Electric School Bus Pilot Project Evaluation

Prepared for the Massachusetts
Department of Energy Resources
By the
Vermont Energy Investment Corporation

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1 Executive Summary

The Massachusetts Department of Energy Resources (DOER) initiated a pilot project to test electric school buses in school transportation operations. The pilot project was a first-of-its-kind deployment of electric school bus technologies in cold weather environments in the United States. Through this project, three electric school buses were deployed at three school districts around the state and bus operations and reliability tracked for approximately one year. The project was designed to understand the opportunities and challenges associated with using electric school buses as a strategy to provide safe, reliable, cost effective school transportation. Electric school buses also present an enormous opportunity to reduce greenhouse gas emissions from school transportation, as well as other tailpipe pollutants. Diesel is known to be particularly harmful to both children's health and the climate. A primary barrier to electric school bus adoption is a much higher upfront vehicle cost relative to diesel buses. However, there is potential that the upfront costs of electric buses are mitigated and even negated in the long term by reduced fueling and maintenance costs. This assumption has not been rigorously tested in the field, and that was a key objective of this pilot. In addition, this project sought to test the potential of electric school buses to interact with the electric grid through the use of vehicle to grid (V2G), as well as interaction with local energy use through vehicle to building (V2B) technology. Vehicle-to-grid interaction can reduce electric school bus costs through financial paybacks to school districts for bus-provided grid services, and strengthen the resiliency of local energy systems.

This pilot project was funded through the Regional Greenhouse Gas Initiative (RGGI) with roughly $2 million and administered by the Massachusetts State Department of Energy Resources. RGGI funding was also used to procure consultant support to help manage implementation of the pilot project and lead an evaluation of the effort. This work, provided by the Vermont Energy Investment Corporation (VEIC) included assistance with soliciting participating schools, evaluating available technology, developing procurement materials, and providing ongoing support to the schools throughout the demonstration project. VEIC also tracked vehicle reliability, vehicle energy efficiency and energy consumption, and led evaluation of the pilot overall.

The project was initiated in the fall of 2015 and following a solicitation process open to Massachusetts public school districts, three school districts were selected for electric school bus deployment: Amherst Regional Public School District, Cambridge Public School District, and Concord Public School District. In the fall of 2016, three electric school buses were deployed at the three sites and tracked for approximately a year, into early 2018.

Although the pilot project faced a range of challenges, ultimately it was successful in gathering valuable data and moving the electric school bus field closer to more widespread deployment. The three buses are still on the road and reviews of the buses and overall pilot experience were positive from many participants. The three buses logged nearly 14,000 miles combined and provided school transportation for an estimated 279 days (including some summer school transportation). Our ability to rigorously compare the reliability and operating costs of electric school buses to diesel over the course of the pilot was severely compromised by lack of data: we had incomplete data from all sites related to diesel bus maintenance and fueling costs, as well as gaps in electric school bus energy usage. We were able to use best estimates and modeling efforts in our analysis to present as complete a picture as possible for this report but recommend that future efforts make consistent data collection a priority and key requirement of participation. The key lessons that were learned through this pilot (the importance of managing school bus charging, the need for local electric school bus technical expertise) will no doubt inform future deployments of this technology.

Key findings of the pilot project include:

Electric school buses require more testing and demonstration.

Participating school districts encountered a number of mechanical and logistical challenges that suggest this emerging technology requires further testing and refinement before widespread deployment can occur. All three of the deployed buses were out of service for a relatively high number of days and ultimately logged fewer than half as many miles than the average diesel bus. Participating schools were approximately 4-5 hours from the bus manufacturer in Quebec, Canada, and the lack of on-the-ground technical assistance was a challenge for the schools.

Unmanaged charging of buses and high vampire loads contributed to electric school bus energy costs being 63% higher than necessary.

Energy savings from electric school buses were much smaller than anticipated, due primarily to uncontrolled charging and high ‘vampire loads’ associated with auxiliary fans and heaters used to heat or cool batteries during charging. In the future vampire loads may be reduced but not guaranteed.Charge rate /ambient temperature and engineering design more important. This excess energy consumption can be avoided through improved managed charging of buses, dramatically increasing the energy savings of electric school buses. This has a lot to do with the battery’s thermal design.

Electric school buses emitted less than half as many tons of GHG over the course of the pilot than a comparable diesel buses.

Emissions of other harmful pollutants, such as volatile organic compounds, carbon monoxide, NOx, and SOx, were also lower.

Fueling costs were not lower for the electric school buses than traditional diesel buses, due again to unmanaged charging of batteries and excess electricity usage and demand charges.

These costs could be reduced, below current diesel spending levels, through a managed charging system.

V2G or V2B electric school bus systems is most likely not cost-effective at present.

Any V2X system would present relatively high risk to participating school districts and require close management by school or district staff to realize financial savings. However Managed charging may enable many of the benefits for cost effectiveness. This can also depend on the value of mobile resilienc.

2 Introduction

Overview

The Massachusetts Department of Energy Resources (DOER) initiated a pilot project to test electric school buses in school transportation operations. The pilot project was a first-of-its-kind deployment of electric school bus technologies in cold weather environments in the United States. It was designed to understand the opportunities and challenges associated with using electric school buses as a strategy to provide safe, reliable, cost effective school transportation. Other goals included reducing greenhouse gas (GHG) emissions associated with the transportation sector and testing the potential of electric school buses to interact with the electric grid through the use of vehicle to grid (V2G) and/or to interact with local energy use through vehicle to building (V2B) technology.

At the time the pilot project commenced, electric school buses had only been deployed in limited numbers in primarily warm weather environments. Consequently, while the technology offered a lot of promise, there had not been a robust demonstration of how well it would perform in different environments and under a variety of circumstances, particularly cold winter conditions. Given the status of the industry, the Massachusetts pilot project set out to test four assumptions about electric school buses:

- Electric school buses are a viable vehicle technology that can reliably be deployed in school bus operations, including in cold weather environments.
- Electric school buses are energy efficient and produce fewer greenhouse gases as compared with diesel school buses.
- Electric school buses have lower operating costs as compared with diesel school buses.
- The battery on an electric school bus can be used as an energy resource that when connected to a building energy management system (V2B) or the grid (V2G) can generate revenue for the owner of the bus.

The electric school bus pilot project was funded through the Regional Greenhouse Gas Initiative (RGGI) with roughly $2 million and administered by the Massachusetts State Department of Energy Resources. The project was designed to support up to four school districts with electric school buses and charging equipment as well as technology and systems needed to support V2B/V2G demonstrations. RGGI funding was also used to procure consultant support to help manage implementation of the pilot project and lead an evaluation of the overall effort. This work, provided by the Vermont Energy Investment Corporation (VEIC) included assistance with soliciting participating schools, evaluating available technology, developing procurement materials, and providing ongoing support to the schools throughout the demonstration project. VEIC also tracked vehicle reliability, vehicle energy efficiency and energy consumption, and led an evaluation of the overall experience.

Project Summary

Yellow school buses have been a part of the education experience for students across the United States for more than 100 years and today, student transportation is provided by the majority of school districts in the country. The majority of all school buses operating in the United States are diesel vehicles. Historically, diesel has offered a low cost, highly reliable and easily maintained technology, but with significant emissions and pollutants. As emission controls system were added to school buses, the vehicle produced fewer emissions, but lost reliability and maintenance became more problematic. In response to changes in diesel technology and a heightened awareness of the impacts of vehicle emissions, the school transportation industry has become more interested in alternative fuels and fuel technologies.

One emerging alternative fuel technology for school buses is electricity. Powered only by electricity, plug-in electric school buses have no tailpipe emissions and offer a clean fuel alternative to diesel. In theory, the technology offers advantages over diesel powered vehicles such as lower fuel costs, lower operating costs, less maintenance and cleaner, quieter operations. Electric school buses are also expected to provide health benefits. There are challenges associated with electric buses, however, including limited experience nationally with the technology and a high cost premium associated with purchasing an electric school bus. The all-in purchase costs of an electric school bus is $350,000, compared to $85,000 to $100,000 for a conventional diesel bus. A primary goal of the Massachusetts project, therefore, was to test and explore these assumptions and understand how well the bus can support school bus operations.

One of the primary reasons for the price premium associated with electric school buses is the vehicle battery. Vehicle batteries account for about 40% of the cost of the vehicle. The size of the battery also determines the vehicle range, so while more or larger batteries will increase range, they also increase cost. The battery on electric school buses also has potential to create value by functioning as an energy storage resource. One of the defining attributes of electricity is that it must be used when it is generated. This limitation can be overcome by converting electricity to another form of energy or storing it in a device, such as a battery. Energy storage systems have increased in importance in the past several years, as energy production has diversified to incorporate renewable energy sources with intermittent supply, such as solar and wind power. Because electric school bus batteries can be used to store energy, this resource has the potential to earn revenue as a storage resource. A second goal of the pilot project, therefore, involved understanding the costs and benefits associated with using a school bus battery as an energy storage resource.

Key Findings

- The Massachusetts Electric School Pilot Project showed that electric school buses are still an emerging technology that requires more testing and demonstration experience before it is widely deployed in school transportation services. Participating school districts encountered a number of mechanical and logistical challenges that suggest this technology requires further testing and refinement before widespread deployment. All three of the school buses in the pilot were out of service for a relatively high number of days and ultimately logged fewer than half as many miles than the average diesel bus.
- Energy savings from electric school buses were considerably smaller than anticipated, due primarily to uncontrolled charging and high 'vampire loads' associated with auxiliary fans and heaters used to heat or cool batteries during charging. This excess energy consumption can be avoided through improved managed charging of buses, dramatically increasing the energy savings of electric school buses. This feature is available on the bus but required programing by drivers which proved to be difficult.
- Electric school buses emitted fewer tailpipe pollutants over the course of the pilot than would have been emitted by comparable diesel buses, including less than half as many tons of GHG.
- Fueling costs were not lower for the electric school buses, due again to unmanaged charging of batteries and excess electricity usage and demand charges. These costs could be reduced, below current diesel spending levels, through a managed charging system.
- The technology for V2G or V2B electric school bus systems is most likely not cost-effective at present. Any V2X system would require close management by school or district staff to realize financial savings.

Report Organization

This report is organized into four chapters immediately following this introductory section:

- Chapter 2 provides an overview of the Electric School Bus: State of the Technology as of 2015. This chapter also includes a description of the available charging technology and systems.
- Chapter 3 describes the pilot planning and experience with implementation and deployment. Most of the information provided in this section is qualitative.
- Chapter 4 highlights electric school bus performance in the field during the pilot period. This section quantitatively evaluates vehicle reliability, costs and emission impacts.
- Chapter 5 summarizes the findings and outlines recommendations for next steps for electric school bus systems and technologies.

3 Electric School Bus: State of the Technology (2015)

The Massachusetts electric school bus pilot commenced in the spring 2015. At this time, national experience with electric school bus technology and V2G/V2B systems was limited. As a first step in the project, therefore, the study team surveyed experience with electric school buses in the United States to understand the types of technologies and systems available for purchase. Our research considered if the available electric school buses would meet the needs of school districts; we also inventoried the expected costs of different systems, technologies and options.

VEIC's review of the market and related technology focused on electric school buses; electric school bus charging technologies; and vehicle to grid / vehicle to building systems. This section is organized according to each of these topics, starting with electric school buses. Recommendations made by the VEIC in 2015, when the analysis was conducted, are also included. A copy of the full cost benefit analysis prepared by VEIC in December 2015 is included as Appendix A.

Overview of Electric School Buses

In 2015, there were on the order of eight electric school buses operating in North America (see Figure 1). In the United States, most of the electric school buses were retrofitted vehicles. This meant that electric motors and drive trains system manufacturers installed their systems into vehicles manufactured by someone else. Many of these manufacturers also developed electric motors and drive train systems for other medium and heavy duty vehicles, including transit vehicles, trucks and tractors. The separation of drive train systems from vehicle bodies is not unique to school buses and is consistent with vehicle manufacturing generally, where separate manufacturers often produce different vehicle parts, which are assembled by the manufacturer who finishes the product, applies their brand and supplies the vehicle warranty. Cost was a driving factor in developing retrofitted electric school buses, but also reflects the fact that the yellow school bus is highly standardized and a sense that the potential for value added design and features is limited. In the U.S. at this time, electric power train manufacturers were exclusively based and largely working in California. As of October 2015, several electric school buses were deployed into regular school bus service, although operations were intermittent.

An alternative approach was pioneered by Lion Bus, a school bus manufacturer in Quebec, Canada. Lion Bus started manufacturing school buses in 2011 and had produced roughly 500 diesel-powered school buses by 2015; these buses were in operation at school districts across Canada and in the United States. Lion also began manufacturing electric school buses; Lion's first electric bus ("eLion") was funded by HydroQuebec and the Quebec Provincial Government. The bus went into service in September 2014 and began transporting students by the end of that year. By 2015, Lion Bus reported having built six eLion school buses, some of which were deployed in pilot projects in Quebec Province.

Figure 1: Electric School Bus Manufacturers and Production (as of October 2015)

Electric Drive Train and Power Systems	School Bus Body/Chassis	Vehicle Type	Number Sold or In Production	Estimated Deployment
Motive Power Systems	TransTech	A, B and C	1 in operation 2 in production	California - Kings Canyon Unified School District California – Colton
Adomani	BlueBird	C	1 in operation More in production	California - Gilroy School District
TransPower	Thomas Built (prototype)	C	6 – in production	California – Torrance, Napa Valley and Bakersfield
Lion Bus	Lion Bus	C	6 in operation	Quebec

Source: VEIC based on conversations with manufacturers and funders

Options for Massachusetts

Given the state of the technology in 2015, the Commonwealth of Massachusetts had three options for their electric school bus purchase: a retrofitted school bus built with a used chassis/body; a retrofitted school bus with a new chassis/body; or a fully manufactured new electric school bus (see Figure 2). These options influenced the price and the expected useful life of the vehicle, but not the functionality of the equipment.

