Electric School Bus Demonstration:

An Edmonton Case Study

Funders:

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Implementing Partners:

Pollution Probe

Mobility Futures Lab

RFS ENERGY

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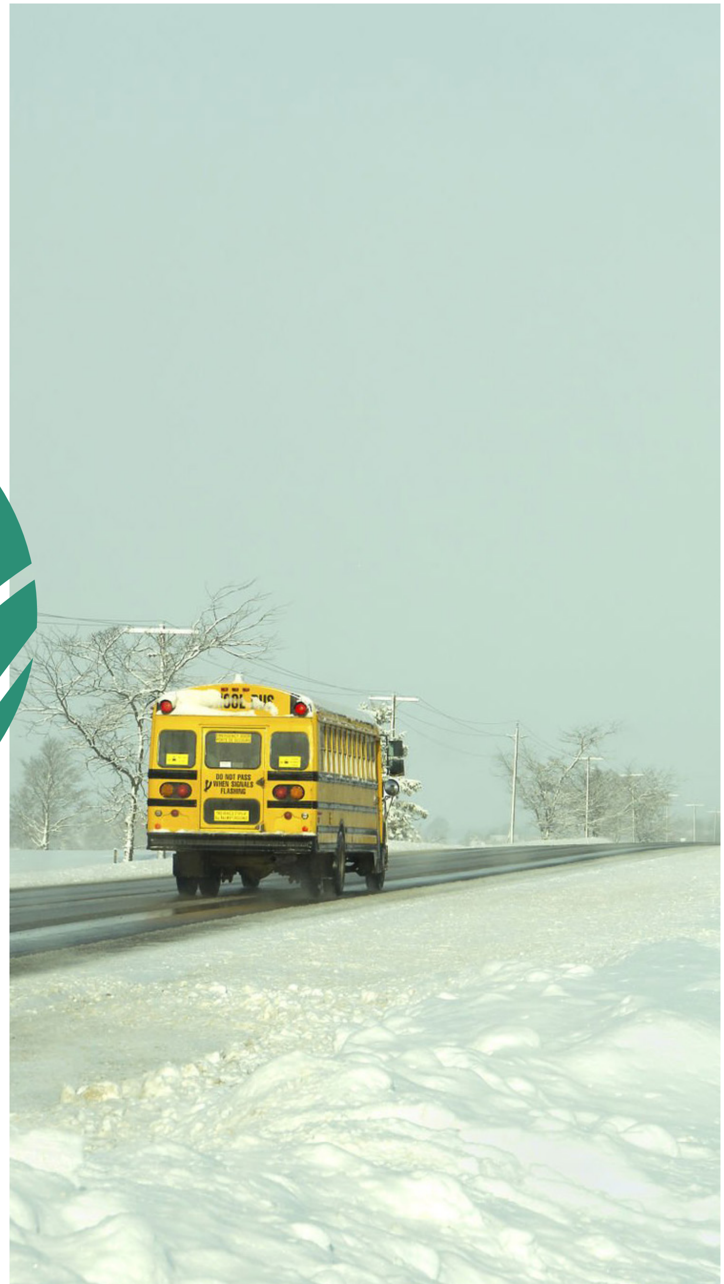

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About Partners

Pollution Probe

Pollution Probe is a Canadian charitable environmental organization founded in September 1969 by University of Toronto students and professors. Over the past 5 decades, Pollution Probe has been at the forefront of progress on a range of environmental issues. Progress on many of these issues took decades of hard work to achieve. We pursue environmental gains by working productively with governments, industry and the public, with a steadfast commitment to Clean Air, Clean Water, and a Healthy Planet. We engage people as thinkers to nurture and act on areas of consensus. Our niche in the environmental movement lies in our systems approach, which embraces three principal drivers for progress: Technology and Innovation; Rulemaking; Behavioural Change.

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.

Executive Summary

As school boards and governments transition toward zero-emission transportation, electric school buses (ESBs) offer a promising way to reduce greenhouse gas (GHG) emissions, improve air quality for children, and meet environmental and public health goals. However, concerns remain about their performance and energy efficiency in cold-weather climates.

