White Paper

Electric School Buses Market Study:

A Synthesis of Current Technologies, Costs, Demonstrations, and Funding

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List of Acronyms

CARB	California Air Resources Board
CEC	California Energy Commission
CMAQ	Congestion Mitigation and Air Quality
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
ConEd	ConEdison
DERA	Diesel Emissions Reductions Act
DOER	Massachusetts Department of Energy Resources
EPA	U.S. Environmental Protection Agency
ESB	Electric School Bus
FAST	Fixing America's Surface Transportation Act
FHWA	Federal Highway Administration
FUSD	Fontana Unified School District
GHG	Greenhouse Gas
GVWR	Gross Vehicle Weight Rating
HVIP	California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
kWh	Kilowatt-Hours
MHDV	Medium- and Heavy-Duty Vehicle

NOx	Nitrogen Oxides
NYSERDA	New York State Energy Research and Development Authority
NYTVIP	New York Truck Voucher Incentive Program
PM	Particulate Matter
RGGI	Regional Greenhouse Gas Initiative
SACAQMD	Sacramento Metropolitan Air Quality Management District
SCAQMD	California's South Coast Air Quality Management District
TCO	Total Cost of Ownership
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
VEIC	Vermont Energy Investment Corporation
ZETI	Zero-Emission Technology Inventory
ZEV	Zero-Emission Vehicle

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Executive Summary

School buses form a critical part of the transportation network responsible for bringing U.S. students to school every day. Each year, approximately 480,000 school buses travel nearly 3.5 billion miles to transport students in every state and municipality, enabling millions of children to receive an education that will form the basis of their professional lives. Many children may not have alternative transportation options and therefore rely heavily upon these buses to get to school. However, current school bus technologies pose short- and long-term hazards. Most school buses in the nation's aging fleet are powered by gasoline, diesel, or propane fuels that emit dangerous criteria pollutants and greenhouse gases (GHGs) into the atmosphere. These pollutants not only contribute to anthropogenic climate change but can also cause significant, long-term health effects on students riding in and around school buses. To address the negative impacts of fossil fuel-powered school bus use, government agencies, school districts, and school bus manufacturers have begun to demonstrate electric school bus (ESB) technology.

Commercial ESB technologies, though relatively new within the past decade, are maturing rapidly to support the growing interest in clean school bus solutions. Vehicles have been deployed and tested in extensive pilot projects around the country, which have validated the technologies and shown that ESBs can meet real-world applications. The demonstration projects establish that school bus duty cycles are conducive to electrification while highlighting areas for improvement in ESB adoption, implementation, and production.

The technological shift to ESB adoption is consistent with CALSTART's framework for heavy-duty vehicle electrification, called the “Beachhead Model.” This strategy identifies a timeline and sequence for vehicles and use cases that are best suited for zero-emission technologies or “beachhead” applications. Following the initial on-road beachhead application of electric transit buses, ESBs are predicted to follow shortly after, joining a broader trend toward medium- and heavy-duty vehicle (MHDV) electrification (Welch, 2020). Vehicle manufacturers, including traditional school bus manufacturers and electric vehicle startups, are meeting current and projected ESB demand with new models (CALSTART, 2020).

Though their purchase costs are falling over time, ESBs may still cost 300 percent more than an equivalent diesel-powered school bus. Lower operating costs improve the total cost of ownership (TCO) over a vehicle's lifetime; however, operators may not realistically achieve payback within an ESB's 12-year lifetime. For school districts with tight budgets, such high incremental costs and uncertain payback periods may present an insurmountable barrier. Funding support or innovative financing models will help make ESBs more affordable to purchase and operate, achieving payback in the short term and bridging the financial gap until ESB technology matures and reaches cost parity with diesel-powered buses.

This report presents the current state of ESB technologies and the market, identifies learnings and conclusions from demonstration projects, and highlights funding opportunities. Such information is intended to guide school districts interested in purchasing and implementing ESBs, as well as inform policymakers on the present status of ESBs and further action required to facilitate ESB adoption.

Section I

I. Background

With their familiar yellow and black color scheme, school buses are some of the most iconic and recognizable vehicles in the United States. In 2017, 480,000 school buses drove a combined 3.5 billion miles in the United States alone, bringing students to and from school, field trips, and sporting events. For many students, this vital service is the only option available for attending school. Nearly a third of students between the ages of five and seventeen rely on school buses to get to and from school every day, making school buses the second most common method of transportation to and from school after private vehicles (Burgoyne-Allen, 2019).

Fleet Composition

The current U.S. school bus fleet is powered predominantly by fossil fuels. Ninety-nine percent of school buses operate on diesel and gasoline, while only 1 percent is electric. Compared to transit buses, school buses lag behind in alternative fuel adoption. As of 2017, 40 percent of transit buses ran on alternative energy sources, such as hydrogen, compressed natural gas (CNG), or electricity (Burgoyne-Allen, 2019). Only 8 percent of school buses sold in 2017 utilized cleaner fuels such as propane or CNG; the rest ran on diesel. Additionally, many school districts cannot afford to replace buses regularly. As a result, diesel- and gasoline-powered school buses tend to be older and more inefficient models, yielding higher fueling costs and emissions outputs.