Retrofitted Vehicle with Used School Bus Body

Electric school bus manufacturers can purchase a used school bus that is structurally sound and will pass vehicle inspection, but has a worn engine and transmission. When the Massachusetts project was evaluating available technologies, most of the available prototype electric school buses developed followed this model. A handful of retrofitted buses had also since been certified for operations and were carrying students. The vehicles are stripped of their engines and drive trains, and equipped with a new electric drive train and battery. The primary advantage of the used body is price – a used school bus costs between $10,000 and $20,000.[1] In addition, because school buses are highly regulated, much of the design and safety features are standardized.

The main disadvantage with retrofitting existing vehicles is that it involves installing high quality, expensive internal systems to an older and outdated vehicle body. The drive train will almost certainly outlast the vehicle body regardless of the condition of the vehicle body and chassis, which is not prudent financially (the least expensive components should wear out first). Installation costs are also high (15-20% of total costs), so installing a viable drive train into a second vehicle would be cost-prohibitive.

In addition, retrofitted vehicles also mean driver information systems, such as the dashboard and driver display systems are also retrofitted. While the gas gauge can be used to provide some information, drivers of retrofitted vehicles felt this was a real disadvantage of the older vehicles. Some manufacturer's have developed workarounds, but some retrofitted vehicles continue to use old dashboard monitors. Finally, the chassis and body almost certainly will not be under warranty, so if something goes wrong with either part, the school district / bus operator will be responsible for repairs.

Retrofitted Vehicle with New School Bus Body

Electric drive train manufacturers are also installing drive train systems into new school bus bodies and chassis purchased from one of the existing school bus manufacturers. In 2015, the largest yellow school bus manufacturers in the United States would not sell an engine-less, "glider" vehicle. Instead, electric school bus manufacturers must purchase a new school bus and remove (and re-sell) the internal combustion engine, transmission, fuel tank, exhaust/emissions systems and replace these with the electric drive train.

This approach ensures the vehicle has the newest systems, most upgraded safety features and interior designs and the vehicle body is built to last between 8 and 12 years, which is more in line with an electric drive train system. Another advantage of buying a new vehicle is that the interior specifications and other special requirements (such as climate control systems) can be accommodated. The body and chassis of a new vehicle will also be warrantied. The main disadvantage of purchasing a new glider body and chassis is the cost, which is higher than a used vehicle. There is also some risk and cost associated with stripping the existing engine and selling it. Finally, similar to a used vehicle, manufacturers will need to either retrofit traditional dashboard systems or install new ones.

Single Manufacturer

In 2015, there was one manufacturer, Lion Bus (or Lion Electric) that fully manufactured an electric school bus, making their own body, chassis and electric drive train (but not the batteries). Lion Bus school buses are made in Canada, deployed in the U.S., and meet both U.S. school bus and "Buy America" standards. The estimated cost of the eLion is within range of vehicles that have been re-powered. Lion Bus vehicles

[1] Conversations with electric school bus manufacturers

also use new construction methods that include a lighter body comprised of a fiberglass composite material and gel-coat that is anti-corrosive, lighter and stronger. The vehicle body is also slightly wider as compared to traditional school buses (102" as compared with the standard 96" body) and the roof is constructed as a single piece fiberglass, which reduces the potential for leaks. The body and vehicle chassis also come with a five-year/100,000 mile warranty.

Figure 2: Electric School Bus Estimated Cost (2015)

	Existing Vehicle (Repower)	New Vehicle (Repower)	New Vehicle (Single manufacturer)	Notes
Vehicle Body and Chassis	$10,000	$60,000	n/a	*Existing school bus purchased from San Diego School District New vehicle body/chassis purchased from manufacture, drive train stripped and sold.*
Develop/Repower Engine and Drive Train	$240,000	$240,000	$325,000	*Estimated by manufacturers Includes batteries*
Installation	$60,000	$60,000		*Estimated by manufacturers*
Warranty and Service	$30,000	$30,000		*Warranty fee estimated at 10% of vehicle cost*
Vehicle Delivery	$5,000	$5,000	$2,500	*Estimated – assumes one-way delivery of finished product*
Estimated Cost per Vehicle	$345,000	$395,000	$327,500	

Source: VEIC Based on Research with Electric School Bus Manufacturers

Recommendations

Our analysis suggests that while retrofitted vehicles are adequate to meet the DOER and school district's needs, fully manufactured vehicles are a preferred product. This preference reflects the following (see also Figure 3):

- Fully manufactured vehicles are a purpose built system, inclusive of the vehicle body, chassis, electric motor and drive train and user interface systems. This creates a more complete, unified product.
- New vehicle bodies will have a longer life and reflect the most up-to-date safety and technological systems available.
- Warranties for the vehicle body and chassis, motor and user systems are held by a single manufacturer. (Battery warranties may be with a different entity.)
- The purpose built systems more easily allow school districts to tailor vehicles to meet their specific needs and requirements (seat belts, cameras, etc.).

The primary challenge with recommending a fully manufactured school bus is that as of December 2015, there was only one manufacturer (Lion Bus) who meet this standard. Thus, in the interest of competition and allowing for comparison between vehicle systems and capabilities, VEIC recommended that the request for proposals seeking electric school bus not be limited to fully manufactured vehicles.

Figure 3: Comparison of Retrofitted and Fully Manufactured School Buses

	Strengths	Weaknesses
Fully Manufactured "New" School Bus	Purpose built vehicle, drive train and driver interface equipment Vehicles can be customized to meet specific needs of school districts Vehicles have been tested in the field and refined based on experience Warranty for vehicle and components are from a single manufacturer	Lack of competition (only one manufacturer in market)
Retrofitted School Bus	More diversity of vendors with slightly different systems and designs Prototypes have been tested in field and refined based on experience	Retrofitted vehicles are estimated to be more expensive Vehicle body is not designed to support electrical systems and controls. Older vehicles do not reflect latest safety and technology

Source: Vermont Energy Investment Corporation

Electric Vehicle Charging Infrastructure

Overview

Electric school buses plug into an electrical source to power the vehicle and consequently, require access to a charging system, or electric vehicle supply equipment (EVSE) to "fuel" or recharge the vehicles. In most cases, EVSE provides a one-way connection between the grid and the vehicle, so the grid (or other energy source) can send energy to the vehicle. This is the most common model used by consumer electric vehicles and electric school buses.

EVSE systems – including those used by buses and light duty vehicles - accommodate three levels of charging: Alternate Current (AC) systems that include both AC Level 1 and AC Level 2 connections that charge vehicles with power that is converted to Direct Current power on the vehicles. These systems charge vehicles more slowly as compared with Direct Current (DC) systems. DC Fast Charging systems charge vehicles by providing a DC connection from the EVSE to the vehicle, eliminating onboard conversion. Two of the charging systems can support electric school buses, although each system has advantages and disadvantages (namely trading off price for the speed of charging):

- **AC Level 1:** Uses a 120-volt (V) alternate current (AC) power connection to a standard residential/commercial outlet capable of supplying 12-16 amps of current, for a power draw of about 1.4 to 1.9 kW when charging. A Level 1 charger will charge an electric school bus with a battery size of 105 kWh in about eight hours. An AC Level 1 charging system costs about $300 and is typically used for home charging. The low level of power and voltage means they are not viable for electric school bus charging systems.
- **AC Level 2:** Uses a 208/240V AC power connection to an electrical outlet capable of supplying 30-80 amps of current with 19.2 kW max. Electric school buses can use AC Level 2 EVSE but require higher amperage and can charge an electric school bus in between four and five hours. Some electric school bus manufacturers allow two AC Level 2 connections at the same time to decrease charging times. There are commercially available AC Level 2 bidirectional chargers, although the technology has only been used in limited applications. Level 2 charging systems for commercial use range between $3,000 and $10,000, including the purchase price and installation costs.
- **DC Fast Charging**: Delivers high power directly into an electric vehicle battery system by converting AC power into direct current (DC), using an inverter built into the EVSE. DC Fast Charges uses 208-600V AC for charging rates of up to 90 kW, enabling an electric school bus to

be charged in between 20 and 30 minutes. DC Fast Charging systems are more expensive, and in 2015, were estimated to range between $15,000 for hardware not including installation, plus another $10,000 to $20,000 for software costs. Standard SAE J1772 covers both AC level and DC fast charging couplers.

Bidirectional Charging Systems

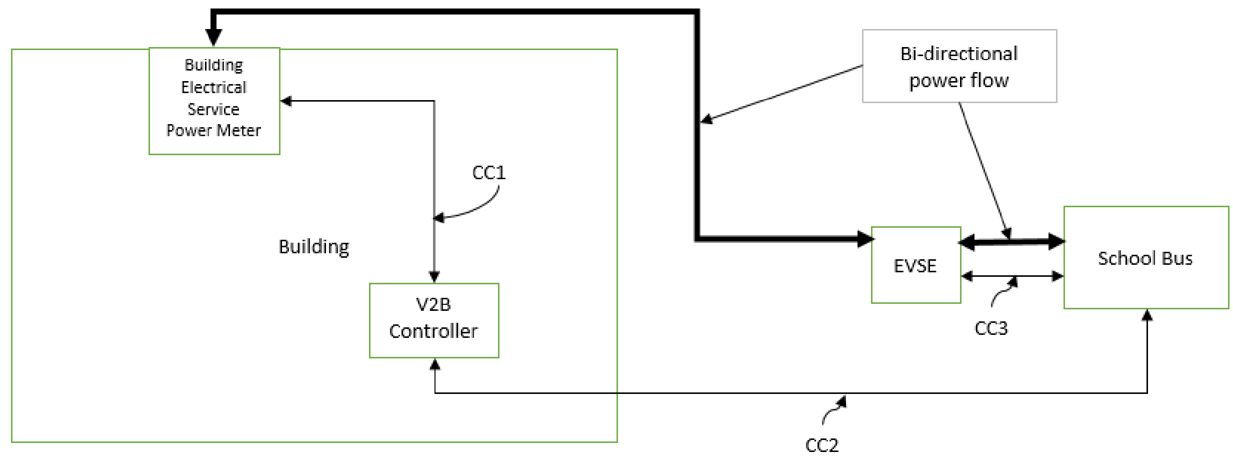
Bidirectional connections allow electric vehicles to both receive energy from the grid (or energy source) and send energy stored in the vehicle back to the grid or a building. Bidirectional electric vehicle charging equipment is more expensive to purchase than traditional EVSE; but the ability to charge and discharge energy from the vehicle battery means the vehicle battery can function as an energy storage resource. As part of the Massachusetts electric school bus pilot, DOER and VEIC explored the potential of bidirectional charging systems. At the time the study commenced in 2015, the technology had been tested and demonstrated, but was not widely available in commercial markets.

At the time the study was initiated, DOER was interested in understanding the opportunities to use V2G or V2B systems to generate revenue and encourage adoption of electric school buses by offsetting the costs. This idea was originally explored and demonstrated by the University of Delaware in their publication, *A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus*. Findings from this study were published in 2014 and represent the first exploration of grid interactive vehicle technologies and their potential application to school buses.

MA DOER and VEIC's research into the technology suggests there are two implementation strategies for where the electrical inverter is located (i.e. on the vehicle or in the EVSE) as part of the bidirectional charging systems used in conjunction with V2G/V2B technology (see Figure 4). The choice of technology depends on site conditions and how the schools intend to take advantage of vehicle grid interactive capability. Both systems require electric vehicle charging infrastructure capable of bidirectional power flow and a building controller that serves as the interface between the building and the bus or the building and the charging infrastructure. The costs of these systems are difficult to estimate given that most systems will need to be procured as part of a request for proposal process. VEIC broadly estimates that the equipment and systems could cost between 125,000 and 175,000 per site (see Figure 5) These estimates are from 2015 and the technology is proving to be less money today. In 2015, the two broad technologies for grid interactive vehicles include:

- **On Board System:** in this scenario a bidirectional charger and communication module are located on the bus and enable communication with the charging infrastructure and building controller. Lion Electric is currently equipped to host an on-board inverter, but the technology is still in development and may not be available until late 2018 at the earliest.
- **Off-Board System:** In this scenario, energy is drawn/sent to a stationary inverter located in a DC fast charger equipped for bidirectional power flow. Depending on the vendor selected, software that enables communication between the bus and the building may be incorporated as part of the building controller system or as part of the charging infrastructure. The only change needed on the bus is installation of a combo plug for a DC fast charger. One advantage of this system is that the technology is more likely to be available "on the shelf."

Figure 4: V2G Communication and Power Flow.



