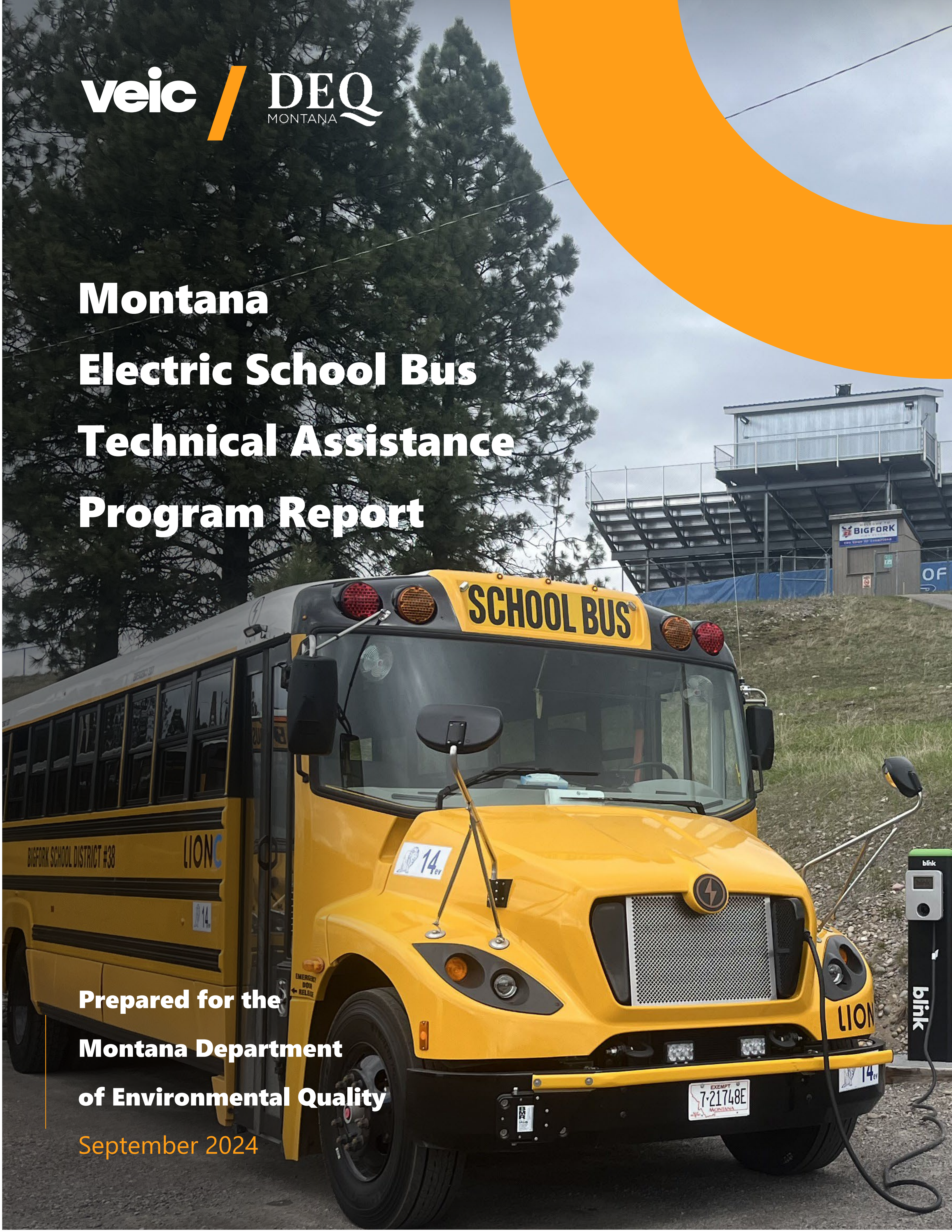
Montana Electric School Bus Technical Assistance Program Report



Prepared for the
Montana Department
of Environmental Quality

September 2024

Acknowledgements

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- **Clinton School District 32 (Handley Transportation):** Ryan Handley
- **East Helena Public Schools:** Dan Rispens
- **Fairfield Public Schools:** Paul Wilson
- **Havre Public Schools:** Allen 'Woody' Woodwick

Thank you to all the drivers, mechanics, electricians, vehicle manufacturer staff, and school district staff who helped procure, deploy, maintain, and operate the buses as well as providing critical and valuable data and insights.

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Executive Summary

The Montana Department of Environmental Quality ("DEQ"), in collaboration with VEIC, implemented the Electric School Bus ("ESB") Technical Assistance Program to support the adoption of electric school buses in school transportation fleets across the state. The program involved school transportation providers in six communities – Bigfork, Billings, Clinton, East Helena, Fairfield, and Havre – each with state or federal grant funding to purchase ESBs and charging equipment. VEIC assisted with the deployment of ESBs at each of these communities by providing comprehensive technical support, evaluation, and reporting.

This report summarizes evaluation activities and results associated with ESB deployments in this program over the 2023-2024 academic school year. Data from each deployment was analyzed individually and collectively to assess outcomes in four focus areas: performance, cost, reliability, and emissions. The key findings in each area emphasize the benefits and challenges associated with the deployment of ESBs in Montana:

- **Performance**: ESBs performed well in all weather conditions and route types. In extremely cold conditions, vehicle efficiency was reduced by up to 40%. However, ESBs were found to start up more consistently and reliably than diesel buses. ESBs were also found to have better acceleration and quieter operation than diesel buses, but a lower top speed.
- **Cost**: Each ESB averaged $1,575 in annual fuel savings compared to diesel buses. Per-mile energy fuel costs for fleets with utility demand charges were 2x higher than fuel costs without demand fees.
- **Reliability**: ESBs in the study were available for service 82% of the time compared to 94% for diesel buses. However, 72% of out-of-service days for ESBs occurred in a single district. Omitting that fleet, the remaining vehicles had an availability rate of 93%. The primary causes of vehicle downtime were related to components outside of the electric drivetrain. Resolving these issues was more challenging with some vendors than others.
- **Emissions**: ESBs significantly reduced emissions of greenhouse gases and criteria pollutants compared to diesel buses, despite emissions from electricity generation and the use of auxiliary diesel heaters in winter months.

This report also highlights operational insights and best practices for integrating ESBs into school transportation fleets in Montana. Incorporating feedback from interviews with 15 transportation managers, school bus drivers, and mechanics who engaged the most with ESBs in this program, the final section of the report offers key guidance for future ESB deployments in Montana, including in the areas of:

- **Training and support**: The quality of the initial training provided by bus manufacturers, the availability of parts, and the responsiveness of technical support all varied widely from fleet to fleet. Robust training and technical support can substantially ease or frustrate an initial ESB deployment. Vendor discussions on training plans should be incorporated into the procurement stages of any ESB deployment, including advanced sharing of slides and other content, physical space needs, and integration of fleet-specific concerns.

- **Change management**: Some managers described needing to address resistance to ESBs from a minority of drivers and mechanics. Involving staff early in the planning and procurement processes and maintaining open communication channels are crucial steps to ensuring a smooth deployment and long-term success.
- **Regenerative braking**: Managers identified optimizing regenerative braking by adjusting vehicle charging strategies as a popular way to improve vehicle efficiency. Ensuring drivers are comfortable with regenerative braking is essential for maximizing ESB benefits.
- **Charging strategies:** Differences in utility rate structures and charging patterns significantly affected the fuel cost savings of ESBs. Managers should plan their ESB deployments carefully to ensure they have tools, knowledge, and resources to meet their financial goals.

Project Overview

Background

DEQ is an executive branch agency led by a mission to "champion a healthy environment for a thriving Montana." DEQ's Energy Bureau is the state's US Department of Energy-recognized state energy office. DEQ serves many stakeholders and partners with members of the private industry, nongovernmental organizations, Tribal and local governments, school districts, and the public. This collaboration is vital to advancing the DEQ mission and enhancing services for those within Montana. As part of its commitment to a healthy environment, DEQ supports initiatives to reduce emissions and improve air quality, which include evaluating innovative options and approaches to transportation models.

The Energy Bureau developed the Electric School Bus Technical Assistance Program to support fleet managers and schools in integrating electric buses into their operations. Through technical assistance, data collection, and reporting, the program aims to optimize the cost savings and environmental benefits of electric school bus deployments in Montana.

ESB Technical Assistance Program

In late 2022, DEQ selected VEIC[1] to deliver the ESB Technical Assistance Program in coordination with school districts and fleet operators throughout Montana. VEIC is a national non-profit with expertise in energy efficiency, building decarbonization, transportation electrification, and demand management for a clean and flexible grid. VEIC's clean transportation team specializes in programs and projects to support electric vehicle (EV) fleet adoption and alternative fuel vehicle technology. VEIC has been collaborating with school districts, utilities, and governments nationwide to advance electric school buses (ESBs) since 2014, and VEIC's work has been influential in developing understanding and awareness of the technology.

Participants

DEQ selected six school districts and fleet operators (hereafter, "districts" or "participants") to participate in the ESB Technical Assistance Program. Each district had been separately awarded state or federal grant funding to help purchase ESBs and charging equipment[2]. Collectively, the program participants represent the diversity of school transportation environments across Montana in terms of demographics, geography, and ownership models. Information on each participating agency, its surrounding community, and the primary point of contact for this project are found in Table 1 below.

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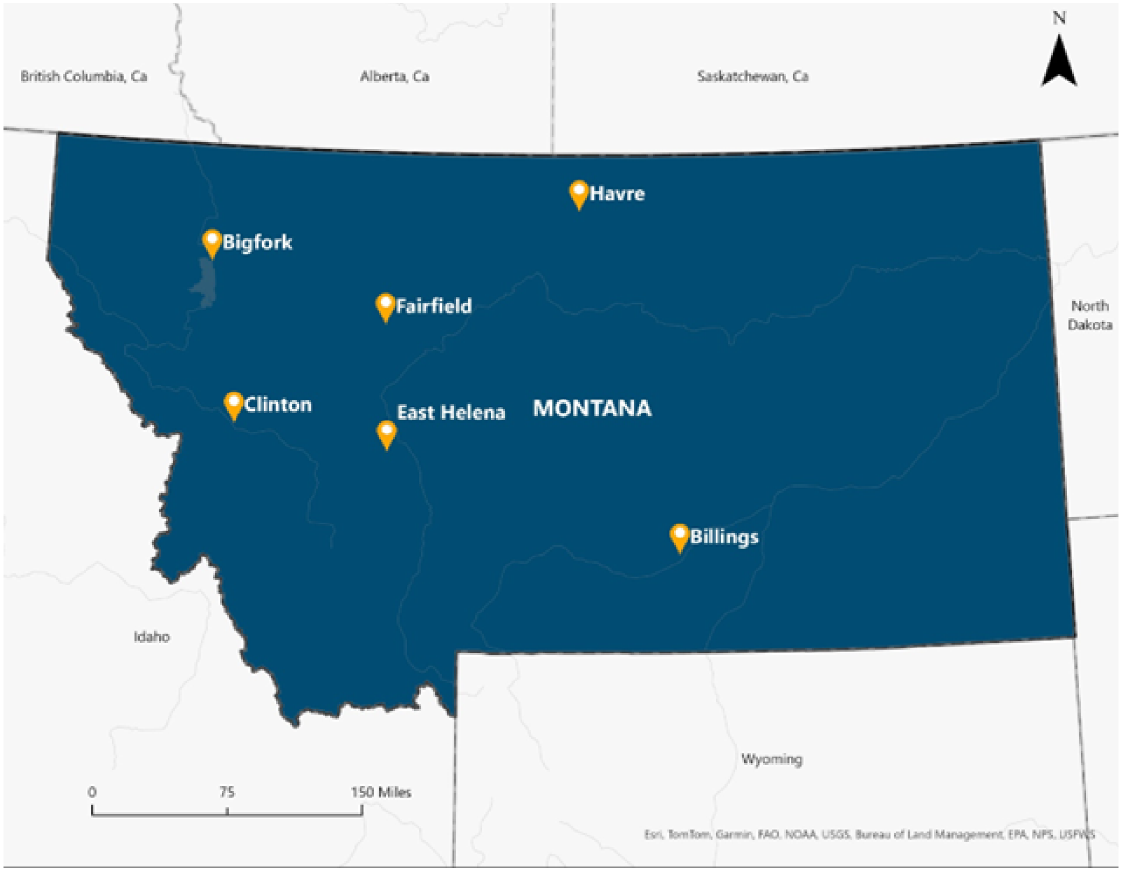
[1] *https://www.veic.org/*

[2] *Grant funding was awarded to each district either through the DEQ's Clean Truck, Bus, and Airport Equipment Program, or the Environmental Protection Agency's Clean School Bus Program.*

Table 1. Program participants and demographics.

School district or fleet operator	Primary contact	Fleet info	Town size
Havre Public Schools	Woody Woodwick, Transportation Supervisor	Own, maintain, and operate their buses	Population: 9,200
East Helena Public Schools	Dan Rispens, Superintendent	Own, maintain, and operate their buses	Population: 1,999
Billings Public Schools (operated by First Student)	Jonathan Scherer, First Student	Largest school district in the state; uses First Student Transportation, a national third-party operator who owns and maintains the buses	Population: 109,000
Fairfield Public Schools	Paul Wilson, Principal and Transportation Supervisor	Own, maintain, and operate their buses	Population: 787
Bigfork Public Schools	Danny Walker, Transportation Supervisor	Own, maintain, and operate their buses	Population: 4,270
Clinton Public Schools (operated by Handley Transportation)	Ryan Handley, Handley Transportation	Uses Handley Transportation, a local third-party operator who owns and maintains the buses	Population: 745

Figure 1. Participating school district locations.



Scope of work

This program provided planning, technical assistance, data collection, and reporting services to each participant, beginning in the pre-deployment phase and continuing through the 2023-2024 school year. VEIC's work was divided into five main areas:

- **Operations and maintenance planning and implementation support,** including monthly calls with each district, route analyses, warranty summaries, and technical performance summaries.
- **Charging equipment planning and implementation support,** including analyzing expected energy cost savings under different operating scenarios, project management, and technical assistance on electrical upgrades and charger installation.
- **Technical assistance consultations** via in-person site visits, including qualitative surveys with drivers and mechanics.
- **Data collection,** including the procurement and deployment of utility-grade submeters on charger electric panels, vehicle telematics data retrieval, NOAA (National Oceanic and

Atmospheric Administration) dataset curation, and defining a variety of cost, performance, and emission scalers.
- **Final report** evaluating and summarizing the ESB deployments in this project, including lessons learned applicable to future ESB deployments in Montana.

Procurement details

Upon entering the Program, each district had already executed purchase orders for ESBs and charging equipment in accordance with their grant funding and agency needs (see "School Experiences" for further discussion). Two bus manufacturers and three charging equipment manufacturers were represented in the program. Table 2, below, summarizes the funding sources and key details for each district's ESB and charging equipment procurements.

Table 2. ESB and charging equipment procurement details by district.

District	Funding source	# of ESBs	ESB manufacturer and type	Battery size and nominal range	Charger manufacturer, type, nominal power
Havre Public Schools	DEQ	2	Lion Electric, Type C	126 kWh, 100 miles	Blink, Level 2, 19.2 kW
East Helena Public Schools	DEQ	1	Lion Electric, Type C[3]	168 kWh, 125 miles	Blink, Level 2, 19.2 kW
Billings (First Student)	DEQ	8	IC Bus, Type C	315 kWh, 200+ miles	Borg Warner, Level 3, 60 kW
Fairfield Public Schools	EPA	3	Lion Electric, Type C	126 kWh, 100 miles	ABB, Level 3, 22kW
Bigfork Public Schools	EPA	1	Lion Electric, Type C	126 kWh, 100 miles	Blink, Level 2, 19.2 kW
Clinton (Handley Transportation)	EPA	2	Lion Electric, Type C	126 kWh, 100 miles	Blink, Level 2, 19.2 kW

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[3] *East Helena had originally intended to purchase one Type D bus. See the "School Experiences" section for details on their procurement experience.*

Deployment Evaluation

Evaluation scope

This section provides a detailed quantitative evaluation of this project's electric school bus deployments, broken into four areas: 1) reliability, 2) performance, 3) cost, and 4) emissions. It is intended to complement the qualitative assessments in the "School Experiences" section of this report.

Due to variations and delays related to procurement and delivery, each district deployed its vehicles for different lengths of time within this period[4]. This ranged from 9 months at Havre (who had deployed their buses in the prior school year) to 0 months at East Helena (who plans to deploy their vehicle in the 2024 – 2025 school year). Billings received their buses in the spring but did not have the vehicles running regular routes until May, the last month of monitoring. Due to the lack of sufficient data from both Billings and East Helena, no data from these districts could be introduced into the following quantitative findings. However, the districts are referenced and their deployments are discussed qualitatively where salient.

Table 3. ESB and charging equipment procurement details by district.

District	Deployment start	Months in the study period
Bigfork	November 2023	7
Billings (First Student)	May 2024	1
Clinton (Handley Transportation)	December 2023	6
East Helena	September 2024 (anticipated)	0
Fairfield	January 2024	5
Havre	January 2023	9

As shown in Figure 2 below, the number of buses on the road increased over the course of the evaluation as districts took delivery. While it was initially hoped that as many as 17 buses would be included in the study, delivery delays, extended driver training, and some initialization issues on one set of vehicle chargers led to only eight buses providing sufficient data to be included in

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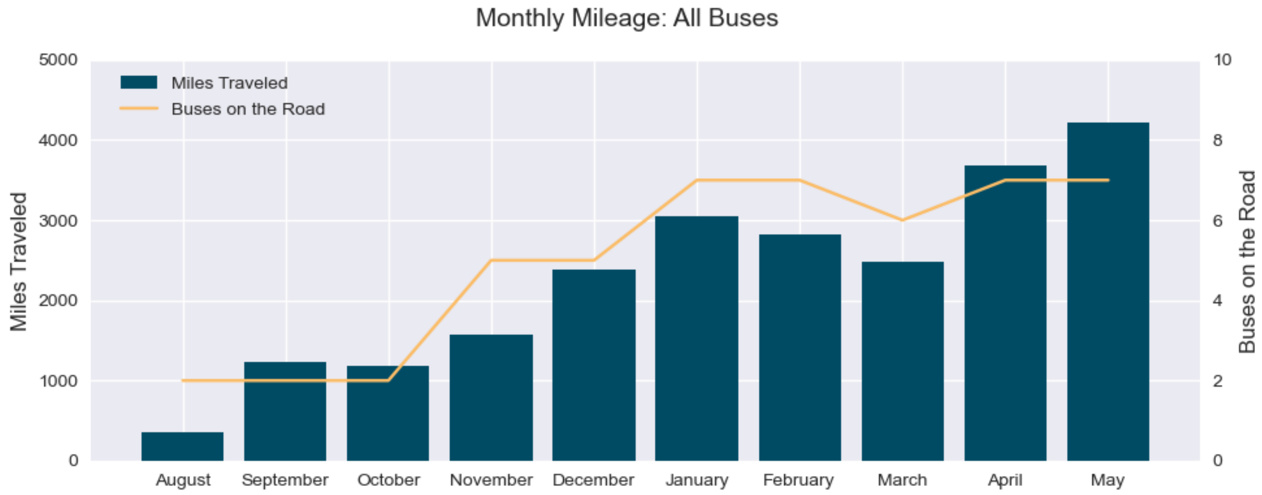
[4] *See the "School Experiences" section for more details on delays and delivery experiences.*

this report's findings. The dip in 'buses on the road' in March, along with that month's mileage, was due to one of Fairfield's buses being out of service that month, which is discussed in the next section. Buses had similar usage among districts, with each bus traveling roughly 500 miles per month on the road.