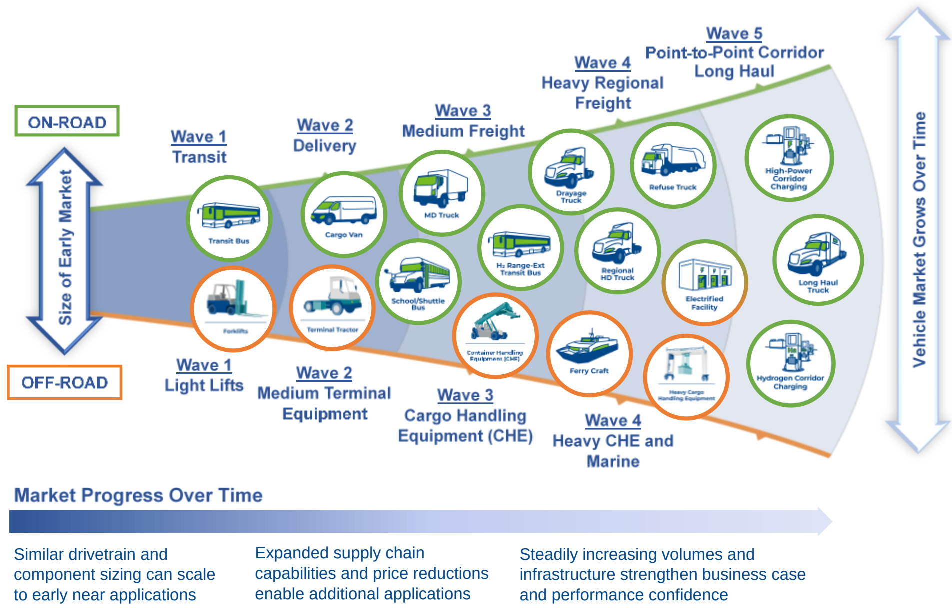
School districts have been slowly exploring ways to reduce air pollution and improve fleet greenhouse gas (GHG) performance while continuing to rely on fossil fuels. This is primarily done by introducing cleaner, low-sulfur diesel fuels and adopting alternative fuels, such as CNG or propane. Both options are significantly cleaner than older, widely used high-sulfur diesel. Given that propane, CNG, and clean diesel buses are considerably less expensive to purchase, require little infrastructure investment, and are well-known and established technologies, these solutions are currently more common than zero-emission alternatives. Alternative fossil fuels have not transformed the clean school bus market, however—only 8 percent of fossil fuel-powered school buses sold in 2017 ran on propane, CNG, or other cleaner alternative fuels (Burgoyne-Allen, 2019). Although cleaner fossil fuels act as a small first step in reducing harmful emissions and providing cleaner air for school children, a full transition to zero-emission fuels must be made to holistically address these problems.

Fortunately, school bus duty cycles are conducive to electrification, as demonstrated by each of the aspects listed below (Duran, 2013):

- Short Ranges: Many heavy-duty vehicles have prohibitively long duty cycles that prevent electrification. However, this is not the case for electric school buses (ESBs). The average school bus travels a 31.7-mile route twice daily for a total of 63.4 miles per day, with 99.7 percent of all school buses traveling less than 155 miles per route (Walkowicz, 2014). These distances are much lower than other heavy-duty fleet vehicles (e.g., transit buses, tractor trucks) (Walkowicz, 2014a). Such short duty cycles allow school buses to comfortably complete entire routes on a single charge, with no worry of operating failure due to a lack of battery power.
- Low-Speed Operations: Large commercial vehicles that drive at low speeds and require frequent stops and starts, such as school buses, operate more efficiently with electric drive trains. Electric motors are more energy efficient at low speeds and can preserve energy through regenerative braking (CARB, 2019). The average speed of a school bus traveling on its route is 23.3 miles per hour, making ESBs approximately four times more efficient than diesel-powered equivalent vehicles. School buses also start and stop frequently on typical routes, with significant idle time, as students enter and exit the vehicle. On conventionally fueled vehicles, this time contributes tremendously to GHG emissions, but electric vehicles do not generate emissions while idling. ESBs stop, on average, nearly twice per mile.
- Charging Opportunities: School buses predominantly operate on two routes per day—one in the mornings to bring students to school and a second in the evenings to return students from school. These routes typically take a few hours each (the average operating time for both routes is 5.26 hours), leaving school buses free to charge and replenish their ranges while sitting idle both during the school day and overnight. This allows buses to take advantage of cheaper electricity prices during the day. Additionally, these significant idle times may allow ESBs to access a new source of revenue in Vehicle-to-Grid (V2G) charging.

The strengths of the ESB duty cycle are described by CALSTART's "Beachhead Model." The strategy defines and identifies "beachheads," or early market applications for successful commercial zero-emission vehicle (ZEV) technological adoption (see **Figure 1**). The beachhead model identifies transit buses as the earliest large-scale, on-road ZEV technology due to their duty cycles and the relatively large budgets, staff, and facilities of transit operators. School buses are part of the second wave of ZEV adoption targets. This strategy was developed by CALSTART in conjunction with the California Air Resources Board (CARB), which has adopted the beachhead model in its strategic investment plans (CARB, 2019a).

Figure 1. The "Beachhead Model" for Zero-Emission Vehicle Applications (Welch, 2020)



Environmental Impacts

Diesel-powered school buses emit dangerous air pollutants and GHGs from their tailpipes. Children are particularly vulnerable to the health effects of diesel exhaust and in-cabin air exposures and have increased risk of developing asthma, other heart and lung-related illnesses, and cancer (Gauderman, 2015). Diesel exhaust emissions, which contribute to developing these diseases, include carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM). These criteria air pollutants spread through school bus cabins during commutes and throughout school vicinities when school buses idle (Li, 2009). A few examples of the negative impacts of diesel-powered school buses include:

- Cancer: Children seated in an older diesel-powered school bus could face toxic air pollutant exposures up to four times as high as a person driving in a car behind a conventional school bus and face up to 46 times greater risk of developing cancer from air pollutants (Weir, 2002).
- Asthma: Though diesel buses were not correlated with a higher prevalence of asthma, diesel emissions were shown to generate "severe wheeze" among children already suffering from the most common childhood disease in the United States (McConnell, 2010).
- Absenteeism: Children with asthma experience higher rates of school absenteeism. By eliminating the health impacts of diesel exhaust exposure, annual absences could be reduced by 14 million incidences across the United States, creating more robust educational opportunities (Adar, 2015).