CC = Communication Channel
Heavy line = Off-board system Power flow
Thin line = system communications flow

Figure 5: V2X System Requirements, Availability and Estimated Costs

	On Board System Requirements	Availability	Estimated Cost	Off Board System Requirements	Availability	Estimated Cost
Bus Upgrades	Bidirectional charger on bus (hardware) and communication module (software) to communicate with EVSE and building controller	Must be from Lion Not fully developed or UL certified (estimated 2019)	$12,000 May cost more if we want to accelerate timeframe	Combo plug on bus	Must be provided by Lion	$8,000 per bus
Charging Infrastructure	Capable of bidirectional flow (UL approved)	Have not yet found Level 2 EVSE capable of bidirectional with the necessary power	$25,000 / unit	DC fast charger with inverter capable of bidirectional power flow	Available from Coritech	$60,000 / unit
Building Controller	Communication device (including hardware and software)	EPRI has one available (not UL certified) - requires additional software	$25,000 / unit	Communication device (including hardware and software)	EPRI has one available (not UL certified) - requires additional software Kisensum has integrated with Coritech	$25,000 / unit for EPRI $20,000 for Kisensum w/Coritech
Building Controller - additional communication software	Depending on vendor for building controller, additional software may be needed	If using EPRI's equipment, additional software to be developed	$50,000 - $100,000 total for all sites	Depending on vendor for building controller, additional software may be needed	If using EPRI's equipment, additional software to be developed	$50,000 - $100,000 total for all sites
Installation and Commissioning		$10,000 / site	$10,000 / site			$10,000 if 3-phase power, 480V is available $20,000 if 3-phase power needs to be run to bus
Total per site			$125,000 - $175,000			$108,000 - $208,000
Contingency (30%)			$37,500 - $52,500			$32,400 - $62,400
Estimated Total Cost			$162,500 – $227,500			$140,400 - $270,400

Recommendations

VEIC's recommendations for the charging equipment evolved as the project developed. At the time the DOER was being designed, there was limited experience with both electric school buses and bidirectional charging technologies. Consequently, there were many unknowns, including the exact specifications of the electric school bus, its warranty and its capabilities to connect with a bidirectional charging technology. Given this, DOER and VEIC decided to:

- Proceed with the electric school bus first and review the systems, technology and warranty requirements before making a determination on the type of technology and required ancillary systems.
- Explore the revenue potential and infrastructure requirements at the school districts participating in the pilot.

VEIC's recommendation to purchase the vehicle first, and then consider EVSE systems second would allow the schools and technical teams to evaluate information on school bus warranties, together with the revenue potential at each school district, so that the combined information would drive decisions about investments in bidirectional charging technologies.

Ultimately, implementation logistics created challenges for this approach. One challenge emerged because buses were scheduled to arrive on site between six to eight weeks after contracts were signed, which was not enough time to design, purchase and install a bidirectional charging system. In the end, after ordering the school buses, school districts purchased single direction, Level 2 chargers and installed those systems before the electric school buses arrived on site.

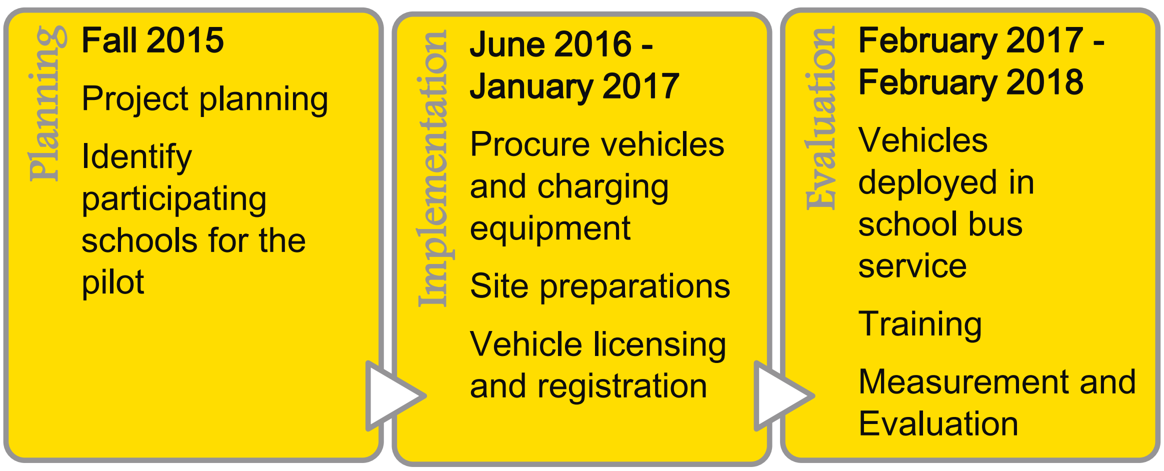
4 Electric School Bus Pilot: Planning, Implementation & Deployment

Introduction

MA DOER and VEIC's work on the electric school bus pilot project started in April, 2015 and ended in March, 2018, roughly a three year period. The project was originally scheduled to end in March 2017, but progress was stalled due to issues associated with grant funding and contracting. This delay occurred between January and June, 2016, after the schools were selected for participation but before implementation began. Once grant funds were secured and contracts established, it took about six months to get electric school buses and vehicle charging systems set up on-site and ready for deployment at each of the school districts. By early 2017, each of the three schools began operating their electric school buses in service and carrying students to school.

This chapter describes pilot project events according to the three main project phases: project design and planning; implementation; and evaluation (see Figure 6). Each section describes the events chronologically together with key findings and summarizes the experience of the individual each pilot sites.

Figure 6: Massachusetts Electric School Bus Pilot Project Schedule



Project Design and Planning

Site Selection

The electric school bus pilot began with the background research and analysis described in Chapter 2. The first publicly facing project steps involved recruiting sites to participate in the project. The application materials provided an overview of the project and its terms, including an estimate of costs and available funds (see Appendix B). To complete the application, schools were asked to summarize their districts' support for the pilot project and provide supporting information by completing a questionnaire about transportation operations, overall energy costs (building and transportation) and relationship with their local utility.

MA DOER used the Program Opportunity Notice (PON) to provide an overview of the demonstration project, noting that the pilot was designed to test battery electric school buses (i.e. 100% electric powered school buses) and the use of bi-directional charging equipment to enable V2G and V2B interactions. The PON also laid out the terms of the grant, namely that funding was available to support the full costs of purchasing a Type C school bus and a companion set of Level 2 bidirectional charging equipment, up to a maximum of $400,000 per demonstration site. Terms also required that school districts install and utilize bidirectional Level 2 charging equipment either on the school premises or at another location approved by DOER. Finally, the PON stated that while grant funds would support the purchase of the charging equipment, school districts were expected to assume financial and administrative responsibility for installing the charging equipment.

The pilot project and PON were posted to the Commonwealth of Massachusetts webpage and online portals to announce the grant availability. The pilot project was also promoted through Massachusetts' Clean Cities and Green Communities program.

Ultimately, four school districts applied to participate in the project and complete application materials were received on time for each of the applicants. MA DOER reviewed and scored the applications and VEIC conducted follow-up phone interviews with each applicant to provide additional information about the project and hear about their interests and expectations. Following this process, all four sites were selected to participate in the pilot project and proceeded to contracting with MA DOER. During the contracting activities, one school district withdrew their application citing concerns about vehicle range and the vehicle's ability to meet their deployment needs over the longer term. By June 2016, there were three school districts in agreement and ready to participate in the pilot project.

- **Amherst Regional Public School District**, in western Massachusetts, is a regional school district that operates in a rural/small town environment. It has a relatively small fleet of about 10 vehicles, which is supported by a single technician. Amherst's local electric utility provider is a large investor owned utility (IOU).
- **Concord Public School District** is a suburban school district just outside of Boston. It is a regional school district and has a large fleet with a dedicated vehicle maintenance facility and a dedicated staff of mechanics. Concord gets its electricity from a municipal utility.
- **Cambridge Public School District**, serves Massachusetts' densest community. Cambridge contracts out for the majority of its school bus service, with contracts for both operations and maintenance. For this pilot project, Cambridge agreed to own and operate the electric school bus. Cambridge is served by the same IOU that serves Amherst.

Procurement

Once schools were under contract with MA DOER, project next steps focused on finding a place to park the bus and moving towards purchasing equipment. The pilot agreement was structured so that schools assumed responsibility for issuing requests for proposals (RFPs) and awarding contracts. As discussed, VEIC recommended that the schools purchase a bus first, and based on the information provided by the vendors, purchase charging equipment.

Electric School Bus

MA DOER and VEIC drafted electric school buses specifications for the pilot sites (see Appendix C). Key features of the vehicle specifications included:

- Preferences for fully manufactured electric school buses, but responses for retrofitted vehicles were allowed.
- Capable of a travel range of 75 miles based on 50% city and 50% highway miles.
- Heating systems capable of sustaining an interior cabin temperature of 60 degrees Fahrenheit when the outside temperature is 32 degrees Fahrenheit.
- On-board and off-board battery management systems (BMS) that communicate remaining range in miles, battery back state of charge, battery pack state of health, battery depth of discharge or other measured battery parameter. BMS must be capable of metering 15-minute average kW readings during charge and discharge operations.
- Training systems for both the driver and mechanics.
- Most of the RFPs also include manufacturing schedules that requested delivery of the bus within six to eight weeks.

Schools were able to adjust and tailor the specifications to meet local needs and equip buses with additional equipment or features required by their individual school districts. Concord Public School, for example, requested that the school bus be equipped with a wheelchair lift. Other schools ordered seatbelts, cameras and other equipment that exceeded a 'standard' school bus.

Each school issued an RFP over the summer 2016; Concord released theirs first, followed by Amherst and Cambridge. The RFPs were sent to all of the known electric school bus vendors, including Lion Electric as well as Adomani, Motiv Power and Transpower. Vendors had approximately three weeks to reply to the response. In each case, only Lion Bus responded to the RFP; Lion Bus was awarded the contract for all three sites. The base cost for the bus was $325,000, which included four batteries that provided 104 kWh of energy storage with an estimated range of 75 miles. The battery was warranted for 160,000 kWh or eight years, whichever comes first. The warranty guaranteed a battery capacity of 65% of the initial range at all times during the warranty period. Other features of the Lion Bus proposal included:

- An estimated 75-mile vehicle range on a single battery charge of 104 kWh. Lion Bus estimated the average energy consumption at 1.4 kWh per mile.
- Auxiliary fuel fire heater (Proheat M80) powered by diesel fuel to ensure cabin temperatures are maintained.
- On-board telematics capable of proving real-time data through a web interface, including state of charge, remaining charge, GPS location, average energy consumption, total energy use, fault codes and diagnostic information
- Power consumption, charge and discharge information is always available on the driver's information systems and is stored in the cloud for up to two months.
- Equipped to host standard 19.2 kWh on-board AC technology conforming to the SAE J1772 standards or equivalent and can provide V2G/V2B bidirectional capabilities as an option.
- Training support consisting of a 1.5 days of training for technicians plus 2.5 hours of training for drivers provided on the day of delivery. Lion also agreed to provide all technical, mechanical, repair and operating manuals.

Based on the proposals received, Lion Bus was awarded the contract for each of the electric school bus demonstration sites.

Electric Vehicle Charging Equipment

Once the electric school bus proposals were received, the demonstration sites were ready to purchase electric vehicle supply equipment (EVSE). VEIC used the battery warranty information to estimate the costs and benefits of different V2B scenarios (see Chapter 4 of this report and Appendix D). This analysis, combined with a handful of practical considerations (the complexity of procuring bidirectional charging equipment, expected delivery schedule for the buses) led VEIC and DOER to postpone purchase of the bidirectional equipment. Instead, standard AC Level 2 EVSE was purchased. Lion Bus recommended Tesla or Clipper Creek charging equipment. The cost of the two charging systems was similar and both vendors were already on the state contract. Two schools purchased the Tesla charger, which was adapted for the SAE J1772 standard and one school purchased the Clipper Creek. Roughly, six months into operations, one of the schools swapped out the Tesla charger for a Clipper Creek.

The requirements for parking and storing the electric bus were access to electricity. Because the project was originally envisioned to include V2G / V2B demonstrations, MA DOER's initial requirements also required access to three-phase power and parking the bus next to a building. The ease of finding a place to park the bus varied by site but ultimately each school was able to install their EVSE:

- In Amherst, the school bus parking area is located adjacent to the middle school. Amherst's transportation director identified a spot for the electric bus that was within a reasonable distance to the schools electrical infrastructure. They arranged to lay conduit (using a vertical drill) so the EVSE could be hooked up when it arrived.
- School bus parking for Cambridge was complicated because the school district contracts with a private transportation operator for service and consequently, does not have a school bus parking lot. The urbanized nature of the community also means that parking space is limited. The City of Cambridge spent several weeks looking for a viable parking spot and ultimately secured a location near one of the schools, on Fulkerson Street.
- Concord Public Schools, like Amherst, operates all of its own bus service. The challenge in Concord was that the school was building a new school transportation facility for vehicle maintenance and bus parking. Concord's existing bus parking site was rented and the depot

would not be available until summer 2017, so the electric school bus was temporarily parked by the middle school.

Implementation and Deployment

The electric school buses were ordered over the summer 2016 and started to arrive in Massachusetts at the end of 2016. While the buses were being manufactured, schools ordered their EVSE and began preparations for installation. The three buses arrived on site within a relatively short period of time.

As part of its role as technical support staff, VEIC stayed in close contact with each of the sites throughout the demonstration project. We developed an Education and Evaluation Plan for the project to ensure that appropriate stakeholder groups (schools, parents, educators, etc.) were aware of planned electric school bus implementation (see Appendix E). Prior to deployment, VEIC visited each site and prepared charging and data collection plans with staff (see Appendix F). Staff from VEIC also visited the demonstration sites at different points during the demonstration projects. In addition, VEIC scheduled and facilitated regular conference calls. These calls helped VEIC keep track of the buses and their performance; they also allowed the schools to share their experience. Biweekly conference calls were held from January to June 2017, and then roughly monthly until February, 2018.

