Electric School Bus Operational Assessment:

A Calgary Demonstration Case Study

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The Calgary Board of Education (CBE) also played a supportive role by involving the electric school bus on their routes and contributing funding for the bus charger.

LAND ACKNOWLEDGEMENT

With a focus on mobility in what is now known as Alberta – subject to Treaties 6, 7 and 8 – this project is inherently land-based. The project team recognizes the true history of these lands and the injustices that First Nations, Métis, and Inuit peoples continue to experience through colonial systems and structures. We acknowledge these lands as the traditional and ancestral territory of many peoples – the Blackfoot Confederacy– Kainai, Piikani, and Siksika – the Cree, Dene, Saulteaux, Nakota Sioux, Stoney Nakoda, the Tsuu T'ina Nation, and the Métis People of Alberta.

We encourage readers to learn about the Indigenous history of where they live and work and the Truth and Reconciliation Committee of Canada's Calls to Action. We invite you to reflect on your own relationship with the lands you occupy and what meaningful actions you can take toward reconciliation.

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Pollution Probe

Pollution Probe is a Canadian charitable environmental organization that is a leading agent of change at the intersection of communities, health and environment. Since 1969, we have been defining environmental problems through research, promoting understanding through education and pressing for practical solutions through advocacy. Pollution Probe has a proven track record of working in successful partnership with industry and government to develop practical solutions for shared environmental challenges.

Pollution Probe is one of Canada's leading independent transportation solution providers. Our work supports aggressive actions to address climate change and reduce air pollution while promoting job creation and economic growth. In addition to projects we actively contribute to expert transportation committees and working groups at local, regional, national and global levels. We are technology neutral and work collaboratively with a wide variety of stakeholders to develop transportation decarbonization solutions across all modes.

Mobility Futures Lab

Mobility Futures Lab is a leading sustainable transportation consulting firm that is at the forefront of innovation and research in the field of mobility. The firm's services are designed to help clients navigate the complex landscape of sustainable transportation, with a focus on proprietary software tools and data-driven solutions. Our approach is based on a deep understanding of the interconnections between transportation, energy, and the environment.

RFS Energy

RFS Energy brings people together to propel planning, research, and climate change policy into the marketplace.

With 50+ years of combined experience working with non-profits, think tanks, 25+ utilities and government agencies across Canada, the RFS Energy team draws from unique experience rooted in on-the-ground program implementation to support clients and bring innovation to life.

Southland Transportation

Founded in 1971, Southland Transportation is a leader in student transportation throughout Canada and a trailblazer in forward-thinking transportation solutions. Operating over 3500 routes daily, Southland understands the GHG impact of the transportation industry and is actively reducing emissions in the communities we serve. With Canada's largest alternative fuel fleet and a growing zero emissions fleet, Southland is creating a sustainable future for the students we deliver Safely Home each day.

Executive Summary

In Canada, over 90% of the entire school bus fleet operates using diesel fuel, leading to the emission of greenhouse gases (GHGs) and detrimental pollutants throughout their operational lives.

Electric school buses (ESBs) present a valuable opportunity to reduce GHG emissions associated with the school bus industry and mitigate the detrimental health impacts of diesel exhaust on children and the general population. Despite recent cost reductions and increased adoption facilitated by federal and provincial incentives, concerns linger around the financial viability of ESBs in different provinces and ESBs' operational performance, especially in cold weather conditions.

To address these concerns, Pollution Probe partnered with RFS Energy and the Mobility Futures Lab, with funding from the Alberta Ecotrust Foundation and the ScotiaBank Zero Emission Fund, to conduct an ESB demonstration in Calgary, Alberta. This project consisted in the deployment of a single Blue Bird Vision ESB in partnership with local operator Southland to monitor its operational performance and associated charger over a school year, marking Canada's first ESB demonstration project with publicly shared real-world operational data.

This report encompasses a business case, a technical brief, and an important discussion about opportunities for advancing an equitable transition.

Business Case Overview

The business case provides a comparative analysis of an ESB and a diesel school bus through the data on costs and operational energy consumption gathered during the demonstration. The report assesses the capital and operational costs associated with the deployment of an ESB and highlights the impact of federal financial incentives available to the sector.

Technological innovations in the battery manufacturing sector have significantly reduced the cost of batteries over the past decade and improved the economics of ESBs. Recent large-scale investments into the supply chain of battery electric vehicle technology manufacturing across North America are expected to continue the cost reductions of the technology over the next decade.

Although the literature to this point indicates that the total cost of ownership (TCO) for ESBs is currently higher than internal combustion engine (ICE) buses in jurisdictions evaluated, federal financial incentives provided through the Zero Emission Transit Fund (ZETF) can make ESBs financially viable for operators willing to pilot the technology and initiate the electrification of their fleet.

Executive summary

The TCO of ESBs varies based on the local operational conditions of the bus, which dictate how much energy the bus is consuming and the local electricity prices, among other factors. Based on operating conditions, ESBs' energy usage can fluctuate, especially in winter. Moreover, each province's unique regulatory framework results in varying electricity costs and billing methods. As a result, assessing the TCO of ESBs at the local level is crucial, considering local electricity expenses and real-world data on operational energy consumption.

Key findings from the business case include:

- In the Albertan context, the TCO for an ESB over a 13-year period is 19% higher than that of a diesel school bus. However, when factoring in the federal financial incentives aimed at capital costs, the TCO of an ESB is 21% lower compared to a diesel school bus.

- The business case for ESBs entails higher upfront costs offset by operational savings throughout the vehicle's lifetime. Financing programs are crucial in enabling fleet operators to overcome the initial higher capital cost of ESBs, particularly in the early stages of the ESB transition, where financial lenders charge higher interest rates for ESBs relative to diesel school buses due to the uncertain resale value of the vehicle in case of a fleet operator default.

- The economics of ESBs varies based on the size of a deployment. Operators could take advantage of the limited infrastructure cost requirements of small deployments to start training staff on the technology in advance of further cost reductions expected in the sector through the recent significant investments from the industry that will promote economies of scale in ESB manufacturing.

- Regulatory and technological barriers to potential revenue sources, such as vehicle to grid (V2G), should be explored further in the Albertan context.

- While the quantitative aspects of ESB adoption are significant drivers, qualitative considerations play a crucial role in shaping the success and acceptance of this transition. These include stakeholder engagement, community support, and education in shaping ESB perception. Internally, successful ESB integration relies on organizational change management, buy-in, and employee training. Additionally, improving driver satisfaction through comfort, features, and charging logistics requires ongoing research to assess the overall impact of ESB adoption on the people involved.

Technical Report Overview

The technical report presents the operational lessons learned and the results of the data analysis conducted based on the energy consumption monitoring of the ESB and associated charger. Telematics equipment was used to collect energy consumption data from December 7, 2022, to June 28, 2023.

The analysis explores the performance of the ESB under different operating conditions, including the impact of outside temperature and regenerative braking. The energy consumption of trips completed by the ESB is evaluated based on a measure of efficiency called energy intensity. Energy intensity, expressed in kilowatt-hours per kilometer (kWh/km), refers to the amount of electrical energy consumed by an ESB to travel a distance of one kilometer. It is a measure of the efficiency of the vehicle's energy usage and represents the energy required to move the bus a specific distance. Lower energy intensity values indicate higher efficiency, meaning the bus can travel longer distances on the same amount of energy.

Executive summary

This report's findings are crucial for fleet operators as they help identify viable routes in their fleet for electrification, particularly during winter conditions. Moreover, the results assist in determining whether specific routes require ESBs with a larger battery, leveraging the availability of multiple battery sizes by some manufacturers. Reliable estimates of yearly energy consumption from charging and required battery capacity for ESBs are also essential elements to consider in the financial assessments related to deploying ESBs.