PHOTO: PARKERDEEN/GETTY IMAGES

To address these questions, Pollution Probe, in partnership with Mobility Futures Lab and RFS Energy, conducted a real-world demonstration project in Edmonton, Alberta. The project evaluated the year-round operational performance of a Lion Electric Type C ESB equipped with a 126-kWh battery and supported by a 19.2 kW Level 2 AC charger. Unlike a previous demonstration in Calgary that relied solely on battery-powered heating, this demonstration followed industry practice by using an auxiliary diesel heater for cabin heating. This approach allowed us to assess how a more typical configuration performs in cold-weather conditions and to compare results with the Calgary trial to better understand the operational trade-offs between different heating strategies.

Data collected over 298 trips between April 2024 and April 2025 show that the ESB operated reliably across seasons. As expected, during the core school months, energy intensity[1] increased moderately—by approximately 12%—between fall and winter (0.73 to 0.82 kWh/km). Comparing the best and worst observed days, energy use increased by 58%—from 0.62 to 0.98 kWh/km—as temperatures dropped to -30°C. Despite these seasonal fluctuations, the ESB generally maintained more than double the range needed for its daily school route. Regenerative braking recovered an average of 20% of energy across all trips, and charging remained stable, with only a minor performance dip (~10%) in extreme cold.

A comparative emissions analysis was conducted through simulation for three types of school buses: a diesel bus with a diesel heater, an electric bus with a diesel heater, and an electric bus with an electric heater. These scenarios were modeled using real-world telematics data from demonstrations to estimate energy use and emissions under each configuration. Results indicate that switching

1 The energy intensity of ESBs is measured in kilowatt-hours per kilometre (kWh/km), unlike diesel buses, which use litres per 100 kilometres (L/100 km). This metric reflects the amount of energy required to travel one kilometre and is a key factor in determining vehicle range.

Executive summary

from diesel to electric reduced annual GHG emissions by approximately 28–38% and nitrogen oxide (NO_x) emissions—pollutants directly linked to health impacts—by about 40–49%, based on Alberta's current electricity generation mix (81% natural gas, 19% renewables). Under current grid conditions, fully electric heating offered the greatest emissions reductions. However, using an auxiliary diesel heater still delivered substantial emissions benefits over diesel buses, while offering reliable winter performance. Crucially, only the fully electric heater configuration completely eliminates localized emissions released near schools and inside the bus cabin, making it the most beneficial long-term option for improving air quality around children.

The findings from this demonstration confirm that ESBs can reliably meet operational requirements in Canadian winter conditions with appropriate strategies in place. While transitional solutions like auxiliary diesel heaters remain practical short-term options, ongoing improvements in battery and thermal management technologies will further reduce reliance on diesel heating systems. As electricity grids become cleaner, prioritizing the full electrification of both propulsion and heating will maximize the environmental and public health benefits of transitioning to ESBs.

Acronym List

Acronym	Definition
AC	Alternating Current
AMTA	Alberta Motor Transportation Association
BMS	Battery Management System
CASA	Clean Air Strategic Alliance
CCS	Combined Charging System
CO_2e	Carbon Dioxide Equivalent
DC	Direct Current
EF	Emission Factor
ESB	Electric School Bus
GHG	Greenhouse Gas
km	Kilometre

Acronym	Definition
kWh	Kilowatt-hour
L	Litre
MFL	Mobility Futures Lab
NO_x	Nitrogen Oxides
NRCan	Natural Resources Canada
OEM	Original Equipment Manufacturer
$PM_{2.5}$	Fine Particulate Matter (diameter ≤2.5 microns)
RBL	Rental Bus Lines
SOC	State of Charge
ZETF	Zero Emission Transit Fund

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Clean Air • Clean Water • Healthy Planet

PHOTO: SHAUNL/GETTY IMAGES

Introduction

School buses play a critical role in student transportation, with millions of children relying on them daily. Traditionally, diesel-powered school buses have been the norm, but they contribute to greenhouse gas (GHG) emissions and air pollution, which have well-documented health impacts, particularly on children. As concerns over air quality and climate change grow, electric school buses (ESBs) are emerging as a cleaner alternative.

Recent advancements in battery technology and significant cost reductions over the past decade have made ESBs increasingly viable. Many jurisdictions are now integrating them into their fleets, in some cases moving beyond the early adoption phase. However, despite rapid technological progress, concerns remain, particularly regarding performance in extreme winter conditions, where cold temperatures can impact battery range.