The following section provides a summary of the experience of each of the three demonstration sites: Amherst, Cambridge and Concord. Information varies by each site and reflects the correspondence, communication and data collection available over the course of the demonstration period.

Amherst

Amherst Regional Public School District is a regional school district located in western Massachusetts, serving the communities of Amherst and Pelham, Massachusetts. Amherst operates its own vehicles and has a relatively small fleet of about 10 vehicles. The fleet is supported by a single technician.

Amherst Regional Public School District eLion Electric School Bus.

Planned Operations

Amherst planned to incorporate the electric school bus into its regular school bus operations. This meant using the bus in service for roughly two hours in the morning (7:00 am to 9:00 am), traveling roughly 15 miles. The bus was expected to be out of service from 9:15 am to 1:45 pm and be back in service at 2:00 pm for two hours, driving another 18 miles. Given the low mileage planned for the morning and afternoon trips, the bus was not expected to be plugged in during the middle of day.

Deployment

Amherst received an eLion battery electric school bus in mid-December 2016. Prior to the bus arriving, Amherst installed a Tesla AC L2 charger with an adapter so that the equipment could work with the J1772 plug. Amherst used this charger for approximately six months but had problems with the connector. They eventually switched the Tesla EVSE for a Clipper Creek charger system; this charging system proved to be better suited for the eLion school bus.

Amherst Clipper Creek Electric School Bus Charging Unit.

The bus was licensed and inspected quickly and the Amherst Public School transportation team began testing their vehicle in January 2017. The electric school bus was put into service in late January, 2017. Drivers began recording data immediately and continued to record data until March 2018. Members of the Amherst Public School Transportation Department were reliable participants in the data collection and demonstration project activities by providing updates on the experience with the vehicle, discussing their experience with researchers and evaluators and making the vehicle available for additional testing.

Amherst integrated the electric school bus into a regular rotation. The bus drove an average of 34 miles per day, with two or three trips to pick up and drop off students carried out in sequence. In total, over the 14-month period, Amherst public schools logged just over 5,000 miles.

Qualitative Summary of Experience with Electric School Bus

The eLion school bus deployed in Amherst accrued more miles than either Concord or Cambridge. Amherst also experienced challenges with their electric school bus, which were categorized into two primary types: vehicle reliability and communication / support from Lion Bus.

Vehicle Reliability

Amherst recorded 9 technical and mechanical issues with the eLion school bus and charging equipment over the 14 month period between January 2017 and February 2018 (see Figure 7). Problems included two breakdowns during school bus operations and over 30 missed service days (roughly 20% of the scheduled service days). There were also four days when the bus was out of use due to problems with the EVSE (late April/early May 2017).

The evaluation team did not have access to the reliability statistics for a diesel school bus. This data was requested from all three demonstration sites, but for a variety of reasons, no complete, reliable set of comparable information was available. As a result, it is difficult to compare reliability and costs across technologies. Anecdotally, however, staff reported that the reliability issues were greater than expected, especially for a brand new vehicle, and were disruptive to school transportation operations.

Figure 7 Amherst Public Schools Vehicle Maintenance and Repair Issues

Number	Issue	Transportation Service Days Missed[2]
1	Fuel tank sending unit failure – in process found access plate was not relocated to accommodate smaller fuel tank. Repair work conducted by external shop.	Delayed start of demonstration project
2	Defective coolant tank	
3	Problems with Tesla EVSE –bus not charging properly.	5 days (April 26 – May 2)
4	Intermittent failures with hardware communication on Controller Area Network(CAN)- faulty main power distribution module (MPDM).	2 days (May 1 – May 2)
5	Sound generator failure – damaged wiring harness found and repaired.	-
6	*Breakdown during operations* Loss of DC/DC converter – breakdown in field; blown fuses of DC/DC converter were replaced in high voltage fuse panel; second DC/DC converter replaced – further testing revealed failed Neuro Unit. Neuro Unit replaced.	9 days (July 17 – July 26)
7	Both headlamps failed at the same time.	1 day (10/18)
8	Intermittent failure of water pump unit on CAN diagnosed to update computer system.	1 day (10/31)
9	*Breakdown during operations* Continued intermittent failure of water pump unit diagnosed to faulty power supply wire on C18 from MPDM2; replaced harness.	2 days (12/7 – 12/8)

Source: VEIC adapted from data provided by Amherst Public Schools

Communication and Customer Support

The transportation team at Amherst Public Schools identified several issues related to customer support and service with Lion Bus.

- **Inadequate Training.** After an introductory session provided when the bus was delivered in December 2016, the next training session was scheduled for March, 2017. Amherst sent staff to this electric school bus training program organized by Lion Bus. Attending training in Canada proved challenging due to limitations on public school staff from traveling internationally. Amherst staff also reported a lack of communication prior to the event with limited information, such as the location of the event and time of the class were not provided until immediately (roughly 48 hours check) prior to the class. The technician who attended the class further reported that it was not well organized and did not provide detailed or highly technical information.
- **Insufficient Supporting Documentation.** In March 2017, after the training workshop provided by Lion Bus, Amherst Public schools requested additional information from Lion Bus, including technical support for their in-house staff. Most of this information was promised in the proposal. The request included 1) a drop box with PDFs of shop manuals and suppliers manuals for trouble shooting; 2) wiring schematics; 3) toll free number for calling Canada; 4) a specific list of Lion Bus components by name; and 5) improved communication between the pilot sites and Lion Bus. Information was ultimately provided by Lion Bus.

[2] Data on missed days not available for all issues.

- **Problems with Warranty Department.** Amherst experienced several problems getting work done under warranty. Challenges included 1) the amount of paperwork required to issue a claim; and 2) negotiations with the Lion Bus over the reimbursement rate for mechanical work. Most major bus manufacturers in the United States work with dealers or licensed representatives of the vehicle manufacturers. Without this relationship, Amherst worked with local automotive repair shops for warranty work. Challenges resulted because Lion was unwilling to pay the hourly rate charged to Amherst for warranty work. An agreement was reached when Lion Bus agreed to an hourly rate where Amherst would lose money on work contracted out, but was adequate for work conducted in house.
- **Difficulty with Parts.** Without a domestic dealership, all parts are shipped from the Lion Bus headquarters in Quebec Province, which means that all parts must be cleared by US customs. This delays vehicle repairs and increases the amount of time a vehicle sits idle. Some parts can be kept in stock but others must be ordered.

At the end of the pilot period, Amherst Public Schools continued to operate their electric school bus, but documented frustration with the vehicle's reliability issues. After negotiations with Lion Bus and MA DOER, Amherst decided to keep their vehicle through the remainder of the contract period. Terms that encouraged Amherst to keep their bus included additional customer support from Lion Bus and extensions on vehicle warranties.

Cambridge Public Schools

Cambridge Public Schools (CPS) provides transportation to and from school for more than 2,500 students. There are between 28 and 33 bus routes, the shortest of which is 1.3 miles and the longest of which is 11 miles. School transportation service is provided by a private operator, which also owns and maintains the buses used for CPS' transportation program. The electric school bus is the only school bus owned by CPS and was parked at a lot on Fulkerson Street in Cambridge. There were no opportunities for vehicle to building demonstrations at this site (there is no building), but charging the bus at this site was not expected to significantly increase the facility electricity load or costs.

Cambridge ordered its Lion Bus in September 2016 and it arrived at the end of 2016. CPS installed a Clipper Creek charger for vehicle charging.

Planned Operations

CPS planned to incorporate the electric school bus into its regular school bus operations and use the bus

Cambridge Public Schools eLion Electric School Bus.

for field trips. The expected daily mileage was 45 miles, which should be within the daily range of the school bus without needing to charge midday. While the operating plan was not expected to deplete the battery below 20% state of charge (SOC); Cambridge's operating plan meant the bus will be close to 20% SOC at the end of the day, so the battery should be monitored closely as the drivers gained experience with the vehicle. The battery and vehicle range also deteriorate (slowly) over time, so CPS should continue to monitor their battery and range.

Deployment

Cambridge, unlike Concord and Amherst does not own its own buses or maintain its own vehicle fleet. Instead, CPS contracts with a private contractor for school transportation service. CPS manages its Transportation Department with two staff persons and a driver. Cambridge did not record data on vehicle operations or mileage, so VEIC does not have a consistent record of usage or deployment during the first 9 months of the demonstration. Instead, VEIC and the evaluation team relied on ad hoc conversations with Cambridge's transportation staff to learn about their experience with the vehicle. After Lion Bus installed vehicle telematics in the vehicle, VEIC was able to monitor mileage and energy consumption. This data shows that the bus odometer has over 4,400 miles, suggesting the bus was deployed closer to 140 days.

MA DOER and VEIC were interested in the school contracting model and learning how the private sector transportation providers could engage in the use of electric school buses. For the electric school bus pilot project, however, Cambridge Public Schools opted to operate and maintain the bus themselves and did not arrange with the private contractor to deploy the electric school bus in their fleet. Instead, CPS assigned their driver to the electric school bus. Maintenance proved to be a challenge under this model because CPS had no staff available to be maintain or service the bus. The lack of onsite support meant that when there were problems with the bus, it sat idle for long periods while repair and servicing was arranged. After a handful of mechanical issues, Cambridge arranged with Concord to service their vehicle. Concord mechanics working on Cambridge's bus were paid by Lion Bus as long as the repairs were under warranty. This helped get repairs done, but meant there were still delays in getting the bus fixed because in most cases, the bus needed to be moved to Concord for repairs.

Cambridge's bus did operate between October 2017 and March 2018, during the period when the data collection system was able to capture actual mileage. This data shows that the bus was in service between October 6th and October 28th and logged roughly 450 miles. The bus was not in service for much of November but was on the road between November 28 and December 21. During this time, the bus logged another (roughly) 500 miles. When CPS left school for the winter holiday, it left the bus unplugged for roughly two weeks. During this time, Massachusetts experienced extremely cold conditions with several continuous days of below freezing temperatures. When Cambridge returned to school, the eLion was unable to start up. Exposure to prolonged cold weather when the bus was not plugged in damaged the low voltage battery system. After several attempts to diagnosis and fix the problem (including replacing the low voltage battery), the bus was towed to Concord for additional diagnostics, and then ultimately back to Lion Bus' facility in Quebec. Cambridge's bus was available for service again on March 12, after being out of service for ten weeks.

Qualitative Summary of Experience with Electric School Bus

Cambridge had problems with their electric school bus. Given the limited availability of their transportation staff, problems ended up keeping the bus off the road for longer periods of time as compared with the other sites. The maintenance arrangement with Concord Public Schools, while extremely useful to CPS, often meant bringing the bus to Concord, a delay that could double or triple the amount of a time the bus was out of service as compared with other sites. As a result, anecdotally, the Cambridge school bus was out of service more often and for longer periods than either of the other two pilot sites.

Cambridge remains optimistic about the electric school bus. The transportation team reported that they liked many things about the bus, including the wider body and larger windows. They intend to keep operating the bus and together with MA DOER, are looking for ways to service the vehicle with local resources, including potentially by the school bus contractor. These details were being arranged at the time this evaluation was being conducted (March, 2018).

Concord

Concord Public Schools (CPS) serves 2,100 students in its pre-school, elementary and middle schools, plus another 1,300 students at the Concord Carlisle High School. Facilities include six school buildings (one preschool; three elementary schools; two middle schools and one high school) plus a central office and bus depot.

CPS owns and operates its school transportation service, which consists of 29 daily routes operated with a fleet of 36 buses. CPS currently parks its school buses outside of town. However, the school district is in the process of building a new transportation depot at 214Y Main Street. The new facility will include four maintenance bays, 40 parking spots for buses, a diesel fueling station, and office space. It will also include an array of solar panels capable of generating 4.8 MW of electricity.

Planned Operations

Concord ordered a bus with a wheelchair lift with plans to use the bus on routes that served students in wheelchairs. The deployment schedule involved using the bus in service for roughly three hours in the morning (6:30 am to 9:30 am) and traveling roughly 45 miles. The bus was not in use from 9:45 am to 1:00 pm, although part of this midday period was used to charge the bus so that it was able to meet afternoon travel needs. The bus was back in service from 1:15 pm to 4:15 pm for another three hours and 45 miles. Concord did not use the bus for special trips, but occasionally runs the bus on other routes, so more children and parents will have a chance to see and ride on the bus.

Concord Public Schools eLion Electric School Bus.

Deployment

Concord received their bus first, in November 2016 and planned to park the bus at the Ripley Administration Building. The bus was inspected and licensed, ready for deployment in early December. Concord was not able to install their EVSE until after the vehicle arrived, which coupled with minor problems with vehicle delivery (incomplete paperwork to get the vehicle lettered, and failure to re-install the vehicle tailpipe after delivery), delayed vehicle licensing, registration. Concord’s electric school bus went into service at the end of January 2017.

Concord's school bus drivers recorded daily mileage and the state of the charge (SOC) at the beginning and end of each shift for the period between January 2017 and June 2017. Concord experienced a handful of challenges with the vehicle and EVSE including the same fuel gauge issues reported by Amherst (fuel tank sending unit failure). Concord also experienced issues with their EVSE that kept the bus off the road for five days. Other than the issue with the EVSE, Concord's eLion Bus experienced multiple problems with the headlights and other minor issues. The bus was in use for 60 of 70 school days, approximately 85% of the time.

In June 2017, the bus experienced a significant issue when one of the four battery packs failed. Lion Bus did work with Concord to solve the issue and the battery repair was covered under the vehicle warranty, but the failure resulted in the bus being sidelined for over a month. After the battery pack was replaced, Concord Public Schools used the electric school bus over the summer, but only occasionally.