Key findings from the technical report:

- The range of the ESB on a single charge varied from 73 km to 213 km based on the 155-kWh battery, depending on the operating conditions, across 81 runs conducted between December 2022 and June 2023. The range of the ESB on a single charge gradually increases from December to June in parallel to warming temperatures. School bus operators can increase their range in winter conditions by installing an auxiliary diesel heater and not relying on electrical heating, which consumes a significant amount of energy.

- Regenerative braking reduces energy intensity by an average of 22%, improving vehicle range. School bus operators should explore driver training programs that generate useful data and maximize regenerative braking to improve vehicle range and reduce charging costs.

- In winter conditions, the use of the bus electrical heating system increases energy intensity by an average of 33%, decreasing vehicle range. Fleet operators should explore bus pre-heating in advance of runs and logistical planning for mid-day charging between runs to ensure sufficient range capabilities on certain routes.

- Energy transfer losses and energy consumption while plugged into the charger increases the energy intensity of ESBs by an average of 41% relative to the energy intensity estimated based on the energy consumption of the bus only while in operation. This increase is more pronounced during winter conditions and relatively smaller during warmer months. ESB manufacturers are continuously improving their battery management systems to minimize this disparity.

Equitable Transition

"Canadians have expressed their expectations that the government will ensure that the low-carbon transition is just and equitable so that equity-deserving groups — such as women, Indigenous Peoples, racialized individuals, people with disabilities and youth — are able to benefit from new jobs and opportunities." [1]

The transition from diesel to ESBs can provide significant social equity benefits by reducing air and noise pollution, particularly in high-density or low-income neighbourhoods where students are most affected by diesel emissions. ESB adoption can promote equitable access to clean, reliable transportation, furthering educational equity. However, the challenge lies in establishing fair prioritization strategies during the adoption phase, considering factors such as geographic and demographic considerations, electric utility infrastructure, funding disparities, job quality, and accessibility.

This report introduces a Social Equity Framework, emphasizing the need to pose equity questions at the outset of ESB projects. Recommendations include collaborating with community organizations to understand existing socioeconomic inequities at a community level and identify key stakeholders, identifying which metrics will help make decisions with equity in mind, and collecting and using data so that metrics can be incorporated and measured at every stage of ESB projects.

1 Institute for Research on Public Policy (2023). Just transition or smart transition. Retrieved from: https://policyoptions.irpp.org/magazines/march-2023/just-smart-transition/

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Clean Air • Clean Water • Healthy Planet

Background

In Canada, the vast majority of school buses, more than 90% of the total fleet, run on diesel fuel, resulting in greenhouse gas (GHG) and harmful pollutant emissions throughout their lifespan.

Diesel exhaust includes pollutants like carbon monoxide, nitrogen oxides, and particulate matter, contributing to serious health issues such as asthma and respiratory illnesses.

Electric school buses (ESBs) present a valuable opportunity to reduce GHG emissions associated with the school bus industry and mitigate the detrimental health impacts of diesel exhaust on children and the general population. While school bus electrification is growing in the United States and warmer climates - gaps in locally relevant data, high capital costs, and reliability concerns are preventing adoption here in Canada. Canadian companies will not invest in transforming fleets without adequate data and confidence to make informed decisions and deliver quality service.

The project aimed to address barriers to adoption and data gaps, which include:

- Reliability and efficiency of ESB energy consumption and charging: This includes assessing ESB performance under extreme Canadian weather conditions, particularly during winters, where data regarding range and charging efficiency is currently lacking.
- Charging infrastructure requirements and costs: The project seeks to fill gaps in knowledge related to the upfront investment required for charging infrastructure.

1 Background

- Real-world data on ESB maintenance events and fuel cost savings: To build a compelling economic case for electric school buses, the project will gather real-world data on vehicle maintenance events and long-term fuel cost savings, providing a comprehensive view of the operational benefits over the vehicle's lifetime.

A collaborative project led by Pollution Probe, with partners Mobility Futures Lab and RFS Energy, focuses on monitoring a single ESB in Calgary over the 2022-2023 school year as a replacement for a diesel bus. The ESB was leased and operated by Southland Transportation, Ltd, who have over 53 years of operational expertise in Alberta and a strong commitment to minimizing their environmental impact.

This research report marks the first publicly published ESB demonstration report in Canada. Components include a business case and a technical brief, underpinned with a strong emphasis on social equity and stakeholder feedback. The project aims to provide data relevant to fleet operators nationwide, supporting the transformation of Canada's 50,000 school buses to electric.

The Business Case

2.1 Introduction

The following sections offer a detailed business case for ESBs compared to diesel school buses, considering the observed costs and operational energy consumption during the demonstration, while also emphasizing the impact of available federal financial incentives on the sector.

Technological innovations in the battery manufacturing sector have significantly reduced the cost of batteries over the past decade and improved the economics of ESBs. Recent innovations in battery manufacturing have significantly reduced battery costs and enhanced the economic feasibility of electric school buses (ESBs). Large-scale investments in North American battery electric vehicle technology manufacturing are expected to further drive down ESB costs in the coming years. While existing literature suggests that the total cost of ownership (TCO) for ESBs is currently higher than internal combustion engine (ICE) buses in certain jurisdictions, federal financial incentives like the Zero Emission Transit Fund (ZETF) can render ESBs financially viable, especially for willing to pilot the technology and initiate the electrification of their fleet.

The TCO of ESBs varies based on local operational conditions, influencing energy consumption and electricity expenses. Operational factors, including weather-related fluctuations, and regional regulatory frameworks all play roles in determining the overall cost-effectiveness of ESBs. As a result, it is crucial to assess the TCO of ESBs at the local level, considering local electricity expenses and real-world data on operational energy consumption. To provide a comprehensive analysis, this report utilizes telematics equipment installed on the bus to collect energy consumption data from December 7, 2022, to June 28, 2023.

2 The Business Case

2.2 Economics of ESBs

2.2.1 Costs

2.2.1.1 Capital costs

ESB deployments involve various capital costs. One of the most significant costs is the acquisition cost of the electric buses themselves. ESBs have a higher upfront purchase price compared to traditional diesel buses. Additionally, charging infrastructure is a crucial capital cost. This includes the installation of charging stations, and any infrastructure upgrades required to support increased power loads. Charging infrastructure costs can vary depending on the number of charging stations required, their capacity, and the electrical upgrades needed. **Table 1** presents the specifications of the ESB and charging station used as part of the demonstration.

Table 1: Vehicle and Charger Specifications

Procurement Item	Specifications	Standards and codes
Blue Bird Vision Electric	Type C, Up to 77 passengers, 145 kWh NMC battery[2]	Level II (AC) - J1772 & Level III (DC) – CCS-Combo
Nuvve charging stations	19 kW level 2 (1 Phase)[3]	J1772

A type C 145 kWh battery capacity 2022 Blue Bird ESB was leased for the duration of the 2022-2023 school year. The ESB was fitted with air brakes, a braking system more commonly found in electric vehicles due to their higher weight compared to diesel vehicles. Drivers need to undergo a one-day training to obtain certification for operating air brake-equipped vehicles. The training expense amounts to approximately $250 per driver.

The purchase cost of a type C ESB is around $400,000 (can vary based on battery size) while a type C diesel school bus costs around $150,000. The economics of ESBs entails higher upfront costs offset by operational savings achieved by lower fueling and maintenance costs throughout the vehicle's lifetime. [4] As ESB manufacturing capacity increases, school boards or bus operators can benefit from lower ESB prices by leveraging joint procurement initiatives through large-scale purchase orders.