Figure 2. Collective miles traveled each month and the number of buses in service.



Reliability

Overview

Over the course of the roughly 10-month study period, the participating school districts used vehicle logs to capture real-time electric school bus activity and performance for each 'ESB Vehicle-Day'.[5] An 'ESB Vehicle-Day' is defined as any day in which a school had operational control of the ESB (which includes all days following vehicle commissioning). 'ESB Vehicle-Days' is an important metric used for fleets to measure the performance of individual vehicles by quantifying the number of days a vehicle was operational. The proportion of 'Vehicle Days' compared to 'Non-Vehicle Days' will determine whether a vehicle meets fleet expectations. Fleet staff filled out log entries to detail the status of each bus and whether it was used in service. Of the six schools involved in this study, four were able to provide data on daily bus usage, including Bigfork, Clinton, Fairfield, and Havre school districts[6]. As noted above, of the 17 buses identified for this study, eight buses were delivered within a sufficient timeframe to track meaningful data.

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[5] *Bus data analyzed in the section was collected between August 2023 and June 2024. Some school districts received and deployed their electric school buses earlier than when data collection and analysis began. To standardize our methodology, bus data shared or collected before August 2023 was not included into this analysis.*

[6] *Billings and East Helena school district had not received their electric school buses in sufficient time to include in this evaluation and were excluded from the bus availability analysis.*

To better quantify the daily usage for each bus, the following four categories were applied:

Table 4. 'ESB Vehicle-Day' categories and their definitions.

Category	Description
Available	The vehicle was operated or readily available for service.
Not Available	The vehicle was not available (out of service).
Road Call	The vehicle required a road call (one or more) during service.
No School/Service	The school was closed or buses did not run this day.

The electric school bus availability results show that the buses were available roughly 82% of the nearly 180 school days accounted for across all schools and buses. In contrast, internal combustion engine buses (ICEB) were available 94% of the time.[7] For comparison, public transit agencies typically aim for a vehicle availability rate of at least 85%[8]. The results indicate that overall, the ESB performance was less consistent than the diesel bus performance during the study period. Note that the distribution of bus availability for each school district is not indicated in Figure 3 below. The reasons that school buses were not available included equipment failures, error codes, and charging equipment malfunctions. The "Individual bus comparison" section below includes a further breakdown and analysis of bus and maintenance issues.

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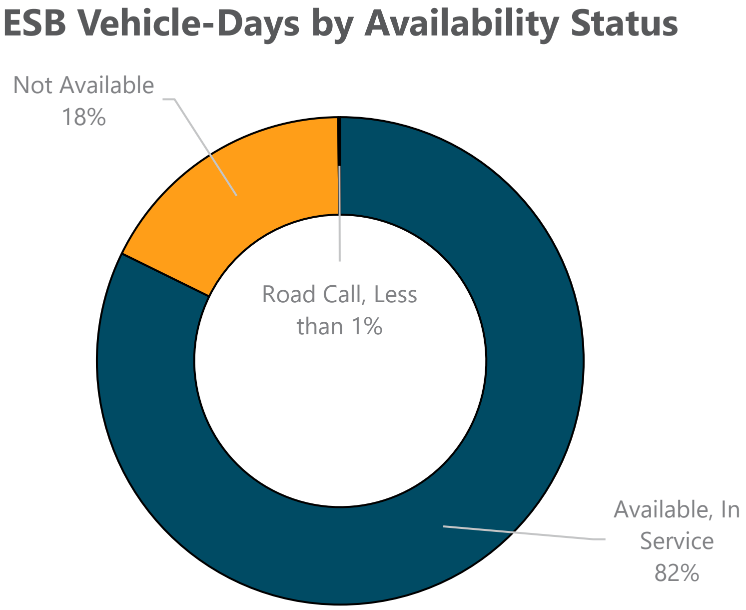
[7] *Diesel bus data is from Havre School District only.*

[8] *Leslie Eudy and Matthew Jeffers. "Foothill Transit Agency Battery Electric Bus Progress Report". National Renewable Energy Laboratory (NREL). May 2019. https://www.nrel.gov/docs/fy21osti/76259.pdf*

Figure 3. ESB vehicle-days by availability status for Bigfork, Clinton, Fairfield, and Havre school districts. [9]



Road calls accounted for less than 1% of the ESB Vehicle-Days reported throughout the study period. Only one incident occurred that required a bus to be towed from the roadside due to a High Voltage Inter-lock Loop (HVIL) error. HVIL is a safety feature commonly used in electric vehicles to ensure that high-voltage systems are properly isolated before maintenance or servicing is performed. When onboard sensors detect a fault (whether real or in error), they react by shutting down the high-voltage system, effectively preventing the vehicle from engaging the traction motor and disabling the vehicle. The roadside call occurred to Fairfield's bus #24-2 in January of 2024. The issue has since been resolved.

Individual bus comparison

To provide a clearer understanding of how each bus performed, total availability was reported for each school district (displayed in Figure 4 below). The distribution of 'Available' days for each bus shows Bigfork and Clinton attaining a perfect record of 'Available' days, while Havre School District saw mostly 'Available' days and Fairfield experienced mostly 'Not Available' days for their electric school buses. Overall, 72% of out-of-service days were experienced at one district (Fairfield). Omitting that fleet, the remaining vehicles had an availability rate of 93%. This finding corroborates anecdotal reports from fleet operators (see "School Experiences" section below).

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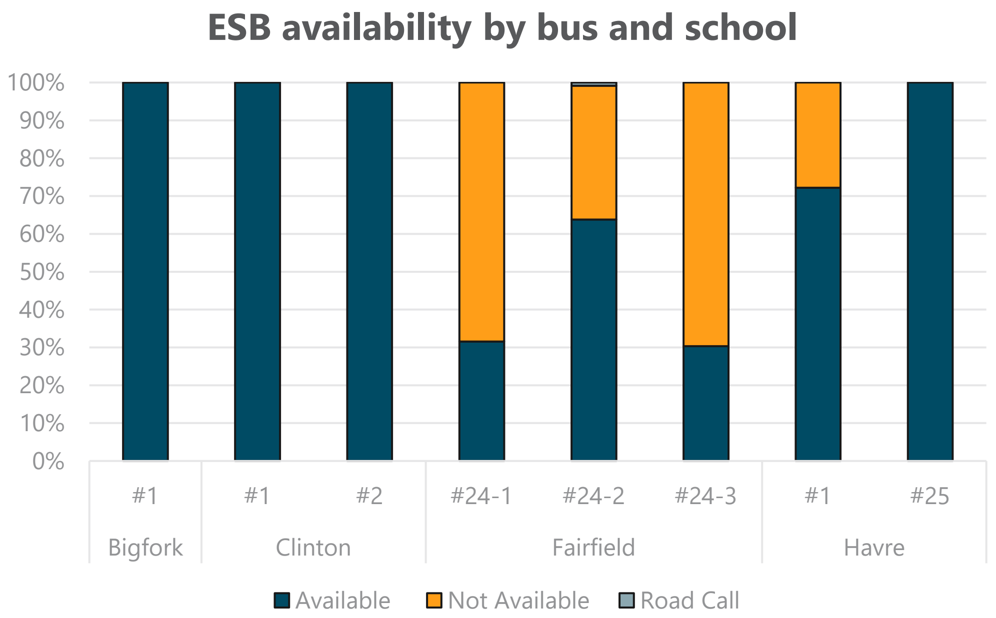
[9] *The 'No school/service day' category was excluded in Figure 3 to provide a clearer picture of bus availability.*

Figure 4. ESB availability by school district and bus number



Reasons for vehicle 'Not available'

This section focuses on reasons for vehicle unavailability, broken down by school district and bus number. Half of the school districts experienced maintenance and operational issues that resulted in their buses becoming 'Not available' at different instances throughout the project. Most notably, Fairfield's ESBs experienced significantly more issues in comparison to all other school districts. Two of Fairfield's three buses were 'Not available' over two thirds of the study period. Specifically, bus numbers 24-1 and 24-3 were 'Not available' 68% and 70% of the time respectively, while bus number 24-2 was 'Not available' 35% of the time. In addition, bus number 24-2 required a single 'Road Call' service. Issues related to Fairfield's buses being 'Not available' were attributed to bus code errors and charging equipment malfunctions. Vehicle-specific issues for all buses are listed below in Table 5. To learn more about each school district's personal experience and insights, see the "School Experiences" section.

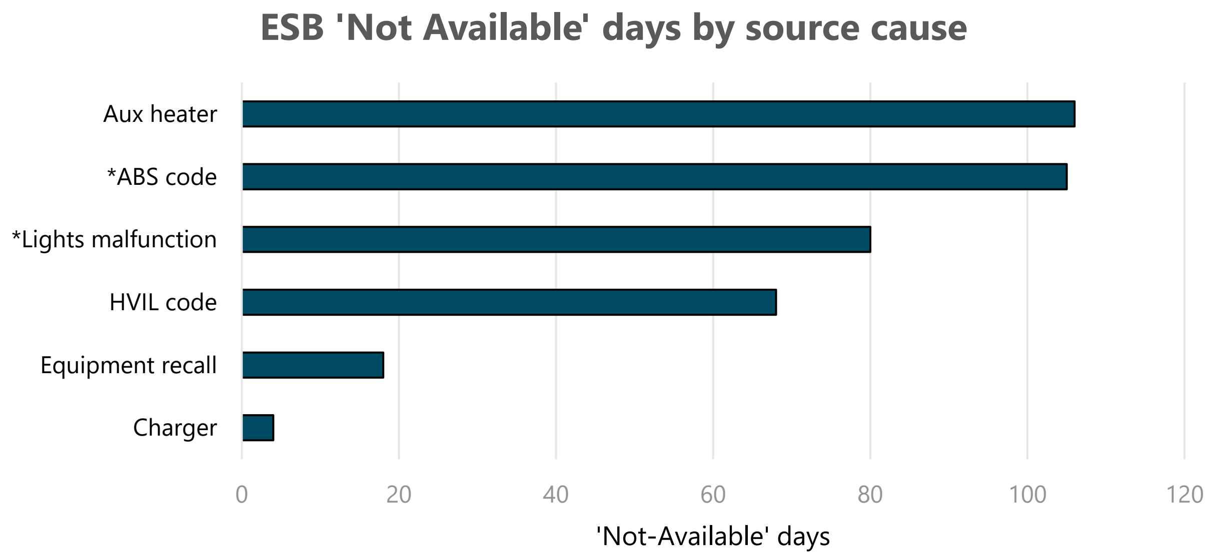
Table 5. ESB maintenance issues by district.

School	Bus tag	Begin date	End date	Service issue
Bigfork	#14	n/a	n/a	No service issues
Clinton	#1	n/a	n/a	No service issues
	#2	n/a	n/a	No service issues
Fairfield	#1	1/2/2024	1/3/2024	Not in service due to charger faults
	#1	1/9/2024	1/16/2024	Not in service due to auxiliary heaters (small fuse, elevation calibration issue)
	#24-1	1/22/2024	2/6/2024	ABS code issue, auxiliary heater issue
	#24-1	2/14/2024	**unresolved**	ABS code issue, auxiliary heater issue
	#24-2	1/2/2024	1/4/2024	Not in service due to charger issues
	#24-2	1/11/2024	1/11/2024	Not in service due to charger issues
	#24-2	1/24/2024	4/1/2024	Had to be towed from service. HVIL code
	#24-3	1/2/2024	1/3/2024	Not in service due to charger issues
	#24-3	1/15/2024	2/6/2024	Auxiliary heater issue
	#24-3	2/9/2024	3/6/2024	Passenger side red flashing lights
	#24-3	3/21/2024	**unresolved**	Passenger side red flashing lights
Havre	#1	4/6/2023	4/24/2023	Taken out of service for hydraulic pump recall
	#1	2/12/2024	4/29/2024	Auxiliary heater issue

Fairfield School District's buses accounts for nine out of the eleven incidents reported. The other two incidents were reported by Havre's school district, which reported an auxiliary heater malfunction and equipment recall (hydraulic pump). All the buses identified as having issues in Table 5 were taken out of service for preventive measures.

Fairfield's bus maintenance issues illustrate some of the challenges that are associated with integrating newer technologies like electric school buses and their associated components. However, Fairfield's experience should also be noted as unique among all the districts evaluated. The other school districts did not experience nearly as many issues. Figure 5 below categorizes the six most common issues that required a bus to be taken out of service listed by total number of days of availability impacted.

Figure 5. A chart showing the total number of 'Not Available' days by category for all vehicles combined.



** Indicates that the problem has not yet been resolved for some buses.*

Auxiliary heater, ABS code, and light malfunctions were the top sources identified for causing electric school buses to be 'Not available.' As of June, the ABS code and light malfunction issues have not been resolved. Bus numbers 24-1 and 24-3 are still 'Not available.' As a result, for the eight buses tracked, the auxiliary heater and light malfunction categories have accumulated over a hundred 'Not available' days each. This is a significant increase in the days listed as 'Not available' for all other issue sources.

While auxiliary heater malfunctions were a persistent cause of 'Not Available' days, that mechanical function is not essential to running an electric school bus in most conditions. The sole function of the auxiliary heater is to provide heat to the bus and keep the passengers warm. However, due to Montana's cold climate – with over half of the year in below-freezing temperatures – having a well-functioning auxiliary heater is essential for safe and comfortable transportation of students. Auxiliary heater repairs and replacements do not typically require complex servicing. However, the unavailability of necessary parts hindered school bus technicians from performing needed repairs, which prolonged bus redeployment.

Other issues resulting in a 'Not available' status stem from software, electrical, or equipment malfunctions and recalls. Fairfield's bus #24-1 experienced a persistent ABS code issue. Bus vibrations were suspected to trigger the sensor code, resulting in a preventative bus shutdown. Additionally, the same bus has been unable to be adequately charged. In both cases, the issues have not been resolved at the time of publishing this report. Separately, Havre's bus #1 was pulled from service due to an OEM hydraulic pump recall. The wait for a new hydraulic pump resulted in the bus being 'Not available' for 13 school days. Subsequently, Havre's bus #1 auxiliary heater failed. This combination of issues resulted in the bus being ‘Not available’ for a little over two months.

Mean Distance Between Failure

To provide a clearer picture of bus reliability throughout the study period, the VEIC team looked at the Mean Distance Between Failure (MDBF) for the total mileage of all buses. MDBF is a metric used to quantify the average distance a vehicle operates before experiencing a critical fault. MDBF is a reliable metric used by fleets to better understand individual vehicle performance. By analyzing MDBF data, fleet managers can make informed decisions to improve maintenance schedules, reduce downtime, and enhance overall operational efficiency. During the study period, there were a total of seven failures over roughly 23,000 miles driven by all buses combined. Six out of the seven failures occurred in Fairfield school buses. To determine the electric school buses’ MDBF, the team divided the total number of electric school bus miles traveled by the total number of failures to estimate an average number of miles driven without failure for a single bus.

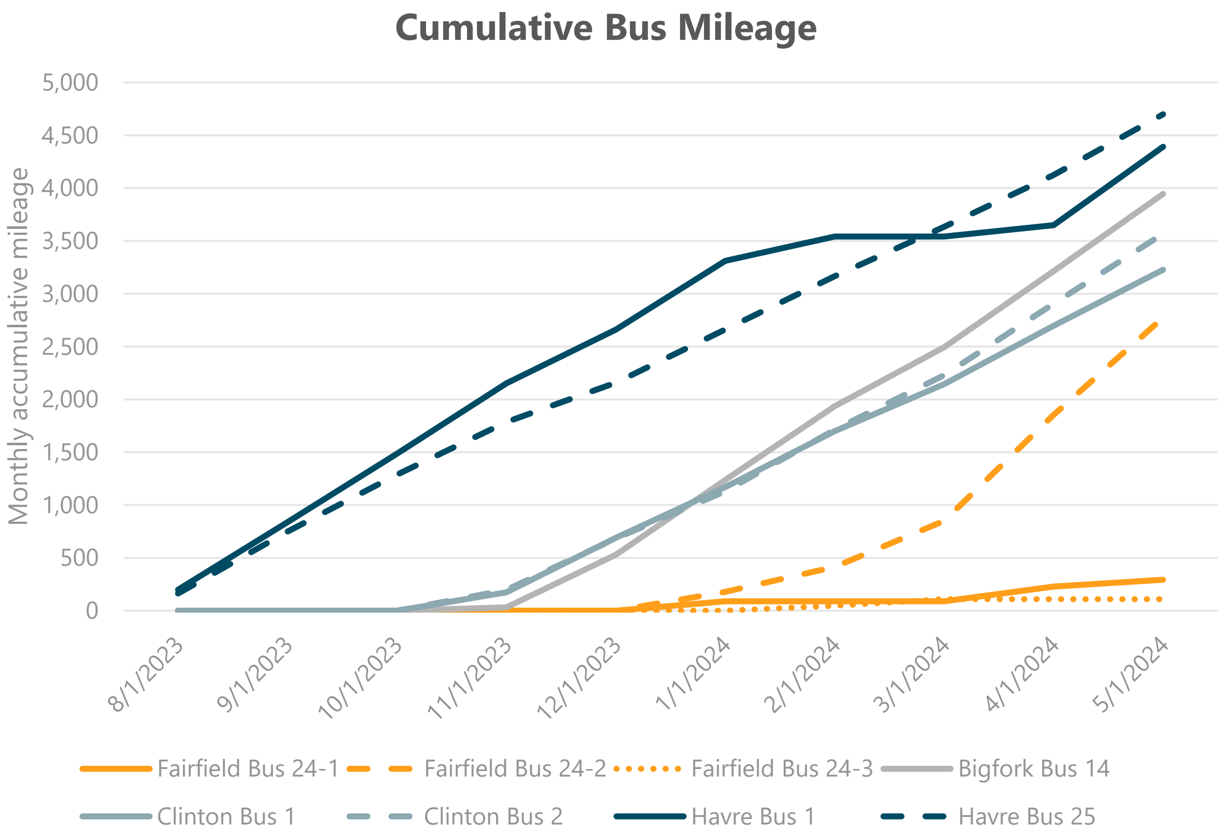
MDBF= 23,008 (total miles)/ 7 (total failures) = ***3,287 (MDBF miles)***

The estimated MDBF for an average electric school bus in this study was 3,287 miles. Each failure occurred in the winter months of 2024, with three failures in January, three in February, and one in March. Further investigation may be warranted to assess whether winter conditions like colder temperatures and harsh weather impacted bus failures. It is well known that colder temperatures can negatively affect ESB battery range, so it is possible that these same conditions could have been a factor in other mechanical issues of the fleet, including ABS/HVIL code errors and charging equipment failures.

An important consideration when evaluating the MDBF is the size of the fleet. The fleet size in this study was much smaller than typical use cases of MDBF analysis. While a larger sample size would have produced a more comprehensive analysis, using the MDBF with this small sample size can still provide useful metrics on overall bus performance and reliability.

To illustrate the MDBF impact on overall bus performance, Figure 6 below captures the total number of monthly mileages driven by each bus between August 2023 and June 2024. The figure provides a more nuanced picture of how individual buses performed at different stages in the study. Results are broken out by bus number and school district.

Figure 6. A chart showing accumulated mileage per bus by month.



Unsurprisingly, the data indicates that electric school buses with minimal or no failures were utilized more, clocking around 3,000 to 4,500 miles. In contrast, electric school buses that encountered one or more failures (such as all three of Fairfield's buses) show a marked decrease in miles traveled, falling below 3,000 miles, with the most troubled buses unable to reach 500 miles of travel during the monitoring period.

