission within five years.[c]

Notes: [a.] Proterra 2021; [b.] DTNA 2022; [c.] Levo Mobility LLC 2022.

2. ELECTRIC SCHOOL BUS BASICS

In preparing for ESB adoption, project developers need to understand considerations for both the buses themselves as well as the charging infrastructure to power them. This section outlines components of the ESB and its charging infrastructure (Tables A1 and A2 in Appendix A provide additional terms and units, respectively) and offers considerations for implementation.

2.1 Electric School Bus

As school districts embrace electric buses, fleet managers, bus drivers, and maintenance technicians will need to familiarize themselves with elements that vary between diesel and electric (Figures 5 and 6). While many elements of the body and inside the cabin remain similar, two key differences are present in electric models:

1. The presence of high-voltage electrical systems
2. The absence of internal combustion–related components

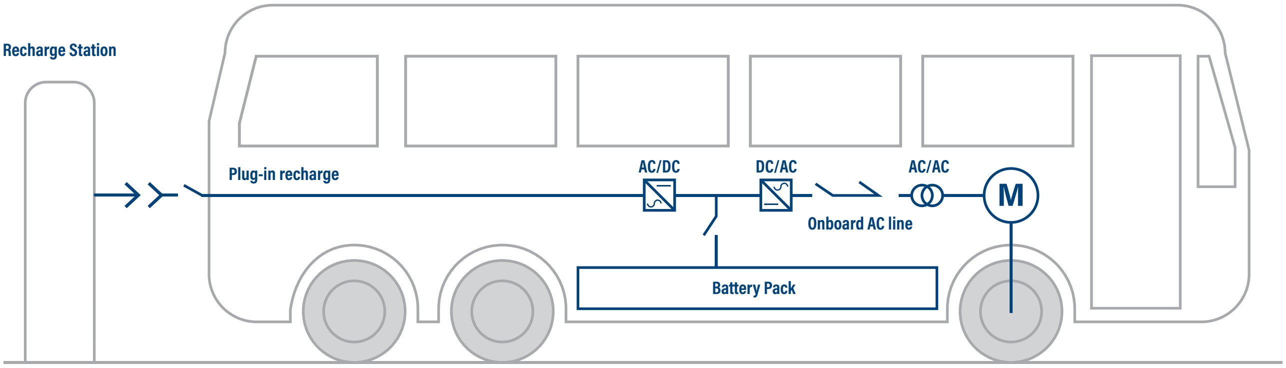
ESBs contain high-voltage systems powered by a large lithium-ion battery pack mounted to the chassis. Power from the high-voltage battery is distributed to the electric motor and other systems using high-voltage cables (colored bright orange), direct current/alternating current (DC/AC or AC/DC) inverters, and AC/AC transformers. The high-voltage battery pack is supported by a thermal management system that maintains battery health and longevity by keeping the batteries within an optimal temperature range regardless of external temperature (vital to ESBs operating in cold and hot climates).

With the inclusion of an electric powertrain, ESBs do not contain internal combustion engine components and systems (see components highlighted in red in Figure 6). Electric buses utilize motors comprising only around 20 parts (compared with 2,000 in a diesel engine); require fewer fluid changes (including elimination of engine oil); and commonly use a direct drive system, eliminating the need for a transmission.

With respect to vehicle servicing, technicians have fewer parts to maintain for electric buses when compared with 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 keep up and service (see components highlighted

FIGURE 5

ELECTRIC SCHOOL BUS DIAGRAM



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

Source: Ainsalu et al. 2018.

in blue in Figure 6). Additionally, like diesel buses, ESBs also have low-voltage auxiliary systems that use a lead-acid battery to support components like the dashboard, lights, and windshield wipers. However, to operate on high-voltage systems, maintenance technicians do need specialized training. For on-site depot maintenance staff, completing this training can be both costly and time consuming.

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

2.2 Charging Infrastructure

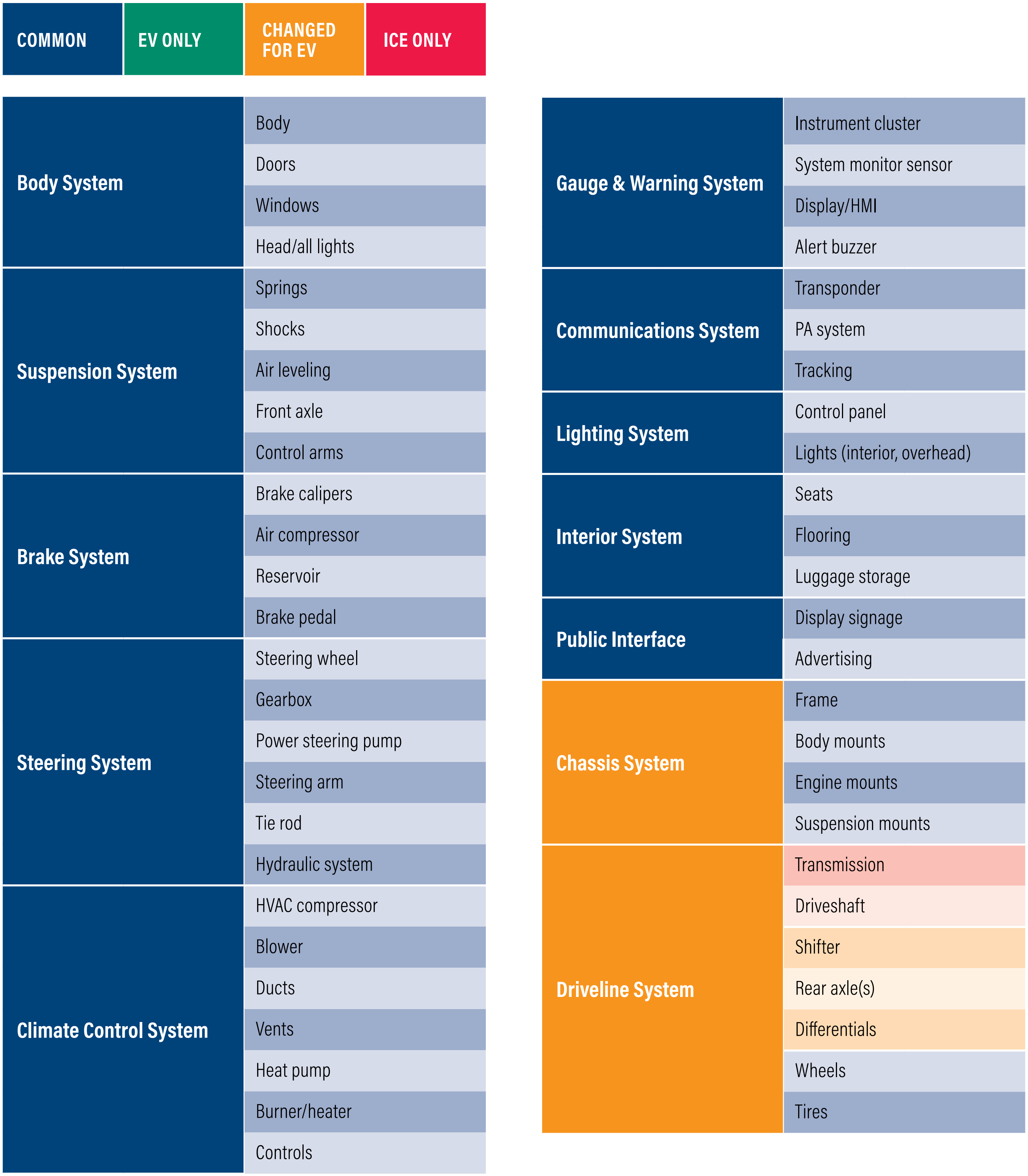
As school districts consider procuring ESBs, they must also think about the corresponding infrastructure needed to charge these buses. Infrastructure can be broken down into hardware and software components. For charging hardware or electric vehicle supply equipment, there are three levels available today (Table 1).