During the summer, Concord Public School's Transportation Department also moved into their facility on Knox Trail. The facility was finished without installing an EVSE. While there continued to be a functioning EVSE at the Ripley Administration Building, the location of the charging equipment (it partially blocked a loading dock) meant that the bus could not be left unattended and charging. These miscommunications at the school district meant that the bus was not used between July 2017 and February 2018, except for an occasional trip. As part of waiting for the EVSE to be installed and deployed, the electric school bus was left unplugged for several weeks. During this same time, the northeast experienced a significant cold snap with several days of frigid temperatures. The bus was plugged in before the exceptionally cold temperatures and did not experience any major problems during this time.

Qualitative Summary of Experience with Electric School Bus

The Concord electric school bus logged fewer miles than Amherst, but the school transportation staff was generally satisfied with bus performance and optimistic about the technology. As discussed, the electric school bus was out of service for most of the Fall of 2017 and did not go back into regular service until February 2018. The break in operations reflected development of the new bus depot and mechanical issues associated with the school bus.

Lack of local expertise was a key problem sited by Concord staff. Although they felt that the initial training provided by Lion at the start of the pilot was sufficient, they would prefer a local dealer or mechanic who could provide help when problems arise (the initial Lion training included a Concord mechanic traveling to the Lion factory in Quebec). More recently, Lion staff were able to access the bus computer and

The wheel chair-accessible electric school bus deployed in Concord.

telematics remotely, which dramatically improved their ability to diagnose problems and provide guidance to Concord staff.

Ultimately, Concord staff indicated that they have confidence in the bus, have no concerns about reliability and intend to keep the bus in use. Lion was able to supply them with a wheelchair accessible bus and they have been pleased with that aspect of bus performance. The bus has been driven primarily by a single driver who has been on medical leave but will be returning by mid-March 2018. The district has immediate plans to train more drivers, including substitute drivers, to drive and charge the bus. The district expressed an interest in acquiring more buses that are electric if funding was available and additional EVSE could be accommodated. The only limitation of the electric bus, as they see it, is that it cannot leave Concord and they do have a need for longer trips, occasionally. This school district was comfortable using a new technology and dealing with the challenges that cropped up over the course of the pilot.

5 Performance in the Field

Introduction

The Massachusetts electric school bus pilot provided an unprecedented opportunity to gather real-world data on bus operations. The goals of this study were to explore:

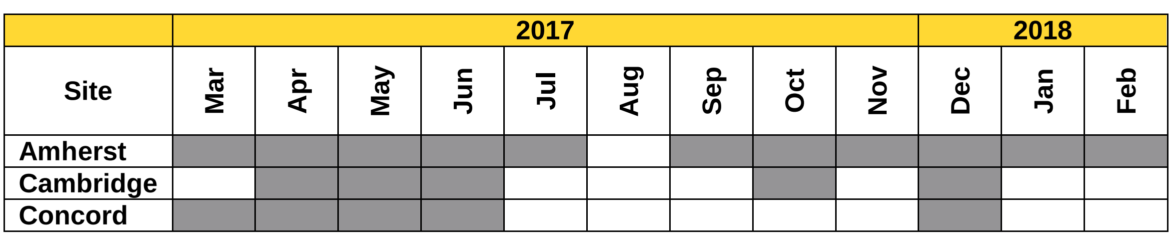
- Is electric school bus technology ready to provide student transportation? Are they comparably reliable to a diesel bus?
- Are electric school buses more fuel efficient than diesel? What are their real-world GHG impacts?
- Are maintenance costs lower for electric school buses relative to diesel?

The data collected over the course of the study was limited. There were three primary reasons for data limitations:

1. Lion Bus promised the installation of vehicle telematics in their proposal, which included data management and collection. These systems were not available when the vehicles were delivered. Lion Bus vehicle telematics eventually became available in the fall, 2018 but remained rudimentary and provided only a portion of the promised data.
2. The Massachusetts pilot project planned to install bi-directional EVSE with V2G and V2B capabilities. When the Level 2 AC EVSE were ordered, they were intended as temporary equipment and consequently were not networked. Without networking capabilities, the EVSE did not automatically track and store information about bus energy usage, miles driven, and charging times. Networking EVSE would have added an additional $300 - $400 in annual fees. Without network-enabled EVSE, VEIC was dependent upon staff at each location to collect data, resulting in many days with incomplete data. Plans for bi-directional charging were delayed to a second phase of the pilot so were not available for this research.
3. Several challenges limited the number of days the buses were in service (see Figure 8). Some of these challenges were related to mechanical issues and repairs and others were related to issues that occurred at the pilot sites. Concord, for example, lost several months of electric school bus operations because of delays installing an EVSE at their new transportation depot. Cambridge lost several days and months of operations because of multiple mechanical issues and delays getting the vehicle repaired.

Even with limited data, the pilot provided valuable information on vehicle reliability, energy efficiency and energy costs. The buses experienced more mechanical problems than anticipated, we learned a great deal about how to manage these challenges as they arose, as well as how to maximize energy savings and minimize fuel costs. Feedback from the school districts was mixed: not all were prepared to deal with challenges as they arose but the experience helps DOER and other states to understand what school district characteristics are important when considering future electric school bus deployment efforts.

Figure 8. Months Electric School Buses were on the Road



Source: VEIC

Figure 9: Summary Statistics of ESB operations and efficiency, as of February 1, 2018.

School	Total Miles	Total Days with Data Recorded	Total Estimated Days on the Road[3]	Average Daily Miles	Average Efficiency (kWh/m)
Amherst	5,302	150	150	34	2.38 (Measured)
Cambridge	4,425	39	142	31	2.38
Concord	4,176	90	90	46	2.38

Source: VEIC adapted from data recorded by demonstration sites and Lion Bus Telematics

Electric School Bus Reliability

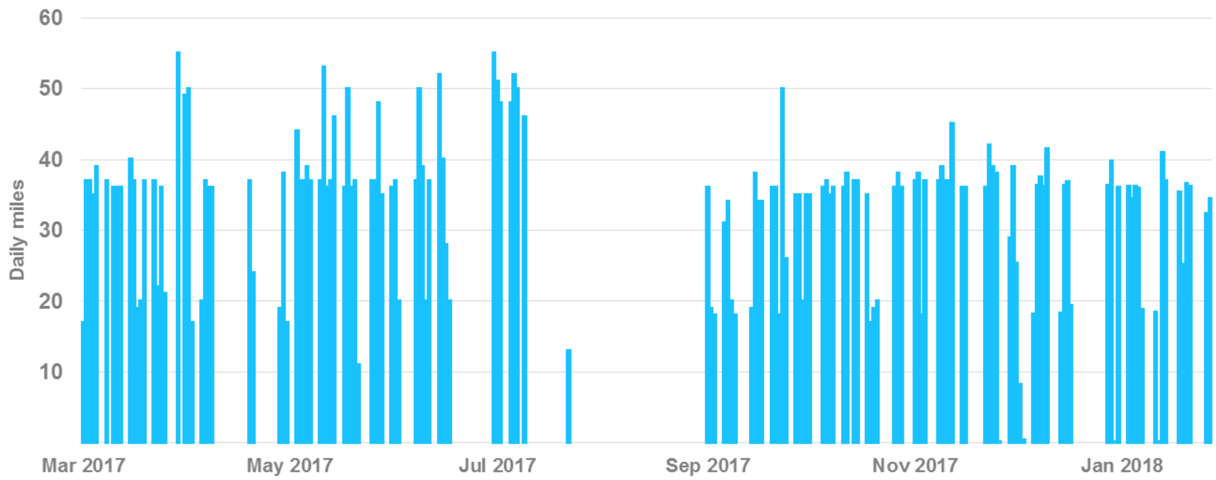
We examined two aspects of electric school bus reliability: the number of days the buses were used over the course of the pilot, and the number and nature of mechanical problems experienced during the pilot. We estimate that Amherst used their bus the most of the three school districts: collecting data for 150 days and logging 5,302 miles over the 12-14 month pilot period (Figure 9). Cambridge logged nearly 4,500 miles but only collected data for 39 days. VEIC used the 39 days for which there were data to estimate this bus's average daily miles (39) and total estimated days on the road (142). Concord logged 4,176 miles and collected data for 90 days. We did not have comparable data on reliability or rates of usage for diesel buses at the participating school districts, but we can note that overall usage of the three electric school buses was lower than the average diesel school bus, nationally, which, according to the magazine *School Bus Fleet*, logs over 12,000 miles per year over the course of the 180 day school year. For all three of the school districts, average daily miles of the electric school buses were far below the electric school bus' range of 60+ miles.

To date, the only other electric school bus demonstration in the US was located in California. A key question for the current study was school bus performance in cold weather. Although total miles were relatively low for the three buses, there was little indication that buses under-performed in winter. The buses operated well across a range of temperatures (0°F - 75°F) without significant impact on bus range (discussed further in the next section, Operating Efficiency and GHG impacts).

The Amherst school bus provided our most complete dataset, with reliable mileage and energy usage data available from January 2017-February 2018. The 150 days that the electric school bus was in use at Amherst includes eight days of summer school in July. The bus was in service for 144 days of the 180 day school year, or 80% of the time between January of 2017 - January 2018. From Figure 10, which includes not only school days but weekends and holidays as well, we see regular, short gaps in bus service (weekends), as well as longer gaps that indicate the bus was either experiencing problems (periods of April and May 2017) or out of use for the summer (June, July, August 2017). We identified eight instances between January of 2017 - January 2018 when the bus was out of service for two or more days. The Amherst bus experienced a series of mechanical problems in the spring and fall of 2017 (see Figure 11 for more detail). In addition, the Amherst bus was kept off the road early in the study due to delays with bus licensing and lettering.

[3] Includes at least 8 summer schools days for Amherst and an unknown number of days for Cambridge.

Figure 10. Amherst daily miles driven, February-June 2017. Longer gaps in usage indicate days when the bus was not in use and school vacations.



Source: VEIC

Vehicle Mechanical Issues

A range of maintenance problems with the buses were documented, including relatively minor problems (with bus headlights, a broken window), as well as more major problems: at one point the Amherst bus required a tow back to the school district garage and work on the bus's central computer system or 'CAN' and the school bus deployed in Concord had a battery pack completely fail. In Table 2, we present a list of all warranty claims received by Lion from Amherst and Concord. These problems were fixed with a combination of telephone support from Lion Bus to the school district's mechanics and visits to each site by Lion Bus technicians. According to Concord staff, beginning in December of 2017, Lion bus was able to access their bus's computer systems remotely, which greatly eased the burden of problem diagnoses and repair. All of the problems presented in Table 2 were under warranty and costs were covered by Lion Bus. Lion approved a total of 36.5 labor hours to repair these problems (15.5 hours allotted to Amherst and 21 to Concord). We do not have documentation of claims from Cambridge.

Figure 11. Warranty Claims Submitted to Lion Bus, February 2017 – February 2018.[4]

Repair Date	Location	Problem	Description/Solution	Authorized Labor Hours
2/8/17	Amherst	Leak in coolant tank	Tank replaced	2
2/8/17	Amherst	Fuel sensor not working	Sensor replaced	1
2/8/17	Amherst	Headlights	Headlights adjusted	1
2/8/17	Amherst	Fog light not installed	Fog light installed	0
3/6/17	Amherst	Electrical issue	Main power distribution module (MPDM or fuse box) replaced	0.5
8/15/17	Amherst	DC/DC converter not working	DC/DC defect replaced	5
8/15/17	Amherst	Electrical short	DC/DC fuse replaced	0
8/15/17	Amherst	DC/DC converter not working	DC/DC converter replaced	2
8/15/17	Amherst	Bus broke down on the road	Required tow back to school, Controller Area Network (CAN) repaired with	3

[4] All information provided by Lion Bus.

Repair Date	Location	Problem	Description/Solution	Authorized Labor Hours
			telephone assistance from Lion	
9/14/17	Amherst	Electrical accessory repair	Replaced CAN accessory	1
1/11/17	Concord	Sound generator not working[5]	Replaced	1.25
12/18/16	Concord	Broken window	Replaced	1
6/9/17	Concord	Bus not working- would not engage in drive or reverse	Battery repaired	6
6/9/17	Concord	Problem with battery pack	Battery pack required maintenance	6
6/9/17	Concord	Bus not working	Problem with brakes- main power distribution module repaired	1
9/14/17	Concord	Update	Electric accessory update	1
9/8/17	Concord	Update	Electric accessory update	1
11/13/17	Concord	Sound generator adjusted	Volume adjusted	0
11/13/17	Concord	Fumes smelled on the bus	Checked for leaks, none located	0
12/20/16	Amherst	Install	Installed lock under first RH seat	0
12/20/16	Amherst	Reprogrammed	Uploaded new eMotor software	0
12/20/16	Concord	Install	Installed lock under first RH seat	0
12/20/16	Concord	Reprogrammed	Uploaded new eMotor software	0
12/20/16	Concord	Incorrect installation	Installed lock under first RH seat	0
12/20/16	Concord	Reprogrammed	Uploaded new eMotor software	0
12/20/16	Concord	Install	Installed additional solenoid for wheelchair function, as per MA DOT	0
4/4/17	Concord	Update	Controller updates, bus speed limit set	0
4/4/27	Concord	Install	Installed update Tracking / Data device	0
4/4/17	Concord	Update	Updated controllers and top speed feature	0
4/4/17	Concord	Install	Replaced data logger	0
4/4/17	Concord	Update	Controller updates, bus speed limit set	0
6/6/17	Concord	Bus would not engage in drive or reverse	Repaired battery and motor cable	3.5
6/6/17	Concord	Battery error message	New battery seals installed	0

Source: VEIC adapted from data provided by Lion Bus

[5] Because electric buses are so quiet relative to internal combustion engine vehicles, they are equipped with sound generators to create noise and alert other users on the road of their presence.