Performance

Moving beyond reliability, VEIC evaluated the electric school buses along several performance metrics utilizing both quantitative and anecdotal information. In comparing the driving experience between the various drivetrain types, the most common feedback from drivers was their appreciation of how quiet the electric buses are to operate (see "School Experiences" section). The analysis shows that driver perceptions of on-road performance across driving conditions, including snow, rain, heat, and extreme cold, met or exceeded that of the fuel-powered vehicles. Cold weather negatively impacts vehicle efficiency across all drivetrain types, but it is typically more acute for electric vehicles. During a short spell of cold weather that dipped more than twenty degrees (Fahrenheit) below zero, the electric buses at one agency were able to continue operation with a 30-40% range reduction. In contrast, the diesel buses had to be taken out of service to avoid fouling their engines as the fuel began to gel.

The performance results were compared to a baseline diesel bus. To make a fair comparison, the baseline bus selected was a new (2024) diesel (the most common fuel type among the fleets in the evaluation) type C school bus. The efficiency of the diesel baseline bus was estimated using the national average MPG (a value of 7.0 MPG taken from Argonne National Lab's AFLEET Tool[10]). As shown in the results below, a parallel approach was taken for a baseline new gasoline fuel type C bus. To fairly compare the performance of vehicles based on ambient temperatures, Internal Combustion Engine (ICE) fuel efficiency was temperature-normalized based on typical local weather conditions[11].

Overall, the on-road efficiency of the electric buses substantially outperformed the average baseline diesel bus. The average observed efficiency was 1.88 kilowatt-hours (kWh) per mile. While bus efficiency is often reported in kWh per mile, by converting to the diesel equivalent of miles per gallon (MPGde), the team was able to more easily compare the electric drivetrains to diesel and gasoline-powered models.

Figure 7 below indicates that the ESBs were 3.9 times more efficient than the diesel alternative, averaging 26.32 MPG_{de} compared to the expected 6.71 MPG_{de}[12] of diesel buses.

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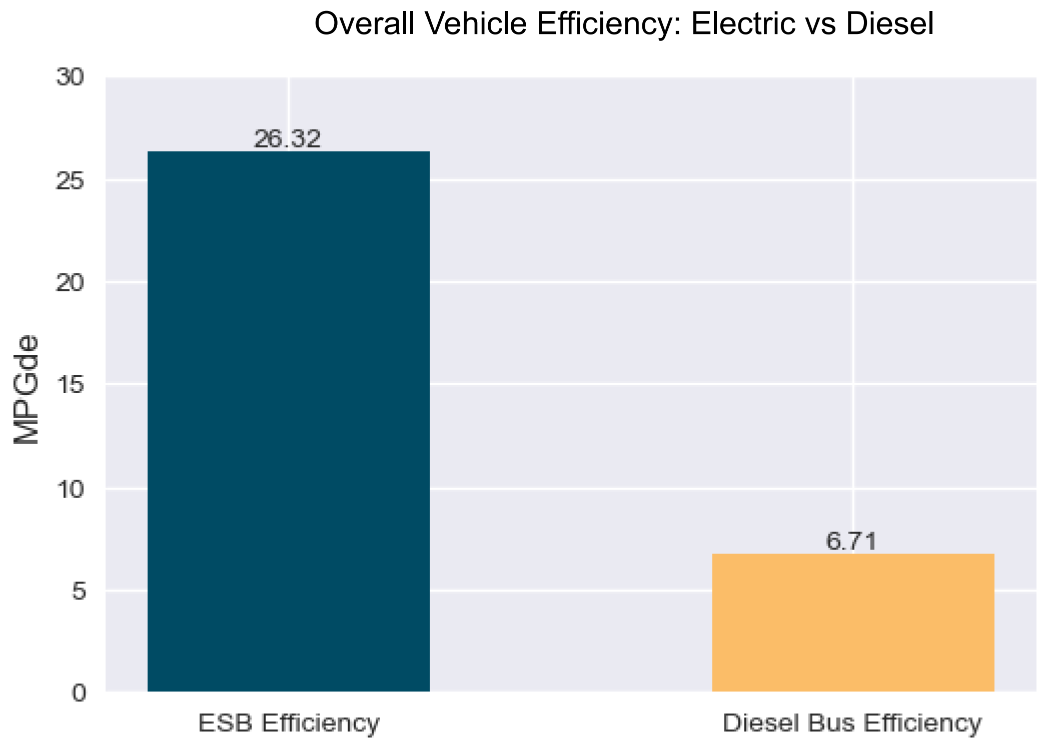
[10] *Argonne National Lab Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool - https://greet.es.anl.gov/afleet_tool*

[11] *Similarly to ESBs, diesel vehicles are found to be maximally efficient at a temperature of about 60F, primarily due to heating and cooling loads. Fuel efficiency factors used in this analysis - 0.17% for each degree below 60F, and 0.68% for each degree above 60F – are taken from: M Henning., A Thomas, A Smyth. 2019. "An Analysis of the Association between Changes in Ambient Temperature, Fuel Economy, and Vehicle Range for Battery Electric and Fuel Cell Electric Buses". PDF Accessed 6/4/2024. <https://cte.tv/wp-content/uploads/2019/12/Four-Season-Analysis.pdf>*

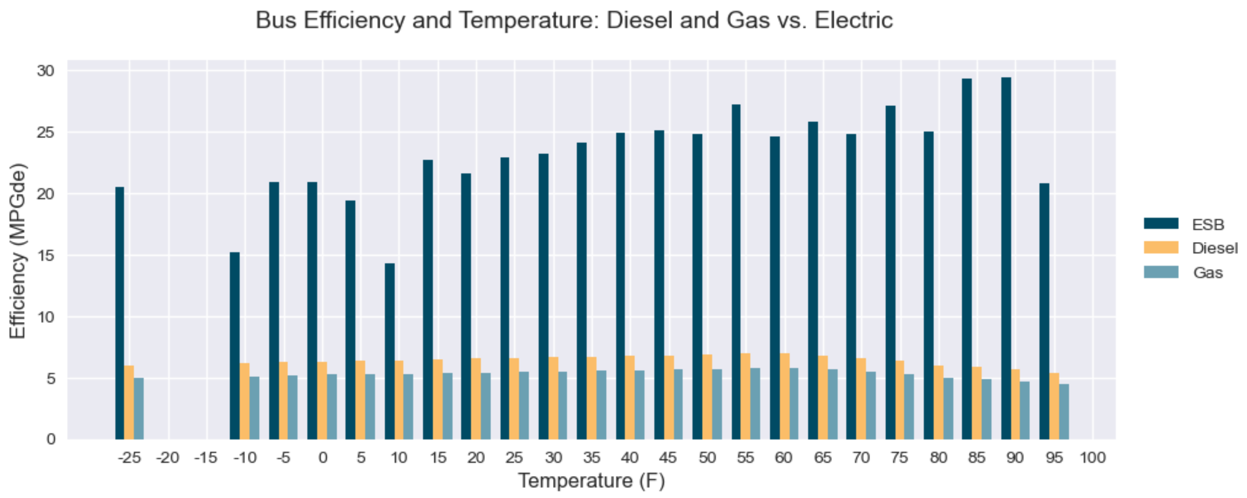
[12] *The conversion factor used, 1 MPG_{de} = 40.26 mile/kWh, is based on standard diesel fuel energy conversions published by the U.S. Energy Information Administration at https://www.eia.gov/energyexplained/units-and-calculators/energy-conversion-calculators.php.*

Figure 7. A chart indicating average ESB versus diesel on-road efficiencies, weather-normalized.



VEIC identified a positive relationship between ESB efficiency and outdoor temperature. This mimics expected patterns based on the documented performance of ESBs across the country. Figure 8 below shows that while ICE drivetrains suffer minor efficiency losses in the heat and cold as well, the variance in efficiency is much less compared to ESBs. Even so, in the worst case the electric vehicle efficiency is double that of the ICE buses. In the best case, the ESBs have almost six times the efficiency of the traditional ICE drivetrains.

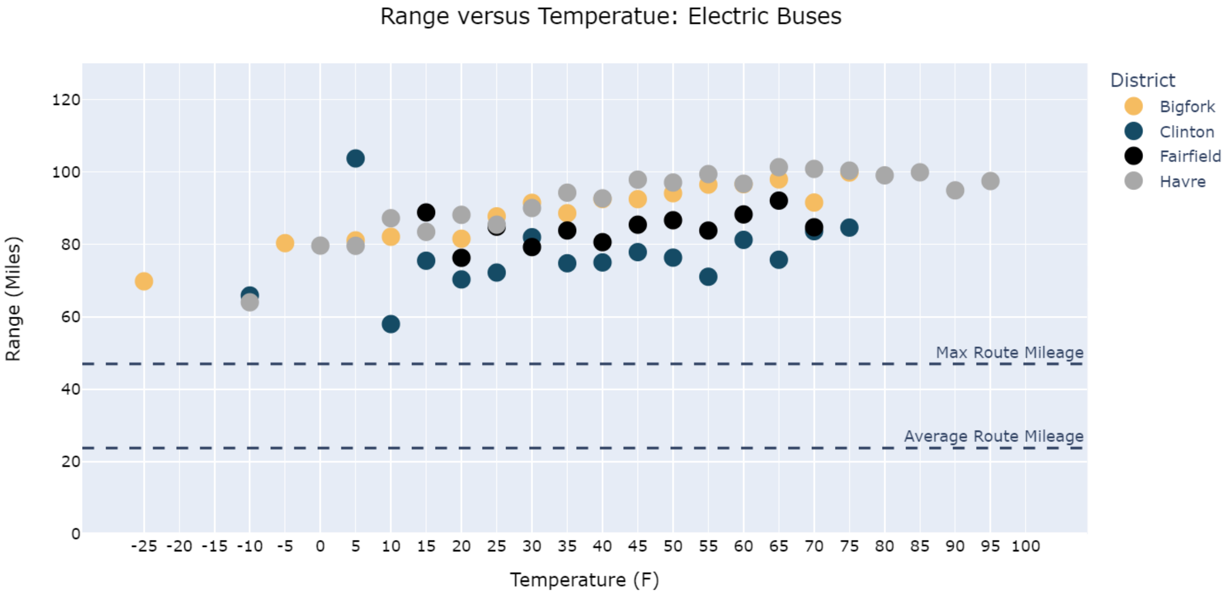
Figure 8. A chart showing the miles per gallon (diesel equivalent) efficiency ratings for electric, diesel, and gasoline school bus drivetrains across the range of outdoor operating temperatures.



When assessing the data on a district-by-district basis, VEIC identified the same efficiency fluctuations based on temperature with more obvious scatter. These variations could be a result of any number of factors, from the speed vehicles went to the driving style of operators. Some of the scatter can be attributed to the limited data set available. With only a few months to a year (180 school days at most) of trips broken out into 20-25 different temperature bins, a few outliers can have an outsized effect on the results. In Clinton, for example, two of the buses saw very little service. What service they did see may not show performance indicators that represent normal operations.

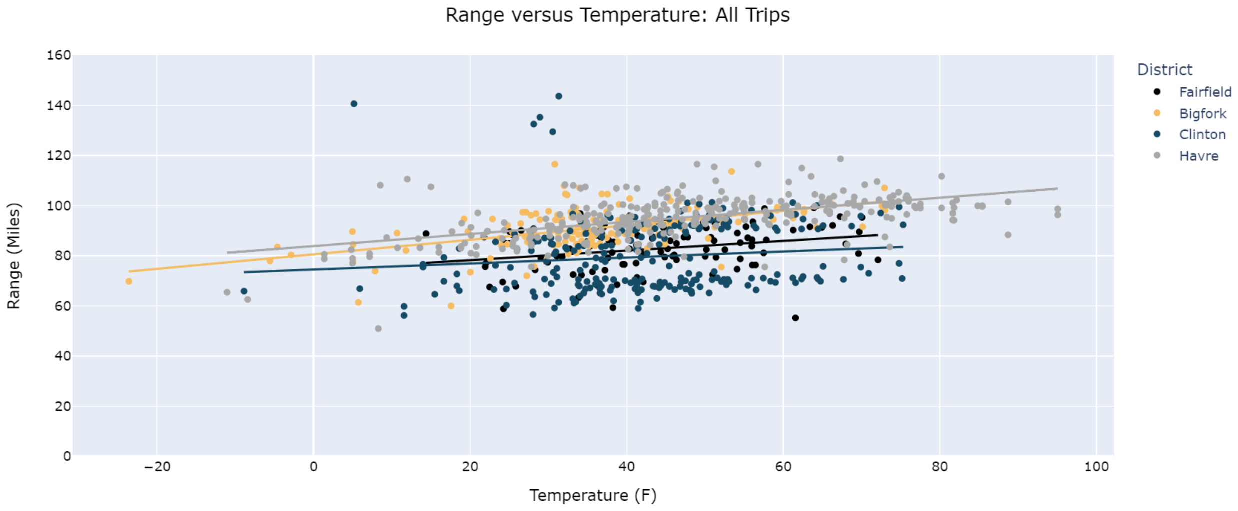
VEIC observed that ESBs displayed more than adequate range ability throughout the evaluation period. Electric vehicle range decreases in colder weather due to reduced chemical activity in the lithium traction batteries (used for primary propulsion). The range is also reduced in hot conditions, though to a lesser extent. Thus, the effects of temperature on range and efficiency were closely monitored throughout the evaluation period. Montana is known for having spells of winter cold that can dive below -20 degrees Fahrenheit and summer heat that can exceed 100 degrees Fahrenheit. However, as Figure 9 below shows, **even under extreme cold conditions the buses had sufficient range to complete their assigned routes.** If needed, the buses could even charge between morning and afternoon runs and effectively double the available ranges noted below.

Figure 9. Average ranges per charge for each district across various outdoor operating temperatures.



VEIC analyzed all trips during the evaluation period, in addition to assessing binned averages. The team demonstrated an observable, positive range-to-temperature trend across all districts. Some variation between districts may stem from an imbalance in the total number of data points, district by district, which is a result of the staggered roll-out of ESBs across the districts.

Figure 10. A scatter plot comparing each district's bus ranges to the average outdoor temperature.



One detraction noted on the ESB performance was that the Lion buses have a governor system that prevents drivers from exceeding 60 MPH. This is particularly noticeable in Clinton, where the bus route includes highway driving. The speed limit on that highway is 80 MPH. The reduced speed did not require any adjustment to route timing, though the drivers did state that they would prefer to travel closer to the speed of other traffic on the highway to reduce the number of vehicles making quick lane changes around the bus. The speed restriction may have more of an impact if ESBs are used for longer trips, such as field trips to other schools.

Another minor critique of the ESBs was their weight. A fuel-fired diesel type C bus typically has a curb weight between 15,000 and 21,000 lbs. That vehicle's Gross Vehicle Weight Rating (GVWR), or the total loaded weight a vehicle can handle including passengers, is around 25,000 - 35,000 lbs. The Lion Type C electric bus with a base model battery pack comes in at the high end of the typical bus weight range with a curb weight of 21,000 lbs. (and GVWR of 30,000 lbs.). While the added weight is seen as a benefit in snowy and icy conditions because it increases traction between the tires and the road, it could be a negative in muddy conditions or on weight-restricted roads and bridges. Additionally, the added weight causes the tires and brakes to experience slightly more wear, which increases particulate matter emissions (see "Emissions" section below). Lastly, the State of Montana has GVWR requirements that some models of ESB may miss, especially for models with extra battery packs[13].

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[13] *The Montana Office of Public Instruction's 2022 Montana School Bus Standards are based on Federal Motor Vehicle Safety Standards (FMVSS), National Highway Traffic Safety Administration (NHTSA) Guidelines for Pupil Transportation Safety, the 2015 National School Transportation Specifications and Procedures, Montana Code Annotated and Administrative Rules, and other best practices. This document can be found at https://opi.mt.gov/LinkClick.aspx?fileticket=Ab5BKCdY9kc%3d&portalid=182.*

Cost

This section analyzes data from this project regarding the three primary cost components of an ESB over its lifetime: capital costs, fuel costs, and maintenance and repair costs.

Capital costs

Capital costs include the purchase cost of the ESB, the charging and installation costs, and the cost of upgrading electrical infrastructure to support charging. Table 6 provides a summary of the up-front capital costs incurred at each district in their project. The actual cost to each district was significantly less than the raw per-bus totals due to state and federal grant support, which ranged from 85% to 100% of the total cost (see "Project Overview").

Table 6. Capital costs for each district in the project.

	High-Level Bus and Charger Specifications			Per-Bus Totals			Grant Funding
District	**# ESBs**	**Battery Size**	**Charger Type**	**Bus**	**Charging Equipment**	**Installation & Electrical Upgrades**	
Bigfork	1	126 kWh	Level 2 AC 19.2 kW	$375,577	$5,551	$14,835	100%
Billings (First Student)	8	315 kWh	Level 3 DC 60 kW	$392,856	$62,515		85%
Clinton (Handley)	2	126 kWh	Level 2 AC 19.2 kW	$374,964	$4,189	$15,928	100%
East Helena	1	168 kWh	Level 2 AC 19.2 kW	$387,051	$6,766	$2,935	85%
Fairfield	3	126 kWh	Level 3 DC 22.2 kW	$375,000	$10,757	$8,858	100%
Havre	2	126 kWh	Level 2 AC 19.2 kW	$345,949	$3,870	$8,378	85%

Table 6 shows the outsized impact of battery size on vehicle cost, with larger battery sizes resulting in higher costs. However, variations in per-bus price are also caused by differences in bus vendor (Billings purchased from IC Bus, while all others purchased from Lion Electric), vehicle configurations, and time of purchase. For example, Havre's purchase was executed in late 2021, almost a year in advance of the other purchases.

Table 6 also shows that charging equipment and installation costs varied significantly across sites. Costs at the most expensive site, Billings (First Student), were driven by the fact that Level 3 charging equipment costs more than Level 2 charging equipment and often requires significant electrical upgrades. At the remaining sites, the costs of installation and electrical upgrades varied from less than half the cost of the charging equipment (East Helena) to almost three times the cost of the charging equipment (Bigfork). **This reflects the significance of nuanced, project-specific factors in determining charger installation and electrical upgrade costs.** For example:

- At Bigfork, installation costs were driven up by the extensive trenching required to place the charging unit in its desired outdoor location.
- Both Fairfield and Havre benefited from economies of scale in their installation costs; Fairfield's Level 3 charging equipment cost was 51% higher than the average cost of Level 2 charging equipment costs in the project, but the combined charging and installation cost was actually lower than the Level 2 average.
- Clinton decided to upgrade their service panel to accommodate future ESBs.
- East Helena's project involved minimal electrical upgrades and a short run of conduit from the service panel to the charger location.