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

Early and frequent engagement with a school district's electric utility is crucial. This is necessary to evaluate the existing power supply and identify required system upgrades and charging configurations to support fleet turnover. Once charging infrastructure is in place, which can take approximately 12 to 24 months, bus operators can take advantage of time-of-use rates (if available) and managed smart charging to help realize greater energy savings. For example, a 2015–18 ESB pilot at three Massachusetts school districts found that unmanaged bus charging and high parasitic loads during charging (e.g.,

FIGURE 6

COMPARISON OF ELECTRIC AND INTERNAL COMBUSTION ENGINE VEHICLE COMPONENTS



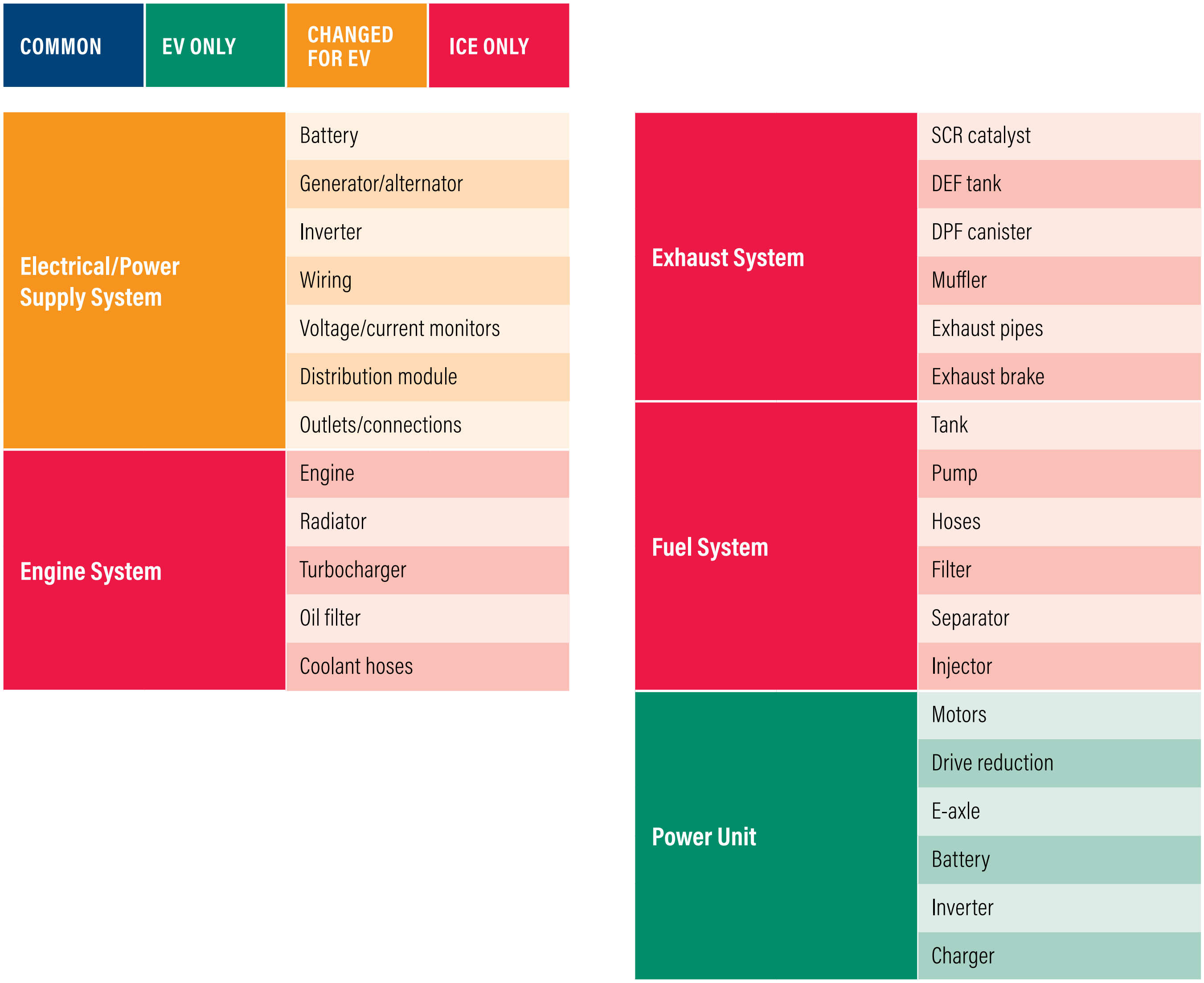
COMMON	EV ONLY	CHANGED FOR EV	ICE ONLY

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 6

COMPARISON OF ELECTRIC AND INTERNAL COMBUSTION ENGINE VEHICLE COMPONENTS (CONT.)



🟦 COMMON	🟩 EV ONLY	🟧 CHANGED FOR EV	🟥 ICE ONLY

🟧 **Electrical/Power Supply System**	Battery
	Generator/alternator
	Inverter
	Wiring
	Voltage/current monitors
	Distribution module
	Outlets/connections
🟥 **Engine System**	Engine
	Radiator
	Turbocharger
	Oil filter
	Coolant hoses

🟥 **Exhaust System**	SCR catalyst
	DEF tank
	DPF canister
	Muffler
	Exhaust pipes
	Exhaust brake
🟥 **Fuel System**	Tank
	Pump
	Hoses
	Filter
	Separator
	Injector
🟩 **Power Unit**	Motors
	Drive reduction
	E-axle
	Battery
	Inverter
	Charger

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.

TABLE 1

CHARGING LEVELS

	Level 1 (L1)	Level 2 (L2) Single Port[a]	Direct Current Fast Charger (DCFC) Single Port
Type of current	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	Alternating Current	Direct Current
Voltage (V)		208/240	200–600
Power level (kW)		~7–20	~24–150
ESB recharge time		5.5–13 hours[b]	1–4.5 hours[b]
Charger equipment cost[c]		$400–$6,500[d]	$10,000–$40,000[d]
Installation cost[e]		$600–$12,700[d]	$4,000–$51,000[d]

Notes: Abbreviations: V = volt; kW = kilowatt; ESB = electric school bus; [a] Potential for dual port offering; [b] See Tables 2, 3, and 4; [c] Costs are largely dependent on the power output (kilowatts) of the charger, the degree of control over charging, and other advanced features; [d] Smith and Castellano 2015; ITSJPO 2019; [e] Installation costs will be site and geography dependent. Estimates do not include potential grid upgrade costs.

bus heaters, fans, lights) contributed to ESB electricity costs being 63 percent higher than necessary (VEIC 2018). To avoid the excess energy consumption, the report authors recommended utilizing managed charging.

Beyond the hardware, managed charging uses software designed to help fleet operators optimize charging schedules, costs, and bus performance. This software, often provided by charging software developers, can allow for scheduling charging times for when electricity prices are lowest or for turning off charging to preserve battery life without manual adjustments, even if the bus is plugged in continuously (Box 5). Chargers equipped with this software will likely be somewhat more expensive upfront and incur ongoing subscription or service fees. Managed charging software can be customized for a fleet, and operators can leverage tools through mobile apps or online platforms.

With the right hardware and software, school districts can take advantage of bidirectional charging, where the vehicle can receive electricity to charge as well as discharge back to a different load or onto the grid. If equipped with this functionality, a bus can serve as a backup battery for a building by providing power during emergencies (vehicle-to-building; V2B) or for another load (vehicle-to-another-load; V2L). Buses can also store electricity in their batteries and later discharge it onto the grid to reduce districts' utility costs (vehicle-to-grid; V2G). Since the first vehicle-to-grid deployment in 2014 at three California school districts, at least 15 utilities across 14 states have committed to pilot ESB V2G programs (PCA 2014; Hutchinson and Kresge 2022). Through V2G programs, buses also have the potential to generate revenue by discharging energy from their batteries back to the grid to be used elsewhere—this is a nascent market but technological advancements should make this widely available in the near future. While these bidirectional concepts have been deployed by only a handful of school districts to date, they offer potential to increase resilience, generate revenue, and reduce costs (Proterra 2019).

Electric bus adoption can also be paired with new or existing on-site solar installation as an energy storage solution (ENGIE Impact 2021; Soneji et al. 2020; Ellis 2020; Riley 2021). 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 reduction or sustainability goals.