ESBs not only decrease the dangerous pollutants that harm children, but they also help safeguard children's futures by reducing the long-term impacts of GHG emissions. According to U.S. Environmental Protection Agency (EPA) estimates, in 2018, 28 percent of all U.S. GHG emissions came from the transportation sector. School buses effectively reduce GHG emissions by decreasing the total number of vehicles needed to transport students. However, greater than 90 percent of all school buses are powered by diesel. A diesel school bus will emit 90 tons of carbon dioxide (CO_2) into the atmosphere over the course of its expected 12-year life span, which is equivalent to the GHG emissions of 23 passenger vehicles over the same time period (Zic, 2019; CARB, 2017). In addition to CO_2, diesel buses emit harmful materials, such as the gases NOx and CO, as well as tiny PM known as PM2.5. Finally, many school districts cannot replace these vehicles as often as expected and will use these vehicles for longer than 12 years, generating even more GHG emissions (CARB, 2020).

ESBs produce no tailpipe emissions, thereby reducing adverse health and environmental impacts. Though improvements in diesel engine technologies and fuels have diminished negative health impacts on children, ESBs eliminate these air pollutants and, in doing so, preserve children's health and environment.

Section II

II. Vehicle Design and Model Availability

School buses are a highly specialized, highly regulated type of medium- and heavy-duty vehicle (MHDV) that come equipped with specific safety features to protect their occupants. School buses are also unique in their classification system—lettered A, B, C, and D. Each category describes the size, passenger capacity, and shape of the bus. Typical design and market characterizations for each type are listed in **Table 1**.

Table 1. Comparison of School Bus Types by Design and Market Representation

Bus Type	Maximum Passengers	U.S. Sales 2019 (All Fuels)	Market Share	Cost Range (Electric)	Electric Offered By:
Type A	16-20	8,242	20.24%	$265,000-$335,000	MicroBird, Lion Electric, BYD, Trans Tech-Motiv, Collins-Motiv
Type B	20-30	0	0.00%	Unavailable	None
Type C	60-72	28,787	70.71%	$300,000-$400,000	Blue Bird, Lion Electric, Thomas Built Buses, ICBus, Starcraft, Motiv
Type D	72-90	3,685	9.05%	$345,000-$410,000	GreenPower, Lion Electric, Blue Bird, BYD

Table 1, which was derived from School Bus Fleet's 2020 Fact Book, details four distinct types of buses. The buses are technically distinguished by design features, such as chassis layout, engine placement, and size, but there are many important details that characterize each type.

- **Type A** buses are the smallest and generally least expensive school bus type, carrying up to 16 and 30 passengers and holding a gross vehicle weight rating (GVWR) of less than 21,000 lbs. (Schetky, 2018). Type A buses typically come in two different variations: the smaller type A-I, with a GVWR less than 14,500 lbs., and the slightly larger type A-II, with a GVWR greater than 14,500 lbs. These vehicles are commonly used for smaller neighborhood schools with short routes and fewer students per route. With their increasing popularity and widespread use, several companies offer type A buses, including MicroBird (a subsidiary of Blue Bird), Motiv, and Lion Electric.
    - The modularity of this bus type supports partnerships between manufacturers and vehicle modifiers and upfitters. Motiv's Type A models offer strong examples of these partnerships, conducted separately with vehicle manufacturers Collins and Trans Tech. The resulting products with each of these partnerships are 24-foot ESB models with a range of 105 miles on a single charge and a Lithium-Ion battery that can produce up to 127 kilowatt-hours (kWh) of power. These models are larger type A-II vehicles and can seat up to 24 passengers (Motiv, 2021).
- **Type B** buses, the next largest classification of buses capable of transporting up to a maximum of 20 and 30 passengers, have practically disappeared from the new school bus market. The type B models available typically consist of older diesel models that are still on the road, but no new 2019 sales were made in this category.
    - No manufacturer currently offers type B electric offerings.
- **Type C** buses, which many consider to be the iconic school bus type, made up 70 percent of the vehicles sold in 2019 (School Bus Fleet, 2020). With a classic, recognizable school bus hood, front fender, and long body (unlike the van-like type A and the transit-style type D), type C buses typically carry up to a maximum of 60 and 72 students and tend to make longer trips than type A buses.
    - Almost every major ESB manufacturer offers a type C bus, giving school districts a variety of options. A selection of type C ESB models is described in Table 2 below.
- **Type D** buses, or transit-style school buses, are the largest type of school bus. They have many features in common with a traditional transit bus, including a flat front and a door placed in front of the front wheels. These buses have the largest capacity of any school bus offered, up to a maximum of 72 and 90 students. Type Ds are the least common of the three school buses sold in the current market, making up 9.05 percent of U.S. school bus sales in 2019. Furthermore, sales in 2019 had decreased 17.9 percent from 2018, as many school districts prefer to rely on the smaller type A (School Bus Fleet, 2020). Several manufacturers do provide electric versions of this school bus type, including GreenPower, BYD, Lion Electric, and Blue Bird.
    - New entrants continue to expand this ESB segment. For example, BYD introduced a type D ESB platform in June 2021. This platform can be modified to lengths of 25, 38, and 40 feet; seat up to 84 passengers; and achieve a 155-mile range on a single charge. The

vehicle comes equipped with optional V2G capability, allowing the bus to sell electricity to the grid and further reduce operational costs (BYD, 2021).