A Level 2 AC 19.2 kW Nuvve charger was purchased and installed at the yard for a cost of $5,100. Level 2 chargers are significantly cheaper than faster-charging DC capacity chargers. The Level 2 charger operated at a charging rate of 12.5 kW, resulting in a full charge in around 11-12 hours. Although bus drivers typically retain the bus throughout the day, in this case, the driver had to return to the yard between runs to charge the bus and ensure sufficient range. Overall, the limited charging time available between runs proved to be adequate when utilizing the Level 2 charger, enabling the bus to complete its scheduled routes. [5]

2 Blue Bird (2023). Vision Electric Bus. Retrieved from: https://www.blue-bird.com/buses/vision/vision-electric-bus

3 Nuvve (2023). Nuvve PowerPort. High-Power AC charging station. Retrieved from: https://nuvve.com/wp-content/uploads/2022/01/nuvve-powerport-single-phase-spec-sheet-jan2022.pdf

4 Dunsky (2023). Pathways for Canadian Electric School Bus Adoption. Retrieved from: https://cms.equiterre.org/uploads/CESBA_STUDY_Pathways-for-electrification_May-2023-ENGpdf.pdf

5 Further testing is required in extreme winter conditions to confirm this finding.

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When deploying ESBs at a yard, the size of the deployment may necessitate grid upgrades to accommodate increased power demands. These upgrades involve increasing the power limit at the yard, enabling multiple buses to charge simultaneously without overloading the electrical system. In the context of this demonstration, a single low power Level 2 charger was installed that fit within the existing power limits at the yard, eliminating the need for grid upgrades.

Additional capital expenses can arise from the need to enhance maintenance and repair facilities to support electric buses. These enhancements often entail the installation of specialized equipment and the training of personnel to handle the maintenance and repair of electric vehicles. Furthermore, there are administrative costs associated with planning and implementation, such as conducting feasibility studies, acquiring permits, and coordinating with relevant stakeholders. Since this demonstration project involved only a single school bus, these costs were negligible. Staff members participated in ESB training offered by the vehicle manufacturer, while maintenance needs were addressed by the local dealership responsible for providing the bus.

2.2.1.2 Operational costs

Maintenance costs

ESBs have a much smaller number of components compared to diesel powertrain technology, leading to decreased maintenance requirements. Additionally, unlike diesel school buses, which necessitate routine fluid changes, oil changes, and brake replacements due to frequent stop-and-go operations, ESBs capitalize on this movement pattern using regenerative braking technology. This technology enables the bus to generate energy during these conditions and reduces brake wear by up to five times compared to diesel buses. [6]

The length and size of this demonstration did not permit an estimation of maintenance costs per kilometer travelled as a larger sample size is required. A total of 81 runs were conducted between December 8, 2022, and June 28, 2023, resulting in a distance travelled of 4,000 km. The number of runs completed by the bus over the course of the demonstration was limited not only by maintenance requirements, but by logistical driver changes that resulted in bus downtime despite the bus and charger being functional. Maintenance costs for an ESB are accounted for in this analysis based on estimates from the Argonne National Laboratory Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool, which assume a 40% reduction in maintenance costs for an ESB relative to a diesel bus per kilometer. [7]

6 US department of Energy (2023). Alternative Fuels Data Center. Flipping the Switch on Electric School Buses: Cost Factors. Retrieved from: https://afdc.energy.gov/vehicles/electric_school_buses_p8_m3.html

7 Argonne National Laboratory (2020). Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool. Retrieved from: https://greet.es.anl.gov/afleet

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Interviews conducted with fleet maintenance personnel indicate that there is a need for capacity building in local technician and dealership expertise for ESB maintenance. Local maintenance expertise would decrease reliance on vehicle manufacturers and reduce maintenance costs (repairs can be conducted locally for a lower price), as well as reduce opportunity costs associated with bus downtime (bus does not need to travel long distances for servicing making repair timeframes shorter).

Maintenance events were tracked during the demonstration and are presented in **Table 2**.

Table 2: Demonstration maintenance events

Issue	Failure Date	Downtime	Required Dealership Servicing
Coolant leak due to loose clamp	November 21, 2022	14 days	Yes
Frozen charging handle	February 27, 2023	1 day	No
12V battery failure	April 10, 2023	2 days	No
Thermal management system coolant error	April 21, 2023	13 days	Yes

Charging costs
Energy consumption was monitored separately in both the charger and the ESB. While operational energy consumption from the ESB showed an average energy intensity across the demonstration of 0.95 kWh/km, the charger consumed additional energy while the bus was parked, resulting in an average energy intensity of 1.35 kWh/km across the school year. The higher energy consumption observed through the charger is due to energy transfer losses from the charger into the bus, charging occurring while the vehicle is parked to pre-heat the bus in winter conditions and charging events that occur particularly in winter to keep the ESB battery at a certain temperature while parked.

The cost of charging for the ESB in this analysis is estimated based on the energy consumption of the charger. Utilities in Alberta do not offer time-of-use pricing, with electricity priced monthly based on weather and market conditions. Based on the historical changes in electricity costs over a 5-year timeframe, an average yearly price of $0.155/kWh is projected and used in this analysis over the 13-year lifetime of the ESB.

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Another critical cost associated with charging is demand charges. Demand charges are fees levied by utility companies based on the peak amount of electricity used within a specific timeframe (charged once per month). Demand charges can become significant in the context of a fleet charging multiple ESBs at a depot. As multiple buses are simultaneously plugged in and charging, they collectively draw a substantial amount of power from the grid, resulting in high peak demand. This peak demand triggers demand charges, which can significantly impact the overall electricity costs for the fleet.

Efficiently managing and minimizing these charges is crucial for the financial viability of the electric bus fleet operation. Strategies such as load balancing, smart charging, and implementing energy management systems can help optimize charging schedules and reduce peak demand, thereby mitigating demand charges and ensuring cost-effective operation of the ESB fleet. In the context of this demonstration, demand charges were negligible as the charging consisted of a single ESB with a low-power Level 2 charger.

2.2.2 Revenue sources and financial incentives

2.2.2.1 Revenue sources

ESB operators have the potential to generate revenue through Vehicle-to-Grid (V2G) technology and Clean Fuel Regulation Credits. V2G enables electric buses to not only draw power from the grid but also send excess electricity back to it when the buses are parked and connected. By participating in V2G programs, operators can offer grid services such as energy storage and load balancing, earning revenue from utilities or grid operators. This can help offset the operational costs of charging the buses and provide an additional revenue stream. However, V2G still faces many regulatory barriers across Canada, with the feasibility of the technology still being explored in the Alberta context. [8] V2G is therefore not considered as a revenue source as part of this analysis.

Clean Fuel Regulation Credits are another avenue for generating revenue. ESB operators can accumulate credits based on the amount of clean energy they use in their fleet. These credits can be sold or traded to other entities that require them to meet their clean fuel obligations. By participating in clean fuel credit programs, operators can monetize their environmentally friendly operations.[9] Potential revenue for operators in Alberta from this program is reduced compared to other provinces as revenue is tied to emission savings potential, and the Alberta grid has a higher emission intensity than other Canadian provinces as of 2023. Clean fuel credits were not tracked during the demonstration as the operator partner had not joined a Clean Fuel Regulations program. The operator partner is, however, in the process of joining a Clean Fuel Regulations program.