BOX 5

ENERGY-AS-A-SERVICE SOLUTIONS

Just as transportation-as-a-service offerings on the bus side have emerged, as-a-service offerings that handle the intersecting charging elements have also proliferated. As-a-service arrangements can help school districts reduce charging costs, finance necessary infrastructure upgrades, and manage their energy needs within the grid capacity of their depots. The robust market extends much beyond services exclusive to the school bus industry, ranging from fleet energy management firms like eIQ Mobility and Olivine to charging- and infrastructure-as-a-service firms like The Mobility House, Amply, and NextEra Energy's Mobility Team. Other entrants in this space include electric utilities and energy services companies, which are experimenting with energy performance contract offerings. This topic requires more detail than covered in this report and is a dynamic space. More information can be found in Cleary and Palmer (2020).

2.3 Considerations for Implementation

School districts that choose to adopt ESBs without contractors or transportation-as-a-service providers generally follow a similar roadmap to adopting ESBs, laid out in Figure 7. Many of these stages overlap and are executed concurrently.

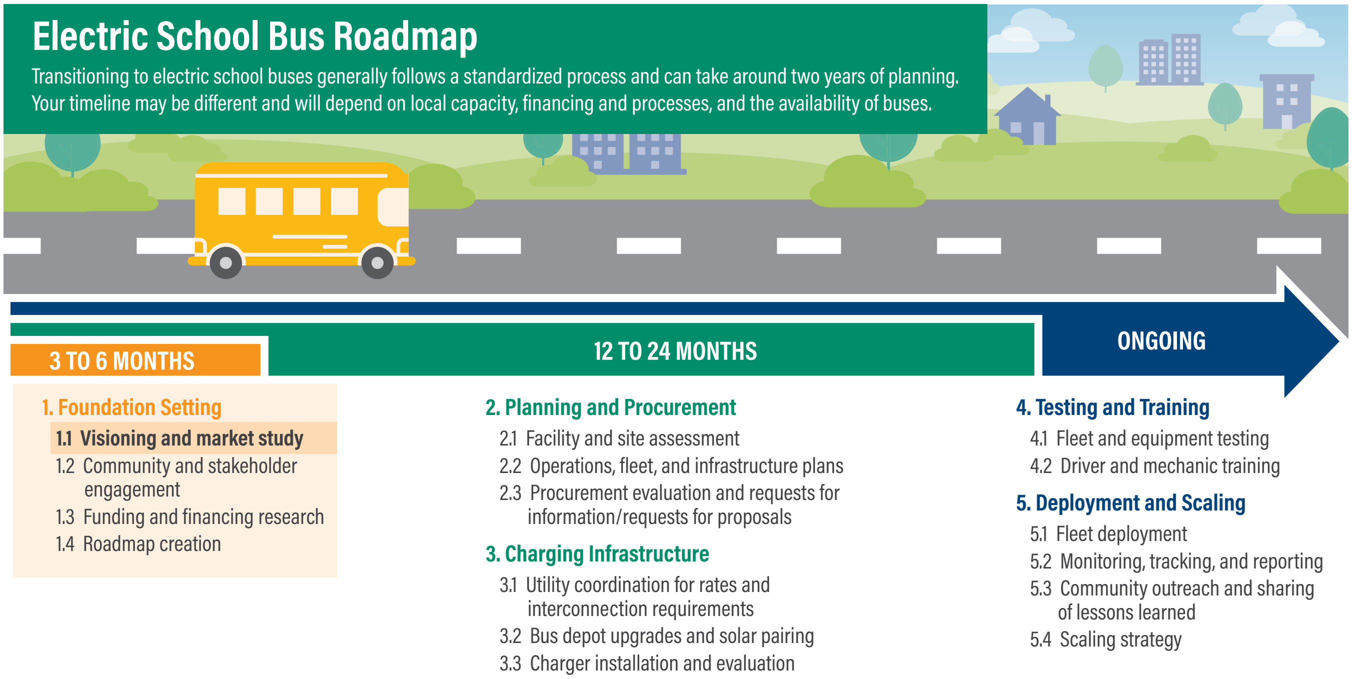
While this publication predominantly focuses on information that can support school districts in the foundation-setting stage (Stage 1.1 in Figure 7), some potential considerations and guiding questions for all five stages are listed below. This list is not exhaustive and will be explored in more detail in future publications.

Stage 1. Foundation Setting

- What are your ultimate electrification goals?
- How are local community-based organizations, students, parents, and other stakeholders being brought into the process?
- Would a school district benefit from leveraging an "as-a-service" model (Boxes 4 and 5)?

FIGURE 7

FIVE STAGES AND CORRESPONDING STEPS OF ELECTRIC SCHOOL BUS ADOPTION



Electric School Bus Roadmap

Transitioning to electric school buses generally follows a standardized process and can take around two years of planning. Your timeline may be different and will depend on local capacity, financing and processes, and the availability of buses.

3 TO 6 MONTHS

1. Foundation Setting

1.1 Visioning and market study
1.2 Community and stakeholder engagement
1.3 Funding and financing research
1.4 Roadmap creation

12 TO 24 MONTHS

2. Planning and Procurement

2.1 Facility and site assessment
2.2 Operations, fleet, and infrastructure plans
2.3 Procurement evaluation and requests for information/requests for proposals

3. Charging Infrastructure

3.1 Utility coordination for rates and interconnection requirements
3.2 Bus depot upgrades and solar pairing
3.3 Charger installation and evaluation

ONGOING

4. Testing and Training

4.1 Fleet and equipment testing
4.2 Driver and mechanic training

5. Deployment and Scaling

5.1 Fleet deployment
5.2 Monitoring, tracking, and reporting
5.3 Community outreach and sharing of lessons learned
5.4 Scaling strategy

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

- What types of funding are available (e.g., voucher, rebate, grant) to reduce the upfront price (Box 6)? Can incentives be stacked?
- How can electrification help increase access to school and after-school activities?
- What are your plans for retiring old diesel school buses?
- Who will be responsible for recycling bus batteries?
- Are you considering newly manufactured or repowered ESBs, or both?

Stage 2. Planning and Procurement

- Which models meet local restrictions and requirements (e.g., street width restrictions, heating and air conditioning requirements)?
- Which models meet your range needs?
- Which models best serve students with disabilities?
- Are there other features, such as Wi-Fi, that could benefit students and communities?

BOX 6

THE REAL COST OF ELECTRIC SCHOOL BUSES (IS LOWER THAN YOU THINK)

While the upfront price of ESBs is substantial, experts anticipate significant price declines over the next decade as battery costs decrease and the electric vehicle industry achieves efficiencies of scale in component markets and manufacturing. In fact, the real lifetime cost of ESBs can be much closer to that of their diesel counterparts due to significant savings on operational expenditures—such as fueling and maintenance—that build up over the years a vehicle is in use. These savings can range from an estimated $4,000 to $11,000 per school bus every year (depending on labor costs, local electric utility rates, and the price of petroleum fuels).[a] Market experts predict that the lifetime costs of ESBs will be around the same as diesel buses for new purchases starting between 2025 and 2030.[b] This total cost parity will be driven mainly by continuation of the precipitous decline in battery prices over the past decade and further development of new battery chemistries.[c]

Notes: [a] Levinson 2022.; [b] Smith 2019; Watson et al. 2020.; [c] BloombergNEF 2021.

Stage 3. Charging Infrastructure

- Questions for utilities:
  - ☐ Are you currently subject to “demand charges?”
  - ☐ Does your electric utility have an electric vehicle–specific time-of-use (TOU) rate?
  - ☐ Have you considered ongoing operations and maintenance of the charger and associated equipment through a service-level agreement with the charger network provider?
  - ☐ Does your electric utility offer bidirectional charging programs?
- What stakeholders will be important to engage beyond utilities (e.g., landlords if facility is leased, city agencies if building or electrical permits are required)?
- How might driver behavioral patterns, like park outs (drivers taking buses home at night), affect charging planning?
- How will charging infrastructure impact your school and surrounding community? Can charging be paired with renewables? Can infrastructure be installed near drivers’ homes in rural areas?
- Do you plan to use your buses as part of disaster response strategies?

Stage 4. Testing and Training

- How are employees being trained to work with this infrastructure (Box 7)? Who has access to training programs and new jobs?