To address these concerns, Pollution Probe, in partnership with Mobility Futures Lab and RFS Energy, has conducted a series of demonstration projects evaluating ESBs under real-world extreme winter conditions. A 2023 demonstration in Calgary tested a first-generation electric school bus without an auxiliary diesel heater, relying entirely on the battery for both propulsion and cabin heating. As temperatures dropped, energy consumption increased substantially, highlighting the impact of cold weather and heating loads on vehicle efficiency.

This second demonstration, conducted in Edmonton and presented in this report, assessed performance under typical fleet operating conditions using an auxiliary diesel heater for cabin heating. This approach reduced the battery's energy burden and resulted in a more moderate increase in energy consumption during cold weather. While the use of a diesel heater introduces some emissions, it reflects common fleet practices (including diesel buses) and offers a practical strategy to support ESB deployment in cold climates while battery technology improves further.

PHOTO: WILLOWPIX/GETTY IMAGES

1 Introduction

This report presents the results of the Edmonton demonstration project, which monitored the operational performance of an ESB from April 2024 to April 2025. The project involved installing telematics equipment on an ESB to collect energy consumption data between April 16, 2024, and April 11, 2025. We outline the deployment characteristics of the bus and analyze its performance under different operating conditions, including the impact of outside temperature and regenerative braking. Finally, we compare emissions from a diesel bus with diesel heater, an electric bus with an electric heater, and an electric bus equipped with a diesel heater through simulation. This comparison helps illustrate the emissions implications of retaining diesel-based cabin heating during electrification versus fully electrifying both propulsion and heating systems from the outset.

The findings from this study help policymakers and fleet operators assess the real-world viability of electric school buses, particularly in cold climates. Policymakers can use these insights to shape incentives and regulations that support ESB adoption, while fleet operators can make informed decisions on deployment, charging, and route planning. By addressing performance concerns, this report provides practical guidance for a smoother transition to cleaner student transportation.

Deployment and Operator Experience

2.1 Vehicle and Charging Infrastructure

The project team partnered with a local school bus operator in Edmonton, Rental Bus Lines (RBL), which has operated an ESB since 2018, the first operator in Alberta to do so. Over time, the original bus was gradually upgraded by the manufacturer, resulting in the deployment of a 2022 Lion Electric Type C ESB with a 126-kWh battery, the smallest capacity option currently offered by the manufacturer.

The bus was charged using a depot-based, 19.2 kW Level 2 AC charger, which provides a low-cost, reliable charging solution suitable for applications where the vehicle remains parked between trips. This charger avoided the higher costs associated with DC fast charging solutions while still reliably meeting operational needs during the demonstration.

The vehicle and charger specifications are presented in **Table 1**.

Table 1: Vehicle and charger specifications

Procurement Item	Specifications	Standards and codes
Lion Electric	Type C, Up to 77 passengers, 126 kWh NMC battery	Level II (AC) - J1772 & Level III (DC) – CCS-Combo
Leviton	19.2 kW level 2 charger	J1772

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2 Deployment and Operator Experience

2.2 Vehicle Performance and Maintenance Events

The demonstration involved monitoring the ESB's performance between April 16, 2024, and April 11, 2025. During this period, two incidents resulted in temporary bus downtime, detailed in **Table 2**. Despite these incidents, the operator described the ESB as the "most reliable bus" in their fleet, highlighting strong satisfaction with its overall performance.

Table 2 summarizes these incidents, including the nature of the issue, the date of occurrence, the duration of downtime, and whether dealership servicing was required. These interruptions offer insight into potential maintenance considerations for ESBs in real-world operations.

Table 2: Demonstration maintenance events

Issue	Failure Date	Downtime	Required Dealership Servicing
Charger wiring failure	May 2024	3 weeks	No
ESB hit by lightning	August 2024	2 weeks	Yes

The operator, with extensive experience managing an ESB, emphasized the significant advantage of remote software updates provided by the original equipment manufacturer (OEM), enabling quick resolution of issues without extensive downtime or frequent dealership visits. They also noted that the manufacturer was highly responsive in addressing any technical issues during the demonstration.

2 Deployment and Operator Experience

2.3 Scaling, Funding, and Community Engagement

Awareness and Community Engagement

Rental Bus Lines has leveraged their early ESB experience to significantly boost community awareness and knowledge about ESBs in Alberta. As one of the region's first ESB operators, RBL regularly participates in community events, including the Edmonton Motor Show, Alberta Motor Transportation Association Expo, and various local parades. This proactive community engagement has supported peer learning, raised the profile of ESB technology, and encouraged broader industry awareness and buy-in.