8 Electric Autonomy (2022). V2G from commercial fleet vehicles can drive Canada to a green future and the time to act is now. Retrieved from: https://electricautonomy.ca/2022/11/08/v2g-electric-school-buses-canada/

9 Environment and Climate Change Canada (2023). Clean Fuel Regulations. Retrieved from: https://www.canada.ca/en/environment-climate-change/services/managing-pollution/energy-production/fuel-regulations/clean-fuel-regulations.html

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2.2.2.2 Financial incentives

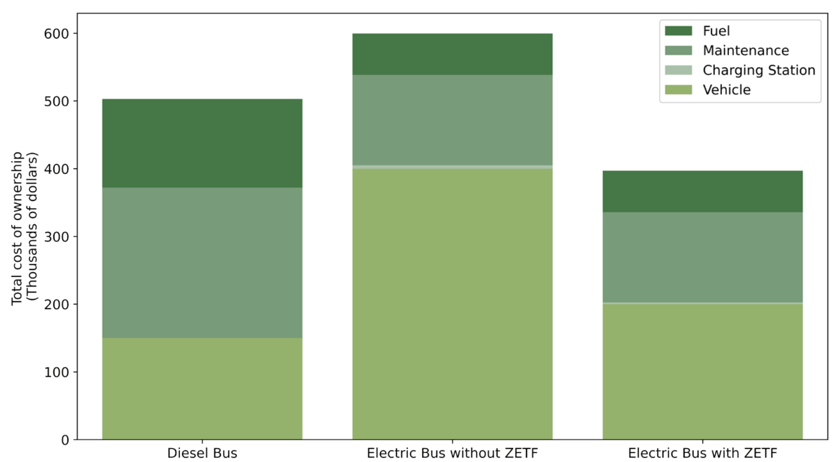
In 2021, the Government of Canada launched the Zero Emission Transit Fund (ZETF), investing $2.75 billion over five years to support public transit and school bus operators to transition to zero-emission vehicles.[10] The ZETF provides subsidies covering up to 50% of the cost associated with purchasing ESBs and charging infrastructure. The fund also covers costs associated with grid capacity required at a site for larger deployments. With no provincial programs available, ESB purchases in Alberta rely entirely on funding from the ZETF. Prior to being awarded grants for the procurement of vehicles and infrastructure, the ZETF requires applicants to conduct a planning study to ensure they have planned and allocated sufficient resources for the successful integration of ESBs into fleets. The ZETF covers up to 80% of the costs associated with the planning stage.

2.3 Total cost of ownership comparison with a diesel school bus

A total cost of ownership analysis is conducted by comparing an ESB and a diesel school bus under an operational lifespan of 13 years.[11]

Figure 1 presents the total cost of ownership of a diesel school bus, an ESB without financial incentives, and an ESB with a 50% cost reduction for the bus and charging station under the federal ZETF financial incentive. The TCO of an ESB without access to ZETF funding is 19% higher than that of a diesel bus due to the significant difference in the capital cost of the ESB. On the other hand, the TCO of an ESB with access to ZETF funding is 21% lower than that of a diesel bus, highlighting the effectiveness of the federal financial incentive in making the business case for ESBs. It is important to note that TCO analysis results can vary depending on the financial assumptions used. Conducting a sensitivity analysis by adjusting factors such as diesel prices and electricity rates can help identify the impact of various components.

Figure 1: Total Cost of Ownership of each technology after 13 years



10 Government of Canada (2022). Zero Emission Transit Fund. Retrieved from: https://www.infrastructure.gc.ca/zero-emissions-trans-zero-emissions/index-eng.html

11 Buses are assumed to operate 22,500 km yearly. Diesel bus efficiency is assumed at 33.13 L/100 km and a diesel price of $1.35/L is assumed based on the average retail cost of diesel in Calgary over the past 3 years as of 2023 (With no consideration for an increase in diesel prices over time through carbon pricing).

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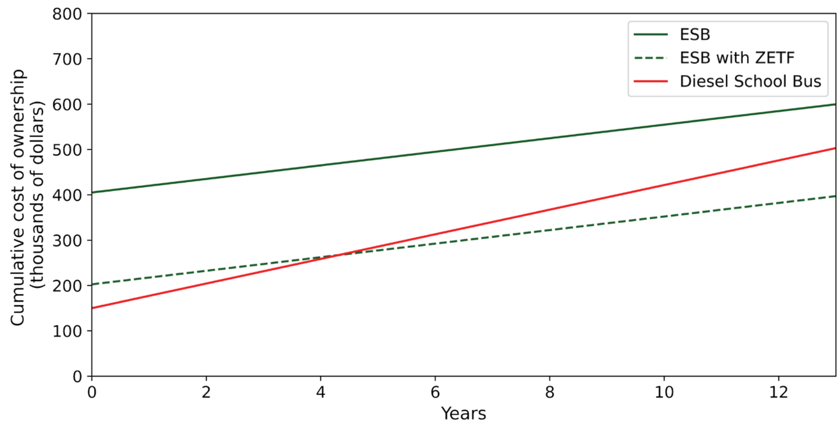
As was mentioned earlier, the economics of ESBs entail higher capital costs that are offset by operational savings through lower maintenance and fueling costs throughout the lifetime of the vehicle. It is therefore possible to estimate the number of years required for an ESB to breakeven with a diesel bus from a total cost of ownership perspective based on yearly costs.

Figure 2 presents total cost of ownership curves over 13 years of a diesel school bus, an ESB without financial incentives, and an ESB with a 50% cost reduction for the bus and charging station under the federal ZETF financial incentive. The reduction in incremental capital costs by 50% through the ZETF fund would reduce the breakeven numbers of years from 20.9 years to 4.3 years. In other words, an Alberta operator can reach cost parity with diesel buses after operating electric school buses under similar deployment conditions for around 4.3 years with the federal ZETF financial incentive. On the other hand, an operator would need to operate an ESB for 20.9 years to reach cost parity with a diesel school bus from a TCO perspective without the financial incentive (Green and red lines to intersect in Figure 2). The average lifespan of a school bus is 13 years.

It is however important to note that the cost of financing is not included in the analysis as it is very dependent on the size and financial strength of the fleet operator purchasing the buses. Cost of financing of electric vehicles tends to be higher than diesel vehicles due to the uncertain resale value price of ESBs at this early stage of the transition. Financial lenders are not able to accurately predict the resale value of ESBs in case of default on the loan.[12] In the present early adoption stage, where resale values of ESBs are still undetermined, the implementation of electric vehicle-specific financing programs can play a vital role in facilitating purchases. The Canada Infrastructure Bank provides such financing through its zero-emission buses initiative. [13]

Figure 2: Cumulative Cost of Ownership of each technology over 13 years



Moreover, the TCO and the time needed to recover costs can vary for a larger deployment due to the following factors. The operational expenses of ESBs in larger deployments, from a single yard requiring simultaneous charging, are subject to demand charges that increase operational costs. Additionally, accommodating a larger fleet often necessitates utility upgrades and more expensive higher power charging station infrastructure expenses. These additional expenses will likely extend the breakeven period to a longer timeframe. However, operators could capitalize on existing financial incentives by starting with small deployments and limited infrastructure costs. This approach allows them to train their staff on the new technology and take advantage of the prominent economic benefits achieved by financial incentives while further cost reductions are achieved through the recent significant investments from the industry that will promote economies of scale in ESB manufacturing.

12 Environmental Defense Fund, M.J. Bradley & Associates and Vivid Economics, (2020). Financing the Transition: Unlocking Capital to Electrify Truck and Bus Fleets. Retrieved from: https://www.edf.org/sites/default/files/documents/EDF_Financing_The_Transition.pdf

13 Canada Infrastructure Bank (2021). Investment in British Columbia support purchase of 280 sustainable school buses. Retrieved from: https://cib-bic.ca/en/medias/articles/the-canada-infrastructure-bank-invests-up-to-30-million-in-its-first-zero-emission-school-bus-project/

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2.4 Qualitative considerations for adoption of ESBs

The adoption of ESBs represents a pivotal shift in the transportation landscape.

While the quantitative aspects of ESB adoption are significant drivers, qualitative considerations play a crucial role in shaping the success and acceptance of this transition. Through interviews with fleet operators - from Directors to Maintenance staff - as well as regularly scheduled updates with project staff and interaction with industry associations, the following qualitative aspects impacting future ESB adoption for operators emerged.

2.4.1 External Drivers

Stakeholder Engagement, Community Support, and Education:
Public perception of ESBs can shape their adoption trajectory. Addressing misinformation and misconceptions through targeted educational initiatives, town halls, and sharing current resources will be essential. Schools, districts, and operators should proactively communicate the benefits of ESBs to parents, students, and the broader community. Highlighting real-world success stories, improved air quality, and reduced noise pollution can enhance the perception of ESBs as a positive and responsible choice for student transportation. Additionally, stakeholders should receive information about integrating ESBs into their school systems, aiming to prevent negative backlash and confusion surrounding the timing and locations of bus deployment during the scale-up period.