Charging Equipment Issues

Both Concord and Amherst also experienced problems related to charging infrastructure that kept their buses off out of use. At Amherst, this resulted in the bus being out of service for four consecutive days in late April and early May of 2017. In Concord, the school district offices relocated in the summer of 2017, requiring new EVSE to be installed at the new location. It took approximately six months (June through November 2017) for the new site to be prepared and EVSE installed.

Electric School Bus Reliability: Key Findings

- Bus usage of 4,000 – 5,000 miles over the 12 month pilot was lower than the national average of 12,000 miles per year.
  - Buses were in use a smaller number of days than the average diesel bus: school bus fleet managers reported that newer diesel buses are rarely out of service except for occasional preventative maintenance. In contrast, by our best estimate, the electric school buses were on the road between 90-142 days out of the 180 school year. Even at Amherst, the site which exhibited the highest level of electric bus use, the electric bus was used less than 80% of 180 day school year.[6]
- On days when the electric school buses were used, it was for a relatively small number of miles; despite this, no school staff expressed concern over bus range.
- When problems came up, it was difficult for school districts to get buses back on the road quickly: lack of local expertise could keep buses out of use for even minor problems.
- Bus performance was not negatively impacted by cold weather.
- Based on warranty claims and rates of usage, bus performance and school district comfort seemed to improve over the course of the pilot, suggesting the technology is ready for more widespread deployment, assuming technical support is readily available.

Operating Efficiency and GHG Impacts

Two commonly expected benefits of electric vehicles were reduced fuel costs and tailpipe emissions. Over the course of this study, we were able to test the validity of both of these claims as they apply to electric school buses in real-world conditions. We collected data related to vehicle mileage, and energy usage (both electricity and diesel fuel for the buses' on-board auxiliary heaters), and explored how vehicle operating efficiency was impacted by factors such as charging time, temperature, and individual driver. We used the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) model, developed by Argonne National Laboratory, to estimate the electric school bus tailpipe emissions to estimate any GHG impacts of electric school bus use, and collaborated with the University of Michigan for a brief study of air quality impacts.

Energy and cost savings of electric school buses over the course of the pilot were lower than anticipated. In their project proposal, Lion bus estimated their bus operating efficiency to be 1.3 - 1.4 kWh. We observed a much lower level of efficiency (or higher level of energy usage per mile), 2.38 kWh/mile, after accounting for 'vampire loads' that occur during charging. This vampire load includes heaters, fans, lights, that operate as the bus charges. We observed a strong inverse relationship between charging time and bus operating efficiency: the longer buses were plugged in, the more energy they used on a kWh/mile basis. In fact, we found that leaving the bus plugged in for longer than 10 hours (which commonly occurs over weekends, school vacations, and even some week nights) can more than double the amount of energy used per mile, reducing overall operating efficiency from ~1.5 kWh/mile to more than 3 kWh/mile.

[6] The Concord electric school bus was only used 90 days over the course of the pilot, meaning it was not in use for half of the school year. However, it is worth noting that low usage was due in part to the relocation of bus parking and installation of new EVSE: presumably, this problem would not occur again and is less indicative of problems with electric school bus reliability, than emblematic of the challenges that come with a new vehicle technology and fueling needs. Ultimately, Concord was satisfied with its electric school bus performance. In the spring of 2017 the Concord bus was in use approximately 85% of the time.

A managed charging system that allows the bus to be plugged in but not begin charging until needed would greatly increase electric school bus operating efficiency.

As noted earlier, none of the three school districts' EVSE were networked, limiting our ability to measure the energy actually taken up by the charger. Initially, we calculated vehicle operating efficiency based on battery state of charge (SOC) because this information was available via the bus's computer system:

$$\frac{[(\%SOC\ USED) * (93kWh\ Battery)]}{Miles\ Traveled}$$

Using this method, estimates of efficiency ranged from 1.3 to 1.4 kWh per mile, par with what Lion Bus stated in their initial project proposal.[7] In September 2017, a meter was installed on the Amherst EVSE,

The eLion on-board telematics available to electric school bus drivers.

allowing for direct measurement of kWh actually taken up by the bus. Using the additional meter,

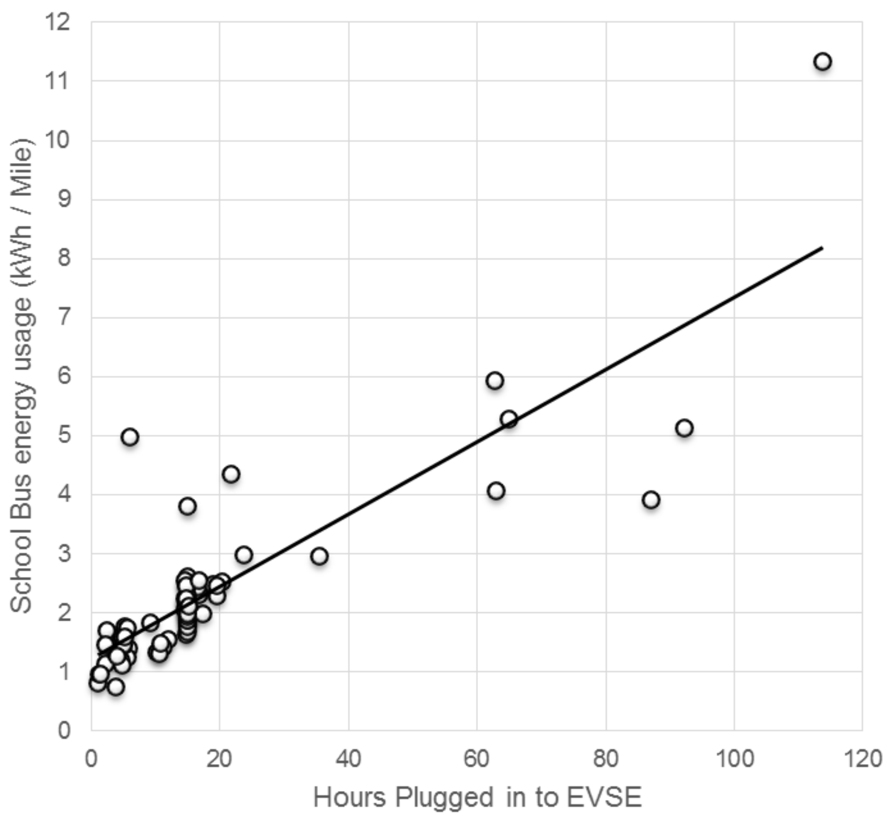
operating efficiency for the Amherst bus averaged 2.38 kWh/mile, approximately 42% less efficient than estimates using state of charge and 70% less efficient that Lion has published rates of school bus energy usage. There are a variety of reasons that actual efficiency was so much lower than efficiency estimated via state of charge: estimated efficiency over-estimated the efficiency of the EVSE and did not account for the 'vampire loads' mentioned above. A meter was installed on the Concord EVSE in December, which showed energy use nearly identical to what was measured in Amherst. For the month of December, energy usage per mile at Concord reached a high of 4.29 kWh/mile, due to the bus being plugged in over the weeklong school break. We were able to use regression analysis based on five months of metered data at Amherst to calculate more accurate estimates of actual energy usage at each site, dating back to the start of the pilot, rather than depending on estimates based on battery state of charge. All estimates of electric school bus operating efficiency reported in this document are based on either actual metered observations or modeled estimates.

Data collected over the course the pilot suggest that both temperature and charging time can affect overall vehicle efficiency. By far, the effect of charging time was larger than that of temperature. At the Amherst location, where we have the most detailed and greatest number of observations, we observed a clear pattern of decreased charging efficiency associated with longer charge times (Figure 12). The longer buses were plugged in, the greater the 'vampire loads' of auxiliary fans, lights, and battery warmers. As seen in Figure 12, these loads were not insubstantial, nearly tripling energy usage per mile from less than 1 kWh/mile for short duration charges (less than 10 hours) to 3+ kWh/mile for charge durations over 30 hours (for instance over the course of a weekend or school vacation). This phenomenon clearly indicates that some sort of controlled or managed charging system is needed. A

[7] According to Lion Bus, electric school bus battery capacity is 93 kWh.

managed charging system would allow buses to remain plugged in for long periods, without actually charging until needed (generally 6-8 hours is sufficient charging time). Further, this pattern is not apparent when bus energy consumption is calculated based on SOC. It was only by attaching a separate meter to the EVSE that we were able to gain a clearer picture of how much electricity the bus was using. It is worth noting that the efficiency of the charger and overall charging efficiency of the bus has no impact on bus range.

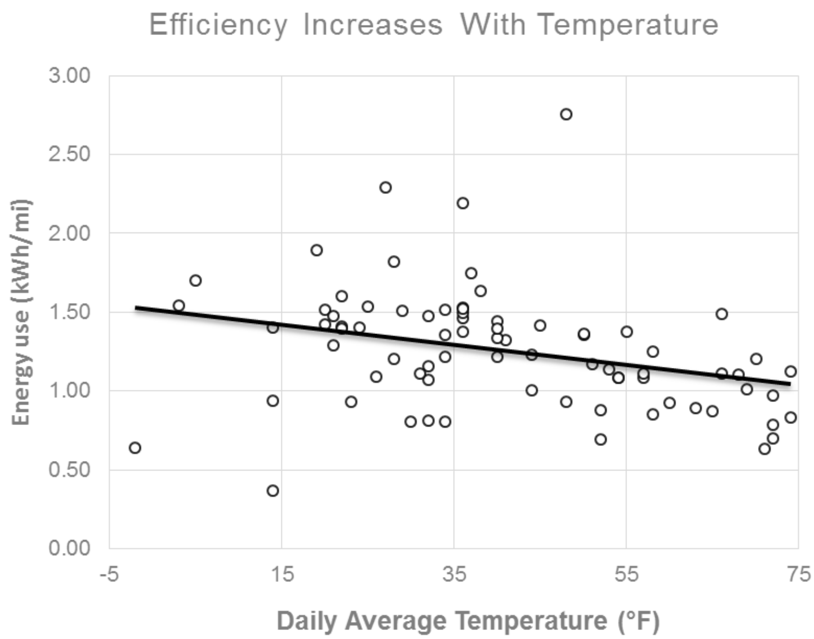
Figure 12. Amherst electric school bus energy usage vs. charging time.



Source: VEIC

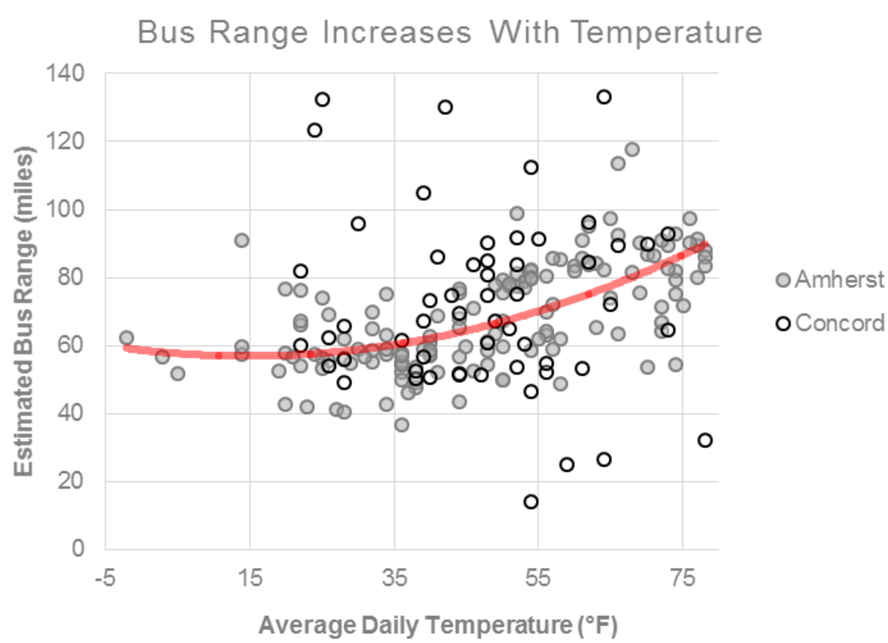
In addition, bus operating efficiency tended to be lower in lower temperatures. Based on the data collected from Amherst, efficiency increases with temperature (Figure 13). At warmer temperatures, the bus batteries operate more efficiently while the bus is on the road and while charging. An auxiliary electric heater is used to warm the batteries at temperatures below 50°F, causing increased energy use but no decrease in range (battery chemistry reduces range at lower temperatures).

Figure 13. Amherst electric school bus energy use vs. daily average temperature. Energy use increases as air temperature decreases. Energy use estimates are from data controlled from charging time.



Source: VEIC

Figure 14. Amherst and Concord electric school bus range vs. average daily temperature.