Various manufacturers offer ESBs for purchase in the United States. Derived primarily from Vermont Energy Investment Corporation's (VEIC) 2019 Electric School Bus Resources, **Table 2** describes the specifications of a select few type C ESBs available in the Drive to Zero program's Zero-Emission Technology Inventory (ZETI), an online, publicly available tool aimed at cataloging models of current and upcoming zero-emission commercial trucks, buses, and select off-road equipment.[1]

Table 2. Comparison of Select Type C Commercially Available ESB Models

Manufacturer	Starcraft	Lion Electric	Thomas Built Buses	Blue Bird	IC Bus	Motiv
Battery Manufacturer / Chemistry	BMW Lithium Ion	Lithium Ion NMC	Proterra Lithium Ion NMC	Lithium-Nickel-Manganese-Cobalt Gel	Lithium Ion	Sodium-Nickel
Battery Capacity	127 kWh	220 kWh	226 kWh	155.5 kWh	107 kWh 214 kWh 321 kWh	217 kWh
Maximum Passenger Capacity	48	72	81	77	Wheelbase dependent	Wheelbase dependent
Range	105 Mi	155 Mi	138 Mi	120 Mi	250 Mi	100 Mi
Heating System	Air Electric Heating	Auxiliary Heating	Electric	Electric	TBD	TBD
V2G Compatibility	V2G Capable	Optional V2G Capability	V2G Capable	Optional V1G Capability	Optional	No V2G Capability
Estimated Full Charging Time	8 hours	4-11 hours	3 hours	7.3 hours	12 hours	8 hours
Price	$300,000	$305,000-$395,000	$320,000-$400,000	Quote from dealer	Quote from dealer	Quote from dealer
States Deployed	CA	CA, MA, NY, MN	Taking Orders	CA, ND, NJ, NY	Taking Orders	Unknown

[1] The ZETI tool can be found online at: https://globaldrivetozero.org/tools/zero-emission-technology-inventory/

Section III

III. Cost Considerations

The costs of owning and operating a school bus are commonly divided into two categories: capital and operating costs. An ESB's total cost of ownership (TCO) may be higher than diesel buses primarily due to higher purchasing costs, but operational costs considerably reduce the overall costs of the vehicle. School districts with tight budgets may not have much extra capital to invest in new technologies, but reduced operating budgets will likely help offset higher capital costs.

ESBs are typically more expensive to purchase than their diesel counterparts due to the relatively new technology and the price of batteries, which, while declining, still adds a significant cost to the ESB. The average new diesel school bus costs approximately $90,000, whereas an ESB can cost between $300,000 and $400,000—up to four times greater than the cost of a diesel school bus. ESBs can typically charge without highly specialized equipment, requiring Level 2 stations that charge vehicles at depots when not in use for extended periods, such as between shifts and overnight. Level 2 charging is considered relatively inexpensive; stations may cost a few thousand dollars, may not require additional electric capacity, and provide electricity at a rate that does not incur expensive demand charges (Saxton, 2011). In cases where fleet operators must purchase and install specialized charging infrastructure, such as direct current fast charging stations, infrastructure costs may ramp up. Potential cost considerations include the price of hardware, installing charging equipment, administering permits and software, and managing parking facilities if more space is required. Further upfront costs may include retraining bus drivers and maintenance staff on ESB operations.

The high upfront costs of transitioning to ESBs will be mitigated by lower fueling and operational costs. Generally less expensive and a more stable transportation energy source than fossil fuels, electricity is highly regulated, and not prone to extreme fluctuations like the price of petroleum-based fuels (Nigro, 2015; EIA, 2021; Baumhefner, 2011). Access to a predictably priced, low-cost fuel is valuable for school districts that often have relatively tight budgets. Given the higher upfront costs, fuel savings are critical to lowering the total cost difference between ESBs and diesel-powered buses. Maintenance costs are also typically lower for electric-powered vehicles, owing mainly to the simplicity of the vehicle design, which uses fewer components. In combination, these lower operating costs make the total cost of ESBs more affordable for school districts.

Funding for ESBs and infrastructure is extremely valuable, and in many cases likely necessary, to make ESBs affordable for school districts. To illustrate the impact of funding availability, **Figure 2** draws from the CARB TCO estimator[2] to show the payback periods of a hypothetical ESB project with (at left) and without (at right) purchase incentives. The projection does not include infrastructure costs.

Figure 2. Payback Periods for a Hypothetical ESB Project (Clean vs. Baseline) Including and Excluding Purchase Incentives (Discounted Cash Flows)

Using funding available only through the California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), this hypothetical bus project achieves payback within the estimated vehicle lifetime, saving school districts money. Without HVIP funding or any other support, current ESB technologies will reduce operating costs but will not achieve payback over the expected 12-year lifetime of a school bus.

In addition to validating early ESB technologies, the following case studies highlight the value of funding. In every case, state funds offset the higher marginal costs of ESBs, and several projects also reduced the costs of purchasing and installing associated charging infrastructure.

[2] The CARB TCO estimator can be found online at: https://www.californiahvip.org/tco/

Section IV

IV. Demonstration Case Studies

ESB solutions are still relatively new, so school districts have been introducing ESBs through demonstration projects to prove the latest technologies. These projects run ESBs in real-world duty cycles to evaluate feasibility.

School districts are examining several aspects of ESB performance, such as evaluating the vehicle's ability to adequately perform a typical school bus duty cycle, becoming familiar with charging practices and procedures, and assessing ESB financial performance. School districts can use the results of these demonstration projects to inform their purchasing decisions and provide specific feedback on how ESBs will fit into their operations.

This section will summarize four different demonstration projects that have recently taken place across the United States. These projects highlight separate, noteworthy issues that school districts consider when purchasing school buses:

- The Twin Rivers Unified School District project, one of the first ESB demonstration projects in the United States, illustrates the feasibility of early technologies in real-world applications and the value of stacking incentives.
- The Fontana Unified School District (FUSD) is part of one of the largest ESB demonstration projects, with dedicated funding and efforts specific to ESB charging infrastructure.
- The Massachusetts Department of Energy Resources (DOER) initiated one of the first pilot projects to demonstrate the feasibility of ESBs in cold weather climates.
- The White Plains City School District's ESB pilot project examines the feasibility of V2G integration in a school bus's duty cycle.