Student and Parent Experience:
The impact of ESB adoption on the daily experiences of parents and students cannot be overlooked, as these are ultimately clients of the operator by way of the school board in Alberta. Overall, ESBs offer a quieter, emissions-free ride, positively affecting students' well-being. However, potential challenges, such as discomfort from unfamiliar features and smoother acceleration, should be anticipated and addressed. Engaging parents and students in discussions about the daily experience on ESBs can contribute to a more student-centric and accommodating adoption process. To this end, feature-specific feedback from students should be actively communicated with bus manufacturers as they work to develop optimal designs. Examples include uncomfortable seat belt placement and less room between seats due to extra seat padding.

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Standardized Solutions:
Operators note that standardization of bus and charging specifications, whether through regulation or manufacturer initiative, will be crucial to widespread implementation.
One such example is the variance in charging cord lengths, which can pose logistical challenges and place a time and cost burden on the operator.

2.4.2 Internal Organizational Drivers

Change Management:
From the executive level down, internal signals play a pivotal role in the successful integration of ESBs. Operators must shift from exploratory to investment mode in their approach and appoint an empowered champion whose sole focus is integration. Transparent communication is also vital, considering existing viewpoints, and honesty about potential challenges and the process's duration is paramount. Operators should treat the adoption of ESBs as they would any new initiative and develop a robust, long-term strategy for all aspects of operations. This includes succession and contingency planning, so the knowledge and management of the buses live with the organization rather than individuals.

Employee Training, Buy-In and Feedback Loops:
Employees, especially school bus drivers and maintenance staff, are at the forefront of ESB operations. Ensuring their buy-in and addressing potential concerns is paramount, and interviews with leadership emphasized that frontline staff perspectives sometimes outweigh those of executives. Organizations should provide comprehensive, hands-on training programs that ensure inclusive and equitable access, impart technical knowledge, and instill confidence and enthusiasm in working with ESBs. Staff should be equipped with knowledge of bus features, maintenance considerations, contingency plans, and standard verbiage around the bus for external communication.
To achieve buy-in, discussions should be rooted in transparency about the operational hurdles and timeframes for deployment. Providing an open platform for staff to voice their opinions, concerns, and ideas and offering anonymous feedback options fosters a sense of ownership and involvement, ultimately leading to smoother adoption.

Driver Satisfaction:
The transition to ESBs introduces features that could improve driver comfort, including reduced noise, vibrations, and fumes, as well as notably smoother acceleration.
These observations were supported during multiple driver interviews, where the consensus was that the electric bus provided a superior driving experience compared to diesel buses. Moreover, the ESB is a source of pride for the drivers, as they recognize their organization's progress towards a net-zero future. As a result, it is crucial to guarantee fair access to training opportunities and the allocation of responsibilities, focusing on involving HR and applying an internal equity perspective.

Nevertheless, the drivers also noted a major inconvenience with the ESB. It is common practice in the school bus industry for drivers to keep the bus with them throughout the day and only return it to the yard after their afternoon run. However, on most routes, the bus was required to return to the yard to be charged between the morning and afternoon runs to ensure enough range. These logistical changes might, in turn, have a detrimental effect on driver satisfaction. An alternative solution for certain routes would involve implementing an auxiliary diesel heater, extending the vehicle's range and eliminating the need for midday charging.

More research is needed to determine the overall impact of a transition to ESBs on driver satisfaction. Should this transition overall have a positive impact, this could provide benefits to operators.

2.5 Key Findings from the Business Case

- In the Alberta context, the TCO for an ESB over a 13-year period is 19% higher than that of a diesel school bus. However, when factoring in the federal financial incentives aimed at capital costs, the TCO of an ESB is 21% lower compared to a diesel school bus.

- The business case for ESBs entails higher upfront costs offset by operational savings throughout the vehicle's lifetime. Financing programs are crucial in enabling fleet operators to overcome the initial higher capital cost of ESBs, particularly in the initial stages of the ESB transition, where financial lenders charge higher interest rates for ESBs relative to diesel school buses due to the uncertain resale value of the vehicle in case of a fleet operator default.

- The economics of ESBs varies based on the size of a deployment. Operators could take advantage of the limited infrastructure cost requirements of small deployments to start training the staff on the technology in advance of further cost reductions expected in the sector through the recent significant investments from the industry that will promote economies of scale in ESB manufacturing.

- Regulatory and technological barriers to potential revenue sources such as V2G should be explored further in the Alberta context.

- While the quantitative aspects of ESB adoption are significant drivers, qualitative considerations play a crucial role in shaping the success and acceptance of this transition. These include stakeholder engagement, community support, and education in shaping ESB perception. Internally, successful ESB integration relies on organizational change management, buy-in, and employee training. Additionally, improving driver satisfaction through comfort, features, and charging logistics requires ongoing research to assess the overall impact of ESB adoption on the people involved.

The Technical Report

3.1 Introduction

The following technical report presents the operational lessons learned and the results of the data analysis conducted based on the energy consumption monitoring of the ESB and associated charger.

The analysis explores the performance of the ESB under different operating conditions, including the impact of outside temperature and regenerative braking. The energy consumption of trips completed by the ESB is evaluated based on a measure of efficiency called energy intensity. Energy intensity, expressed in kilowatt-hours per kilometer (kWh/km), refers to the amount of electrical energy consumed by an ESB to travel one kilometer. It is a measure of the efficiency of the vehicle's energy usage and represents the energy required to move the bus a specific distance. Lower energy intensity values indicate higher efficiency, meaning the bus can travel longer distances using the same amount of energy.

This report's findings are crucial for fleet operators as they help identify viable routes in their fleet for electrification, particularly during winter conditions. Moreover, the results assist in determining whether specific routes require ESBs with a larger battery, leveraging the availability of multiple battery sizes by some manufacturers. Reliable estimates of yearly energy consumption from charging and required battery capacity for ESBs are also essential elements to consider in the financial assessments related to deploying ESBs.

3

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3.2 Deployment planning

3.2.1 Vehicle and Charging Station Specifications

The project was launched in September 2022 in partnership with local fleet operator Southland. A 2022 model-year Blue Bird ESB with a battery capacity of 155 kWh was leased to operate until June 2023. The ESB was fitted with air brakes, a braking system more commonly found in electric vehicles due to their higher weight compared to diesel vehicles. Drivers need to undergo a one-day training to obtain certification for operating air brake-equipped vehicles.

Multiple charging station models were considered for the demonstration, focusing on level 2 AC chargers to limit installation costs. Following discussions with various EVSE providers, a level 2 19 kW Nuvve PowerPort station was selected. [14] The vehicle and charger specifications are presented in **Table 1**.

Table 1: Vehicle and charger specifications

Procurement Item	Specifications	Standards and codes
Blue Bird Vision Electric	Type C, Up to 77 passengers, 155 kWh NMC battery[3]	Level II (AC) - J1772 & Level III (DC) – CCS-Combo
Nuvve charging stations	19 kW level 2 (1 Phase)[4]	J1772

3.2.2 Deployment and Maintenance

The first step of the demonstration consisted of the selection and installation of the charging station and vehicle telematics equipment. The charging station was shipped to the yard and installed by a local technician. A DataHub vehicle telematics device from ChargePoint was selected to install on the ESB and shipped to the yard. [15]

The installation of the telematics device required an electrical technician to be contracted to conduct the installation. ESB manufacturers do not all have direct partnerships with telematics device providers, which results in the bus models not always having easily accessible ports to connect with energy consumption monitoring devices. However, partnerships are quickly evolving in the industry, with certain OEMs launching telematics monitoring software services.

Following the installation of the charging station hardware, software, and vehicle telematics, data collection covered the period of December 7, 2022, to June 28, 2023, with a number of interruptions to operations resulting in bus downtime. Table 2 presents the maintenance and weather-related incidents that resulted in bus downtime. Vehicle malfunction events included the 12V battery of the bus having to be replaced and two coolant-related issues. The vehicle also had a one-day downtime because of the charger's unplugging handle being frozen.