Fuel costs

VEIC applied the performance findings from the previous section along with local and regional fuel and electricity monthly pricing information to develop operational cost estimates for running the electric buses. Auxiliary heater fuel costs were also included on the electric bus side of the equation. These costs were based on the monthly fuel use reported for that purpose by project participants.[14]

Overall, ESBs outperformed the diesel baseline across all locations with sufficient enough data to perform a valid analysis. On average, ESBs cost $0.17 less per mile to operate than diesel buses. Annualized savings fluctuate depending on a given route, driving style, and operating conditions. However, by taking the average route length across all districts and multiplying it by 180 days of school per year (the typical length of a Montana school year), VEIC analysts calculated total average annual fuel savings. The team projected annualized diesel fuel costs as approximately $4,495 per bus. Electric buses, on the other hand, cost approximately $2,920 each year. On average, each ESB saves a district roughly $1,575 per year in fuel costs.[15]

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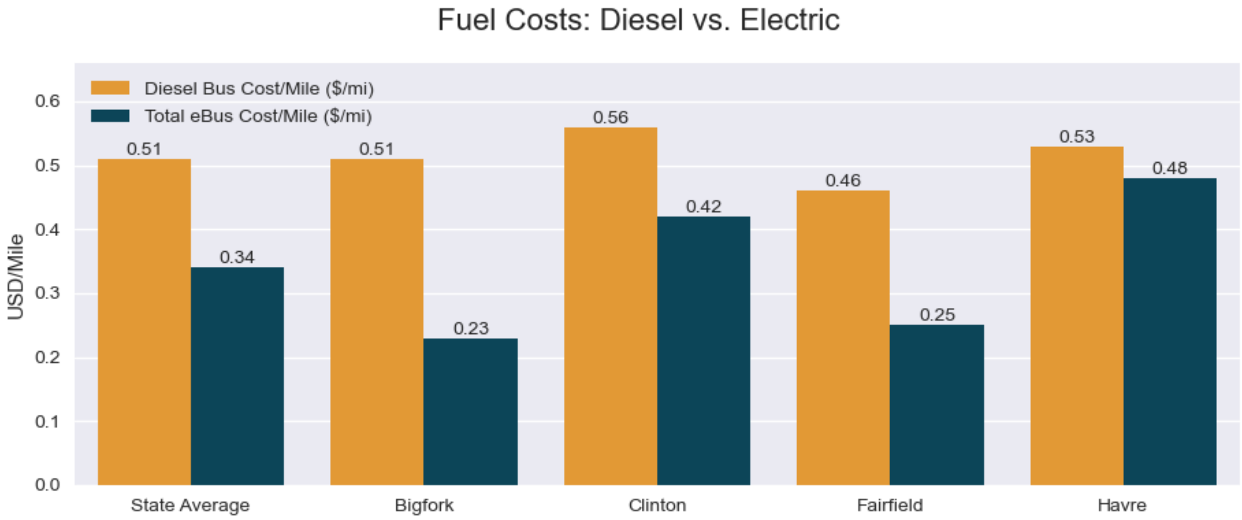
[14] *Calculation of fuel cost differs considerably between electric and diesel/gas buses. For ESBs, VEIC included volumetric energy costs, demand costs (where relevant), and auxiliary fuel heater costs. For diesels, calculations only include the cost of diesel fuel.*

[15] *To validate the cost calculation methodology, analysts compared calculated values to utility bills shared by districts and fleet operators. VEIC looked at a subset of billing periods from December 2023 to May 2024. On average, VEIC's calculated costs were within 1.5% of the reported utility bill values.*

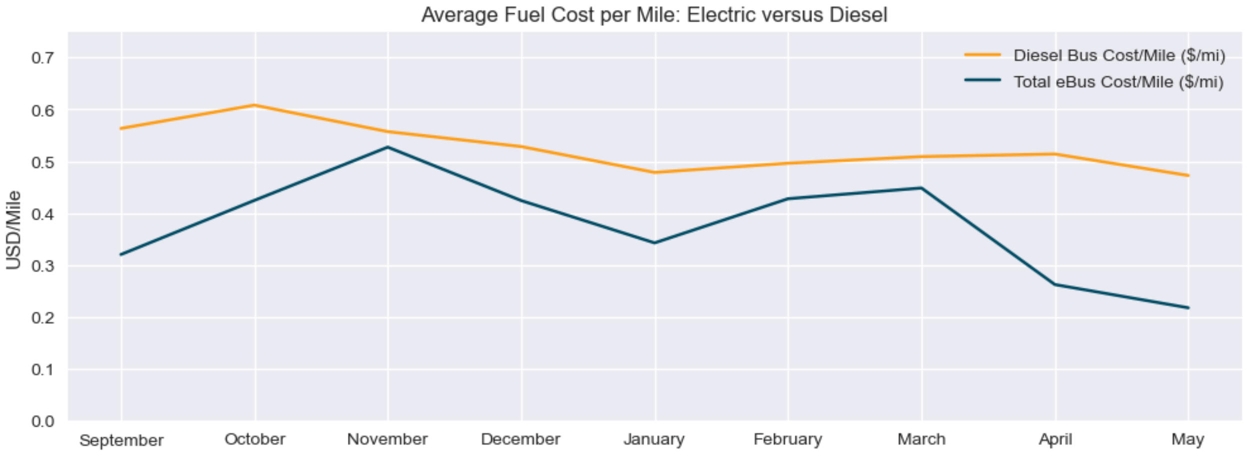
Figure 11. A bar chart showing the annualized average fuel cost per mile for ESB and ICE drivetrains, broken out by district.



To compare the operational costs of the ESBs to those of baseline diesel buses, VEIC analysts determined the costs associated with vehicle charging and auxiliary heater operations. Electric cost assessments used charger energy usage—measured in kilowatt-hours (kWh)—and charger-driven increases in peak demand—measured in kilowatts (kW). As noted above, VEIC used submeters to collect energy measurements. Analysts aligned submeter data with telematics data to determine the energy and demand associated with each individual charge event. The team collected this data on a per-charge-event basis, though most cost values provided in this report have been aggregated into monthly or per-mile intervals.

Figure 11 above shows that the districts fell mostly into two groups: Bigfork and Fairfield saw around $0.24/mi fuel costs for their ESBs, while Clinton and Havre saw fuel costs closer to $0.45/mi. The prime driver of this cost difference was utility bill demand charges, the utility fee imposed on some rate plans based on the maximum power used by a site. Havre and Clinton do have demand charges, whereas the other districts do not have this expense. Figure 13 and Figure 14 below show a cost breakdown of the effect of demand charges. Figure 12 shows the variance of average costs during the monitoring period. Variation in ESB costs from one month to the next are mostly due to temperature effects, whereas variations in diesel costs are due to both weather and variability in fuel prices. Since electric rates seldom change, ESB fueling costs are typically more consistent than those of fuel-fired drivetrains. Across the evaluation period, fuel costs for ESBs averaged $291 per month.

Figure 12. A line graph indicating how diesel and ESB fueling costs vary on average from month to month.



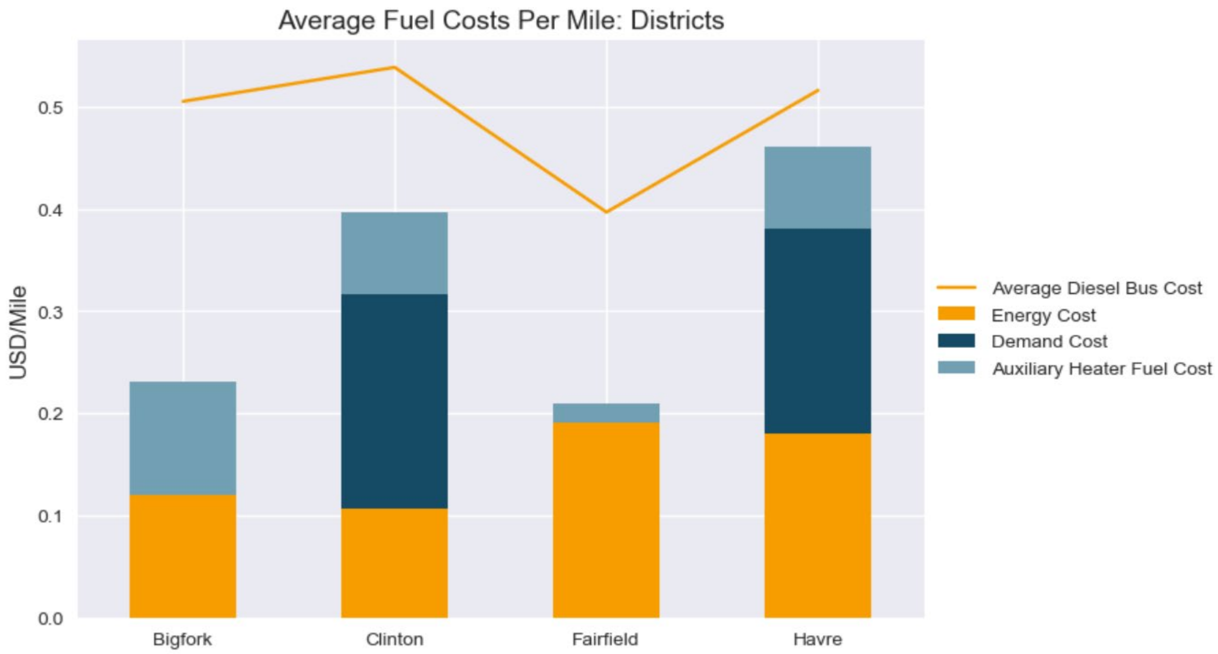
VEIC analysts calculated energy costs across months by multiplying each district's respective electric rate by the summation of measured charger energy. Volumetric energy costs reflected the total mileage driven over the month, with some variances in electricity rates and weather-related operational efficiency.

On the other hand, the impact of ESBs on district demand charges was not calculated purely based on the peak demand of the chargers. To determine the additional demand attributable to buses (rather than other building loads), the team accounted for the overlap between the chargers and the rest of the building loads. Utilities typically calculate demand charges based on the highest 15-minute average load recorded each month, though some utilities use 30-minute averages or other intervals. If that period occurs when no vehicles are plugged in, then, effectively, the chargers do not increase the demand costs that month. However, if peak building loads and charging periods overlap, the EV charger proportion of the load during that 15-minute window should be attributed to the demand costs of running the ESBs. The team adopted this approach to calculate new 'bus-induced' demand on each electrical service.

Mimicking common utility billing practices, the team resampled power measurements to 15-minute intervals when calculating demand. VEIC determined the maximum building demand on the service point with bus charging removed, which the team used as a baseline value for peak demand. Analysts then calculated the true peak monthly demand, or the value that the district was billed. Bus-induced demand was then calculated as the difference between the building-load peak demand and the total site-peak demand. In all recorded instances, the peak 15-minute period coincided with bus charging, indicating that the ESBs consistently led to increased demand. More on this topic, along with suggestions on how to reduce these costs, is covered toward the end of this report under "Utility pricing and managed charging."

Monthly demand increases ranged from 4kW to 19.5kW, with an average value of 13.9kW. Figure 13 below shows how demand charges led to significant differences in fueling costs between districts. Notably, the economic impact of an increased demand charge varies dramatically, depending on a district's utility rate structure. Some districts in this evaluation do not pay demand charges and, therefore, saw no increase in cost. Those districts with demand charges—Havre and Clinton, specifically—saw an increase of up to $200 per month caused by bus-induced demand increases.

Figure 13. A bar chart showing the breakout of charging expenses by source of expense and by district.

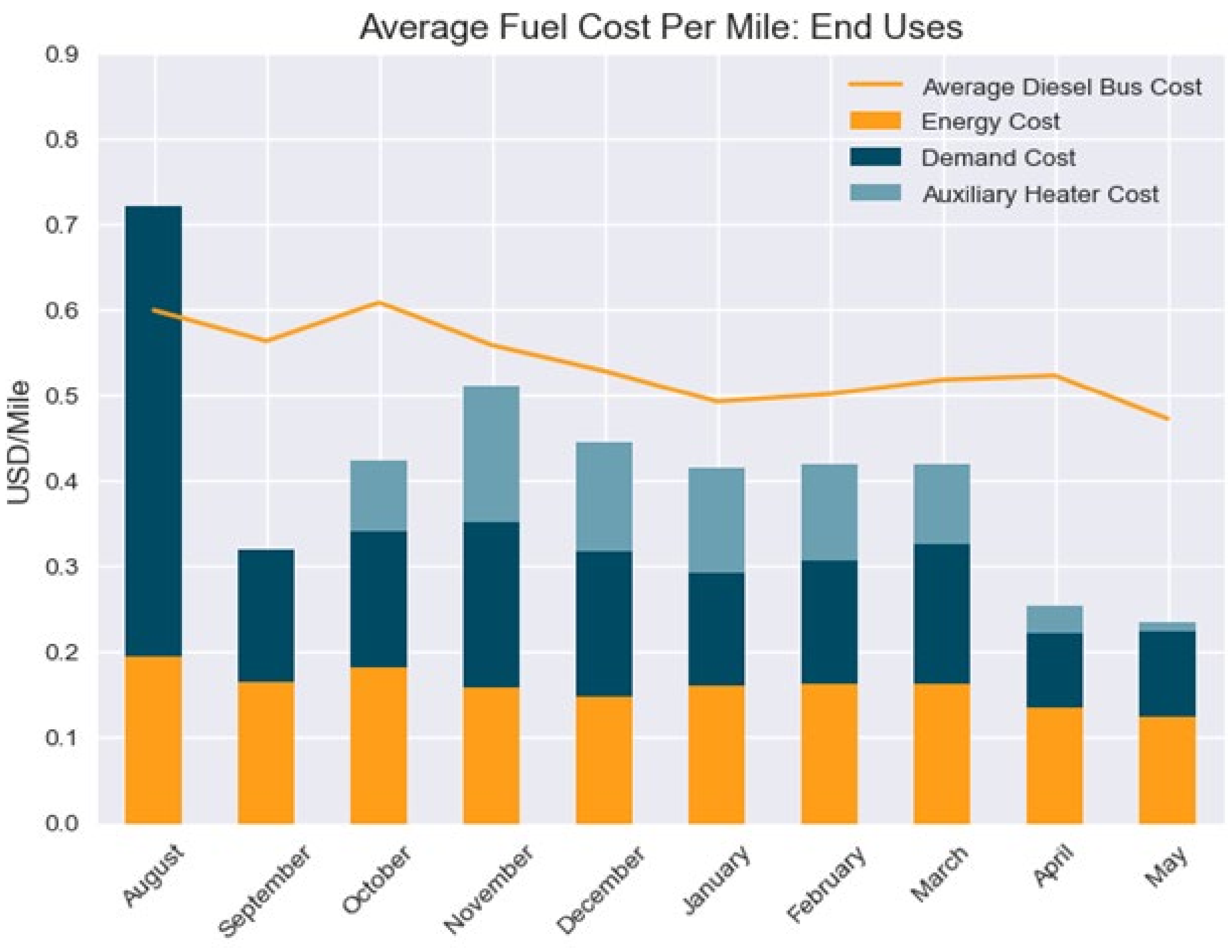


As part of the data collection process, district fleet operators supplied auxiliary fuel heater data, noting the date, price, and amount of diesel per fill-up. VEIC used a calendarization method to align auxiliary heater diesel use with ESB mileage and trips. This allowed analysts to distribute fuel usage proportionally over the school year based on seasonal weather variation. It is worth noting that this auxiliary fuel heater cost may not apply to some ESB models, as some use electric heating instead. However, all buses evaluated for this report were outfitted with diesel auxiliary heaters out of a concern that using electric heat in such a cold climate would too severely impact range. (See the "Cold weather performance" section of the "Operational Insights" below for more information on auxiliary heaters and their use). As a result, diesel costs constituted a considerable portion of the total operating costs across winter months. During the study period, Montana saw periods of extremely low temperatures. One measured period of bus operation averaged -23 degrees Fahrenheit. The severe nature of Montana's winters, combined with the unique diesel heater model, drove this particularly high operating cost. Average heater fuel costs for each bus were $48 per month.

To determine the costs for a hypothetical baseline diesel bus, the team used recorded mileage of the deployed electric buses, localized diesel costs reported by districts, and an assumed vehicle efficiency pulled from ANL's AFLEET database. While diesel bus operational costs fluctuate slightly based on weather conditions over the course of the school year, the ESBs do see considerably more variability (see the efficiency variation across temperatures in Figure 8 in the "Performance" section above).

This variability is illustrated in Figure 14, which shows the quantities and sources of costs for fueling or charging the buses for each month of the school year[16]. Unsurprisingly, the chart shows that heater costs are most prevalent during the coldest months. However, demand charges also increased in the winter. This may result from increased overlap with building loads (like HVAC, block heaters, and lighting), though some of these demand charges may simply be because the districts were still figuring out the best methods to reduce power draws and learning how to schedule longer charge sessions.

Figure 14. A bar chart indicating the variation in fuel cost sources over the course of a school year.



In part, the staggered rollout of ESBs across the district drove cost variability. Some of the fluctuations in cost stem from introducing new buses onto the road (and, thus, into the data). In the figure above, ESB operational costs appear to increase in November. Digging deeper into the

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[16] High per-mile demand costs in August 2023 are the result of low vehicle usage in that month (Havre's first day of classes in the 2023 - 2024 school year was in late August). See "Cost per mile affected by usage."

data, the team determined that the deployment of Bigfork's buses—in particular, the initial fill-up of the auxiliary diesel heater combined with a relatively low number of miles in the first month of operation—drove the dollar-per-mile measurement up.

Figure 14 includes August 2023, despite the month being both an outlier and outside of the energy monitoring period, because it indicates the importance of overall mileage and time on the road when considering the cost competitiveness of ESBs compared to the diesel baseline. Demand charges stem from increased power draw during the most heavily loaded time of the month, regardless of the number of trips taken. In other words, when measuring operational costs on a dollar-per-mile basis, demand costs can be seen as a fixed cost. Thus, on a per-mile cost basis, an electric bus that stays on the road for the entire month will be significantly more cost-competitive than one that does not operate every day (see "Cost per mile affected by usage").

In August 2023, only one district, Havre, had deployed its vehicles (two ESBs). The figure demonstrates that the demand cost per mile works against an ESB if the vehicle does not drive a typical number of miles. Jointly, Havre's buses only traveled 361 miles in August compared to a monthly average of 909 miles over the rest of the year. Ultimately, the economic advantages of ESBs increase with an increase in utilization.

Figure 14 also displays the role of the auxiliary heater fuel in driving up operational costs during the winter. Over the course of the year, auxiliary fuel constituted nearly 25% of total fuel costs for the electric buses. VEIC's team observed that the buses in the study maintained efficiency and range during winter months better than buses in previous studies.[17] Though VEIC has not assessed this relationship fully, nor the cost or emissions implications, the team hypothesizes that the auxiliary fuel heater allows the buses to continue operating efficiently at low ambient temperatures compared to buses that use electric resistance elements for cabin heating.

Maintenance and repair costs

Maintenance and repair costs will comprise a significant component of the total cost of ownership of an electric school bus. However, due to the short duration of this study, VEIC did not specifically track data in this area. Maintenance and repair costs change significantly over a vehicle's lifetime and are impacted by the specific duty cycles and level of care provided to the vehicle. A useful accounting of maintenance and repair costs for ESBs would track both labor and parts costs over the entire lifetime of a vehicle, as well as ICE vehicle maintenance for comparison.

While the topic is complex, there have been efforts to quantify the expected savings in maintenance and repair costs for ESBs compared to diesel buses. Since ESBs do not have an engine, they will not require maintenance related to engine components like oil changes or

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[17] https://www.nrel.gov/docs/fy22osti/83038.pdf

transmission servicing. However, they will still need regular maintenance on other systems like brakes, power steering, and air conditioning. While some in the market have raised a concern that electric buses will require mid-life battery servicing or replacement, most vendors offer extended warranties that can cover the batteries for up to 12 years, which is the typical lifespan of a school bus. One recent study by the California Air Research Board estimated ESB lifetime maintenance costs are 18% less than diesel school buses[18]. A comparable study of battery electric transit buses found their maintenance costs were 44% less over a one-year study period.[19]

Emissions

Reviewing the weather-normalized data from all the electric school buses monitored during this project, as well as route information provided by the school districts, VEIC was able to calculate annual operations for a 'typical' electric school bus in Montana. The average annualized distance traveled is roughly 8,500 miles, and electric school bus auxiliary heaters averaged 117 gallons of diesel consumed.