Twin Rivers Unified School District: The Pilot Project of Electrification Transition

Table 3. Twin Rivers Unified School District ESB Pilot Project Details

Pilot Project Duration	School Bus Manufacturer(s)	Number of Buses	Cost per Bus	Funding Organization(s)	Funding Received
2016-2018	Lion Electric, Motiv	16	$60,000-$100,000	CARB, CEC, SACAQMD	$8.5 million

The Twin Rivers Unified School District in north-central California was one of the first school districts in the nation to purchase new ESB technologies. The school district is located in a relatively low-income area, with 97 percent of its 5,000 students relying on reduced-cost lunch programs at schools. Reflecting its limited budget, the buses that Twin Rivers operated before the demonstration project were old and out of date. To finance its ESB project, Twin Rivers relied principally on external funding sources to make up the marginal costs of the buses and infrastructure. The school district's financial challenge of acquiring ESBs represents the challenges that many other U.S. school districts pursuing electrification will encounter.

The project (**Table 3**) was undertaken in 2016 with funding from CARB, the California Energy Commission (CEC), and the Sacramento Air Quality Management District (SACAQMD). These agencies awarded Twin Rivers a total of $7.5 million to purchase 16 buses and the accompanying charging infrastructure. The Sacramento Municipal Utilities District also provided Twin Rivers with financial assistance, giving $1 million for charging and preferential electric rates. The school district used these funds to reduce the marginal cost of purchasing 16 buses, split equally between Lion Electric and Motiv/Trans Tech. Each purchase cost the school district between $60,000 and $100,000 for buses that would typically cost up to $400,000.

The findings from the project were primarily positive, but the project also uncovered a few challenges:

- ESB operators reported no consistent issues on the school bus range, confirming that the buses could complete their entire daily duty cycles but were unable to complete some field trips.
- Operators also reported considerable operating cost savings, particularly from reduced fuel costs. Twin Rivers paid $0.10 per kWh, approximately 80 percent less than the cost of diesel on an energy-equivalent basis.
- A few minor equipment issues, such as production delays or faulty lightbulbs, were experienced by the Motiv vehicle, but issues were addressed during the project and will continue to be improved upon by the manufacturer.

- Additionally, Motiv's previous battery technology required a couple of days to warm and has experienced intermittent failure to charge overnight. Two of these buses did not have the range to be used on all the field trips that Twin Rivers had planned. Since 2018, Motiv has updated their battery makeup to address the issues experienced.

Twin Rivers judged the project as a success despite any challenges, subsequently expanding their ESB fleet by purchasing nine more buses—five Blue Bird buses and four additional Lion Electric buses. The fleet now operates 25 ESBs, along with 37 CNG-powered buses, out of a total of 125 school buses. The school district's director has become an ambassador for ESBs, giving interviews and talking regularly about the successes of the Twin Rivers demonstration project. The school district also loans the buses to neighboring districts for testing before purchasing ESBs of their own.

Fontana Unified School District (FUSD) and SCAQMD: Large-Scale Ordering and Infrastructure Challenges

Table 4. FUSD and SCAQMD ESB Pilot Project Details

Pilot Project Duration	School Bus Manufacturer(s)	Number of Buses	Cost per Bus	Funding Organization(s)	Funding Received
2017	Blue Bird	2	$248,000	HVIP, Carl Moyer Program	$536,000

In 2017, California's South Coast Air Quality Management District (SCAQMD) funded one of the largest ESB demonstration pilot projects to date in the United States. SCAQMD provided $8.8 million to 16 California school districts and two charter schools, many of which were located in disadvantaged communities. A total of 33 ESBs were ordered across the school districts: seven from Blue Bird, four from Green Power, five from Lion Electric, and 13 from Motiv. FUSD, one of the 16 districts funded by the SCAQMD project, used $496,000 to purchase two type D Blue Bird ESBs (**Table 4**). The funding allocation also included an additional $40,000 ($20,000 per bus) for two 19.3 kW charging stations, with Edison International providing technical assistance.

Production delays initially beset the SCAQMD bus deployments. By the end of the testing period, on September 30, 2018, 12 of the 33 purchased buses had been delivered: those from Blue Bird and Lion Electric. The remaining 21 buses would be delivered over the course of the following year, much later than the intended delivery date. These delays may indicate that while some manufacturers may be able to produce ESBs at initially smaller volumes, scaling production to greater volumes may require added experience and expertise. Installing charging equipment proved to be one of the most time-consuming and complex steps of ESB adoption for many of the project's school districts. The time required and costs to install charging infrastructure varied greatly by school district, as each district had unique charging site characteristics. The project budgeted nine months for infrastructure installation, but many school districts needed additional time. Issues such as upgrading the power supply, installing a dedicated meter, requiring public works triggers for contracting bids, navigating permitting processes and California Highway Patrol Certification, and scheduling contractors all caused major delays. For two charging stations, total installed infrastructure costs ranged from $40,000 up to $100,000, varying due to factors such as access to adequate power supply, the distance between charging site and power supply, and the power rating of the charging infrastructure.

The statewide project provided $20,000 for the purchase and installation of each charging station. This amount was sufficient only in best-case scenarios and generally fell short of fully supporting the installations. FUSD's charging station installations cost $25,000, over half of the total infrastructure budget. The installation costs did not include the hardware, training costs, technical assistance, or any project management costs. FUSD was able to limit additional costs because it did not need to upgrade existing electrical capacity to accommodate charging its two ESBs. Policymakers and school districts should be aware of the total costs of purchasing and installing charging infrastructure. With greater planning and expertise for vehicle production schedules and the actual costs of infrastructure, funders and school districts should be able to expand their ESB fleets more smoothly.