14 Multiple EVSE providers had lead times of above 6 weeks, highlighting some of the supply chain issues and high demand in the industry during that period.
15 ChargePoint (2023). Telematics. ChargePoint Hardware. Retrieved from: https://www.chargepoint.com/fleet/telematics

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3.3 Evaluation of bus operations

3.3.1 Importance of ESB energy consumption monitoring

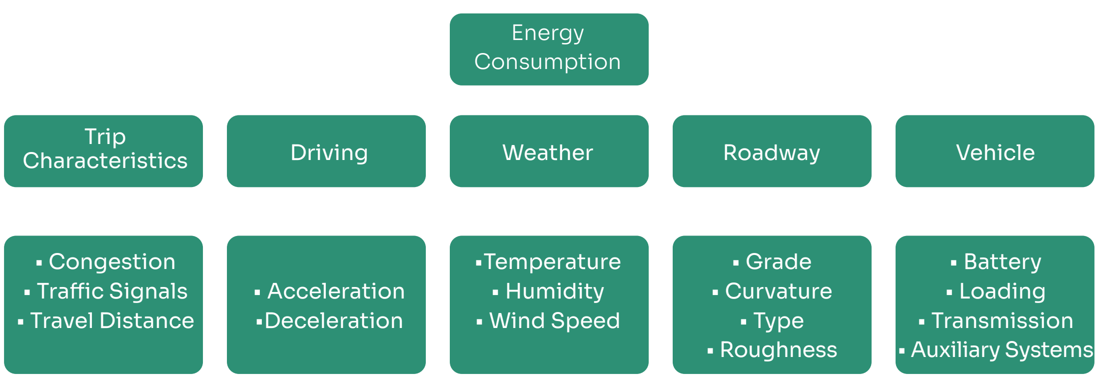
Several studies have investigated how driving behaviour affects fuel consumption in diesel buses, and some fleet operators utilize real-time telematics to optimize driving behaviour to reduce fuel usage.

Similarly, ESBs exhibit variations in energy consumption based on driving conditions, but these fluctuations tend to be more significant than those in diesel technology. The energy consumption fluctuations in ESBs primarily stem from two factors. Firstly, the electrical HVAC (Heating, Ventilation, and Air Conditioning) systems consume higher power compared to traditional internal combustion engines, particularly in winter when they cannot benefit from the excess heat generated by an internal combustion engine. Secondly, regenerative braking technology enables ESBs to recover energy under certain driving conditions, further impacting energy consumption patterns.

Furthermore, different battery chemistries entail trade-offs in cost, range, charging speed, longevity, safety, and performance.[16] Over the next decade, considerable investments in battery manufacturing are anticipated to lead to diverse battery chemistries in the market, each offering different performance characteristics.

In this context, a better understanding of the energy consumption of ESBs using real-time monitoring is of greater importance with this new technology for both fleet routing planning and right sizing. Gaining a deeper insight into the range of ESBs helps alleviate fleet operators' range anxiety. This also enables them to avoid purchasing an ESB with a larger, more expensive battery than what is actually required for their operations, thus enhancing the economics of ESBs. Presented in Figure 3 are some of the factors that impact the energy consumption of ESBs.[17] This report explores how some of these factors affect the range of ESBs.

Figure 3: Factors that impact ESB energy consumption



16 National Academies of Sciences, Engineering, and Medicine (2020). Reducing Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report. Washington, DC: The National Academies Press. https://doi.org/10.17226/25542.

17 ICCT (2023). Operational analysis of battery electric buses in Sao Paulo. Retrieved from: https://theicct.org/publication/brazil-hvs-zebra-operational-analysis-electric-bus-sao-paulo-feb23/

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3.3.2 Routes and data sample size

A total of 81 runs were conducted between December 7, 2022 and June 28, 2023. The ESB was operated on three different routes presented in **Figure 4**.

Figure 4: Routes evaluated during demonstration

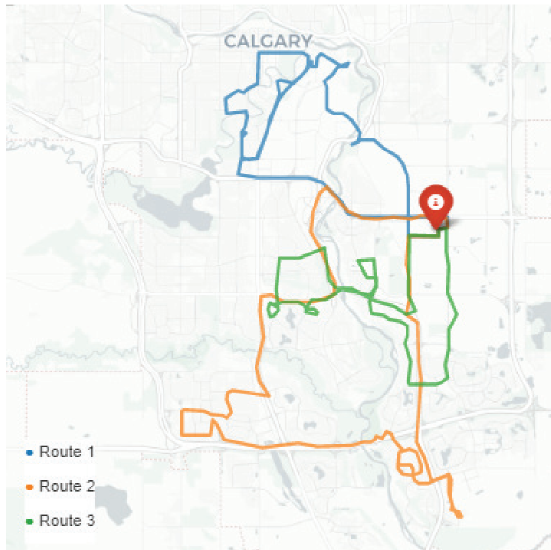

Table 3 presents the total number of runs conducted on each route, along with the average distance and speed of the runs. The number of runs is limited relative to the number of days of operations in the school year due to logistical challenges that had to be overcome. Additionally, the project team faced delays during the demonstration whenever the ESB was handed over to a new driver, as each driver needed to complete the air brake training.

Table 3: Characteristics of ESB routes evaluated

Routes	Number of runs	Average distance (km) [min,max]	Average Speed (km/hr) [min,max]
1	13	54 [47,59]	28 [26,31]
2	8	61 [60,62]	42 [39,45]
3	60	41 [34,51]	37 [32,41]
Total	81	45 [34,62]	36 [26,45]

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During the initial stages of the demonstration in winter conditions, the bus was only sporadically operated during either the morning or afternoon run to evaluate its range capabilities. The operation of the bus in cold weather showed high energy consumption mainly due to the energy intensive electrical heating system and the ESB was only able to complete a single run (morning or afternoon) on a single charge. The bus was required to return to the yard to be charged in between the morning and afternoon run to ensure enough range. However, it is common practice in the school bus industry for drivers to keep the bus with them throughout the day and only return it to the yard after their afternoon run. Drivers expressed some dissatisfaction with these logistical changes that were required, and delays were incurred to allocate the ESB to drivers that could return to the yard in between the morning and afternoon runs.

Over the course of the demonstration, operational staff from Southland, in partnership with the project team, gradually tested the use of an auxiliary diesel heater instead of the electrical heating system of the bus to improve the ESB range. Pre-heating of the bus in the morning while it was still plugged into the charger was also added to the operational practices to limit the usage of the electrical heating system during operations. During these tests, the bus system was operated solely with an auxiliary diesel heater, without using the bus electrical heating system, in temperatures ranging from -5°C to 5°C. However, it was observed that the diesel heater alone was inadequate to maintain the internal bus temperature at outside temperatures lower than -5°C without the assistance of the bus electrical heating system.[18] The impact of these tests on the energy intensity of the bus is presented in the following sections.

3.3.3 Energy consumption and role of regenerative braking

Figure 5 presents the energy intensity of the bus in kWh/km and associated bus range on a single charge based on the 155-kWh battery on each of the dates in which the ESB was operated between December 2022 and June 2023. Throughout the length of the demonstration, a minimum and maximum energy intensity of 0.67 kWh/km and 1.31 kWh/km respectively were observed. In other words, the range of the ESB on a single charge varied from 73 km to 213 km depending on the operating conditions of the ESB.

A high energy intensity is observed in the winter months of operations followed by varying energy intensity between February and April as HVAC usage varied depending on daily temperature. The energy intensity of the bus subsequently decreased from April to June 2023 as temperatures increased. The energy consumption of an ESB can be impacted by the ambient temperature due to the usage of the electrical HVAC system for heating or cooling, as well as a variation in the performance of the battery itself depending on its chemistry.

18 This finding is based on the size of the diesel heater available in this project. A larger diesel heater could allow ESB operation by entirely relying on a diesel heater without using the electrical heating system for heating at lower temperatures.