Using these values and the temperature variable efficiency findings noted in the "Performance" section above, VEIC then utilized the Argonne National Lab AFLEET Tool[20] to calculate the differences in emissions expected between different drivetrains in Montana, as seen in Figure 15 below. While the electric buses have no on-road emissions (except particulate matter off the tires and brakes), the table below also accounts for upstream emissions for each fuel type. For example, emissions at the power plant or oil refinery and all other emissions associated with the production and transportation of materials from their source to their point of use. The AFLEET tool factored in the Montana grid fuel mix to account for emissions from the regional power plants supplying power to the ESBs. Likewise, upstream diesel and gasoline production emissions were incorporated in addition to vehicle exhaust, allowing VEIC to approach a true comparison. Vehicle manufacturing emissions were not included due to significant variations between vehicle brands and a rapidly evolving vehicle supply chain.

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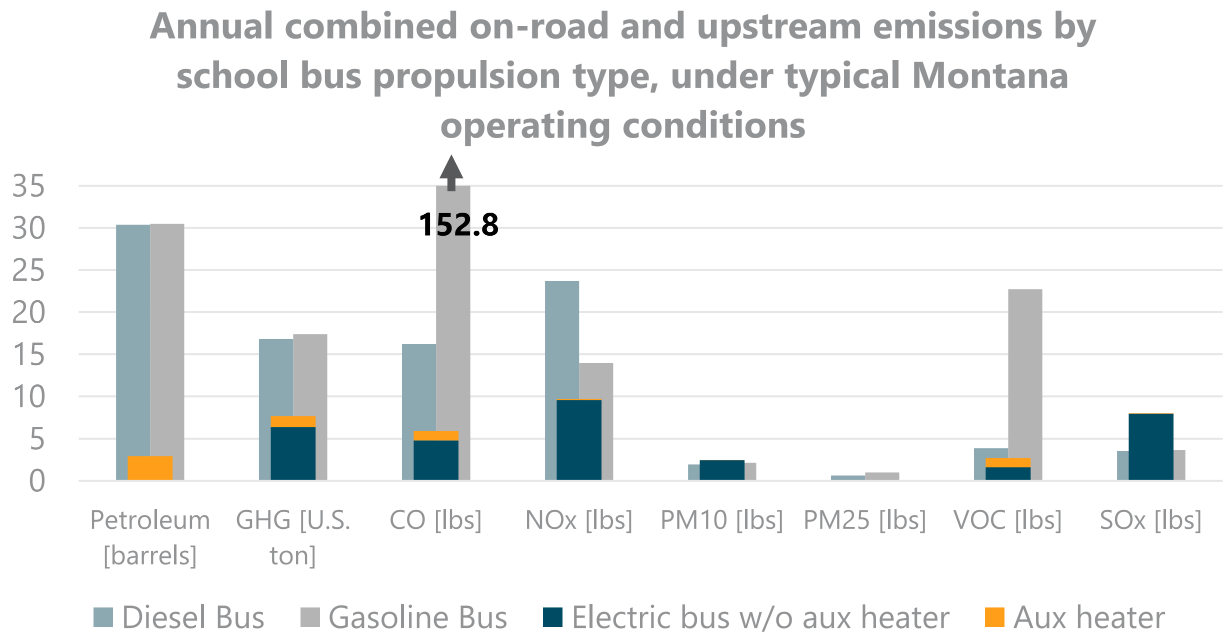
[18] *California Air Research Board (CARB). Cost Effectiveness Model for Battery Electric School Buses. 2020. https://www.energy.ca.gov/sites/default/files/2020-04/Cost-Effectiveness_ada.pdf*

[19] *Federal Transit Administration. Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses. 2018. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/115086/zero-emission-bus-evaluation-results-king-county-metro-battery-electric-buses-fta-report-no-0118.pdf*

[20] *Argonne National Lab Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool - https://greet.es.anl.gov/afleet_tool*

Figure 15. Annual criteria pollutant totals for the different bus drivetrain types utilized, including auxiliary heater emissions on the electrics.



As shown in Figure 15 above, using auxiliary diesel heaters during winter months increased emissions in each category from 0-100% higher than they would be otherwise. These heaters do not fall under the same strict EPA regulations as vehicle engines and exhaust systems. While far less fuel was used by those heaters than by ICE vehicle engines, the emissions from this source are proportionally higher per gallon, depending on the pollutant being considered.[21]

The ESBs are substantially cleaner than their fuel-fired counterparts in most cases. Looking at the exceptions to that statement, particulate matter at the 10-micron level (PM10) indicates the electric buses produced more PM10 than diesel and gas buses. This is primarily due to the increased weight of electric buses, which impacts tire and brake wear. ESBs also have higher Sulfur Oxides (SOx) emissions; this and several other metrics listed would be lower for ESBs if low or zero-emitting electricity-generating resources were a larger share of Montana's grid mix.

While electric buses clearly pollute less than buses with internal combustion engines, the difference in health impacts is even more substantial because ESB pollutants are emitted at the power plant, not in the immediate vicinity of students. In a recently published, peer-reviewed Harvard study, researchers found that replacing older diesel buses with electric buses can

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[21] *For those not familiar with ICE stoichiometry (the specifics of the chemical reactions in fuel combustion), the reason for the spike in carbon monoxide from gasoline engines is due to the fact that gasoline engines introduce less air into the burn compared to diesel engines which achieve roughly the same power output by introducing excess air into the combustion. Combined with higher temperatures and pressures in the cylinder, this is also why diesel engines produce NOx in much higher quantities than gasoline powered vehicles.* https://www.ncbi.nlm.nih.gov/books/NBK294260/ https://chemcollective.org/tutorials.phprg/wiki/Diesel_exhaust

drastically reduce health risks by reducing exposure to fine particulate matter (PM2.5). Those particulates may come from fuel combustion directly or from chemical reactions in the atmosphere involving vehicle-exhausted NOx, SOx, ammonia, and VOCs. Electric buses are estimated to provide average health benefits of $43,800 per bus over the life of the vehicle. These costs are a result of reduced adult mortality and childhood asthma brought on by diesel exhaust fumes. The same study found an additional $40,400 worth of climate benefits from reduced greenhouse gas emissions of an electric bus over a diesel equivalent.[22] Other studies have found that diesel engine exhaust is linked to cancer and deteriorated lung health. Nitroarenes, a type of mutagen, are present in diesel exhaust and have been found to cause genetic mutations. There is a strong correlation, but further research is needed as the long-term effects of exposure to diesel exhaust are not fully understood.[23]

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[22] *Choma, Ernani F., Lisa A. Robinson, and Kari C. Nadeau. "Adopting Electric School Buses in the United States: Health and Climate Benefits." Proceedings of the National Academy of Sciences 121.22 (2024): 1-6. doi: 10.1073/pnas.2320338121. https://stnonline.com/wp-content/uploads/2024/06/choma-et-al-2024-adopting-electric-school-buses-in-the-united-states-health-and-climate-benefits.pdf*

[23] *National Institutes of Health (.gov). Diesel Exhaust Particles. [Online] Last accessed June 26, 2024. Available from: https://www.ncbi.nlm.nih.gov/books/NBK531294/*

School Experiences

Photo Credit: First Student

Integrating ESBs involves the participation of many people from across a school district and its wider community. In addition to the quantitative evaluation completed in the prior section, VEIC sought to understand these ESB deployments from the perspective of people involved with the planning, deployment, and operation of the vehicles. Their experiences reveal important perspectives on ESB deployments, including benefits, challenges, and lessons learned.

As described in the "Project Overview" section, VEIC staff met monthly with the transportation manager at each school district throughout the project. Additionally, VEIC scheduled two site visits at every location towards the beginning and end of the study period. These meetings created space for consistent and detailed perspectives on the experiences involved with each deployment.

VEIC also interviewed school district staff at the end of the school year in late May and early June. The team conducted interviews with fifteen (15) individuals across the six deployment sites[24]. This

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[24] See the Appendix for a list of individuals interviewed and the questions asked.

included transportation managers, bus drivers, and mechanics at each site. Collectively, these schools deployed 16 ESBs into service, including vehicles at Billings that were not part of the Deployment evaluation (see Table 2).

This section synthesizes the deployment experiences at each district into major themes.

Overall impressions

When asked about their overall impression of ESBs, managers, drivers, and mechanics were mostly positive:

- Managers at every site '*would recommend*' ESBs to other school districts in Montana.
- Among drivers and mechanics, 100% agreed that ESBs were easy to use and that ESBs were quieter than diesel buses.
- Among drivers and mechanics, 80% agreed that ESBs were a good fit for their school district.
- When asked what they specifically liked about ESBs, the most common responses included: cold-weather performance, acceleration, quietness, and regenerative braking.
- When asked what they specifically disliked about ESBs, the most common responses included: the design and layout of vehicle controls, difficulty troubleshooting issues, and poor customer service from the manufacturer.

Procurement and planning

For each district, choosing specific vendors, models, and configurations for their ESBs and charging infrastructure involved balancing considerations of cost, intended use, and future plans (see "Project Overview" for details on each district's selections). Each district spent considerable time meeting with vendors and discussing options with their contacts at other school districts before executing purchase orders. With Havre's deployment ahead of the other districts by almost a full year, Havre's transportation manager, Allen 'Woody' Woodwick, was an important resource to many of the other districts during this period.

Towards the end of the study period, VEIC asked participants what advice they would give to other districts intending to deploy ESBs. Several managers reflected on their procurement decisions. Three managers emphasized, "Make sure you've done your homework," regarding vehicles and charging equipment. One manager said that it was invaluable to be able to "speak the same language as the sales reps and mechanics." Another manager recommended not simply going with the cheapest manufacturer, noting the benefits of working with a familiar vehicle chassis and standardizing parts in your fleet.

Vehicle configurations

Five out of six districts chose vehicles from Lion Electric, a Canadian manufacturer that produces exclusively all-electric trucks and buses. Of those five, all but East Helena chose the smallest available battery pack (126 kWh), which offered a nominal range of 100 miles. This decision on battery size was driven primarily by two factors. First, several districts noted that the lower purchase price of a smaller battery pack was an important factor. Second, each of these districts had shorter routes in their system that were a good fit for the 100-mile range. East Helena chose a slightly larger battery pack, at 168 kWh capacity, to fit their plans for deployment on longer routes. VEIC bolstered each district's specific vehicle plan with a detailed route evaluation (see "Project Overview").

First Student, in Billings, whose parent company had substantial experience deploying ESBs throughout North America, chose vehicles from IC Bus with a substantially larger battery pack (315 kWh). This choice aimed to compensate for decreases in efficiency during Billing's cold winters, as well as to allow for future vehicle-to-grid (V2G) pilots with Northwestern Energy.[25] However, it also led to an unexpected complication: the larger battery pack increased the weight of the vehicle so that it could not accommodate its nominal passenger capacity and still comply with state and federal GVWR standards. As a result, First Student was required to reduce the maximum number of passengers carried by its ESBs. It opted to deploy the vehicles exclusively on special needs routes.

Every district chose to equip their buses with fuel-fired diesel heaters to ensure winter occupant comfort. Havre and Billings (First Student) also equipped their vehicles with additional electric-based heating (see the "Cold weather performance" section below).

Charging equipment

Every district planned for a single dedicated charging plug to accompany each ESB. And, with the exception of Billings (First Student), every district purchased charging equipment that was available and recommended by their ESB vendor. In four out of six districts, each charging plug was comprised of a single Level 2 Alternating Current (AC) charger from Blink Charging (19.2 kW nominal power rating at 240VAC). Two districts, Fairfield and Billings (First Student), chose Level 3 Direct Current (DC) chargers. Fairfield's chargers, produced by ABB, were rated slightly faster at 22.5 kW per charger. First Student's chargers, produced by Borg Warner, offered significantly more charging capacity at 60 kW per charger, which was intended to provide operational flexibility. First Student's chargers were unique in the project because they involved multiple (five) charging plugs (or 'dispensers') per 'power control system' (or PCS) cabinet. Borg Warner's system is designed to stage vehicle charging sequentially to save on demand charges as well as reduce the supporting electrical infrastructure required.[26]

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[25] Vehicle-to-Grid (V2G) is a system that enables electric vehicles to both draw power from the grid and send power back, helping to balance and stabilize the grid, particularly during peak demand.

[26] https://www.borgwarner.com/technologies/highlight/sequential-charging

Vehicle deliveries and delays

In every deployment, the ESB start date was later than the initial targets (see Table 3 for the actual service start dates at each district). The most common cause of these delays was vehicle manufacturer production delays.

At Clinton, Bigfork, and Fairfield, vehicle production was delayed by a few months. However at East Helena, the only district to order a Type D bus, production delays held the start date by more than one year. Ultimately, Lion Electric determined that they could not deliver a Type D ESB within the required timeframe. East Helena has since changed their order and expects a Type C ESB delivery in the summer of 2024.

Charging equipment installation

Photo Credit: VEIC

When planning an ESB deployment, one of the key milestones installing charging equipment so it is operational before the arrival of the new ESB. In broad terms, there are three phases involved here: 1) execute any needed electrical upgrades, 2) install the charging equipment, and 3) commission the charging equipment to ensure that it is fully operational.[27]

In this project, every district successfully executed the required electrical upgrades and installed their charging equipment before the vehicle(s) arrived. However, several districts had complications getting the charging equipment fully operational. Districts installing the greatest number and highest-powered chargers experienced the most significant challenges.

Overall, perceptions on charging equipment installations were mixed, ranging from "charger installation was a breeze" to "getting the charging stations operational has been the biggest challenge so far."

Scoping electrical needs

Districts that installed Level 2 chargers required fewer electrical upgrades overall, with Havre only needing to run power from the existing panel to the charging equipment locations. The most complex electrical upgrades and installations were at Fairfield and Billings, which had the largest fleet sizes and included Level 3 DC chargers. Below is a summary of the varying levels of electrical work undertaken in each district:

- One district (Fairfield) upgraded to three-phase power.
- Two districts (Billings and Fairfield) upgraded their transformers.[28]
- Two districts (Billings and Bigfork) required significant trenching across their site to optimally locate their chargers and electrical equipment.
- Five districts (Bigfork, Clinton, East Helena, Fairfield, and Billings) upgraded their service panels.

Several districts (Fairfield, Billings, and Clinton) explicitly installed additional capacity in their service panels and/or transformers to accommodate future electric buses.

Coordinating between electrical professionals

Every district needed to work with a local electrician, the charging equipment manufacturer, and their utility to execute electrical upgrades and install their charging equipment.[29] While the level of complexity varied, overall managers felt they had the resources, funding, and support

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[27] *Optionally, and recommended, just as one might want to track fuel usage, one might also add independent submetering to the electrical panel to aid in tracking electricity usage and to provide further insight into any troubleshooting issues.*

[28] *In both of these cases, transformer upgrades were executed by Northwestern Energy, who partially paid for the upgrades through an allowance for commercial line extensions based on expected consumption. The level of support for transformer upgrades will vary by utility.*

[29] *There were three different electric utilities represented in this project: Fairfield, Havre, Billings, and East Helena were served by Northwestern Energy; Clinton was served by Missoula Electric Cooperative; Bigfork was served by Flathead Electric Cooperative.*

necessary to complete the upgrades and installation. One manager described the process: "Everyone talked to each other and let them know exactly what they needed…it was very unstressful [sic]". Another commented, "The installation instructions for the charger were cut and dry. The local electrician was able to follow them and get it installed instantly."

Challenges with charger commissioning

At Fairfield, two of the three chargers delivered by ABB (Level 3 DC, 22.5kW) had faulty circuit boards that prevented the chargers from operating correctly soon after installation. Due to the location of these circuit boards, ABB entirely replaced each of these charging units. One of the replacement units had a software issue that was resolved within the first few weeks after delivery. Complicated by the Thanksgiving, Christmas, and New Year's holidays, it took about three months from the initial installation of Fairfield's three chargers for each of them to be fully operational (see the "Deployment evaluation: Reliability" section for details on service impacts).

In Billings, First Student staff had initial challenges keeping their Borg Warner chargers (Level 3 DC, 60 kW) up and running, particularly with their sequential charging capabilities. As noted previously, each of the 60kW chargers was equipped with five dispensers and designed to deliver charge to one dispenser at a time. If multiple buses were plugged into a charger at the end of the day, drivers expected that each bus would be fully charged overnight in sequence. However, staff repeatedly encountered issues with charging or connectivity at some point in a charging sequence, leaving some buses less than fully charged (or not charged at all) the next morning. First Student's mechanics admitted it was challenging to troubleshoot and fix the problem, with their manager noting: "Getting the charging stations to operate properly has been the biggest challenge with this project so far." Ultimately, mechanics discovered the problem resulted from interoperability issues between their bus and charger model. It was solved with software and firmware updates about five months after the bus delivery.

At Havre, one of the two chargers delivered by Blink Charging (Level 2 AC, 19.2 kW) failed within the first few months of operation. According to Havre's fleet manager, Blink was fast in sending out a replacement unit and this did not lead to any vehicle downtime (see "Deployment evaluation: Reliability", and "Service and support" later in this section).

Vehicle performance

The "Deployment Evaluation" section of this report provides a data-driven account of the reliability, performance, costs, and emissions impact of each ESB deployed in this project. Based on interviews with drivers, mechanics, and managers, the current section complements that analysis by highlighting perspectives on vehicle performance and driving experience from people who engaged with the ESBs daily.

Vehicle range

The most common sentiment among managers was that the ESBs performed well within the constraints of their specific vehicle's expected range.[30] One manager, whose ESB has a nominal range of about 100 miles, said, “It’s been working perfectly for our application.” Another manager, whose vehicle also has a nominal range of 100 miles, said, “If you’re under 100 miles a day, these buses are perfect for you.”

Several managers mentioned that their buses, each with a nominal range of 100 miles, were not well suited for long cross-state sports trips that are common in Montana.[31] However, some districts have gradually tested the capabilities of their ESBs, deploying them on field trips and extending the time between charges. One manager put it this way: “As we are learning more about them, we are getting bolder.”

Comparisons to diesel

Apart from range limitations described in the previous section, none of the districts identified any specific operational constraints with the ESBs. Rather, they found ESBs just as capable as diesel buses. Points of contact at the districts had the following comments:

- “It has the same passenger capacity and would climb any grade at the same speed as a diesel bus.”
- “I'd recommend an electric bus even on a gravel road, a hilly road…because it works. Electric buses can do the same as diesel buses.”
- “It’s just like a regular bus, just a little snappier acceleration.”

Several people noted positively that the acceleration in the ESB was better than what they experienced with a diesel bus. One driver described the effect: “It has good acceleration…vehicles behind you aren't thinking, ‘Oh man, there's a school bus in front of me, we're never going to get through this intersection.’”

Cold weather performance

Four of the districts (Havre, Bigfork, Clinton, and Fairfield) operated their ESBs in the winter months of the study period. Each district reported that their vehicles performed exceptionally well in both cold and extreme cold temperatures. One driver noted, "They do excellent in the winter, especially our winters when it's 30 below.” These positive evaluations of cold-weather performance were attributed to two factors:

- First, each of the ESBs in deployment during the winter was equipped with a programmable pre-heating function. In most cases, this automatically warmed the cabin

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[30] *ESB range is a function of battery size, which is customizable at the point of purchase.*

[31] *It should be noted that these vehicles were specified with the smallest available battery pack at the time. Currently, there are ESBs on the market that offer nominal range of greater than 300 miles.*

in advance of morning pullout. As one driver explained it, "The heaters are nice. You can program them so when it's 10-, or 15-below, your bus can be ready." In one district, cabin preheating was also found to help eliminate window icing: "The icing up of windows doesn't happen on these because you can get enough heat on the window."