Massachusetts Department of Energy Resources (DOER): ESBs in Cold Weather Climates

Table 5. Massachusetts DOER ESB Pilot Project Details

Pilot Project Duration	School Bus Manufacturer(s)	Number of Buses	Cost per Bus	Funding Organization(s)	Funding Received
2015-2017	Lion Electric	3	$133,000	RGGI	$400,000

In 2015, the Massachusetts DOER, in conjunction with VEIC, began a pilot project with three school districts in the state: the rural and small-town Amherst Regional Public School District, the suburban Concord Public School District, and the densely populated Cambridge Public School District (**Table 5**). The project was funded by proceeds from the Regional Greenhouse Gas Initiative (RGGI) and administered by the Massachusetts DOER and VEIC with the stated purpose of monitoring the economic and practical feasibility of ESB technologies as practical alternatives to traditional diesel buses. This project was the first of its kind to take place in a cold-weather climate, which can reduce the energy efficiency of ESBs by generating heat to control cabin temperatures—diesel-powered buses are able to apply waste heat from their engines without sacrificing efficiency. Prior to the Massachusetts project, most early ESB demonstration projects took place in California, where winters are not typically as cold.

The project's three school districts were chosen to represent different segments of the commonwealth: rural Amherst Regional Public School District, suburban Concord Public School

District, and densely populated Cambridge Public School District. Each school district was awarded $400,000 for a single ESB and charging equipment. All three school districts purchased a Lion Electric school bus for $325,000 each and spent the rest of the funds on three alternating current Level 2 chargers, two from Tesla and one from Clipper Creek. However, one of the Tesla chargers was swapped out for a Clipper Creek charger during the demonstration project.

VEIC summarized the 14-month project results when the demonstration project concluded in 2017 (VEIC, 2018):

- The buses used diesel-powered auxiliary heaters to heat the cabins during the winter months. Therefore, cold weather had little tangible impact on ESB range and performance. The buses' range fluctuated between 80 miles above 75 degrees Fahrenheit and down to 60 miles at 20 degrees Fahrenheit. The 25 percent range decrease did not prevent the buses from completing their routes.
- The diesel-powered auxiliary heaters preserved range but may have generated in-cabin air pollutants at a rate similar to traditional school buses powered entirely by diesel. Air quality measurements were performed in January, during peak winter hours, so VEIC attributes the lack of improvement to the diesel pollution emitted in-cabin.
- Driver experience had a much greater impact on bus range and energy efficiency than cold weather. School districts that used the same driver throughout the project had much higher and more consistent ranges than those rotating their drivers. Drivers that are experienced ESB operators are better able to maximize factors such as regenerative braking to keep the vehicles as efficient as possible.
- Unmanaged charging, or charging the vehicles without consideration of factors that impact costs such as the time of day or total load uses, caused fueling costs to be much higher than school districts had expected. The additional charging costs increased from an anticipated $1.40 per kWh up to $2.38 per kWh. School buses remained plugged in, incurring demand charges during peak hours and drawing loads 63 percent higher than necessary. School districts found that plugging in the buses solely overnight and during the weekend significantly reduced costs and increased efficiency. A cost-effectiveness analysis on potential managed charging cost-savings concluded that it would have saved school districts up to $477.28 per month.
- Coordinating with the vehicle manufacturers and vendors is critically important to keeping the vehicles available and operational. Technical issues with buses included problems with the headlight, the onboard computer, and the battery. Technical support was made more difficult by the newness of the technology and managing shipping parts across the U.S. border from Canadian-based Lion Electric. As the industry grows and matures, and robust training programs become more available, technical and vendor coordination issues should become less frequent and more easily managed.
- VEIC conducted an exploratory analysis on V2G and Vehicle-to-Building (V2B) integration,

concluding that the equipment required would cost upwards of $10,000, which may not be feasible for school districts on restricted budgets (VEIC, 2018).

Each district decided to retain its ESB as a part of its fleet, and Concord has instigated preliminary steps to purchase more buses. The project concluded that ESBs offer a promising alternative to diesel-powered buses but require additional development and demonstration. Issues with ongoing maintenance and coordination, managed charging, and air pollution from diesel-powered auxiliary heaters need to be resolved before ESBs are truly practical as replacements for diesel-powered school buses. As one of the earliest completed ESB demonstration projects, the Massachusetts DOER supported technological and management improvements and facilitated future efforts to transition to clean school bus technologies effectively.

White Plains City School District: Demonstrating V2G Integration

Table 6. White Plains City School District ESB Pilot Project Details

Pilot Project Duration	School Bus Manufacturer(s)	Number of Buses	Cost per Bus	Funding Organization(s)	Funding Received
2018 - Ongoing	Lion Electric	5	$50,000	NYSERDA, ConEd	$250,000

The White Plains City School District, located outside of New York City, began an ESB demonstration project in 2018 with the intent to test the feasibility of V2G integration in school buses (**Table 6**). V2G describes a system that allows electrified vehicles to communicate and interact with the electric grid to manage charging or send power from the vehicle batteries to the grid. Utilities and school districts may be interested in V2G by using ESB batteries to manage electric grid demand during peak hours or provide regulating services. The project brought together multiple regional partners to raise the funding and help manage the project.

- The school district works with bus operator National Express to transport 5,000 students (over 70 percent) to and from school.
- White Plains and National Express partnered with the New York State Energy Research and Development Authority (NYSERDA) and the local utility company, ConEdison (ConEd), to purchase five Lion Electric school buses. The project received $100,000 from NYSERDA and $120,000 from ConEd to buy the five buses and accompanying infrastructure (New York State DPS, 2021).
- The New York Truck Voucher Incentive Program (NYTVIP), administered by NYSERDA with support from CALSTART, provided $110,000 for the purchase of each bus.

ConEd proposed the White Plains project primarily to test the viability of V2G integration technology with ESBs. ConEd has access to the bus batteries during the middle of the day and summer months when the buses sit idle in depots to store power and offset demand. ConEd pays the school district for the use of its ESB batteries, and the utility has also paid for specialized equipment to enable V2G integration, such as adaptors and converters, to allow for bidirectional power flow and charging management software to regulate this process. Through the project, ConEd plans to evaluate V2G's technical and operational viability in school bus fleets, with particular attention paid to the rate of physical degradation that regular V2G operations have on ESB batteries.