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Figure 5: Energy intensity of trips and range implications across days of operations

Table 4 presents the average energy intensity and associated vehicle range on a single charge based on the 155-kWh battery for each of the months in which the ESB was operated. The range of the ESB on a single charge gradually increases from December to June in parallel to warming temperatures. Fleet operators should consider addressing these range variations either by utilizing auxiliary systems (such as diesel heaters) to limit them or by factoring them into their route planning and ESB charging strategies during deployment.

Table 4: Average energy intensity and range by month

Month	Average Energy Intensity (kWh/km)	Average Single Charge Range (km)
December	1.25	83
January	1.14	93
February	0.99	114
April	0.83	156
May	0.75	189
June	0.75	189

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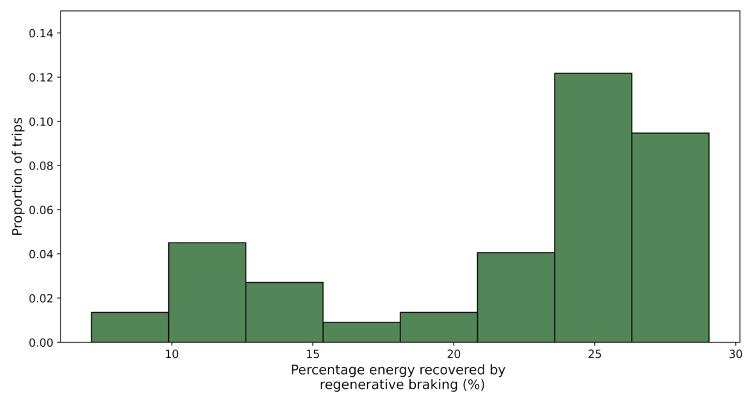
Figure 6 presents the percentage of total energy consumption recovered with regenerative braking for all runs conducted throughout the demonstration. An average proportion of 22% of total energy consumed was recovered through regenerative braking across all runs, with a minimum of 7% and a maximum of 29%.

Regenerative braking energy recovered varies based on the characteristics of a route and the driving behavior of individual drivers. The number of runs conducted on Routes 1 and 2 as part of this demonstration were significantly lower than Route 3, making a comparison across routes not statistically significant. However, the limited observations show that Route 3 had a significantly higher proportion of energy recovered through regenerative braking. Further exploration on the conditions in which the proportion of energy recovered with regenerative braking increases is needed. School bus operators should explore driver training programs that generate useful data and maximize regenerative braking to improve vehicle range and reduce charging costs.

Figure 6: Proportion of energy recovered through regenerative braking across trips



3.3.4 Impact of temperature on energy intensity

As mentioned earlier, the energy consumption of an ESB can be impacted by the ambient temperature due to the usage of the electrical HVAC system for heating or cooling, as well as a variation in the performance of the battery itself, depending on its chemistry.

Figure 7 presents the energy intensity of runs conducted relative to the outside temperature on the day of each trip, distinguishing between runs conducted with the electrical heating system turned on and off. Trips conducted in winter conditions at less than -10°C with the electrical heating system on had an average intensity of 1.18 kWh/km, which translates to a range of 95 km on a single charge based on the 155-kWh battery size.

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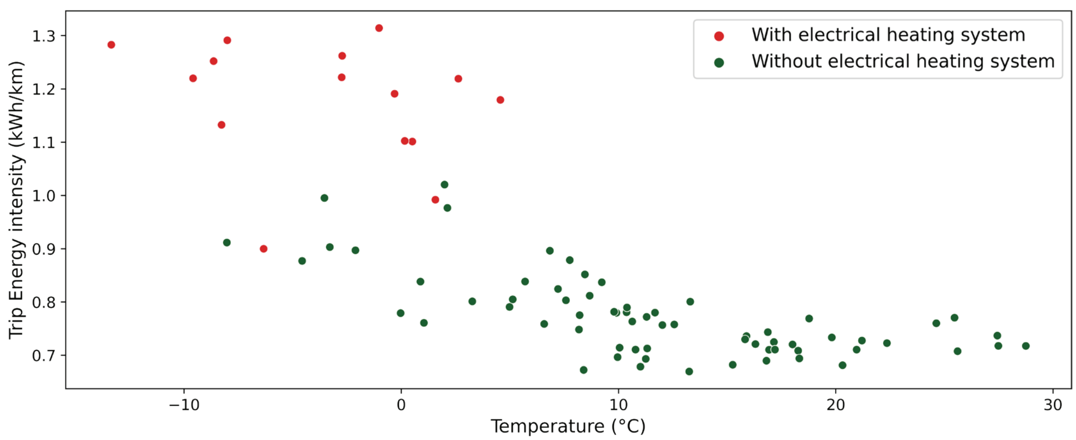
Between -5°C and 5°C, Southland staff were able to test operations with and without the electrical heating system by relying on an auxiliary diesel heater as well as pre-heating of the bus prior to the start of a run while plugged into the charger. These tests showed that operations in winter conditions with the electrical heating system active increased the energy intensity of trips by an average of 33%, thereby reducing vehicle range. [19]

At a temperature of 10°C and above, the energy intensity of the bus decreases to reach an average of 0.73 kWh/km, which translates to a range of 210 km based on the 155-kWh battery size. It is in these 'optimal' conditions that the ESB can reach the highest ranges advertised by manufacturers.

Figure 7: Impact of HVAC electrical system and outside temperature on trip energy intensity



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3.3.5 Charger energy consumption

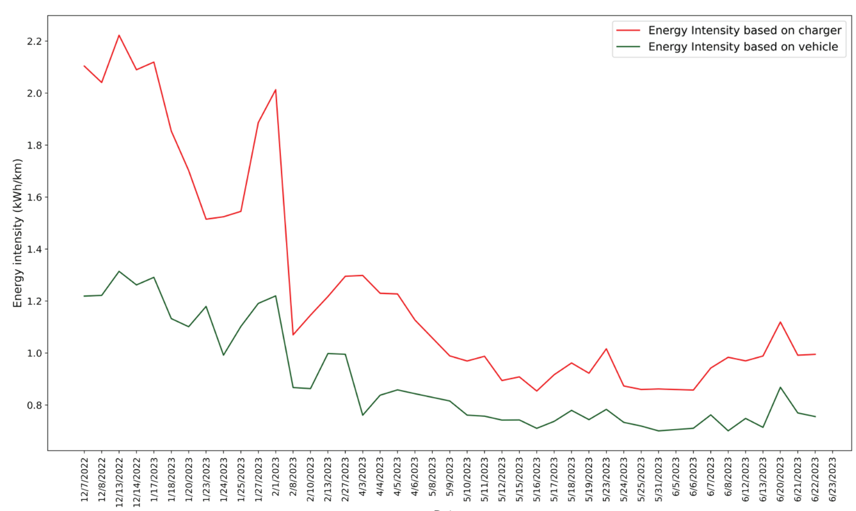
The ESB was charged daily in between runs or after the afternoon run. The charging power was consistent at 12.5 kW, lower than the 19.2 kW the Nuvve charger is capable of. This difference is likely due to the ESB hardware that does not allow AC charging above 12.5 kW. Under a 12.5 kW charging speed, the ESB can be fully charged in 11-12 hours. Developments are taking place in the manufacturing realm of ESBs to enhance the charging power capacity of newly developed ESB models.

Charging stations require energy to power their own operations and experience energy losses during the charging process when supplying energy to the vehicles. Consequently, the charger's daily energy consumption tends to be higher compared to the energy consumed by the ESB during operations.[20] Additionally, in cold weather conditions, ESBs consume energy and require charging while parked to ensure that the battery management system keeps the battery at an optimal temperature for starting. This precaution is taken because extreme cold can affect battery performance and reduce its ability to provide sufficient power for the bus to start and operate effectively. Lastly, pre-heating the bus prior to a run while the vehicle is still plugged into the charger results in energy consumption that is not accounted for when looking exclusively at operational energy consumption of the ESB.