Source: VEIC

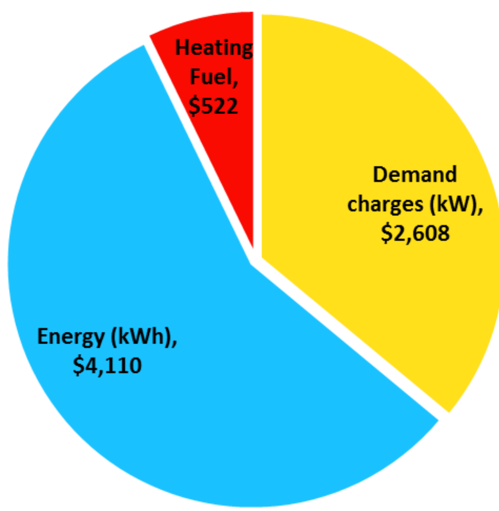
Electric school bus range also increased with temperature (Figure 14). We saw a steady increase in bus range above 20° F, from about 60 miles at 20° F to over 80 miles at 75° F. Below 20° F, bus range leveled out around 58 miles; this may be the effective minimum range for the bus. Variability in bus range was smaller at Amherst than Concord, due perhaps to driver consistency. Generally, one driver operated the electric school bus at Amherst while Concord rotated its drivers.

Driver experience was considered as a factor in efficiency. Since the electric bus drives slightly differently than a conventional bus, efficiency gains seemed possible as drivers became accustomed to the vehicle. However, we detected no measurable efficiency gains that could be attributed to driver experience.

Electric School Bus Fueling Costs

We estimate an overall bus efficiency of 2.38 kWh/mile and energy costs of $7,240 over the course of the 12-month pilot, for all three buses.[8] We estimate that driving an equivalent number of miles (13,902) in a diesel bus would have cost only $4,413.[9] Fueling costs for the electric school buses are based on actual electric rates at all three sites, and actual demand profiles at Concord and Amherst. Demand charges made up a significant portion of total costs: $2,608. These are fees incurred by large commercial and industrial users of electricity. Specific demand charges differ by utility but often apply to customers who consistently use more than 2,000 kWh /month. Charges are based on the highest 15-minute average usage recorded in the past month. By spreading out electricity usage more evenly throughout the day and charging school buses at night, rather than during the day when school electricity usage is already high, most school districts can avoid demand charges.

Figure 15. Total energy costs for all three electric school buses.



Source: VEIC

Another component of electric school bus operating efficiency is diesel fuel used for the buses' auxiliary heaters. To maintain a comfortable cabin temperature, each of the three buses was outfitted with a diesel-powered heater. On average, each bus used only one gallon of diesel for every 78 miles driven over the course of the year-long pilot, amounting to $0.04/mile. Although not a sizable cost, preliminary testing on the electric school buses suggests that the emissions from the auxiliary heater did negatively affect air quality of the bus cabin (discussed further in this chapter under 'Emissions').

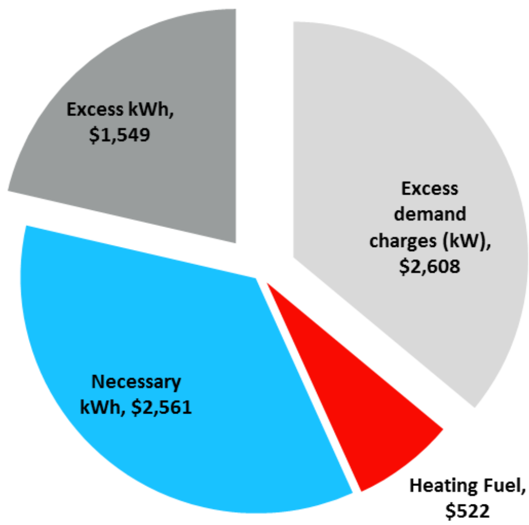
[8] Electric rates were $0.13/kWh on average in 2017.

[9] The school fleets are able to purchase diesel fuel in bulk at a discounted rate. We assumed an average of $2 per gallon. We assumed diesel fuel efficiency to be 6.3 miles/gallon.

Potential for energy cost savings

Using a bus operating efficiency of 1.47 kWh/mile,[10] the schools' electric rates, hours of bus use, and mileage, VEIC was able to estimate the cost savings available if charging were to be managed to a minimum number of hours, outside of peak demand times. Based on the mileage that the schools drove on a typical day and the minimum ranges of the buses, recharging during peak demand hours should not have been necessary. If each bus were properly configured to use no energy during peak hours (meaning all demand charges would be avoided), and to draw power from the EVSE only as long as needed to recharge the battery, the schools would save an average of 63% on electric costs. Program total energy costs would have been $3,083, avoiding the $2,608 in demand charges and an excess of $1,549 spent on electricity (Figure 16), and less than what estimate diesel costs would have been ($4,413), even at the school districts' reduced diesel costs. Bus total energy costs would have been $0.22 / mile and efficiency 1.47 kWh / mile, much closer to Lion bus has purported operating efficiency of 1.3-1.4 kWh/mile.

Figure 16. Total energy costs, with avoidable energy costs noted.



Source: VEIC

Electric School Bus GHG Emissions

A primary potential benefit of electric school buses is reduced tailpipe emissions. Diesel tailpipe emissions are particularly harmful, containing high levels of both greenhouse gases and compounds known to be damaging to human health, including particulates (PM10, PM2.5), carbon monoxide (CO), NOx, SOx, and volatile organic compounds (VOC). These compounds are especially harmful to children, whose breathing rates are faster than those of adults and whose respiratory systems are still developing. We used the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) model, to estimate the electric school tailpipe emissions from the pilot (all three school districts combined; Figure 17).[11] The AFLEET model provides estimates of emissions and life cycle costs associated with diesel, gasoline and alternative fuel vehicles, including electric vehicles. The model's estimates of electric vehicle emissions are location-specific, accounting for the regional electric generating mix.

We used AFLEET to estimate total emissions associated with the pilot, as well as what diesel emissions would have been, had those miles been driven by a diesel bus. We also used AFLEET to estimate what emissions would have been for the electric school bus pilot under a managed charging scenario (Figure 18). Managed charging increases bus efficiency by almost 40%: from 2.38 kWh/mile to 1.47 kWh/mile.

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[10] Electric school bus operating efficiency for short charging events (<10 hours), calculated from EVSE meter data.

[11] AFLEET is available for download here: https://greet.es.anl.gov/afleet_tool

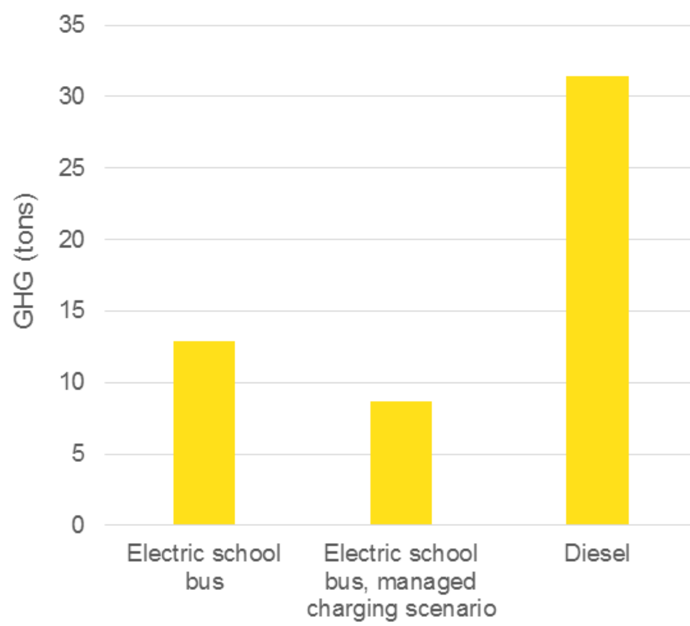
Figure 17. Electric school bus pilot total emissions. Equivalent diesel and managed charging electric school bus emissions provided for comparison.

School bus fuel type	Miles driven	GHG (tons)	CO (lbs.)	NO_x (lbs.)	PM_{10} (lbs.)	$PM_{2.5}$ (lbs.)	SO_x (lbs.)	VOC (lbs.)
Electric[12]	**13,902**	**12.9**	**0**	**0**	**3.2**	**0.4**	**0**	**0**
Diesel	13,902	31.4	31	19.6	3.5	0.7	0.3	2.9
Electric with managed charging [13]	13,902	8.7	0	0	3.2	0.4	0	0

Source: VEIC

AFLEET indicated substantial tailpipe emissions savings from the electric school buses, as expected. Although the use of the diesel-powered heater reduced savings, they were still substantial: the pilot emitted less than half as much GHG than would have been emitted by a diesel bus driving an equivalent number of miles: 10.2 tons GHG emitted by the electric school buses in the pilot vs. 23.7 tons GHG that would have been emitted by a diesel. A managed charging system would further reduce these emissions, to 7 tons GHG. Carbon monoxide, NOx, and VOC emissions were zero for the electric school buses.

Figure 18. GHG emissions of electric school bus pilot, projected emissions under a managed charging scenario, and emissions of an equivalent number of miles powered by a diesel school bus.



School Bus Cabin Air Quality

VEIC collaborated with researchers at the University of Michigan for a short study to compare air quality in the cabins of electric school buses equipped with auxiliary diesel heaters, with cabin air quality of traditional diesel-powered buses. Indoor air quality of school buses is of particular concern, in addition to tailpipe emissions, because previous research has suggested that harmful compounds can concentrate inside the bus, exposing children as they ride. Preliminary results suggest that air quality on the electric

[12] Assumes bus operating efficiency observed over the course of the study (2.38 kWh/mile); includes 135 gallons of diesel fuel for heating of school bus cabin.

[13] Assumes bus operating efficiency with minimized charge times (1.47 kWh/mile); includes 135 gallons of diesel fuel for heating of school bus cabin.

school buses was not necessarily better than the diesel buses. We assume these results are due to the diesel-powered heating system the electric buses employed (the study was performed over the course of 3 weeks in January 2018).

Electric School Bus Vehicle Efficiency and GHG Impacts: Key Findings

- Actual electric school bus operating efficiency was 70% less than Lion's published values due primarily to unmanaged charging of buses.
- Fuel costs were higher for the electric school buses than they would have been for a comparable diesel, again due to unmanaged charging, which resulted in higher than necessary energy use and excessive demand charges.
- Electric school buses have clear GHG benefits: the pilot emitted less than half as many tailpipe emissions than would have been emitted by a diesel bus.
- Preliminary testing suggests that electric school buses may not have improved air quality within the bus cabin due to the diesel-powered auxiliary heater.

Electric School Bus Maintenance Costs

The engines of electric school buses have fewer than ten moving parts, while diesel engines have hundreds. Because there are so few parts to maintain, overall maintenance costs are often assumed to be lower on electric vehicles in general. Because the technology is relatively new, however, this assumption has not been rigorously tested in real-world conditions. A primary goal of this study was to assess whether there are real maintenance savings for school districts and whether these reduced operating costs can lead to reduced cost of ownership overall, especially after accounting for any savings in fuel costs. In the section above, we discuss why fuel savings were not realized, although under a scenario of managed charging, they could be. Unfortunately, were not able to gather maintenance costs for the three electric school buses nor comparable diesel buses from the participating school districts. We do have an estimate of hours of maintenance for which warranty claims were allotted for Amherst and Concord over the course of the study: 36.5 hours, meaning that Lion Bus reimbursed these school districts for 36.5 hours of their mechanics' time over the course of the pilot for bus maintenance problems that arose (see Table 2 for a list of problems and authorized hours of maintenance). We were not able to get a sense from the participating school districts of how these 36.5 hours of labor required for maintenance of two electric school buses over the course of 12 months compares the labor generally required to maintain to an equivalent diesel bus. However, we were told by school district staff that newer diesel buses require minimal maintenance, primarily just preventative maintenance.

Vehicle to Grid & Vehicle to Building Technology

Although the vehicle-to-building component of this study was not implemented, VEIC conducted a number of analyses to assess the potential costs and benefits of V2B program. We examined electricity usage data at individual schools to estimate their current demand charges and the extent to which a V2B system could reduce those costs. We estimate that the bus batteries would need to have between 10-12% of the stored capacity available to power the school building. Building demand varies monthly, and we estimate that schools could potentially earn between $80 - $450/month by reducing their buildings' demand by 3-19 kW/month, earning approximately $1,700 - $2,000+ over the course of two years. Figure 19 presents potential financial savings for one school building within the participating school districts.

Figure 19. Potential V2B financial savings from one month of reduced peak demand charges for a single school.

Time	Peak demand (kW)	Max demand allowed to limit demand charges (kW)	KW required from battery	kWh from battery
12:00 PM	1695	1695	0.1	0.03
12:15 PM	1694	1695		
12:30 PM	1686	1695		
1:00 PM	1711	1695	16.9	4.23
1:15 PM	1703	1695	7.7	1.92
1:30 PM	1687	1695		
2:00 PM	1699	1695	4.3	1.08
2:15 PM	1714	1695	19.4	4.86
2:30 PM	1695	1695		
Total demand reduction (kW)			19.4	
Total energy drawn from battery (kWh)				12.12

This initial analysis did not indicate that financial savings of V2B would be substantial enough to merit investment in the required hardware. Exact software costs for a V2B are not known but may be upwards of $10,000. In addition, risk is high that projected financial savings will not be realized. The value of V2B lies in reducing building energy use during hours of peak demand for utilities (generally between 8 or 9AM and 6PM). We identified two hour blocks at a number of schools where mid-day peak shaving could occur, that is, if school electricity demand could be reduced by a minimum amount during these times of peak demand, the school's demand charges would be reduced or disappear altogether. If schools could reliably draw energy from school bus batteries, instead of or in addition to, the grid, they could realize financial savings. However, in order for demand charges to be reduced, schools would need to achieve reductions in demand across ALL 15 minute periods of peak demand.