The project kicked off in the fall of 2019 with a three-phase structure:

1. Operate and monitor the five buses throughout the 293 days of the 2019-2020 school year, proving the viability of ESBs in White Plains.
2. Demonstrate V2G technology and ensure the technology will work when the buses are not in service.
3. Demonstrate an "on-road" V2G technology test that combines the two previous phases to establish that ESBs and V2G are compatible for a typical school bus duty cycle. (Note that this phase is still in progress, and results have yet to be publicized.)

Although the demonstration is ongoing, a ConEd progress report indicates that the ESB operations have been "stable and excellent," noting that drivers tend to prefer operating the ESBs more than the conventional diesel-powered buses (ConEd, 2020). The ESBs experienced relatively little downtime due to maintenance issues; in total, ConEd reported the buses had an uptime of 95 percent during the 2019 testing period. The most significant downtime was unrelated to typical maintenance issues, occurring during a five-week stretch when the buses were retrofitted with the V2G technology.

Section V

V. Funding Opportunities

The prevalence of funding programs in each demonstration project indicates how important bridging the financial gap between diesel-powered school buses and ESBs will be for school districts. This section provides examples of funding programs and opportunities that are currently available, though funding availability is likely to change over time and new programs may emerge. School districts and fleet operators should search for all available funding streams to support their ESB transition, particularly since separate funding programs may often be stacked and create greater financial incentives for ESB adoption. For fleet operators in California, the "Funding Finder" tool developed by CALSTART enables a search for all applicable funding streams.[3] Specific funding opportunities and strategies exist that can be and have been pursued by school districts looking to electrify their school bus fleet.

Federal programs offer widespread opportunities to reduce the costs of ESB adoption. Funding for ZEVs, including ESBs, may be available through several agencies and programs that include:

- The Diesel Emissions Reductions Act (DERA) initiated an EPA-managed program that finances the replacement of old diesel-powered vehicles of all types with newer, cleaner technologies. The DERA program frames clean technologies broadly, listing new diesel vehicles, ZEVs, and other technologies as eligible under the replacement program (EPA, 2021).
- The School Bus Replacement Program nested under the DERA program specifically funds school bus replacements or retrofits. Funding amounts for this program have steadily increased—in 2019, DERA awarded $11.5 million to replace or retrofit old diesel school buses to school districts across the country (EPA, 2021a).

In many cases, federal or regional funding is awarded to states to allocate discretionarily, as seen in the following programs:

[3] CALSTART's Funding Finder Tool can be found online at: https://fundingfindertool.org/?

- The federal Fixing America's Surface Transportation (FAST) Act is managed by the Federal Highway Administration (FHWA) to allocate federal transportation funding. The FHWA operates several distinct programs through the FAST Act, including the Congestion Mitigation and Air Quality (CMAQ) program that disburses funding to individual states to finance air quality improvement projects (FHWA, 2016).
- Appendix D of the Volkswagen Settlement created a single Mitigation Trust that disburses the settlement funds to individual states based on an established schedule (C2ES, 2016). Each state can choose from a suite of mitigation actions, including replacing or repowering existing school buses with ESBs (Burgoyne-Allen, 2019). Several states, including Vermont, Minnesota, Arizona, Washington, and Michigan, are dedicating a portion of their funds from the Volkswagen settlement towards new, cleaner school buses, with some, like Washington, establishing specific funds for ESBs. The NYTVIP blends funds from CMAQ and the Volkswagen Settlement to provide point-of-purchase rebate vouchers for eligible commercial vehicles, including ESBs (NYSERDA, n.d.).
- The RGGI in New England and the Mid-Atlantic places a cap on electric sector GHG emissions and generates revenue through an auction system. These proceeds are distributed to participating states, which can choose from eligible GHG abatement categories that include transportation programs (RGGI, 2020).

States may provide dedicated funding programs that are specific to ESBs or more broadly for clean commercial vehicles:

- California is a leader in ESB adoption and has established many programs that assist school districts in purchasing ESBs. The CEC School Bus Replacement Program is a $94 million program that replaces school buses with ESBs in public school districts and county offices of education. CARB's HVIP operates similarly to NYTVIP, offering point-of-purchase rebate vouchers for eligible commercial vehicles, including ESBs. CARB also manages the Rural School Bus Pilot Project that replaces older school buses in rural areas with clean vehicles, including ESBs.
- Several other states manage programs that financially support school districts' transitions to ESBs:
    - Oregon's clean school bus grant program funds purchasing new buses or retrofitting old buses to reduce overall emissions (DEQ, n.d.).
    - The Illinois School Bus Retrofit Reimbursement Program funds retrofitting old diesel buses, but also provides funds for purchasing new ESBs (AFDC, n.d.i).
    - Mississippi's revolving loan program offers zero-interest loans to school districts for purchasing alternative fuel school buses and the necessary infrastructure to power them (AFDC, n.d.ii).

Utilities are natural partners for ESB projects, and in some situations, they can provide financial support to school districts or fleet operators:

- In Minnesota, the Lakeville Area School district partnered with the local utility companies, Dakota Electric Association, and Great River Energy to fund a pilot ESB in the fall of 2017 (Jossi, 2017).

- Dominion Energy in Virginia works with school districts to pay for the marginal costs of up to 50 ESBs and, similarly to ConEd in White Plains, will test V2G technologies when the buses are idle (Dominion Energy, 2020).
- California's SB 350 requires utilities to consider transportation electrification in their public utility rate filings (CPUC, n.d.). The California Public Utilities Commission has approved ESB demonstration projects at each of the three investor-owned utilities, which also plan to invest in expansive non-residential charging station rebates to financially support school districts (Baumhefner, 2019).