Figure 8 presents the energy intensity in kWh/km based on the charger and the ESB for each of the dates of operations for which data was available for extraction from the charger software. The energy intensity based on the charger is calculated by dividing the total energy consumption of the charger on that day by the total distance travelled by the ESB. The energy intensity based on the vehicle is calculated by dividing the total energy consumption of the bus during operations on that day by the total distance travelled by the ESB.

The energy intensity based on the charger is found to be on average 41% higher than the one based on the vehicle. This additional energy consumption can be attributed to bus pre-heating while it is plugged into the charger prior to runs, top-up energy consumption to maintain adequate battery temperature, energy losses during charging, and energy consumed to power the charger hardware.

Figure 8: Net Energy Used for charging relative to energy consumed by vehicle on days of operation



20 Vermont Energy Investment Corportation (2018). Electric School Bus Pilot Project Evaluation. Retrieved from: https://www.mass.gov/doc/mass-doer-electric-school-bus-pilot-project-evaluation/download

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In winter months, the disparity between the energy intensity of the charger and the vehicle is at its greatest due to vehicle pre-heating and battery temperature preservation heating. However, this gap decreases significantly during warmer months, accounting for only energy losses during charging and the energy consumed to power the charger hardware (Table 5).

Table 5: Average energy intensity based on vehicle and charger by month

Month	Energy intensity based on ESB (kWh/km)	Energy intensity based on charger (kWh/km)	Percent increase (%)
December	1.25	2.11	69
January	1.14	1.74	52
February	0.99	1.35	36
April	0.83	1.22	48
May	0.75	0.92	24
June	0.75	0.98	30

3.4 Lessons Learned

- The range of the ESB on a single charge varied from 73 km to 213 km based on the 155-kWh battery depending on the operating conditions across 81 runs conducted between December 2022 and June 2023. The range of the ESB on a single charge gradually increases from December to June in parallel to warming temperatures. School bus operators can increase their range in winter conditions by installing an auxiliary diesel heater and not relying on electrical heating, which consumes a significant amount of energy.

- Regenerative braking reduces energy intensity by an average of 22%, improving vehicle range. School bus operators should explore driver training programs that generate useful data and maximize regenerative braking to improve vehicle range and reduce charging costs.

- In winter conditions, the use of the bus electrical heating system increases energy intensity by an average of 33%, decreasing vehicle range. Fleet operators should explore bus pre-heating in advance of runs and logistical planning for mid-day charging between runs to ensure sufficient range capabilities on certain routes.

- Energy transfer losses and energy consumption while plugged into the charger increases the energy intensity of ESBs by an average of 41% relative to the energy intensity estimated based on the energy consumption of the bus only while in operation. This increase is more pronounced during winter conditions and relatively smaller during warmer months. ESB manufacturers are continuously improving their battery management systems to minimize this disparity.

Transitioning with Equity

4

It is crucial to consider social equity in the transition from diesel to electric school buses.

As with many aspects of the energy transition, there is enormous potential to advance our collective understanding of the adverse consequences of new technology and ensure that implementation includes a strong effort to negate these consequences.

ESBs inherently bring equity benefits. Students who rely on school buses face greater exposure to air and noise pollutants from diesel buses, especially those in high-density or low-income areas, compared to students driven to school in single-family vehicles. Adopting ESBs can ensure that all children can access safe, dependable, and environmentally friendly transportation options, ultimately advancing educational equity. However, a significant challenge lies in establishing fair prioritization strategies tailored to local contexts, particularly during the initial adoption phase.

4 Transitioning with equity

ESBs intersect with equity in the following areas:

- Geographic and demographic considerations regarding location, route choice, and scheduling of buses
- Electric utility infrastructure and access to supportive grid technology
- Funding and financing disparity
- Quality and availability of jobs and training, including areas such as manufacturing, maintenance, management, and support jobs
- Ability equity and health equity - Accessibility and inclusive design are critical components of this effort; this includes considerations related to lighting and sound, both inside and outside the bus, and service provision to those with different abilities.

This project set the stage for an evolving Social Equity Framework that can be used in a localized context to ensure that future demonstrations and scale-up efforts include a social equity lens. Several questions emerged that should be asked in developing a tailored equity framework:

- How are we defining equity in relation to the adoption of ESBs?
- Who stands to gain the most from adopting ESBs, and who is most at risk if they are not adopted?
- Are there any groups or individuals who might experience negative impacts due to this project?
- Are there any local organizations that can help us identify all potential stakeholders impacted by this project to ensure that all voices are heard?
- Are there communities that are connected to polluting energy sources in ways that make them more vulnerable to the negative effects of diesel emissions?
- How can this project build upon existing efforts to expand the concept of energy poverty to include transportation-related energy costs?
- What criteria should be used to prioritize regions and routes for early ESB adoption, considering health impacts, air quality, idling time, average family household income, and energy poverty?
- Are there communities with naturally shorter bus routes that could help address concerns about range, charging infrastructure, and parking/staging?
- Can certain communities access additional funding to support the purchase of ESBs and the required infrastructure?

4 Transitioning with equity

The Canadian Electric School Bus Alliance[21], the Victoria Transport Policy Institute[22], and the Electric School Bus Initiative[23] have placed focus on equity in their work, and these resources provide a strong starting point for incorporating social and environmental equity into individual projects and implementation organizations. Through research and stakeholder engagement, the following recommendations emerged:

- Recognize that organizations may have varying priorities and degrees of interaction with groups impacted by inequity, and outlining the project's approach to encompassing this work inherently identifies opportunities. Collaborate with community organizations that serve equity-deserving groups, such as the United Way, newcomers associations, friendship centers, and school boards engaging with marginalized communities. Actively engage in ongoing dialogues regarding equity, seeking insights into how these organizations define, assess, and address equity

- Support transparent and inclusive processes that value and center the voices and needs of community-based stakeholders, partners, and rights-holders in decision-making. A strong example noted by the Canadian Electric School Bus Alliance alludes to upholding Indigenous rights to self-determination and the choice to adopt ESBs.

- Collect and leverage data to uncover existing power, cost, and opportunity imbalances. Data and information from municipalities and governments can help understand shifts in poverty, infrastructure, and funding, but also many tools are in development to assist in understanding how imbalances are represented in our country. The Canadian Urban Sustainability Practitioners present an example in the form of an energy poverty mapping tool.[24]

- Seek out organizations or funding entities that offer training programs to improve skills and expertise related to the maintenance and repair of electric school buses. This would serve to advance equity within the realms of operations, maintenance, and manufacturing.

- Develop a monitoring and evaluation plan that includes feedback from affected groups, recognizing the power of sustaining conversations on this topic and the importance of accountability. This could involve a working group within an organization to regularly revisit data, contact stakeholders, or research emerging equity awareness trends.

This report underscores the importance of addressing equity considerations at every project stage, emphasizing that even seemingly small conversations about equity are crucial. ESBs present an opportunity for promoting a just and equitable energy transition, but a localized approach and a comprehensive social equity framework are necessary to address adoption challenges and disparities. This project has laid the foundation for such a framework. It calls for collaboration with community organizations, transparent decision-making, data-driven assessments, and training programs to enhance equity within ESB operations. Ultimately, ESB adoption should not only reduce emissions but also promote fairness and inclusivity in the communities they serve.

21 Canadian Electric School Bus Alliance (2023). Addressing inequities in the transition from diesel to electric. Retrieved from:https://eschoolbusalliance.ca/bringing-environmental-justice-to-electric-school-buses-rollout/

22 Victoria Transport Policy Institute (2023). Evaluating Transportation Equity. Retrieved from: https://www.vtpi.org/equity.pdf

23 Electric School Bus Initiative (2023). Evidence. Retrieved from: https://electricschoolbusinitiative.org/evidence

24 Canadian Urban Sustainability Practioners (2023). Energy Poverty and Equity Explorer. Retrieved from: https://energypoverty.ca/mappingtool

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