Stage 5. Deployment and Scaling

- How is route electrification executed? Can routes that serve disadvantaged riders or drive through underserved communities be prioritized when electrifying?
- How can fleet electrification positively impact other energy- or sustainability-related goals?
- Can regional collaboration and support networks be formed among schools converting their fleets to electric to support field trips or sporting events (e.g., creating mutual aid networks for charging based on existing or new partnerships; see Box 3)?

BOX 7

LESSONS LEARNED ON THE ROAD TO ELECTRIFICATION IN CARMEL CLAY, INDIANA

Carmel Clay Schools received Indiana's first ESB in the summer of 2020. The school district is keen on finding new technologies to improve air quality and reduce emissions and has pursued alternative-fuel school buses for several years. After being awarded Volkswagen settlement funding, the school district paid the equivalent price of a diesel bus for a first-generation Type D electric bus.

In its year and a half of electric school bus operations, Carmel Clay has learned from several challenges, mostly operational issues affecting range and reliability. For example, in winter months, the bus's 12-volt onboard electric heater drained the battery faster than anticipated and it was a struggle to maintain temperatures above 40°F inside the cabin. To resolve the issue, the manufacturer performed several modifications, including rewiring the bus so the onboard battery did not draw as much power, but this adjustment did not fully resolve the issue.

Despite some challenges, Gary Clevenger, the assistant director of transportation and facilities for the school district, remains optimistic about the potential of ESBs. He believes that the predictability of school bus routes makes them particularly conducive to electrification if reliability issues can be addressed. However, he would like to see additional efforts to improve not just the technology itself but also the training provided to maintenance technicians, as much of the down time resulted from waiting for technicians trained to work with high-voltage equipment.

Source: Clevenger and Decker 2022.

3. SUMMARY OF AVAILABLE ELECTRIC BUS MODELS

As of January 2022, there were 22 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.[6] Among the available electric models, the Type C offerings are the most mature, or commercially ready. Manufacturers gauge commercial maturity as they move from pre-production assembly to full production, a process that achieves modest volumes and means a vehicle model is available for retail sale. Moreover, electric bus models that enter commercial production will have undergone multiple testing iterations prior to factory line assembly and are more mature as a later-generation product. Finally, a test of maturity can be applied to a supportive supply chain where manufacturers and their dealers establish formal maintenance networks to service ESBs after delivery. In today's market there are a mixture of early-stage ESB models that have not yet been deployed and mature models that are sold like conventional school bus models.

3.1 Newly Manufactured Electric School Buses

A newly manufactured bus is one that has been designed and built to operate with an electric powertrain from the ground up, with one exception being some electric Type A cutaway buses (see Type A). Although the purchase price of newly manufactured buses 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 are substantially lower. According to one analysis, fueling and maintaining electric models could be less than half the cost of diesel over an expected lifetime of 12 years (Tables 2, 3 and 4; EDF 2021). When considering models, school districts should keep in mind the difference between a newly manufactured ESB and a repowered bus (see Section 3.2).

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 powertrain, the body). Available electric models are presented in Table 2.

Type A buses are constructed using three distinct approaches:

- New repower cutaway: The diesel or gasoline powertrain is removed from a new internal combustion engine cutaway (usually produced by

Ford or General Motors) and replaced with an electric powertrain. A school bus body is attached to the new repowered cutaway.

- E-cutaway: The school bus body is attached to a new purpose-built, electric cutaway.
- Non-cutaway: The bus chassis, powertrain, and body are all assembled as a single integrated unit. The bus is not built on a cutaway platform. This model is comparable to Type C and D manufacturing.

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 C offerings are the most mature for the ESB market and are listed in Table 3.

Type D

Type D, the largest of school buses seating up to 90 students, make up approximately 20 percent of the market (Matthews 2021). Electric offerings are presented in Table 4.

TABLE 2

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE A)

						COMING SOON	
	Lightning eMotors[a]	Lion Electric	Micro Bird	Motiv[b]	Phoenix Motorcars[c]	Endera	GreenPower
MODEL	ELECTRIC E-450	LIONA	MICRO BIRD G5	EPIC E-450	ZEUS 600	O-SERIES	NANO BEAST
BUILD TYPE	NEW REPOWER CUTAWAY	NON-CUTAWAY	NEW REPOWER CUTAWAY	NEW REPOWER CUTAWAY	NEW REPOWER CUTAWAY	NEW REPOWER CUTAWAY	E-CUTAWAY
Price range[d]	*Not available*	\$340,162–\$343,162[e]	\$236,390–\$251,425[f]	Collins Bus: \$300,784 Trans Tech: \$322,015[g]	*Not available*	TBD	TBD
Length (L)/ width (W)/ height (H)[h]	L: 290″ W: 96″ Height not available	L: 313″ W: 96″ H: 111″	L: 283″ W: 96″ H: 113–118″	L: 288″ Width and height not available	L: 277″/288″ W: 96″ H: 120″	L: 288″ W: 98″ H: 108″	L: 300″ W: 91″ H: 124″
Passenger capacity	24	24	30	24	23	24	20
Charger connector	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CC1S	L2: J1772 DCFC: CCS1 or CHAdeMO	DCFC: CCS1	L2: J1772 DCFC: CCS1
Capable of bidirectional charging	Coming 2022	Yes	Yes	*Not available*	Optional	Yes	Yes
Battery size (kWh)	120	84/168	88	127	94/125/156	151	118.2
Range (miles)	100	75/150	100	105	100/130/160	135	150

TABLE 2

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE A) (CONT.)

	Lightning eMotors[a]	Lion Electric	Micro Bird	Motiv[b]	Phoenix Motorcars[c]	COMING SOON	
						Endera	GreenPower
MODEL	**ELECTRIC E-450**	**LIONA**	**MICRO BIRD G5**	**EPIC E-450**	**ZEUS 600**	**O-SERIES**	**NANO BEAST**
BUILD TYPE	**NEW REPOWER CUTAWAY**	**NON-CUTAWAY**	**NEW REPOWER CUTAWAY**	**NEW REPOWER CUTAWAY**	**NEW REPOWER CUTAWAY**	**NEW REPOWER CUTAWAY**	**E-CUTAWAY**
Battery thermal management	Dynamic liquid cooled system	Liquid cooled	Liquid cooled	*Not available*	Liquid cooled	Liquid cooled	PTC heating, liquid cooled
Recharge time	L2 (13.2 kW): 5.5–7.5 hours DCFC (80 kW max): 1.5 hours–2 hours	L2 (19.2 kW): 6.5–11 hours DCFC (24 kW): 5–9 hours or (50 kW) 2.5–4.25 hours	L2 (19.2 kW): 7 hours DCFC (50 kW): 2 hours	L2 (19.2 kW): 8 hours DCFC (60 kW): Charge time not available	L2 (13 kW): Depends on battery pack size DCFC (50 kW): Depends on battery pack size	Onboard AC charger (6.6 kW): 7 hours DCFC: (~50 kW) 2.5 hours or (~125 kW) 1 hour	L2 (11 kW): 11 hours DCFC (60 kW): 2 hours
Charge port location options	Front driver's side fender	Rear driver	Front nose	*Not available*	Front driver's side fender	Front grille	Front driver's side
Electric drivetrain (Mfr.)	Cascadia Motion	DANA TM4 SUMO-MD	EcoTuned	Motiv	Phoenix/TM4	Endera	TM4
Transmission (direct drive/2-speed)	None (direct drive)	None (direct drive)	2-speed	*Not available*	None (direct drive)	2-speed	None (direct drive)
Brakes (air/hydraulic)	Hydraulic	Hydraulic	Hydraulic	*Not available*	Hydraulic	Hydraulic	Hydraulic (front—disc; rear—drum)
Heat type (electric/diesel)	Electric	Auxiliary diesel or electric	Electric	*Not available*	Electric	Electric	Electric
Delivery time	2 months (dependent on chassis availability)	7–9 months	Up to 8 months	*Not available*	6 months	Expected production 2023	6 months (production TBD)
WARRANTY INFORMATION							
Battery	5 years/ 60,000 miles	8 years	8 years/ 100,000 miles	*Not available*	5 years/ 150,000 miles	5 years/ 100,000 miles	5 years/ 100,000 miles
Drivetrain	5 years/ 60,000 miles	5 years/ 160,000 miles	5 years/ 100,000 miles	*Not available*	5 years/ 60,000 miles	5 years/ 60,000 miles	3 years/ 150,000 miles

TABLE 2

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE A) (CONT.)