Private companies may also emerge to provide financial management services to school districts unable to afford the higher upfront costs of ESBs and associated charging infrastructure. For example, Highland Electric Transportation borrows strategies from the energy sector by purchasing the vehicles and infrastructure and leasing the equipment to school districts, earning back their investment through operational savings and V2G operations. Highland placed the fourth ESB in Massachusetts, following the three vehicles deployed during the Massachusetts DOER demonstration project (Shemkus, 2020).

Section VI

VI. Future Outlook

ESBs appear to have strong potential for rapid market growth. Demonstration projects have exhibited that zero-emission technologies present viable, cleaner alternatives to traditional diesel buses. Additional demonstration projects are being funded in increasingly diverse geographical locations beyond California. Production scale is increasing, and the decreasing costs of vehicle production are making ESBs more affordable to any school district. Bloomberg predicts that by 2030, battery pack prices will drop nearly 65 percent from 2018 prices (Goldie-Scot, 2019). With improved battery price and performance, ESB TCO will likely outperform diesel-powered school buses.

New technologies and models will also help ESBs fully meet all duty cycles and fleet needs. The ESB market is relatively new, yet by 2021, nine different manufacturers plan to offer 17 distinct school bus models in the North American market, with multiple model options available for each currently commercial school bus type (CALSTART, 2020). Additional model availability and flexibility may occur as zero-emission technology companies continue to develop and innovate. For example, zero-emission transit bus manufacturer Proterra has partnered with traditional school bus manufacturer Thomas Built Buses to produce ESB models (Sustainable Bus, 2018). Sustained innovation in zero-emission commercial vehicles, which use similar drivetrains and other components, will reduce costs and yield benefits for ESBs and other ZEV applications (Welch, 2020).

V2G integration also offers promising cost-saving potential. ESBs are situated well to incorporate V2G operations, with predictable duty cycles and long downtimes during the day—this often lines up precisely when electricity demand is highest and creates the greatest opportunity for V2G cost savings. Utilities and private companies are already incorporating V2G into their projects and business models in White Plains, Virginia, San Diego, and Beverly, Massachusetts. While actual cost savings have not yet been assessed given the newness of the technology, many experts are beginning to report that ESB solutions are viable and cost effective.

Funding to help school districts bridge the financial gap of purchasing ESBs has increased at federal levels and across states. Total DERA grant values for school buses have increased every year since 2006, Volkswagen Settlement funding has been creatively distributed to help zero-emission fleets grow across the country, and funding programs for commercial ZEVs have proliferated in-state programs) such as New Jersey's recently proposed program for Supporting the Transition to Zero-Emission Commercial Transportation (Motavalli, 2020; NJEDA, n.d.). These programs and funding streams will be needed in the short term to support a transition to a sustainable, affordable ESB market. School districts and fleet operators can choose from several tools to estimate their financial needs and find appropriate funding streams. VEIC's online calculator is specifically designed to help school districts calculate the costs of electrifying their fleet by estimating maintenance costs, energy costs, and any local grant funding that may be available (Wallace-Brodeur, 2019a).

Section VII

VII. Conclusions

ESBs are an emerging, multi-faceted technology that can resolve the problems of dangerous air pollution and GHG emissions emanating in and around school buses. From the research and case studies presented in this report, ESBs can be shown as:

- **Technologically viable:** School bus duty cycles are ripe for electrification, confirmed by ESBs' performances in demonstration projects. ESBs were able to meet daily driving ranges consistently and performed reliably in cold weather. In Twin Rivers and White Plains, drivers reported that they preferred operating ESBs over diesel-powered models. Maintenance issues impacted two of the earlier demonstration projects, but the more recent projects indicate that vehicle performance and maintenance management has dramatically improved, making ESBs a reliable technology.
- **Healthier:** ESBs provide a solution to two persistent problems: unhealthy air in and around school buses and GHG emissions that endanger the climate. With the electric grid producing fewer emissions and the energy efficiency of electric motors, ESBs greatly reduce GHG emissions from diesel-powered bus operations. ESBs also eliminate tailpipe air pollutants and significantly reduce PM emissions. To ensure these air quality benefits, cold weather operators may need to find alternate solutions to fuel-fired diesel heaters.
- **Available:** The number of ESB models and manufacturers has proliferated over the past decade; by the end of 2021, nine manufacturers will offer 17 distinct models covering each commercially viable school bus type. These vehicles are broadly available across North America, with deployments ranging from California to Massachusetts and New York. Manufacturers are scaling up production and improving upon delivery schedule performance.
- **Affordable to operate:** TCO calculations and demonstration projects show that ESBs reduce costs and save money over time due to lower fueling and maintenance costs. To fully realize these benefits, school districts and fleet operators must manage charging to avoid excessive

demand charges and must coordinate with vendors to plan for maintenance projects. Training drivers and keeping them on ESB routes also generates savings by improving efficiency. V2G integration may add a significant revenue source for school districts and has already drawn partnerships with utilities and third parties, though the technology must be validated in practice.

ESB deployments are also currently reliant on alternative financing to reduce higher upfront costs. The new vehicle technologies can cost up to $400,000, more than four times the cost of a comparable diesel bus, and infrastructure may add significant costs before an ESB can start to earn a return on investment. School districts often do not have large capital budgets and must balance other priorities with clean transportation, so many are not able to afford the long-term investment of ESBs. Federal, state, and local funding programs are dependable resources for reducing ESB costs, and partnerships with utilities and third parties are providing innovative new strategies to support school districts. Though the costs of batteries and zero-emission technologies are falling over time, alternative financing will be needed in the next decade to support rapid ESB growth. With a lower barrier to purchasing and operating ESBs, school districts can use the new technologies to reliably and cleanly transport their students, all while saving money in the process.

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