- Second, the ESBs were easier to start in extreme cold than diesel buses. This was primarily due to the absence of DEF fluid, which is required in diesel buses to reduce vehicle emissions. Several managers described challenges with DEF fluid 'gelling' in extreme cold temperatures. One manager described the coldest morning of the year: "When it was 26, 29, 30 below, that electric bus was the only bus that started. All our diesels gelled."

It is worth noting that none of the fleet managers, drivers, or mechanics noted a reduction in vehicle range and efficiency during cold weather. While this effect was well documented, (see "Deployment Evaluation"), it did not cause any noticeable operational challenges. As described above, each agency deployed ESBs thoughtfully so vehicles could complete their expected routes in all weather conditions.

Driving experience

Photo Credit: VEIC

When describing their experience with ESBs, driver responses were personal, often relating to the specific details of their vehicle or route. Drivers most frequently noted the quietness, smoothness, and acceleration of the vehicle. One driver even said, “It’s a very quiet ride—like a ride at Disneyland.” All drivers and mechanics interviewed agreed that ESBs were ‘easy to use.’

One driver noted that the bus's interior rattled a lot, which was exacerbated by the otherwise quietness of the bus. This contributed to an overall unsafe feeling for the driver: “I don’t always feel safe on it—that’s just a personal thing.”

At First Student in Billings, where the ESBs are used on routes that serve special-needs students, the quietness of the bus was seen to have a calming effect on student behavior. One mechanic described the reaction of a driver witnessing this change in student behavior: “He didn’t realize how much the noise was setting off the kids.”

The most cited negative aspect of the ESB driving experience related to the layout and configuration of controls. One driver noted that the controls were more spread out and different from the other buses in their fleet: “The handbrake is right where you need to sit down…the seat belt is not adjustable." Another driver pointed out that the turn signal on their vehicle did not always stay down, adding, "I wish the visibility outside the driver's mirror was a little better."

In one district, drivers noted that the ESB experienced some rollback on hills during the time between depressing the brake and pressing the accelerator. According to the manager, this took some getting used to on the part of drivers but has not been a big problem for them.

Single-pedal driving

Regenerative braking is a feature on most electric and hybrid vehicles that converts some of the energy involved in braking the vehicle into electrical energy used to replenish the vehicle's battery. This has the net effect of increasing the vehicle's range and reducing the utilization of brake pads.[32] It also can be adjusted so that it is strong enough to take over the majority of the 'non-emergency' braking for the vehicle, resulting in what is often termed 'one-pedal driving.' This means that a driver can effectively control both acceleration and deceleration via a single control pedal. Not only does this make the vehicle slightly easier to operate, but it also improves efficiency and safety as the vehicle will begin slowing down as soon as the accelerator is released.

Given these benefits, managers at several districts (Bigfork, Clinton, and Havre) deployed strategies to maximize regenerative braking. These strategies involved limiting or derating charging in advance of vehicle runs because managers found that regenerative braking was most pronounced when the battery's starting state of charge was less than full (see "Regenerative braking"). Havre was the first district to use ESB on-board configurations to schedule and derate charging for this purpose (as well as to control costs by reducing peak demand). These controls were intuitive and powerful, so they were used at Bigfork and Clinton as well.

From a driver's perspective, regenerative braking causes more pronounced deceleration when releasing the accelerator. The two drivers who noted this had an overall positive impression of the technology, with one stating, "It's nice not to have to use the brakes so much…I just let off the accelerator." However, the same driver expressed difficulty adjusting to the inconsistent levels of regenerative braking, which is less pronounced when the battery is close to full. This challenge was particularly acute in the ice and snow, causing the driver to sometimes feel unsafe in those conditions. Electric vehicle manufacturers have been developing controls that could allow mechanical braking to automatically turn on to take over more of the work if regenerative braking does not sufficiently slow the vehicle down, but this technology has not yet made its way into the ESB market.

One manager acknowledged that regenerative braking takes some getting used to for drivers: "It's like driving a stick shift. It takes time to learn how to operate a clutch, but once you get it down you know it."

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[32] *Islameka, Mehta, et al. Energy management systems for battery electric vehicles (Chapter 5). 2023. https://www.sciencedirect.com/science/article/abs/pii/B9780323905213000065.*

Maintenance and servicing

There was a common perception among both managers and mechanics that ESBs are overall easy to work on and maintain (see the next section, "Training, service, and support," for a separate discussion on accessing technical support from vendors). Managers and mechanics noted the following about ESBs:

- "They are very simple and easy to work on."
- "Basic maintenance, it's about the same as a regular bus."
- "The ESBs get rid of a lot of the stuff I work on…you don't have to worry about the belts. You don't have to worry about an engine leak. You don't have to worry about a transmission oil leak."

Training, service, and support

Training

Fleet managers and drivers had mixed reactions to the initial training provided by bus manufacturers. One manager felt that the initial training provided by Lion Electric was "exceptionally smooth," while another's assessment was that "there wasn't a lot of substance to it." Some drivers felt that their introductory training fell short, with one driver stating, "There was an intro presentation, but I would have liked to see more follow-up." At Billings, the initial training for their IC bus was described as "a little subpar."

Mechanics also had mixed reactions to their training. One mechanic was impressed by the online training offerings by Lion Electric, saying that he could "give himself hands-on training" by working through many of the modules on individual bus systems. The mechanics at Billings felt that the one-week training provided by IC Bus was very good. One mechanic said, "I think it was better than trainings I've had from Allison[33] on hybrids."

Several mechanics noted they would have liked more training and support on the electrical systems and charging equipment. According to one mechanic, these systems are more time-consuming and intimidating to repair: "You're dealing with a lot of electricity… For someone that's been in this industry a long time, it's not hard to learn. But somebody new, it'd be quite scary to step into." Billings' mechanics reported that there was little to no training on how to fix charging equipment, which complicated their ability to resolve problems during their initial period of troubleshooting. One said, "It took a lot of trial and error to figure out how the chargers work and how to fix them."

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[33] *Allison Transmission (https://www.allisontransmission.com/), is a leading manufacturer of transmissions and vehicle propulsion systems, which are commonly found on diesel school buses.*

Service and support

District perceptions of the service and support provided by vendors after delivery varied widely across vendors and products. Overall, managers and mechanics had a positive view of products that were supported by responsive and knowledgeable vendor service, even if those products needed repairs or replacements. For example:

- At Havre and Bigfork, issues with their charging units required replacements by the manufacturer (two at Havre and one at Bigfork). In both cases, Blink Charging responded to their issues and quickly provided replacement units. The manager at Bigfork said that after a replacement was deemed necessary, "Blink was able to get one out here two days later." As a result, these issues did not cause any significant charger or vehicle downtime at either location. They also did not require a notable time investment from agency staff.
- At Billings, two of their buses were sent back to the dealer for repairs in the first few months after delivery. However, the mechanics described the experience positively, saying they were impressed by the support from "excellent engineers" at IC Bus, who "either told us what to do to fix the problem, or the bus went back to the dealer."
- At Fairfield, the manager found their charging equipment manufacturer (ABB) easy to work with in resolving initial issues with their chargers and assessed the experience as positive.
- At Bigfork, the manager said they didn't have many reasons to engage with technical support for their Lion bus, but when they did, "…the support was dead on – they knew exactly how to fix things and were able to instruct us step-by-step".

Conversely, some managers and mechanics described the challenges caused by support that was less responsive or efficient[34]:

- At Havre and Bigfork, they experienced challenges and delays in getting replacement parts to resolve issues with their Lion buses. When discussing an auxiliary heater problem that grounded one of Havre's buses for a period (see "Deployment evaluation: reliability"), the manager said that Lion's automated parts replacement system didn't work well: "You can replace a heater, but you can't get a part for it." Bigfork's manager described the process of replacing a faulty seat belt, noting that "getting the part here took the longest."
- At Clinton and Fairfield, both managers felt they received poor support from Lion when resolving bus issues. Clinton's manager explained, "For the first six months, we had the same problem coming up again and it never got fixed." Similarly, Fairfield's manager noted that they had to keep going over the same issues with Lion: "It felt like they just handed us the keys, and said, 'Good Luck.'"

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[34] *See the "Deployment Evaluation: Reliability" section for a more detailed analysis of technical issues that were encountered.*

- Several managers described challenges dealing with a high turnover rate among technicians and sales support staff at Lion Electric.

At two districts, staff members put the issues they had experienced with the ESBs into perspective, emphasizing that technical issues with new buses are common regardless of the drivetrain technology. For example:

- “In the last year, [we've] gotten both a new electric bus and a new diesel bus – both have been in the shop more than they’ve been on the road.”
- "We bought two more brand-new diesels after the electrics, and even those had issues. So that's just going to happen with anything."

Future ESB plans

PHOTO CREDIT: VEIC

Pragmatic approaches

Most managers are taking a pragmatic approach to future ESB plans. Two managers who were impressed by the ESB performance so far were still planning to “wait and see” how they continue to perform after the first year. According to one manager, “I want to see how they run for the next three to five years” before purchasing additional ESBs.

State and federal incentive availability plays a central role in the future considerations of most managers, who noted:

- "If you can get them paid for with grant funding, the district will save money through cheaper electric costs and cheaper maintenance.”
- "If the grants weren't available, it wouldn't be worth spending that kind of money for an ESB."
- "With grant funding, you can afford to experiment and see how good of a fit they would be for your district."

Change management

Several managers described driver or mechanic resistance to ESBs, which they attributed to a general resistance to change. At one district, the manager explained, “A few drivers out of 15 don’t want anything to do with [ESBs] because they're different." At another district, the manager said that of the two drivers who operate ESBs, "One loves them and one hates them…I think they just don’t like change."

At one district, the manager explained that driver resistance to ESBs related to specific concerns over fire danger and the politicization of electric vehicles. The manager further noted that these concerns contrasted with the perceptions of drivers who operated the ESBs: "Some of the drivers are reluctant to drive them...but the drivers who do, they love them".

At another district, the manager explained that their mechanic was resistant to ESBs from the start. Because of this, the manager was more inclined to take an active role in helping to resolve issues with their buses or chargers. He agreed it was possible this had an impact on the speed with which technical issues were resolved, although things got better over time.

Operational Insights

Photo Credit: VEIC

This section aims to distill key insights from this study that will be especially useful to future ESB deployments in Montana. Drawing on detailed qualitative and quantitative analyses, this section highlights unique and important results that will help other districts deploy ESBs in the most effective way possible.

Change management

Change is experienced differently across organizations, and the introduction of ESBs is no exception[35]. While school boards, superintendents, and transportation managers decide to purchase ESBs, drivers and mechanics are the ones required to use, maintain, and repair them. Several districts in this study described driver and mechanic resistance to ESBs. While these attitudes were in the small minority, it is important for school managers to realize that these

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[35] *Harvard Business School. "Organizational Change". https://online.hbs.edu/blog/post/organizational-change-management*

attitudes may be present among their staff. Moreover, they have the potential to complicate the smooth rollout of an ESB deployment. While some resistance will occur in response to any changes within an organization, it is particularly true in the rollout of ESBs. As electric vehicles rise in mainstream awareness, bias and misinformation regarding the technology have also risen. Managers can get ahead of these issues by including staff early on in planning and procurement decisions and keeping communication channels open and responsive throughout ESB deployments.

Regenerative braking

While driving an electric school bus is nearly identical to driving a bus with any other drivetrain, one significant difference is the regenerative braking feature on electric buses. This braking system typically improves battery efficiency by 16-25%.[36] For more details on 'regen'—as some drivers call it—see the "Single-pedal driving" section of this report.

As noted by some drivers in this study, the amount of braking force provided by regenerative braking varies. The strongest settings are the most efficient in terms of energy; they can also take over most of the vehicle's braking needs outside of hard emergency braking and holding a stop. This means that drivers may be able to use 'single pedal' driving most of the time, where the regenerative braking comes on and becomes stronger as the accelerator pedal is released more and more. Drivers reported that single-pedal driving took time to get used to, but it was easier overall and akin to shifting into a lower gear to slow down.

Transportation managers can optimize the benefits of regenerative braking by adjusting their vehicle charging strategies. Since 'regen' is automatically turned off when batteries are full, one way to boost a vehicle's overall operational efficiency and reduce charging costs is to fill the batteries below 100%. The 'regen' ramps up in power as the battery state of charge reduces, allowing more battery capacity. By reducing the top end of the charge to only 80-90% full, fleets may see as much as a 5% increase in on-road efficiency compared to charging the bus to 100%.

Clearly define training, service, and support expectations

In this study, vendors had a high degree of variability in the type and quality of training, service support, and availability of spare parts. Several districts expressed challenges in dealing with a lack of dedicated service technicians or service centers that were far away. To address these issues, future ESB deployments can consider these elements when procuring vehicles and charging equipment. Agencies without dedicated maintenance staff may want to weigh these factors more heavily and assess their overall ability to deal with technical issues. Statewide training events with individual vendors could be an effective way to bring increased technical

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[36] *IJARIIT Vol.3 Issue 3, "Energy Efficient Electric Vehicle Using Regenerative Braking System": 2017. http://large.stanford.edu/courses/2017/ph240/leis-pretto1/docs/lakshmi.pdf*

resources to Montana. Providing regionally based service centers by popular ESB vendors would have a long-term positive effect.

Lower-speed charging is more reliable and cost-effective

Compared to Level 3 DC chargers, Level 2 AC chargers in this study had lower up-front costs, fewer technical problems, and caused far less vehicle downtime. While several of the Level 2 units did need replacement, new units were delivered efficiently by the manufacturer. Local electricians could also easily execute their installation. In both places where Level 3 DC chargers were deployed (Fairfield and Billings), the charging equipment required multiple months of troubleshooting to get completely up and running. While Level 3 chargers offer potentially useful features such as fast charging speeds and smart charging controls, school districts should carefully consider the need for these features. If they are not needed, Level 2 chargers may offer a more reliable and cost-effective alternative.

Utility pricing and managed charging

As fleet managers look beyond the basics of operating and charging their new electric buses, they can consider more advanced charging strategies to reduce fuel costs. 'Managed charging' strategies can effectively reduce fuel costs at sites where the electric utility has a rate structure that includes either a 'demand' or a 'time-of-use' component. Sites without these types of utility charges enjoy a fixed and predictable cost per kWh regardless of when or how fast they charge, so they will not reduce fuel costs through managed charging. However, they can still pursue these strategies to optimize battery health, improve vehicle efficiency, and minimize the need for electrical upgrades.

In this study, districts demonstrated managed charging in two main ways: 1) by limiting charging on Lion ESBs to occur at a slower rate using on-board software controls, and 2) by staggering the charging of multiple vehicles to occur sequentially instead of at the same time through the use of smart charging capabilities on Borg Warner Level 3 DC charging equipment (Billings). Both strategies have the potential to offer significant monthly savings for schools. However, these strategies require careful consideration of utility rates, operational needs, and the technological capabilities of vehicles and chargers. See the Appendix, "Optimizing ESB charging to reduce fuel costs" for a more detailed discussion of managed charging strategies.

Cold weather performance

Cold weather operation is often touted as a weak point for EVs due to the reduced energy availability of lithium batteries as temperatures drop. As a result, all districts were interested in how well the electric buses would work in a place like Montana, where it is common for temperatures to drop well below zero during the winter.

Overall, the electric buses performed reliably in the cold. In the coldest weather observed (below -20 degrees Fahrenheit), buses lost around 30-40% of their range (which is a nominal 100 miles for base model Lion Type C buses).[37] Since the longest bus route was only 34 miles, the ESBs could do their morning run, though they might need to charge up midday in the worst-case scenario to cover the afternoon run.

In comparison, many of the diesel vehicles were unable to operate at all on those coldest days due to fuel and DEF 'gelling.' Gelling is an issue whereby waxes in the diesel fuel begin to crystallize at around 15 to 20 degrees Fahrenheit. This can clog fuel filters and seriously impact engine performance or prevent operation altogether. DEF fluid is also used in diesel exhausts to reduce emissions, but it is water-based and also prone to freezing up. Therefore, maintenance crews in cold climates tend to use special additives to allow fuel to run colder. Still, the fleets in this project reported that even with additives they saw enough issues in the coldest weather this year to require them to suspend service until it got warmer. As a result, while the electrics had range reductions, this was a major improvement over having to cancel transportation services.

Some factors aided the schools in finding success in cold weather. First, some of the districts have bus barns that allow vehicles to be stored inside. While not a fully conditioned space, these barns help keep the electrons flowing. Chargers and buses kept inside for most of their lives should experience significantly fewer maintenance issues over time. That said, the buses at Bigfork were parked outside and that ESB still did not experience many issues.

Another major factor supporting cold-weather operation was the inclusion and use of auxiliary diesel-fired heaters to aid with cabin HVAC. On one hand, adding these heaters and not relying on electricity to heat the cabin helps electric buses maintain their range better (based on observed heater use and basic energy conversions) in extremely cold temperatures. However, as seen in the "Emissions" section above, these auxiliary heaters can cause more direct emissions. Additionally, this extra vehicle system is prone to failures, particularly in the coldest weather when they are most needed. As seen in the "Reliability" section of this report, auxiliary heaters were the number one cause of service interruptions, accounting for over 120 days of lost service across all the vehicles tracked. Given that the bus range substantially exceeded the route mileage needs, and since the above-noted results were achieved while most of these buses were procured with the smallest battery packs available, districts may want to consider the long-term value of opting for a larger battery pack and switching over to an all-electric heating system[38].

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[37] *Conventional ICE buses can also vary in efficiency due to temperature. See M Henning., A Thomas, A Smyth. 2019. "An Analysis of the Association between Changes in Ambient Temperature, Fuel Economy, and Vehicle Range for Battery Electric and Fuel Cell Electric Buses". PDF Accessed 6/4/2024. <https://cte.tv/wp-content/uploads/2019/12/Four-Season-Analysis.pdf>*

[38] *At the time of this writing, the larger battery packs and all-electric heating systems are not available vehicle configurations with all ESB manufacturers*

Costs per mile affected by usage

For school districts whose utility rate structure includes demand charges or significant fixed charges, the level of utilization of an ESB largely determines its per-mile fuel cost. This effect was seen most strongly in this project in August 2023, when per-mile fuel costs were extremely high due to low miles incurred during the first few days of the school year (see Figure 14). While there are additional factors affecting per-mile fuel cost outcomes, it is important for ESB operators to be aware of the relationship between vehicle usage and demand charges. Expected vehicle usage and charging strategies should be considered when making decisions on battery pack sizing for ESBs. The increased cost of a larger battery pack may be offset on a per-mile basis if it enables significantly more usage of an ESB over its lifetime.

Appendix

Data sources and methodology

Over the course of this evaluation, VEIC monitored several separate and overlapping sources of real-world data. These included telematics data captured by vehicles which provided distances traveled, battery state-of-charge, and vehicle status logs on a trip-by-trip (or even turn-by-turn) basis. Fleet managers also provided periodic quantitative feedback to help verify the telematics and other data, as well as maintenance and reliability feedback that would otherwise have been difficult to capture. Third-party, utility-grade submeters installed at each site captured electric energy consumption and demand at a one-minute resolution. These devices also monitored total site power consumption to allow for the disaggregation of ESB demand charges from other building loads. This provided a more accurate representation of the increased cost of utility bills due to bus electrification.