	Lightning eMotors[a]	**Lion Electric**	**Micro Bird**	**Motiv**[b]	**Phoenix Motorcars**[c]	**COMING SOON**	
						Endera	**GreenPower**
MODEL	**ELECTRIC E-450**	**LIONA**	**MICRO BIRD G5**	**EPIC E-450**	**ZEUS 600**	**O-SERIES**	**NANO BEAST**
BUILD TYPE	**NEW REPOWER CUTAWAY**	**NON-CUTAWAY**	**NEW REPOWER CUTAWAY**	**NEW REPOWER CUTAWAY**	**NEW REPOWER CUTAWAY**	**NEW REPOWER CUTAWAY**	**E-CUTAWAY**
WARRANTY INFORMATION							
Chassis	*Not available*	5 years	Body (1 year/12,000 miles) and structure (5 years)	*Not available*	3 years/36,000 miles	3 years/36,000 miles	3 years/250,000 miles
Additional	Bumper to bumper 3 years/36,000 miles	Up to 12 years	*Not applicable*	*Not available*	Bumper to bumper 3 years/36,000 miles	For the earlier of 2 years/75,000 miles, Endera warrants that all vehicle components will be free from defects	Additional warranties offered for various parts Extended warranties available case by case

Notes: Abbreviations: TBD = to be determined; kWh = kilowatt-hour; PTC = positive temperature coefficient; DCFC = direct current fast charger; AC = alternating current; L2 = level 2 charger; Mfr. = manufacturer. [a] As of April 2022, WRI was aware of an established public relationship between Lightning eMotors and bus body manufacturer Collins Bus; [b] As of April 2022, WRI was aware of established public relationships between Motiv Power Systems and bus body manufacturers Collins Bus and Trans Tech; [c] As of April 2022, WRI was aware of an established public relationship between Phoenix Motorcars and bus body builder Pegasus Bus; [d] Based on lowest price authors found announced publicly to date. Prices are meant to be illustrative. School districts or contractors will need to work with a local dealer for an accurate price quote. Prices vary from state to state and depend on bus specification needs; [e] Lion: STBC 2020; DTS 2020; [f] Micro Bird: NYOGS 2022; KDE 2022.; [g] Motiv: NYOGS 2022; [h] State and city requirements and needs will influence a school district's dimension needs. For example, some geographies have a width maximum for school buses.

Sources: WRI author collaboration with Micro Bird, Lion, Phoenix Motorcars, Lightning eMotors, Endera, and GreenPower. Other information gathered from public specifications.

TABLE 3

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE C)

	Blue Bird	Lion	Thomas	IC Bus/Navistar	BYD
MODEL	**BLUE BIRD VISION**	**LIONC**	**SAF-T-LINER C2 JOULEY**	**IC CE SERIES ELECTRIC BUS/ PB10E**	**TYPE C**
Price range	\$326,810–\$365,000[a]	\$338,253–\$422,302[b]	\$335,287–\$437,000[c]	\$347,870–\$364,123[d]	Not available
Length (L)/width (W)/height (H)	L: Max 477″ W: 96″ H: 123″	L: 473″ W: 96–102″ H: 122″	L: 396″ W: 96″ H: 144″	L: 303.9″/474.9″ W: 96″ H: 123″	L: 435″/462″ W: 102″ H: 132.9″
Passenger capacity	77	77	81	29–72	78
Charger connector	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1
Capable of bidirectional charging	Yes	Yes	Optional	Yes	Optional
Battery size (kWh)	155	126/168	226	210/315	255.5
Range (miles)	120	100/125	138	135/210	155
Battery thermal management	Liquid cooled	Liquid cooled	Set to maintain 70°F battery temp	Set to maintain 70°F battery temp	Water cooling
Recharge time	L2 (19.2 kW): 8 hours DCFC (60 kW): 3 hours	L2 (19.2 kW): 6.5–11 hours DCFC: (24 kW) 5–9 hours or (50 kW) 2.5–4.25 hours	DCFC: (25 kW) 8.25 hours or (60 kW) 3.4 hours	L2 (19.2 kW): 8 hours DCFC (60 kW): 3 hours	L2 (20 kW max): 12.5–13 hours DCFC (150 kW): 1.5–2 hours
Charge port location options	Rear or front passenger side/front passenger side	Rear passenger, front nose, or both	Front passenger side—optional rear charge port curbside	Front right side—optional rear right side	Curbside rear
Electric drivetrain (Mfr.)	DANA TM4	DANA TM4 SUMO-MD	Proterra	DANA TM4 SUMO-MD	BYD
Transmission (direct drive/2-speed)	None (direct drive)	None (direct drive)	2-speed	None (direct drive)	None (direct drive)
Brakes (air/hydraulic)	Air disc or drum (hydraulic in 2022)	Hydraulic (air available)	Air	Air disc	Front/rear air disc, ABS
Heat type (electric/diesel)	Electric (diesel supplemental heat option)	Auxiliary diesel or electric	Electric	Electric (optional diesel)	Electric or diesel
Delivery time	8 months	6–8 months	6–8 months	7–11 months	*Not available*

TABLE 3

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE C) (CONT.)

	Blue Bird	**Lion**	**Thomas**	**IC Bus/Navistar**	**BYD**
MODEL	**BLUE BIRD VISION**	**LIONC**	**SAF-T-LINER C2 JOULEY**	**IC CE SERIES ELECTRIC BUS/ PB10E**	**TYPE C**
WARRANTY INFORMATION					
Battery	8 years/125,000 miles/160,000 kWh discharge	8 years/160,000 kWh discharge (12-year extend available)	8 years/175,000 miles/200,000 kWh discharge	8 years/ 175,000 miles	15 years
Drive	5 years/ 100,000 miles	5 years/ 100,000 miles	5 years/ 100,000 miles (motor, transmission, inverter)	5 years/ 100,000 miles	5 years/ 250,000 miles
Chassis	Standard Blue Bird chassis warranty (5 years or more)	Standard warranty bumper to bumper (8 years)	3 years/ 50,000 miles	Standard IC Bus chassis warranty (5 years or more); basic chassis warranty is 1 year	12 years/ 500,000 miles
Additional	*Not applicable*	Extended warranties up to 12 years available	Extended warranties up to 12 years available	1 year/unlimited mileage for high-voltage steering pump, air compressor	*Not applicable*

Note: Abbreviations: TBD = to be determined; kWh = kilowatt-hour; °F = degrees Fahrenheit; DCFC = direct current fast charger; L2 = level 2 charger; Mfr. = manufacturer; ABS = antilock braking system.

Sources: WRI author collaboration with manufacturers listed in table. [a.] Blue Bird: Farquer 2021; NYOGS 2022; [b.] Lion: KCRISD 2020; HPS 2020; [c.] Thomas: Farquer 2021; Lydersen 2021; [d.] IC Bus/Navistar: NYOGS 2022; KDE 2022.