Financial Considerations and Barriers to Scaling

Drawing from their pilot experience, RBL recently pursued expansion of their ESB fleet through funding from the federal Zero Emission Transit Fund (ZETF).[2] However, they reported significant challenges related to funding uncertainties, including unclear application timelines and delays in funding decisions. These issues have hampered their infrastructure investments and forced interim diesel bus purchases to maintain operational capacity.

According to the operator, prolonged uncertainty has had tangible operational and financial impacts, affecting their ability to engage in effective long-term planning (5–10 years). Traditional financing institutions have also been hesitant to support ESB investments, primarily due to difficulty estimating residual value for the new technology, creating additional financial barriers.

The operator emphasized the importance of clearer federal funding processes to support timely and effective scaling of ESBs. Specifically, RBL recommended that future funding programs consider adopting a tiered structure, with initial stages offering faster, simpler access to funding for early-stage deployments, followed by more rigorous but clearly defined pathways for larger-scale expansions. This scaling process should also consider equity considerations of deployments.[3]

As summarized by the operator:

"We [fleet operators] have a legit plan to make this work and we hear nothing, so we'll need to readjust how we do business. We can't buy 50 ESBs on our own, but we could totally buy 50 diesel buses."

2 Government of Canada (2025). Zero Emission Transit Fund. Retrieved from : https://housing-infrastructure.canada.ca/zero-emissions-trans-zero-emissions/index-eng.html

3 Pollution Probe. (2023). Electric School Bus Operational Assessment: A Calgary Demonstration Case Study. Retrieved from: https://www.pollutionprobe.org/wp-content/uploads/2024/05/Pollution-Probe-Calgary-School-Bus-Report_Scotiabank-Research.pdf

Energy Performance and Driving Conditions

3.1 Factors Influencing Energy Consumption

The energy efficiency of ESBs is measured in kilowatt-hours per kilometre (kWh/km), unlike diesel buses, which use litres per 100 kilometres (L/100 km). This metric reflects the amount of energy required to travel one kilometre and is a key factor in determining vehicle range.

Electric bus batteries are rated by manufacturers in kilowatt-hours (kWh), representing their total energy storage capacity. While this rating provides a general indication of how far a bus can travel on a single charge, the actual usable capacity is often 5% to 20% lower depending on the battery chemistry. This is due to battery management systems that optimize performance and extend battery life by reserving a buffer and preventing deep discharges or full charges.

Several factors influence an ESB's energy consumption, some of which are similar to those affecting diesel buses:

- **Driving conditions** – Frequent acceleration and high-speed driving increase energy use, while steady speeds improve efficiency.
- **Weather –** Cold temperatures reduce battery efficiency and increase energy use for heating, while extreme heat may require additional cooling.
- **Battery Management System (BMS) Configuration –** The BMS regulates charging, discharging, and thermal management to optimize performance and battery life.
- **Regenerative Braking –** Recovers energy during deceleration, improving efficiency on stop-and-go routes by offsetting some of the energy used for acceleration.
- **Battery Chemistry –** Different battery chemistries affect energy storage capacity, lifespan, and cold-weather performance, which can influence range and long-term charging needs.

Understanding these factors is essential for right-sizing battery capacity to ensure ESBs can reliably complete daily routes without excessive range fluctuations or unnecessary oversizing of the battery pack. By identifying the conditions that reduce range, like cold weather or

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3 Energy Performance and Driving Condition

high auxiliary loads, fleet operators can take steps to limit their impact, such as adjusting charging schedules or using pre-conditioning. Proper energy consumption analysis helps fleet operators optimize route planning, charging schedules, and operational strategies for improved reliability and cost-effectiveness.

3.2 Route Characteristics and Data Collection

A total of 298 trips were recorded between April 16, 2024, and April 11, 2025. For the purposes of this study, a trip is defined as any time the bus was driven without stopping for more than one hour.

Most trips followed a consistent school-day route, conducted twice per day—once in the morning and once in the afternoon. These trips covered approximately 55 km and involved a round trip from the depot to two school locations, as shown in **Figure 1**. In contrast, a smaller number of extracurricular trips took place during weekends and summer months, and these followed varied, less predictable routes.