Photo Credit: VEIC

The districts provided auxiliary diesel heater fueling quantities and pricing to enable a comprehensive fuel cost savings analysis. Federal Energy Information Administration (EIA)[39] and State-reported[40] regional fuel price indices were used when combining the results across all districts, though actual district pricing was used when providing district-specific results. VEIC also utilized hourly National Oceanic and Atmospheric Administration (NOAA) ambient temperature and humidity data collected from weather stations located near each site. Additionally, qualitative data was captured over two rounds of site visits, including a VEIC-conducted survey completed at each site to collect feedback on vehicle operations, impressions, and other stakeholder feedback not captured through other means.

VEIC's team collected, organized, and stored the raw data noted above using a Python-based analytics engine. In post-processing, VEIC analysts thoroughly checked for sources of error in the data and then used standard analytic practices to refine the raw data down into meaningful metrics, such as operational efficiency (total energy purchased per mile of travel) and on-road range modeling (max distances vehicles could have traveled given state-of-charge data and pertinent real-world conditions).

VEIC further utilized its analytics engine to combine the primary metrics across all buses and districts under evaluation to surface larger trends. Efficiency and range were normalized against ambient weather data. Cost and environmental impacts were modeled across a typical year to provide an indicator of what these districts (and other Montana districts) may expect as they continue to transition more of their vehicles to electric drivetrains. VEIC drew cost comparisons against the operational expenses that would be expected if the new buses had been standard diesel models, using federal fuel economy ratings and adjusting for temperature-related efficiency losses where relevant. Those ratings, as well as emissions factors across a range of criteria air pollutants, were gleaned from the Argonne National Laboratory's 'Alternative Fuel Life-Cycle Environmental and Economic Transportation' (AFLEET) Tool[41]. Results were checked against the real-world results seen by the districts to date. The results were then summarized into the graphs and findings presented in this report.

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[39] *U.S. Energy Information Administration, Petroleum & Other Liquids, Weekly Retail Gasoline and Diesel Prices – Rocky Mountain (PADD 4) Monthly pricing: https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_r40_m.htm*

[40] *Montana Department of Transportation (MDT). (n.d.). Monthly Average Fuel Prices. Retrieved from https://www.mdt.mt.gov/business/contracting/fuel-prices.aspx*

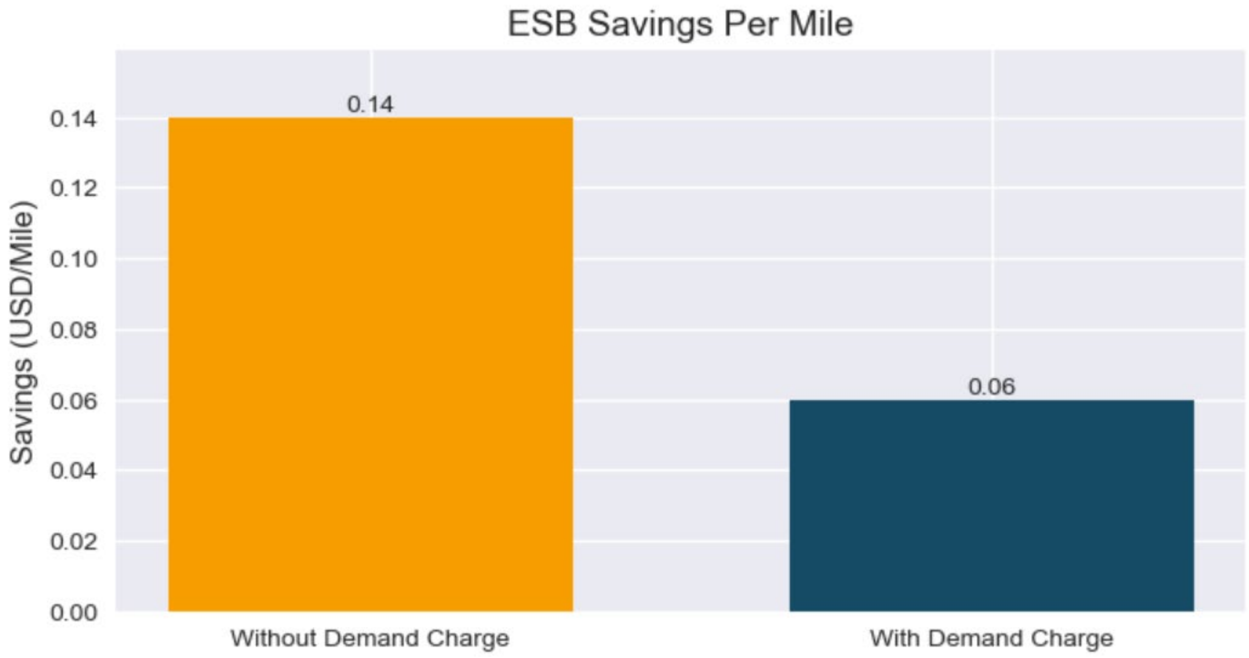
[41] *Argonne National Lab Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool - https://greet.es.anl.gov/afleet_tool*

Optimizing ESB charging to reduce fuel costs

This section demonstrates the main principles of managed charging strategies and their effectiveness in reducing the overall fuel costs of ESBs. Managed charging strategies involve adjusting the timing and/or speed of charging an ESB, usually to reduce utility charges. This is typically achieved through software, either on the ESB vehicle itself or through the charging equipment. While these strategies are only effective in reducing utility charges at sites where the electric utility has a rate structure that includes either a 'demand' or a 'time-of-use' component (or both), they can also be used to optimize battery health, improve vehicle efficiency, or minimize the need for electrical upgrades.

In this study, differences in utility rates across districts considerably impacted the fuel cost savings offered by ESBs, as demonstrated in Figure 16 below.[42] Each district without demand charges (Bigfork and Fairfield) realized greater than $0.14 per mile fuel cost savings. At districts with demand charges (Clinton and Havre), fuel cost savings were significantly more modest, around $0.06 per mile.

Figure 16. A comparison of fuel cost savings, per mile, differentiated based on utility demand charge structure.



Throughout this project, VEIC worked with districts to assess the importance of charging optimization for cost-effective operation of electric buses. Specifically, the team dove into the bus-induced demand charges to determine how a district or fleet operator might best schedule

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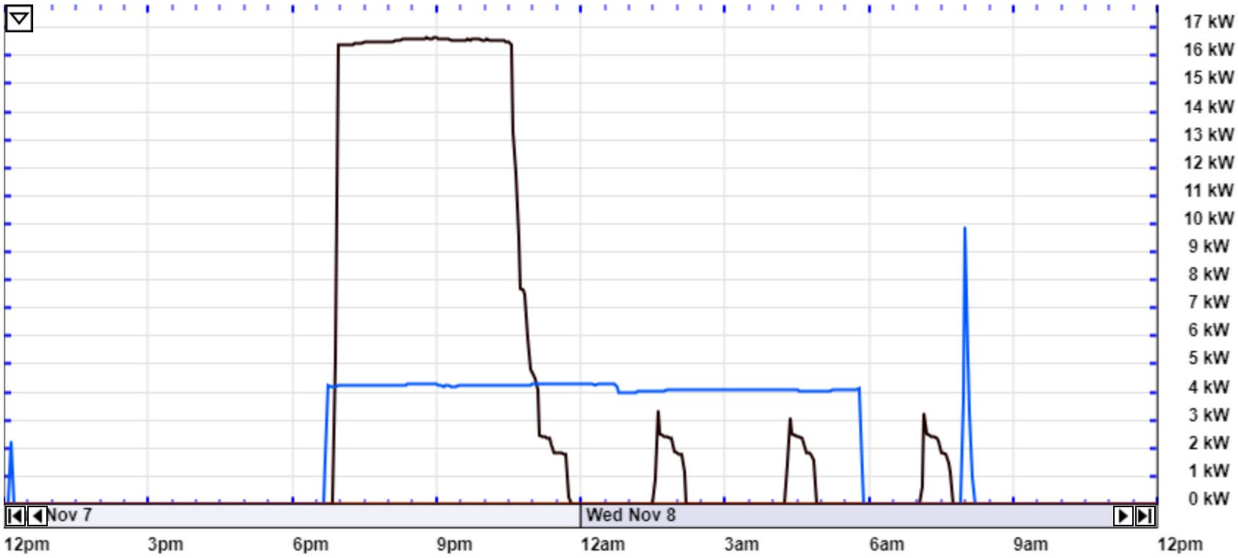
[42] The utility rates observed in this study include a range of fixed, volumetric, and demand charges. The distinguishing difference we are referring to is whether a demand charge was applied, or not. None of the utility rates included a time-of-use charge.

bus charging. Because demand charges are based on the maximum observed power (kW) during the billing period, fleet operators can see considerable savings by **limiting charging speed** or **staggering charging times** to reduce peak demand.

The most straightforward approach to managed charging is limiting charging speed. This involves 'de-rating' the power provided to an ESB at the expense of increasing the charging duration. Figure 17 below illustrates this concept with charging data from two buses charging overnight at Havre in November 2023[43]. The black line shows what an unmanaged charging load profile looks like for a single ESB: power quickly ramping up to max, staying at that level for a short duration, and then trailing off again over an hour or two. The second ESB charging that day (the blue line) had been configured to limit the power the bus would accept to roughly 25% of max[44].

Figure 17. A screenshot of the electricity submeter dashboard indicating the loadshape differences between two different charge management strategies.



The black line in Figure 17 shows that charging at full power usually fills the battery in Havre's ESB in roughly three to four hours. Reduced to 25% of max power (the blue line in Figure 17), that time extends to about 12 hours[45]. While roughly the same amount of energy is consumed in

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[43] *The source of this charging data is a submeter that was installed by on Havre's power panel that provides energy to the ESB charging equipment*

[44] *The tall, thin spikes in this graph – 3 black, 1 blue – are automatic thermal management events that are caused by the ESB's battery energy storage system. These spikes are too short or too low of a draw to significantly affect demand charges, which are based on 15-min or 30-min averages depending on the utility and their rate structure.*

[45] *This analysis assumes that the state of charge of each vehicle's battery was about the same prior to beginning charging.*

both scenarios, limiting charging speed (and thus extending the charge duration) reduces the peak load by about 12 kW. With a demand charge of about $13 per kW[46], this strategy (if applied consistently) could result in monthly demand charge savings of more than $150 per vehicle.

In this project, each district with Lion ESBs (Bigfork, Clinton, and Havre) was able to successfully limit overnight charging speeds by utilizing on-board software controls provided by the vehicle. In other cases, so-called 'smart charging' software controls embedded in charging equipment can achieve the same result. The degree to which charging speed, and thus demand charges, can be reduced depends on how much charge needs to be delivered and the time available for charging. Each of district was able to easily determine a de-rating strategy that met their operational requirements. (In the case of Bigfork, which does not have demand charges, this was not widely applied). Some districts even limited their charging to aim for their vehicles to begin the next morning's run with a specific state of charge less than 100% to take better advantage of regenerative braking (see "Regenerative brakingRegenerative braking").

The other primary managed charging strategy, staggering charging, involves adjusting the time during which ESBs are charged in order to minimize overlapping loads. There are two cases where this strategy can effectively reduce utility demand charges:

- First, *for a district with multiple ESBs and multiple chargers*, staggering charging involves adjusting the timing of charging in order to minimize the simultaneous charging of multiple ESBs at once. While this increases the total time required to recharge a fleet of ESBs, this strategy is usually feasible for small fleets to implement in an overnight scenario.
- Second, *in cases where ESB charging equipment is located on the same utility meter as other building loads*, staggering charging involves timing ESB charging to coincide with periods of low auxiliary building demand (or to avoid periods of high auxiliary demand). Since auxiliary building loads at schools typically peak in the middle of the day, this strategy would likely involve avoiding midday charging between ESB runs.

Billings implemented the first case of staggered charging for their fleet of eight ESBs. Their Level 3 Borg Warner charging equipment includes software controls that allow charge to be delivered to one bus at a time in sequence rather than all at once[47]. Since their buses are spread across two charging units, this strategy nominally reduces their peak charging load, and thus demand charges, by 75%.

The second case of staggered charging is more nuanced and was not actively implemented in any of the districts in this study. As is commonly the case, some of the districts' ESB charging

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[46] *Northwestern Energy, General Service – 1 Secondary Demand Electric Rate. https://rates.northwesternenergy.com/GSSecondaryDemandrates.aspx.*

[47] *Billings' charging equipment is comprised of two 'PCS' units, each with 4 charging plugs. Each PCS units charges 4 buses in sequence.*

equipment is on a separate utility meter and has no coincident auxiliary building loads. However, in districts where ESBs are co-located on an electric utility meter with other building loads, optimizing the timing of ESB charging has the potential to reduce the ESBs' net effect on demand charges. Where auxiliary building loads are greater than ESB charging loads, it could be possible to time the charging of ESBs such that they result in minimal, if any, increases in demand charges. However, implementing this form of staggered charging would involve the significant technical and administrative overhead associated with tracking temporal variations in both building and charging loads, in coordination with operational needs.

Fundamentally, staggered charging involves enforcing specific schedules for ESB charging. For small fleets, this may be possible to achieve on a vehicle-to-vehicle basis using on-board software controls like those offered by the Lion ESBs in this study. Larger fleets, like in Billings, will likely find value in more coordinated controls offered by some Level 3 charging equipment.

As discussed previously, none of the school districts involved with this project have an electric utility rate that includes time-of-use charges. However, the same staggered charging strategies described above can be used to reduce costs under that pricing structure. For example, in a hypothetical utility rate, if 'peak' pricing hours are from 6 am to 6 pm, software controls (either in the vehicle or the charging equipment) can restrict all charging to occur outside of those hours.

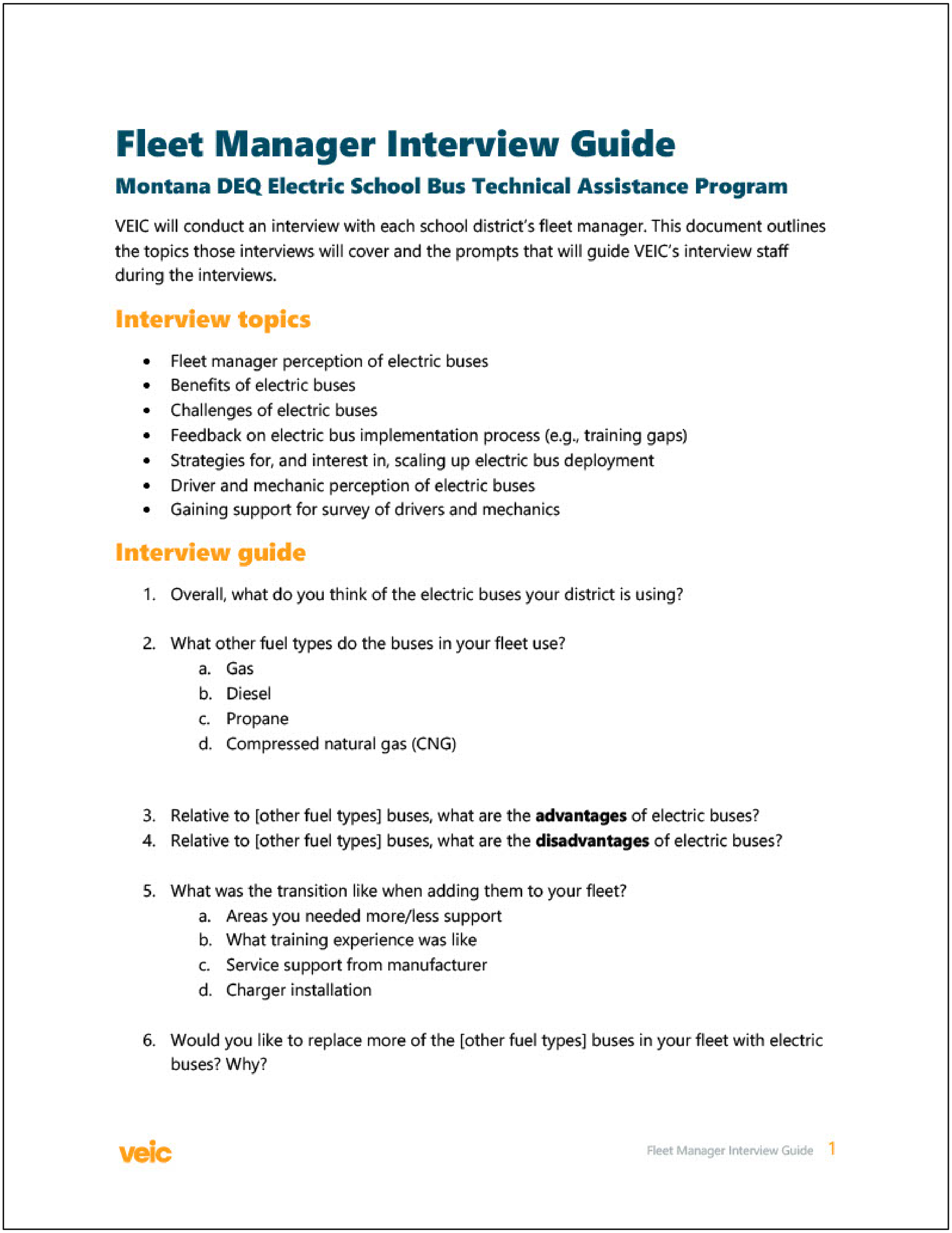
The managed charging strategies described above create a playbook that ESB operators can apply in different situations to optimize their fuel costs. The strategies can change over time and they are not mutually exclusive; a district can limit charging speeds, stagger charging times, or do both simultaneously. Beneficial strategies available to an ESB operator will depend on their operational needs, utility rate structure, and the technical capabilities of their equipment. Therefore, the greatest opportunities for managed charging will be realized in deployments that are carefully planned, executed, and evaluated.

School District Staff Interviews

To inform the findings in this report, the following individuals were interviewed about their experiences using ESBs in the spring of 2024.

Date	Name	Location	Role
4/25/2024	Rob Tracy	Bigfork	Driver
4/25/2024	Danny Walker	Bigfork	Manager
4/25/2024	Marvin Loftus	Bigfork	Mechanic
5/21/2024	Kathy Veseth	Clinton (Handley)	Driver
5/21/2024	Chris Vicens	Clinton (Handley)	Driver & Mechanic
5/21/2024	Ryan Handley	Clinton (Handley)	Manager
5/30/2024	Bruce Sprinkle	Havre	Driver
5/30/2024	Alan "Woody" Woodwick	Havre	Manager
5/30/2024	Seth Hamilton	Havre	Mechanic
5/31/2024	Don Hanson	Billings / First Student	Mechanic
5/31/2024	Tracy Hightower	Billings (First Student)	Mechanic
5/31/2024	Larry Fielding	Billings (First Student)	Manager
5/31/2024	Mike Niemeyer	Billings (First Student)	Manager
7/9/2024	Paul Wilson	Fairfield	Manager
7/12/2024	Ruth Berglund	Fairfield	Driver

Fleet Manager Interview Guide



Fleet Manager Interview Guide

Montana DEQ Electric School Bus Technical Assistance Program

VEIC will conduct an interview with each school district's fleet manager. This document outlines the topics those interviews will cover and the prompts that will guide VEIC's interview staff during the interviews.