TABLE 4

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE D)

	Blue Bird	**Lion**	**GreenPower**	**BYD**
MODEL	**ALL-AMERICAN**	**LIOND**	**BEAST 90**	**TYPE D**
Price range	$340,445–$373,239[a]	Not available	$371,900[b]	Not available
Length (L)/width (W)/ height (H)	L: Max 489″ W: 96″ H: 123″	L: 473″ W: 102″ H: 122″	L: 480″ W: 102″ H: 138″	L: 435″/462″/486″ W: 102″ H: 132.9″
Passenger capacity	84	83	90	84
Charger connector	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1
Capable of bidirectional charging	Yes	Yes	Yes	Optional
Battery size (kWh)	155	126/168	193.5	255.5
Range (miles)	120	100/125	150	155
Battery thermal management	Liquid cooled	Liquid cooled	PTC for heating, liquid cooled	Water cooling
Recharge time	L2 (19.2 kW): 8 hours DCFC (60 kW): 3 hours	L2 (19.2 kW): 6.5–11 hours DCFC: (24 kW) 5–9 hours or (50 kW) 2.5–4.25 hours	L2 (19.2 kW): 10.5 hours DCFC (60 kW): 3.5 hours	L2 (20 kW max): 12.5–13 hours DCFC (150 kW): 1.5–2 hours
Charge port location options	Rear of bus/front driver's side	Rear passenger	Rear driver's side	Rear curbside
Electric drivetrain (Mfr.)	DANA TM4	DANA TM4 SUMO-MD	TM4	BYD
Transmission (direct drive/2-speed)	None (direct drive)	None (direct drive)	None (direct drive)	None (direct drive)
Brakes (air/hydraulic)	Air (disc or drum)	Air	Air disk brakes, ABS	Front/rear air disc brakes, ABS
Heat type (electric/diesel)	Electric	Auxiliary diesel or electric	Electric	Electric or diesel
Delivery time	8 months	7–9 months	6 months	Not available
WARRANTY INFORMATION				
Battery	8 years/125,000 miles/160,000 kWh discharge	8 years/160,000 kWh discharge (12-year extend available)	5 years/100,000 miles	15 years
Drive	5 years/100,000 miles	5 years/100,000 miles	5 years/100,000 miles	5 years/250,000 miles

TABLE 4

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE D) (CONT.)

	Blue Bird	Lion	GreenPower	BYD
MODEL	**ALL-AMERICAN**	**LIOND**	**BEAST 90**	**TYPE D**
WARRANTY INFORMATION				
Chassis	Standard Blue Bird chassis warranty (5 years or more)	Standard warranty bumper to bumper (8 years)	3 years	12 years/500,000 miles
Additional	*Not applicable*	Up to 12 years	Additional warranties offered for various parts Extended warranties available case by case	*Not applicable*

Note: Abbreviations: TBD = to be determined; kWh = kilowatt-hour; PTC = positive temperature coefficient; DCFC = direct current fast charger; L2 = level 2 charger; Mfr. = manufacturer; ABS = antilock braking system.

Sources: WRI author collaboration with manufacturers listed in table. [a.] Blue Bird: KDE 2022; NYOGS 2022; [b.] GreenPower: Walker 2020.

3.2 Repowered Electric School Buses (Types A, C, and D)

Electric repowering is the process of taking an existing school bus, removing the internal combustion engine components, and replacing them with a new electric powertrain and high-voltage battery (Kelly and Gonzales 2017).[7] Repowered buses can be half the price of a newly manufactured electric bus, be assembled in a shorter timeframe, and work within an existing fleet by extending the useful life of the bus body (Wachunas 2022). Additionally, repowered buses present an opportunity to reduce scrappage and waste—and with fewer components required to complete a build, repowers can limit susceptibility to supply chain delays. A fleet can consist of both repowered and newly manufactured buses as both use the same charging infrastructure.

As of April 2022, there were three companies offering repower solutions—SEA Electric, Unique Electric Solutions, and Lightning eMotors. Table 5 shows currently available options for repowered ESBs from these three manufacturers. As this approach grows in popularity and availability, repower kits, produced by these types of companies, could be used by entities such as dealers and post-production service providers to repower buses nationwide. A repower kit would include all the necessary components and software to fully integrate a new electric powertrain into an existing bus.

Even with this range of benefits, ESB repowering is not without its own set of challenges. On the regulatory side, some states have regulations capping school bus age. In those states, the potential for repowering is limited because buses generally retain their vehicle identification number and therefore their age is not reset after being repowered. Additionally, not all federal funding streams for ESBs can currently be applied to repowers. As of April 2022, repowers remained an emerging solution that could bring dramatic cost savings but had 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. Notable commitments include Unique Electric Solutions' deployment of five repowered Type C buses in New York City and SEA Electric's deal with Midwest Transit Equipment to repower 10,000 school buses through 2026.

TABLE 5

AVAILABLE REPOWERED ELECTRIC SCHOOL BUSES (TYPES A, C, AND D)

	SEA Electric				**Unique Electric Solutions**			**Lightning eMotors**
MODEL	**SEA DRIVE 70A/SEA DRIVE 100A/ SEA DRIVE 100B**	**SEA DRIVE 120A/SEA DRIVE 120B/ SEA DRIVE 120C**	**SEA DRIVE 180A**	**SEA DRIVE 180B**	**UNIQUEEV PLATFORM—TYPE A**	**UNIQUEEV PLATFORM—TYPE C**	**UNIQUEEV PLATFORM—TYPE D**	**ELECTRIC E450**
BUS TYPE (A, C, D)	**A**	**C**	**C AND D**	**D**	**A**	**C**	**D**	**A**
Manufacturer list price	Work with local dealer				$85,000	$125,000	$150,000	$119,900 (powertrain only)
Charger model	SAE J1772 compliant				Compatible with all major brands			Compatible with all major brands
Charger connector	L2: Type 1, Single Phase (208/240 VAC) up to 19.2 kW DCFC (optional): provided through standard CCS1 (Type A, up to 100 kW)				L2: SAE J1772 DCFC: CCS1			L2: SAE J1772 DCFC: CCS1
Capable of bidirectional charging	Yes	Yes	Yes	Yes	Yes			Yes
Battery size (kWh)	88–100	138	220	220	Up to 100	Up to 200	Up to 200	120
Range (miles)	Not available	170–200	Not available	Not available	Up to 180			100
Battery thermal management	Engineered out the need for thermal management				Yes			Dynamic liquid cooled system
Charge port location options	Flexible charge port location				Front, back, left, right	Front, back, right	Front, back, right	Front driver fender
Electric drive-train (Mfr.)	JJE/Dana/provider agnostic				Unique Electric Solutions			Cascadia Motion
Transmission (direct drive/2-speed)	None (direct drive)				None (direct drive)	Direct drive or 2-speed	Direct drive or 2-speed	None (direct drive)
Brakes (air/ hydraulic)	Hydraulic	Hydraulic/air	Air	Air	Hydraulic	Air	Air	Hydraulic
Heat type (electric/ diesel)	Electric				Either electric or fuel fired			Electric driver and cabin heat

TABLE 5

AVAILABLE REPOWERED ELECTRIC SCHOOL BUSES (TYPES A, C, AND D) (CONT.)

	SEA Electric				Unique Electric Solutions			Lightning eMotors
MODEL	**SEA DRIVE 70A/SEA DRIVE 100A/ SEA DRIVE 100B**	**SEA DRIVE 120A/SEA DRIVE 120B/ SEA DRIVE 120C**	**SEA DRIVE 180A**	**SEA DRIVE 180B**	**UNIQUEEV PLATFORM—TYPE A**	**UNIQUEEV PLATFORM—TYPE C**	**UNIQUEEV PLATFORM—TYPE D**	**ELECTRIC E450**
BUS TYPE (A, C, D)	**A**	**C**	**C AND D**	**D**	**A**	**C**	**D**	**A**
Delivery timeline	Electrify in less than 1 month				1–1.5 months			2 months (dependent on chassis availability)
WARRANTY INFORMATION								
Battery	8 years (optional extension up to 12 years)				Up to 8 years			5 years/ 60,000 miles
Drive	3 years/50,000 miles				Up to 8 years			5 years/ 60,000 miles

Note: Abbreviations: kWh = kilowatt-hour; DCFC = direct current fast charger; L2 = level 2 charger; Mfr. = manufacturer; ABS = antilock braking system.

Source: WRI author collaboration with manufacturers listed in table.

4. CONCLUSION

Although school bus electrification is still in its early stages, the school transportation industry has made considerable progress since the first ESBs were deployed in 2014. In particular, the ESB model range has grown—from 60 to 100 miles during Kings Canyon's and Escondido's 2014 deployments to models today that offer between 75 and 210 miles in range, depending on bus type and model. These vehicles were once limited to a handful of pilot programs, but by March 2022, the number of school districts procuring electric models and integrating them into their fleets had grown to 415. At the same time, the number and production capacity of ESB manufacturers has grown substantially, and vehicle features, such as range and bidirectional charging, have improved considerably. As of January 2022, manufacturers offered 22 models of ESBs across Type A, C, and D school buses with more expected to enter the market. Like any new technology, there are still barriers to adopting these buses, such as high upfront bus prices and new infrastructure needs, reliability issues with earlier bus models, and insufficient access to specialized maintenance and technical support. However, ESBs could provide a number of benefits, such as lowering operations and maintenance costs, reducing pollution and emissions, improving students' health and academic outcomes, and bolstering resilience. As school districts navigate this growing market, we hope this publication and its future updates will serve as a valuable resource for school transportation providers interested in adopting electric school buses.