Figure 1 presents a map of the ESB's typical school-day route, including the locations of the schools and the bus depot, along with the extracurricular routes. **Table 3** summarizes the key characteristics of both school-day and extracurricular trips included in the dataset.

Figure 1. Routes evaluated during the pilot study

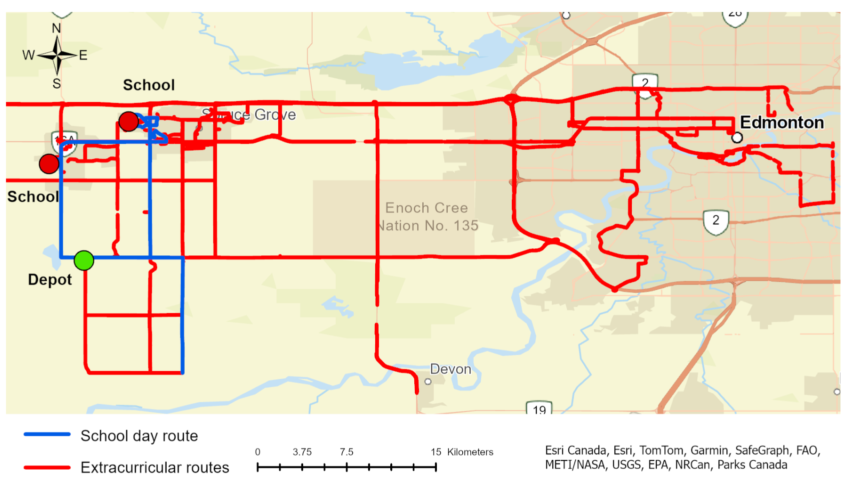

Table 3: Characteristics of school day and extracurricular routes

Route	Number of trips	Average distance (km) [min, max]	Average speed (km/hr) [min, max]
School day route	268	54 [33, 78]	34 [15, 49]
Extracurricular routes	30	54 [11, 117]	41 [14, 85]

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3.2.1 Energy Consumption and Regenerative Braking

Figure 2 presents the energy intensity of the bus in kWh/km and associated bus range on a single charge based on the 126-kWh battery on each of the dates in which the ESB was operated between April 2024 and April 2025. Throughout the length of the demonstration, a minimum and maximum energy intensity of 0.62 kWh/km and 0.98 kWh/km respectively were observed. In other words, the range of the ESB on a single charge varied from 111 km to 228 km depending on the operating conditions of the ESB.

A higher energy intensity (lower range) was observed in the colder months, i.e. early spring, late fall and winter compared to the energy intensity during the summer months and early fall.

Figure 2. Energy intensity of trips and range implications across days of operations

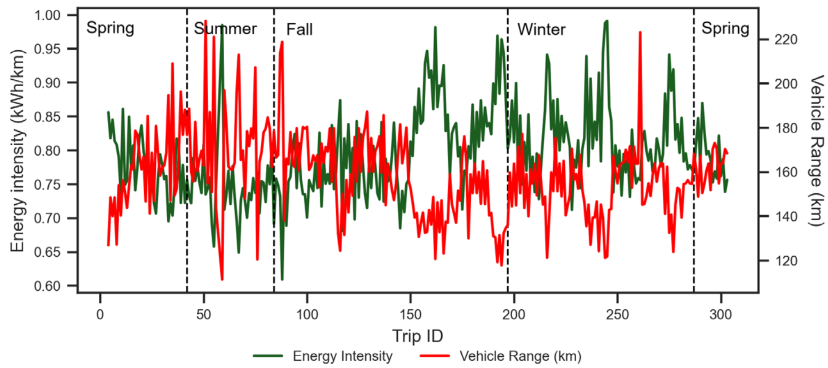
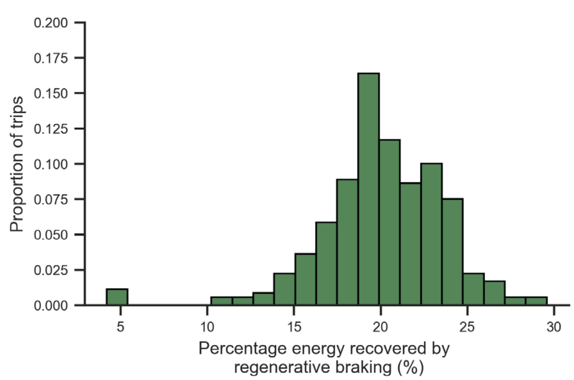


Figure 3 illustrates the percentage of total energy consumption recovered through regenerative braking across all trips conducted during the demonstration. Regenerative braking is a system that captures and converts kinetic energy into electrical energy during braking, storing it in the vehicle's battery for future use. This process improves overall energy efficiency by reducing the amount of energy lost as heat.