Schools' monthly demand charges are based on their greatest energy use within any 15-minute block, during hours of peak demand. High-energy usage during a single 15 minute period is enough to trigger a demand charge for a school, regardless of reductions that are achieved in all other 15 minute blocks. Unless schools are able to perfectly orchestrate providing adequate supplemental energy from the battery to the building, while also maintaining an adequate state of charge to complete their afternoon route, financial savings of V2B will not be fully realized. Logistically, this could create difficulties for school fleet managers and drivers. Any V2B system would need to be closely managed.

Concord Light Department expressed interest in learning how the bus could interact with their system and, after two meetings, has agreed to plan with the Town of Concord to explore the impact of managed charging and, in a potential future phase, bi-directional charging/discharging. The municipal power entity is particularly interested in more discussions on the following:

Managed charging to address:

- Reducing peak electricity usage (to avoid increased iCap and monthly transmission charge)
- Reducing photo voltaic (PV) export during system minimum loads to increase PV hosting capacity and reduce cost to interconnect PV on the circuit

Bidirectional charging:

- Resiliency – serving building as backup during an outage
- Serving building peaks
- Working with other markets (ISO has frequency regulation market, arbitrage, etc.)

We estimated potential savings in demand charges achieved through V2B peak reductions on a monthly basis at a number of sites (see Appendix D for more background information). Below we present our estimate of V2B savings at a single site. Savings range from $268 in November to $477 during the summer months. It is important to note that in this analysis we assumed that buses would not be in use in the summer outside of the 180 day school year and would available to provide V2B services. This assumption should be revisited in future analyses: over the course of the demonstration project, we found that school buses are commonly used over the summer for summer school and other special events.

Figure 20. Potential monthly V2B financial savings for a single school, 2015-2016.

Summary of Savings Results			
Year	**Month**	**kW reduction**	**Demand savings**
2015	May	18	$ 344.70
	June	19	$ 477.28
	July	19	$ 477.28
	August	19	$ 477.28
	September	19	$ 477.28
	October	19	$ 477.28
	November	14	$ 268.10
	December	18	$ 344.70
2016	January	19	$ 363.85
	February	19	$ 363.85
	March	19	$ 363.85
	April	19	$ 363.85
		Total	$ 4,799.30

6 Findings, Recommendations & Next Steps

The Massachusetts Department of Energy Resources (DOER) initiated a pilot project to test electric school buses in school transportation operations. The pilot project was a first-of-its-kind deployment of electric school bus technologies in cold weather environments in the United States. The project was designed to understand the opportunities and challenges associated with using electric school buses as a strategy to provide safe, reliable, cost effective school transportation. Other goals of the project include reducing greenhouse gas (GHG) emissions associated with the transportation sector and to test the potential of electric school buses to interact with the electric grid through the use of vehicle to grid (V2G) and/or to interact with local energy use through vehicle to building (V2B) technology.

At the time the pilot project commenced, electric school buses had only been deployed in limited numbers and in a handful of primarily warm weather environments. This means that while the technology offered promise, there had not been robust demonstration of how well it would perform in different environments and under a variety of circumstances. Given the status of the industry, the pilot project set out to specifically to test four assumptions about electric school buses:

- Electric school buses are a viable vehicle technology that can reliably be deployed in school bus operations.
- Electric school buses are energy efficient and produce fewer greenhouse gases as compared with diesel school buses.
- Electric school buses have lower operating costs as compared with diesel school buses.
- The battery on an electric school bus can be used as an energy resources that when connected to a building energy management system (V2B) or the grid (V2G) can generate revenue for the owner of the bus.

This section summarizes the findings associated with each of these project goals as well as other lessons learned through the demonstration project.

Viability of Electric School Bus Technology

The three electric school buses deployed as part of the Massachusetts electric school bus pilot logged nearly 14,000 miles and were in service an estimated 298 days over the 14 month demonstration period. The participating school districts also agreed to continue to deploy the electric school buses beyond the demonstration period. In addition, electric school bus technology overall was enthusiastically received in each of the communities with support from school administrators, parents and students. The Massachusetts pilot also proved that electric school buses could successfully operate in cold weather environments, using auxiliary heaters to manage cabin temperatures.

Despite these successes, the demonstration also offers some caution regarding the readiness of the technology. Findings from Massachusetts suggest that electric school buses require more testing and demonstrations before they can be widely deployed in school bus fleets. Schools that participated in the Massachusetts pilot encountered a number of mechanical and logistical challenges that required considerable effort, time and energy from fleet managers, mechanics and technicians that persisted over the life of the project. Based on this experience, lessons learned and recommendations for subsequent deployments include:

- Customer / vehicle support systems – the Massachusetts electric school buses were the first vehicles sold by Lion Bus in the United States and the manufacturer had not fully developed technical training materials or the customer response systems required to support new vehicle technologies. Some of these challenges were exacerbated by the fact that technical support was based staff was in Canada and shipping parts across the border was difficult and slow at times. The combined impact was that problems with the electric school buses were more challenging and took longer to resolve than expected. Future deployments should require a more robust training program and customer support network.
- Vehicle telematics and diagnostic systems – while the onboard driver displays provided on the Massachusetts school buses are excellent, the vehicles lack robust telematics that provide data

on vehicle state of charge, remaining charge, energy consumption, mileage and diagnostic information. More and better data will help school transportation staff understand vehicle and battery performance and help staff deploy the vehicle efficiently and with fewer risks. Real time diagnostic data will help technicians and mechanics manage vehicle operations, report and respond to error and fault codes, and help avoid vehicle break-downs in the field. Next generation demonstration projects may require demonstrations of the proposed vehicle telematics and diagnostic systems before relying on them. There may also be opportunities to integrate after-market telematics to strengthen these systems.

- Managed charging systems – managed charging technology is designed to automatically control electric vehicle charging to meet operational needs (a fully charged battery when the bus needs to be deployed in service) and control energy costs (avoid charging when electricity charges are highest). Sophisticated systems should also be able to manage charging rates across multiple vehicles. They become even more important as the number of electric school buses in a single fleet increases. Electric school bus charging can be better measured and controlled by using networked vehicle chargers (EVSEs). These systems are more expensive for the school districts but the additional costs may be offset by lower energy costs.
- Auxiliary heating units – the Massachusetts buses were equipped with fuel fired diesel heaters to maintain cabin temperature without compromising the vehicle travel range. The heaters are an effective heating system but erode greenhouse gas and air quality benefits. Future generations of electric school buses may look to new systems and technologies to manage cabin temperatures.

Lack of Managed Charging Systems Erode Efficiency Gains

Electric school buses are energy efficient, when energy efficiency is measured in terms of miles per kilowatt hour (kWh) during vehicle operations (i.e. energy used to move the bus). The electric school buses consistently *operated* with an efficiency of 1.3 to 1.4 kWh per mile. At this efficiency, the school bus battery with 104 kWh is able to reliably support a travel range of between 70 and 80 miles. Findings also suggest that with experience, drivers are able increase vehicle efficiency by maximizing the benefits of regenerative braking. Further, the impacts of cold weather on vehicle range and efficiency were minimal.

Challenges, however, occurred when energy efficiency estimates include total energy consumed, inclusive of both vehicle operations and charging. The Massachusetts electric school bus pilot project showed that the energy consumed to heat and cool vehicle batteries, even if when the battery was not charging, were significant enough to erode energy efficiency achieved during operations. The energy efficiency of an electric school bus plugged in overnight drops to roughly 2.4 kWh per mile; if the bus is plugged in over the weekend, efficiency declines even further to roughly 4.3 kWh.

Vehicle charging can be managed by the EVSE, if it is programmed to shut down all vehicle systems when the battery is not charging. The Massachusetts pilot project did not purchase networked EVSE that could manage vehicle charging because the manufacturer claimed that this feature was embedded in the vehicle. However, prior to the Massachusetts pilot, the manufacturer was not aware that the vehicle's managed charging system continued to consume energy when the bus was plugged in but not charging, and thus did not control this aspect of energy consumption at all. This vehicle managed charging system is currently being refined.

Clear Greenhouse Gases Reductions

Despite the excessive energy use by electric school buses that was documented over the course of this study, there were still clear GHG benefits. The electric school buses deployed through the pilot emitted less than half as many tons of GHG than would have been emitted by comparable diesel buses.

Unclear if Electric School Buses Have Lower Operating Costs

Moving forward from this pilot project, operating costs of electric school buses are difficult to predict. Operating expenses include both fuel and maintenance costs.

We did not observe the anticipated financial and energy savings associated with lower fuel costs over the course of this project, due primarily to high vampire loads that occurred during long, unmanaged charging events. However, if vehicle charging can be managed, the data suggest that electric school buses would have lower fuel costs compared to diesel vehicles. Indeed, reports from other electric school bus pilot projects that controlled their charging using networked EVSE to manage charging have been able to lower energy consumption and costs. However, fuel cost savings should include the incremental costs associated with network charging to measure actual fuel cost savings.

The other major consideration in operating expenses is maintenance costs. The data on maintenance costs for the electric school buses was limited, in part because the buses were under warranty during the pilot. Data on maintenance costs for diesel school buses is also limited. It is unclear if electric school buses will be more or less expensive as compared with diesel school buses. The experience of the participating school districts during the pilot phase, when the vehicles were brand new, was one of regularly mechanical and logistical issues. However, the pilot phase also suggests that the electric school buses are becoming more reliable over time, suggesting that training and experience may help manage ongoing maintenance costs,

School Bus Battery as an Energy Storage

As discussed, the Massachusetts Electric School Bus Pilot intended to demonstrate grid interactive vehicle technology. While the official “pilot” phase of the project is ending, at least one of the school districts hopes to work with MA DOER to explore this technology in the coming months.

The Massachusetts Electric School Bus Pilot did not get to this phase of the work for two related reasons. The first is that the systems are sufficiently complex that they will be best implemented with project partners that have a keen interest in the technology and outcomes. While school districts are interested in reducing energy consumption and lowering energy costs, most do not have sufficient resources to undertake a project of this magnitude. In the case of the electric school bus pilot, there was enough “pilot fatigue” associated with keeping the electric school bus on the road that taking on another experimental technology was not attractive.

Although no V2X systems were implemented at participating school districts, VEIC conducted exploratory analysis and modeling efforts to better understand how such systems could work and what the financial returns might be. Schools were best suited for vehicle to building (V2B) systems rather than vehicle to grid (V2G). VEIC’s analysis shows that while there is potential to raise revenues, there is also some risk involved. School buses’ primary obligation is to be used in transportation operations. If a bus is needed to transport students and is not plugged in and providing energy back to the grid or building during a peak event, all savings for a given month could be lost.

However, there is potential in using electric school buses as an energy storage resource, especially with an active partner, like a utility, looking to shave peak demand events during targeted times when the bus is not needed for service, i.e. during the summer months. Other factors that will strengthen the case for V2G/V2B strategies is lowered cost and complete technology that is easily integrated with vehicle charging technology.

- School districts are in the business of educating students, not testing new energy systems technologies. As a result, success is most likely when there is a partnership.
- At the sites examined, V2B systems do not create a sufficiently robust revenue stream to offset the potential risks and disruption to the transportation functions of the vehicle.
- Potential collaboration with a utility during the summer months may provide value.
- Aggregation may be key – small batteries 104 kWh and AC Level 2 charging systems that max out at 19.2 KW limit the value of an individual electric school bus. However, the ability to aggregate vehicle batteries is considerable (i.e., having multiple electric school buses with V2G/V2B capability in a single fleet).

Demonstration Project Design and Structure

In addition to learning about the energy and operating performance of electric school buses, the Massachusetts pilot also offers lessons for the design and structure of future similar types of demonstration projects:

- Require vendor to provide local support for demonstration vehicle. One of the strongest lessons learned from the Massachusetts pilot project was the need for local support for the demonstration vehicles. All parties, including VEIC and MA DOER, but also Lion Bus under-estimated the amount of technical support required to keep the electric school buses on the road. More and more accessible customer support would have averted many of the challenges and frustrations experienced by the team.

- Require schools to have or develop a vehicle support plan. In addition to requiring more support from the manufacturer, the Massachusetts project shows that schools should also allocate additional resources to support deployment of new technology. The demonstration sites that were able to allocate additional resources to support the vehicle logged more miles and/or had a more positive experience with the pilot than the sites that did not have onsite support.
- Ensure support for the electric school bus demonstration is available from school administrators and transportation departments. The experience in Massachusetts suggests that there is a lot of enthusiasm for electric school bus technology, including from individuals and organizations external to the school transportation departments. While this enthusiasm is necessary to advance new technology, it is most effective when coupled with support and commitments from all levels of the school bus operating team, including facilities managers, mechanics, and drivers.

- Future demonstrations should consider assigning multiple buses to a single site. Assigning multiple buses to a single site offers several advantages including that it allows one school district to broaden and deepen their knowledge of and experience with the technology. The findings in Massachusetts suggests that electric school bus operations improve as both drivers and mechanics gain experience with the technology. Having access to multiple vehicle will expedite staffs' expertise. In addition, the next steps for electric school bus demonstrations will be to move beyond single vehicle deployments and start to bring the technology to scale.
- Implement networked EVSE as a backup measure to vehicle managed charging systems. A weakness of the Massachusetts study was the lack of data related to charging times and energy use. These systems were promised in the vehicle bids but ultimately were not delivered by the manufacturer. Linking EVSE into a network would improve the ease and accuracy of data collection, allow for remote access to data (by the bus manufacturer, project consultants, project funder), and reduce the administrative burden on participating schools.