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

The following tables provide key terms, units, definitions, and parallels to diesel operations, where applicable, for ESBs. Table A1 defines terms, and Table A2 defines units.

TABLE A1

ELECTRIC SCHOOL BUS KEY TERMS, DEFINITIONS, AND PARALLELS TO DIESEL OPERATIONS

Term	Definition	Parallel to Diesel (if applicable)	Reference or Example
state of charge (SOC)	For buses: The charge level of the battery	Fuel tank level (full/half/empty)	SOC refers to the level of charge left in the battery, which ranges from 0 to 100% or empty to full on the dashboard.
state of health (SOH)	For buses: Battery health and useful life	No exact diesel parallel; however, general wear and tear has similarities	SOH refers to the maximum charge or capacity of the battery over time and use. Repeated complete discharge or use of a full battery charge (i.e., running until empty) can accelerate battery degradation. Degradation is a normal part of the battery life cycle and will decrease gradually over time.
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 is cheaper than fast chargers with regard to hardware, installation, and utility upgrades.
direct current (DC)	For chargers: A type of electrical current associated with the charger	Refueling—a diesel pump and hose equate to a charger and connector cable	DC is used to describe the electrical current coming from a charger into the bus. Unlike AC chargers, DCFCs deliver DC current directly to the battery so they can charge school buses at faster rates (1.5–4 hours). Fast charging is approximately 8–10 times the cost of L2 charging for the hardware and may incur additional demand charges for electricity. Fast charging may have more of a detrimental effect on battery life and longevity.
bidirectional charging capacity	For buses and chargers: Allows vehicles to both receive and deliver energy externally (V2G, V2B, V2L—collectively V2X)	Unique to electric vehicles	Vehicle-to-grid (V2G): Stored energy is delivered back through facility infrastructure (reverse power flow) to the grid. Vehicle-to-building (V2B): Stored energy in the vehicle is delivered to a facility/building, enabling the bus to serve as an emergency power source. Vehicle-to-another-load (V2L): V2L allows the bus to serve as a mobile charging source to power another load.

Note: Abbreviations: AC = alternating current; DCFC = direct current fast charger; L2 = level 2.

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

TABLE A2

ELECTRIC SCHOOL BUS KEY UNITS, DEFINITIONS, AND PARALLELS TO DIESEL OPERATIONS

Unit	Definition	Parallel to Diesel (if applicable)	Reference or Example
kilowatt (kW)	For buses: Measure of power	Horsepower (HP)	Manufacturers specify a bus motor's power in kW. For example, a typical electric motor can provide 230 kW (308 HP).
	For chargers: Measure of power	No diesel parallel	Different vehicle chargers can deliver electricity at different power levels.
kilowatt-hour (kWh)	For buses: Measure of battery pack energy capacity either as rated (advertised total battery capacity for vehicle), usable (actual accessible battery capacity for operating), or passively consumed (while bus is not driving but still powered on) Unit 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 an 80-to-120-mile range (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/mile for an ESB and 7.5 miles/gallon for a diesel bus. Today's ESB models have the range to serve more than 90% of routes in the United States.
	For chargers: Kilowatts multiplied by total hours, which is a measure of energy	Gallon or liter of fuel	kWh are measured by a utility and charged to customers on their electricity bills.
kWh per mile (kWh/mi)	For buses: The battery capacity (kWh) used for every mile driven Unit 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 is route and climate dependent and impacted by use of air conditioning, heat, or other factors. The greater the efficiency, the lower the energy cost per mile—efficiency can be further 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 while each DC fast charger requires a minimum of 120 amps.
volts (V)	For buses and chargers: Measure of electric potential or electromotive force	Both diesel and electric buses have components that are measured in volts—some applications vary	Voltage varies by battery size and state of charge. For example, both diesel and electric buses have a 12 V battery to power low-voltage components like the radio, clocks, and lights—this battery also provides the starter motor and spark plugs with the energy needed to start an internal combustion engine. With regard to charging, L2 chargers typically use a 208 or 240 V AC power and DC fast chargers can use 200–600 V DC power.

TABLE A2

ELECTRIC SCHOOL BUS KEY UNITS, DEFINITIONS, AND PARALLELS TO DIESEL OPERATIONS (CONT.)

Unit	Definition	Parallel to Diesel (if applicable)	Reference or Example
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: Abbreviations: ESB = electric school bus; L2 = level 2; DC = direct current; AC = alternating current.

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

APPENDIX B. ADDITIONAL RESOURCES

Additional resources that can provide information on ESBs include the following:

World Resources Institute Resources

- Homepage, Electric School Bus Initiative: https://www.wri.org/insights/where-electric-school-buses-us
- Blog Post: "The State of Electric School Bus Adoption in the US" with accompanying dataset—dataset and visualization of ESB adoption nationwide (blog: https://www.wri.org/insights/where-electric-school-buses-us; dataset: https://datasets.wri.org/dataset/electric_school_bus_adoption)
- Highlight Stories—school district experiences with deployment of ESBs including in Stockton, California (https://www.wri.org/update/electric-school-bus-series-stockton-california), Knox County, Missouri (https://www.wri.org/update/electric-school-bus-series-knox-county), and Fairfax County, Virginia (https://www.wri.org/update/electric-school-bus-series-electrifying-partnership-fairfax-county-virginia)

Webinar Recordings and Presentations

- CTE. 2020. "Electric School Bus Webinar Series." https://cte.tv/ctes-electric-school-bus-webinar-series/—Three parts: buses, charging, and costs and funding
- Vermont Energy Investment Corporation. 2019. "Electric School Bus Planning and Lessons Learned." https://www.veic.org/clients-results/reports/electric-school-bus-resources—Webinar
- Dallas Fort Worth Clean Cities. 2022. "EV School Bus." https://www.dfwcleancities.org/events—Three-part webinar series

Electric School Bus Reports and Resources

- Alliance for Electric School Buses. 2022. Washington, DC: electricschoolbuses4kids.org—Resources for advocates and other members of the community.
- Bellwether Education Partners. 2019. From Yellow to Green: Reducing School Transportation's Impact on the Environment. Sudbury, MA: Bellwether Education Partners. https://bellwethereducation.org/sites/default/files/Bellwether_WVPM-YellowToGreen_FINAL.pdf—Examines cases of ESB pilots, pros and cons of impact reduction strategies, funding streams, and recommended next steps for states and districts
- CALSTART. 2021. Zeroing In on Electric School Buses—The Advanced Technology School Bus Index: A U.S. ESB Inventory Report. Pasadena, CA: CALSTART. https://calstart.org/wp-content/uploads/2022/01/ZIO-Electric-School-Buses-2021-Edition.pdf—Inventory of the number of ESBs currently present within the United States
- CALSTART. 2021. Electric School Bus Market Report. Pasadena, CA: CALSTART. https://calstart.org/wp-content/uploads/2021/12/Electric-School-Bus-Market-Report-2021.pdf—Includes vehicle design and model availability, cost considerations, demonstration case studies, and funding opportunities
- Electrification Coalition. 2021. "Dashboard for Rapid Vehicle Electrification (DRVE Tool)." Washington, DC: Electrification Coalition. https://www.electrificationcoalition.org/resource/drve/—Microsoft Excel–based tool that can 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/—Insights from conversations with school districts, private fleet operators, utilities, worker organizations, and others; 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—Guide to school districts on the benefits and challenges of electric buses, how to get started, selecting a manufacturer, and more
- School Transportation News. 2022. 2022 Buyers Guide. https://content.yudu.com/web/1qiu9/0A1rp8i/bg22/html/index.html?origin=reader—School—Bus buyer's guide including but not limited to electric variants, with contact information for manufacturers and dealers
- U.S. PIRG and Environment America. 2021. Accelerating the Transition to Electric School Buses. https://environmentamericacenter.org/sites/environment/files/reports/US_EL%20buses%202021%20Final.pdf—How schools, lawmakers, and utilities can work together to speed the transition to zero-emission buses
- Vermont Energy Investment Corporation. 2019. "Electric School Bus Resources." https://www.veic.org/clients-results/reports/electric-school-bus-resources—Resources include bus model comparisons, utility bill considerations, a charging guide, funding tips, and fuel comparisons
- Vermont Energy Investment Corporation. 2018. Electric School Bus Pilot Evaluation. Winooski, VT: VEIC. https://www.veic.org/clients-results/reports/electric-school-bus-pilot-project-evaluation—Pilot project was a first-of-its-kind deployment of ESB technologies in cold weather environments in the United States