During this demonstration study, regenerative braking recaptured on average 20% of the total energy consumed, with values ranging from a minimum of 5% to a maximum of 29%. The amount of energy recovered varies depending on route characteristics and individual driving behavior. These results align with findings from the previous Calgary demonstration study, confirming that regenerative braking can consistently reduce overall energy consumption by approximately 20%.

Figure 3. Proportion of energy recovered through regenerative braking across trips



3 Energy Performance and Driving Condition

Further research is needed to better understand the conditions that maximize energy recovery through regenerative braking. Additionally, school bus operators should consider driver training programs that optimize braking strategies, as these could help improve vehicle range and lower charging costs.

3.2.2 Impact of Temperature on Energy Consumption

Temperature is a well-documented factor influencing the energy consumption of electric vehicles, with colder conditions generally leading to higher energy use.[4] This increase is typically driven by two main factors: (1) the operation of heating systems, which place significant demand on the battery, and (2) reduced battery efficiency at low temperatures.

In this demonstration, the ESB used an auxiliary diesel heater for cabin heating, allowing us to isolate the impact of temperature on propulsion energy consumption. Because the battery was not used for cabin heating, any increase in energy use during colder weather can be directly attributed to how temperature affects the drivetrain and battery performance, not cabin heating, giving us a clearer picture of temperature-related efficiency losses.

Table 4 presents the average monthly energy intensity and estimated single-charge range based on the ESB's 126 kWh battery. Energy intensity improved from April through midsummer, reaching a low of 0.71 kWh/km in July (177 km range), before increasing again through the winter months. By December, energy intensity reached 0.84 kWh/km, with an estimated range of 150 km.

Table 4: Average energy intensity and range per month

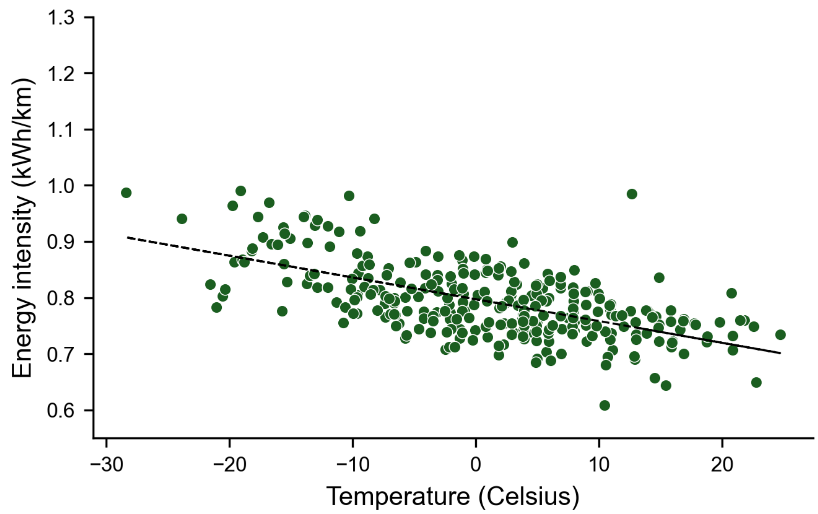
Month	Number of trips	Average energy intensity (kWh/km)	Average single charge range (km)	Temperature (°C)
April	25	0.79	159	1.3
May	N/A	Maintenance	Maintenance	Maintenance
June	37	0.76	166	11.9
July	11	0.71	177	16.7
August	6	0.71	177	15.6
September	23	0.73	173	10.6
October	46	0.77	164	3.9
November	30	0.82	154	-6.6
December	31	0.84	150	-7.8
January	37	0.82	154	-3.8
February	24	0.82	154	-7.8
March	28	0.81	156	-3.8

4 Skuza, A., & Jurecki, R. S. (2022). Analysis of factors affecting the energy consumption of an EV vehicle-a literature study. IOP Conference Series: Materials Science and Engineering, 1247(1), 012001.