Interview topics

- Fleet manager perception of electric buses
- Benefits of electric buses
- Challenges of electric buses
- Feedback on electric bus implementation process (e.g., training gaps)
- Strategies for, and interest in, scaling up electric bus deployment
- Driver and mechanic perception of electric buses
- Gaining support for survey of drivers and mechanics

Interview guide

1. Overall, what do you think of the electric buses your district is using?

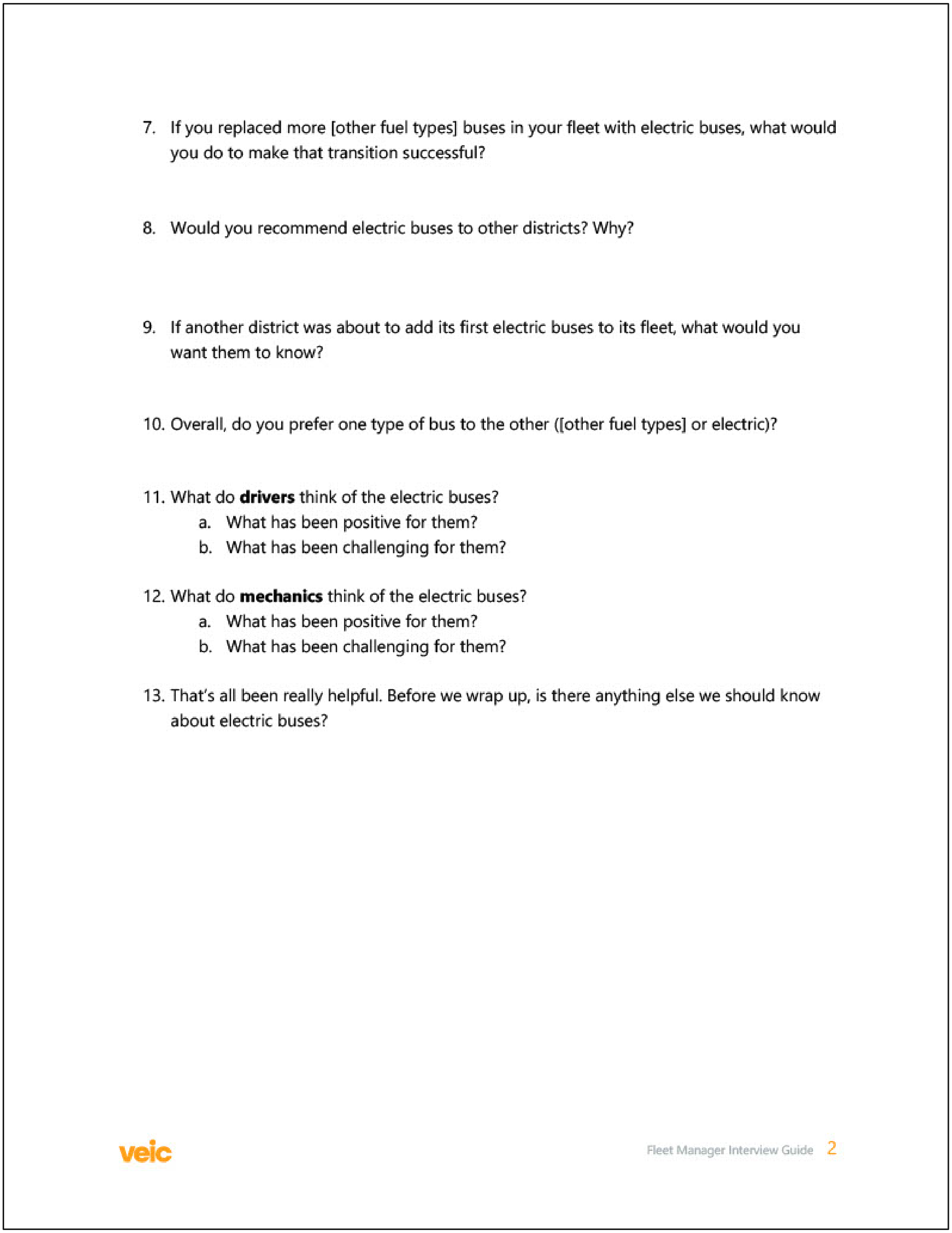
2. What other fuel types do the buses in your fleet use?
    a. Gas
    b. Diesel
    c. Propane
    d. Compressed natural gas (CNG)

3. Relative to [other fuel types] buses, what are the **advantages** of electric buses?
4. Relative to [other fuel types] buses, what are the **disadvantages** of electric buses?

5. What was the transition like when adding them to your fleet?
    a. Areas you needed more/less support
    b. What training experience was like
    c. Service support from manufacturer
    d. Charger installation

6. Would you like to replace more of the [other fuel types] buses in your fleet with electric buses? Why?

veic Fleet Manager Interview Guide 1



7. If you replaced more [other fuel types] buses in your fleet with electric buses, what would you do to make that transition successful?

8. Would you recommend electric buses to other districts? Why?

9. If another district was about to add its first electric buses to its fleet, what would you want them to know?

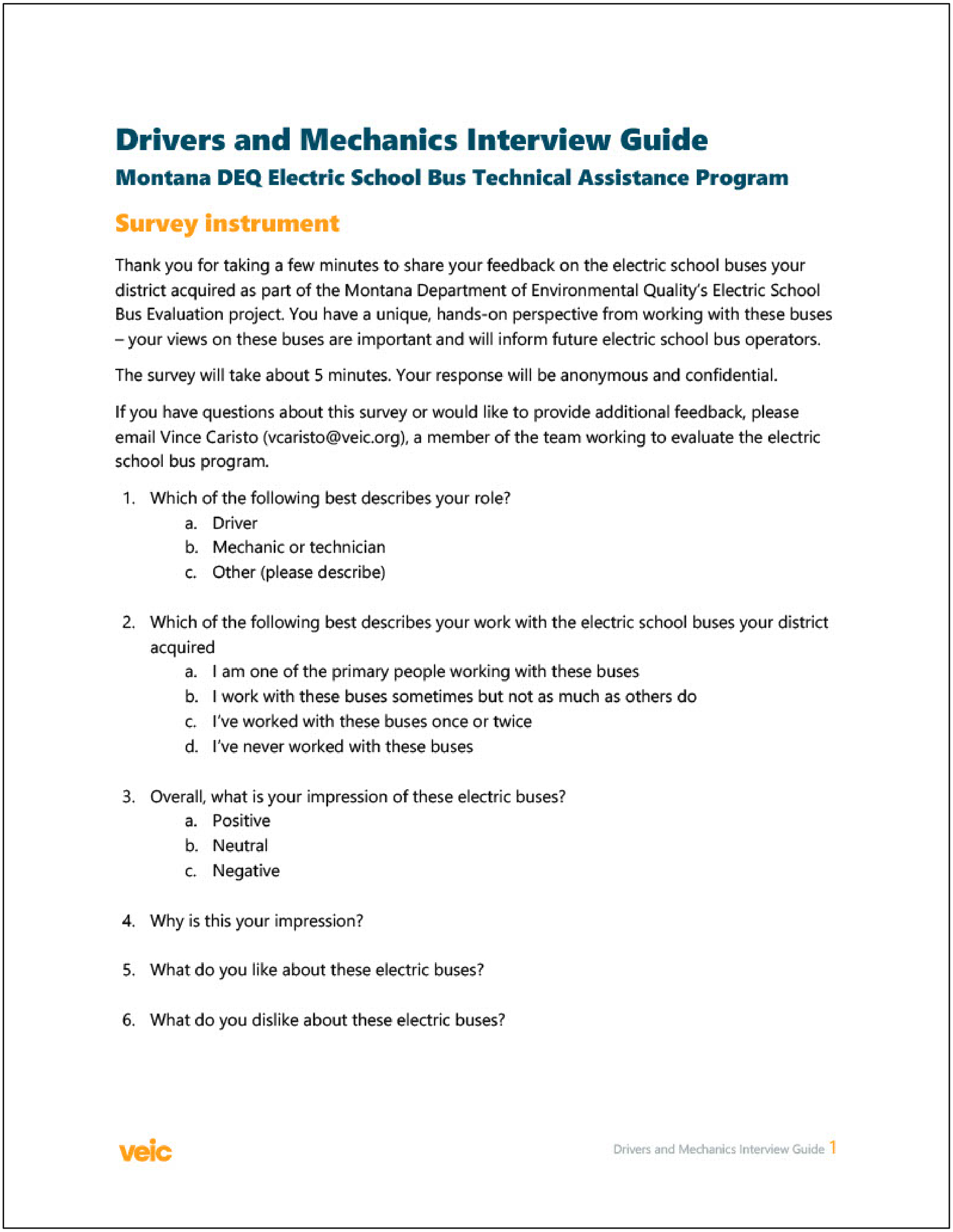
10. Overall, do you prefer one type of bus to the other ([other fuel types] or electric)?

11. What do **drivers** think of the electric buses?
    a. What has been positive for them?
    b. What has been challenging for them?

12. What do **mechanics** think of the electric buses?
    a. What has been positive for them?
    b. What has been challenging for them?

13. That's all been really helpful. Before we wrap up, is there anything else we should know about electric buses?

Drivers and Mechanics Interview Guide



Drivers and Mechanics Interview Guide

Montana DEQ Electric School Bus Technical Assistance Program

Survey instrument

Thank you for taking a few minutes to share your feedback on the electric school buses your district acquired as part of the Montana Department of Environmental Quality's Electric School Bus Evaluation project. You have a unique, hands-on perspective from working with these buses – your views on these buses are important and will inform future electric school bus operators.

The survey will take about 5 minutes. Your response will be anonymous and confidential.

If you have questions about this survey or would like to provide additional feedback, please email Vince Caristo (vcaristo@veic.org), a member of the team working to evaluate the electric school bus program.

1. Which of the following best describes your role?
    a. Driver
    b. Mechanic or technician
    c. Other (please describe)

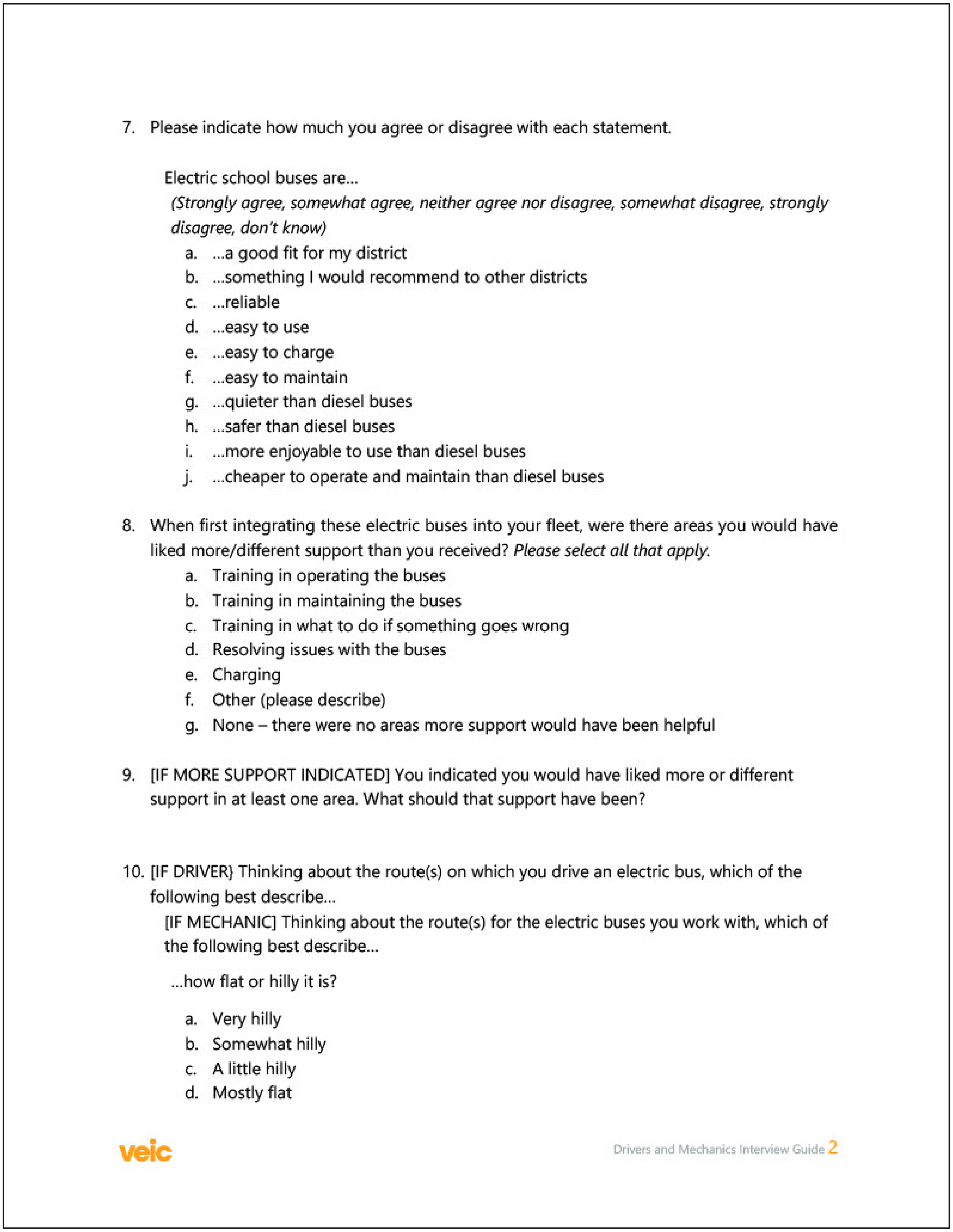
2. Which of the following best describes your work with the electric school buses your district acquired
    a. I am one of the primary people working with these buses
    b. I work with these buses sometimes but not as much as others do
    c. I've worked with these buses once or twice
    d. I've never worked with these buses

3. Overall, what is your impression of these electric buses?
    a. Positive
    b. Neutral
    c. Negative

4. Why is this your impression?

5. What do you like about these electric buses?

6. What do you dislike about these electric buses?



7. Please indicate how much you agree or disagree with each statement.

   Electric school buses are…
   (Strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, strongly disagree, don't know)
   a. …a good fit for my district
   b. …something I would recommend to other districts
   c. …reliable
   d. …easy to use
   e. …easy to charge
   f. …easy to maintain
   g. …quieter than diesel buses
   h. …safer than diesel buses
   i. …more enjoyable to use than diesel buses
   j. …cheaper to operate and maintain than diesel buses

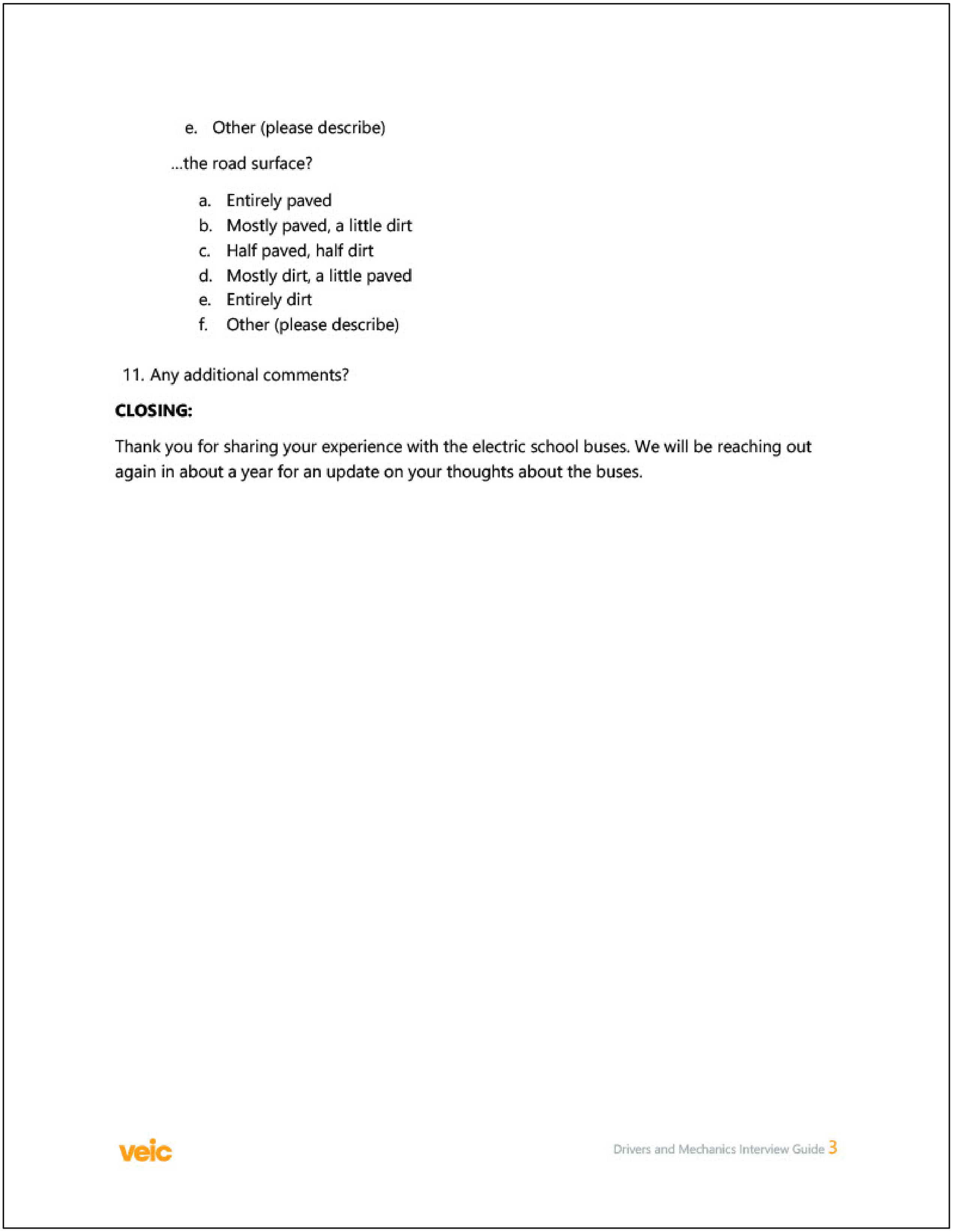
8. When first integrating these electric buses into your fleet, were there areas you would have liked more/different support than you received? *Please select all that apply.*
   a. Training in operating the buses
   b. Training in maintaining the buses
   c. Training in what to do if something goes wrong
   d. Resolving issues with the buses
   e. Charging
   f. Other (please describe)
   g. None – there were no areas more support would have been helpful

9. [IF MORE SUPPORT INDICATED] You indicated you would have liked more or different support in at least one area. What should that support have been?

10. [IF DRIVER} Thinking about the route(s) on which you drive an electric bus, which of the following best describe…
    [IF MECHANIC] Thinking about the route(s) for the electric buses you work with, which of the following best describe…

    …how flat or hilly it is?

    a. Very hilly
    b. Somewhat hilly
    c. A little hilly
    d. Mostly flat



e. Other (please describe)

...the road surface?

a. Entirely paved
b. Mostly paved, a little dirt
c. Half paved, half dirt
d. Mostly dirt, a little paved
e. Entirely dirt
f. Other (please describe)

11. Any additional comments?

CLOSING:

Thank you for sharing your experience with the electric school buses. We will be reaching out again in about a year for an update on your thoughts about the buses.

Reliability summary metrics

Table 7. Summary reliability metrics for each ESB in the project that spent sufficient time in the field to report upon.

School	Timeframe	Bus	Available	Not Available	Road Call	No school/service days
Bigfork	11/13/23 - 6/13/24	#1	147	0	0	18
Clinton	11/13/23 - 6/7/24	#1	115	0	0	20
Clinton	11/13/23 - 6/7/24	#2	115	0	0	20
Fairfield	1/1/24 - 5/31/24	#24-1	18	39	0	4
Fairfield	1/1/24 - 5/31/24	#24-2	74	41	1	4
Fairfield	1/1/24 - 5/31/24	#24-3	17	39	0	4
Havre	1/9/23 - 6/7/24	#1	122	47	0	69
Havre	1/9/23 - 6/7/24	#25	169	0	0	69