Electric School Bus Manufacturer Websites

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

GLOSSARY

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

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 capable of vehicle-to-grid (V2G), vehicle-to-building (V2B), and vehicle-to-another-load (V2L) are also referred to as being capable of bidirectional charging because of the two-way flow. A vehicle capable of V2G/V2B/V2L (collectively V2X) can serve as a clean energy asset through energy storage, 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 to the battery. The charger cable connection type is specific to the vehicle. It is best for fleets to use the same charger connector, but adaptors are available. SAE J1772 is the industry standard for level 2 (L2) charger connectors. Direct current fast chargers can use either a CHAdeMo or CCS connector. While the CCS plug allows for alternating current and direct current charging on the same port (i.e., L2 or direct current fast charging) as ports come with both CCS and J1772 plugs, CHAdeMo would require an additional J1772 connector to charge with L2.

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 potential cheaper energy but may also 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 so that higher energy is provided to a smaller number of vehicles: 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 could include being parked at or near a driver's home. These operating conditions need to be considered when planning for charging infrastructure. Solutions could include utilizing public charging or installing chargers at other sites such as schools or drivers' homes.

range: Battery capacity, which influences range, can be broken into two components: rated capacity and usable capacity. The rated capacity captures the advertised total capacity of the vehicle while the usable capacity is the actual accessible battery capacity for operating (i.e., some manufacturers may reserve 10 percent of the battery for critical loads). For example, if a school bus is advertised as having 150 kilowatt-hours (kWh) of battery capacity, only 90 percent (135 kW) may be accessible for driving. Range can also be impacted by idling—there are significant potential cost and emission savings for vehicles that idle often, like school buses. Rated and usable capacity and energy used idling are all measured in kWh.

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. This improves overall efficiency and range.

time-of-use (TOU) rates: Through TOU rates, utilities charge a customer on total energy consumed based on the time of day the energy is used. Utilities send price signals to customers to shift consumption from when electricity demand is high to times of day when energy supply is the least expensive to produce or most abundant from specific resources. Customers can save money if they align consumption with off-peak times. Often, TOU rates are designed specifically to support programs like electric vehicle charging or to encourage 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.

ENDNOTES

1. An ESB is considered "committed" starting from the point when a school district or fleet operator has been awarded funding to purchase it or has made formal agreement to purchase it from a manufacturer or dealer. We would not consider an ESB committed if a school district or other fleet operator only expressed interest in ESBs or stated that they plan to acquire ESBs, without awarded funding or an agreement with a third party. More information can be found in L. Lazer and L. Freehafer, *Technical Note for a Dataset of Electric School Bus Adoption in the United States* (Washington, DC: World Resources Institute, 2022), https://www.wri.org/research/technical-note-dataset-electric-school-bus-adoption-united-states.

2. Compared with newly manufactured school buses that are built as electric from the start, a repowered bus removes a vehicle's existing engine and replaces it with a new engine or power source (e.g., an electric drive system). See Section 3.2 for greater detail on repowered buses.

3. More resources from the Electric School Bus Initiative can be found at https://www.wri.org/initiatives/electric-school-bus-initiative.

4. As part of the settlement between Volkswagen and the federal government following allegations that Volkswagen violated the Clean Air Act by selling vehicles equipped with "defeat devices" (i.e., computer software designed to cheat on federal emissions tests), Volkswagen will contribute to an Environmental Mitigation Trust to provide states, territories, and tribes funding to mitigate sources of nitrogen oxides. Each state designated a lead implementing agency, conducted stakeholder meetings, and submitted a state action plan (also known as a Beneficiary Mitigation Plan, or BMP) for use of the funds. One of the eligible mitigation actions was the replacement of school buses. To date, Volkswagen settlement funds have been a critical source of state funding for transportation electrification. More information can be found in K. McLaughlin and J. Balik, *5 Ways US States Can Get More Electric School Buses on the Road* (Washington, DC: World Resources Institute, 2022), https://www.wri.org/insights/how-states-can-transition-electric-school-buses, and Environmental Protection Agency, *Volkswagen Clean Air Act Civil Settlement* (Washington, DC: Environmental Protection Agency, n.d.), https://www.epa.gov/enforcement/volkswagen-clean-air-act-civil-settlement.

5. Electric school buses were considered part of the same batch if any of their time-series data (when they were first awarded, ordered, delivered, or operating) occurred in the same quarter or in adjacent quarters. Batches can consist of ESBs in any phase of the adoption process, meaning that not all are currently in operation. Original analysis was conducted by the Electric School Bus Initiative based on WRI's Dataset of Electric School Bus Adoption in the United States: https://datasets.wri.org/dataset/electric_school_bus_adoption.

6. There are currently no electric models available for Type B school buses as the United States no longer produces Type B school buses for any fuel type.

7. Certain specifications for repowers depend on the vehicle being used, which is why we have removed certain specifications such as passenger capacity, length/width/height, and recharge time.

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ACKNOWLEDGMENTS

This publication was made possible thanks to the support of the Bezos Earth Fund, which provides funding for the Electric School Bus Initiative.

The authors would like to extend their appreciation to everyone at various manufacturers who provided critical insights and information to create a comprehensive scan of the electric school bus market: Andy Moore, Blue Bird Corporation; Daniel Niu, BYD; Ryan Polanco, Endera; Lisa McGhee, GreenPower Motor Company; Randall Ray, IC/Navistar; Jennifer Lawrence, Lightning eMotors; Richard Lee, Lion; Thomas Allen, Phoenix Motorcars; Chris Charlton, SEA Electric; Mark Childers and Greg Webb, Thomas Built Buses; and Michael Backman, Unique Electric Solutions.

We would like to thank the following internal and external reviewers for their feedback and valuable insights (in alphabetical order): Ian Elder, Lorraine Gonzalez, Ron Halley, Dan Lashof, Ryan Sclar, Andy Turgeon, Dan Welch, Benjamin Welle, and Lulu Xue. We would like to thank the following members of the Electric School Bus Initiative: Justin Balik, Brittany Barrett, Tim Farquer, Sue Gander, Greggory Kresge, Stephanie Ly, Michelle Levinson, Lacey Shaver, Hamilton Steimer, Katherine Roboff, and Sebastian Castellanos. Finally, the authors also thank Robin King, Emily Matthews, Carlos Muñoz Pina, Emilia Suarez, and Gregory Taff of WRI's Research, Data, and Innovation Department for their insights; Romain Warnault for coordinating the production process; Bill Dugan, Rosie Ettenheim, and Shannon Collins for design and layout; and Sarah DeLucia for copyediting.

Text in this Isuue Brief was corrected on August 18, 2022. The statement that the range of current electric buses can cover 99% of school bus routes across the country was revised. It was replaced with a statement that the range of current electric buses cover most school bus routes. The citation was removed from the references list.

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ABOUT WRI ELECTRIC SCHOOL BUS INITIATIVE

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

ABOUT WRI

World Resources Institute (WRI) is a global research organization that spans more than 60 countries, with international offices in Brazil, China, India, Indonesia, Mexico, and the United States, regional offices in Ethiopia (for Africa) and the Netherlands (for Europe), and program offices in the Democratic Republic of Congo, Turkey, and the United Kingdom. Our more than 1,000 experts and staff turn big ideas into action at the nexus of environment, economic opportunity, and human well-being. More information at www.wri.org.

Our Challenge

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

Our Vision

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

Our Approach

COUNT IT

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

CHANGE IT

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

SCALE IT

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

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PAGE 2
FatCamera/iStock

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https://doi.org/10.46830/wriib.21.00135

Revised on August 18, 2022