3 Energy Performance and Driving Condition

Figure 4 illustrates the relationship between ambient temperature and energy intensity on a per-trip basis. As temperatures dropped from 20°C to -30°C, energy intensity increased by approximately 58%—from 0.62 kWh/km (estimated range of 228 km) to 0.98 kWh/km (111 km range). Despite this increase, the bus generally maintained more than double the range required for its regular 55 km school-day route.

Figure 4. Electric school bus energy consumption versus ambient outdoor temperature



These results contrast with findings from a previous ESB demonstration in Calgary, where battery-powered cabin heating was used. In that study, energy intensity rose by approximately 85%—from 0.7 to 1.3 kWh/km—as temperatures dropped from 20°C to -10°C.[5] The more moderate increase observed in the current study highlights the benefits of using an auxiliary diesel heater to preserve efficiency in cold weather. Even without the heating load, colder temperatures still reduce energy performance, likely due to increased battery resistance (which limits power flow in cold weather) and reduced efficiency in converting battery energy into vehicle motion.

These findings highlight the importance of considering seasonal impacts when evaluating the performance of ESBs. Even in the absence of electric heating loads, colder temperatures lead to higher energy consumption, which can affect operational planning. However, with appropriate system design, such as sufficient battery capacity, pre-conditioning, and thermal management, ESBs can continue to perform reliably in winter conditions.

5 Pollution Probe. (2023). Electric School Bus Energy Assessment: A Calgary Demonstration Case Study. Retrieved from: https://www.pollutionprobe.org/electric-school-bus-operational-assessment-a-calgary-demonstration-case-study/

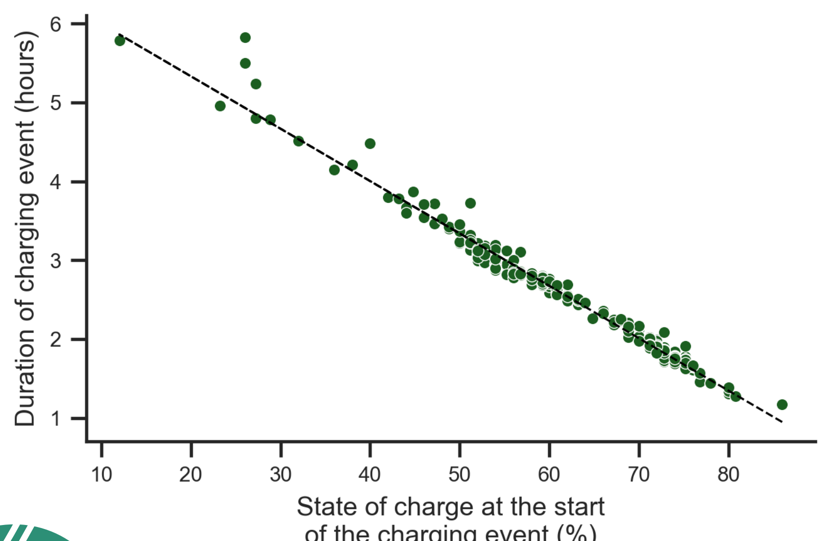
3 Energy Performance and Driving Condition

3.3 Charging Patterns and Performance

Throughout the demonstration, the bus was charged exclusively at the depot using a 19 kW Level 2 AC charger. On school days, it followed a consistent charging routine, plugged in after the morning trip (around 8:50 a.m.) and again after the afternoon trip (around 4:30 p.m.). Each school-day route covered approximately 55 km, which the bus completed with ease on a single charge, returning to the depot with an average state of charge (SOC) of 64%. The vehicle typically remained connected to the charger between trips.

Charging durations were closely linked to the SOC at the start of each session. On average, recharging from 64% to full took between 2 and 3 hours, as shown in **Figure 5**. The longest recorded charging event lasted around 6 hours, beginning from an SOC of 10%. The charger delivered consistent power output across all sessions, with only a slight decrease—approximately 10%—observed during extreme cold conditions (-20°C to -30°C), suggesting stable charging performance even in harsh winter temperatures.

Figure 5. Time needed to fully charge the bus as a function of the state of charge at the start of the charging event



Emissions Analysis

PHOTO: JUSTIN SMITH/GETTY IMAGES

4.1 Understanding Emissions from Diesel and Electric School Buses

Transitioning from diesel to ESBs significantly reduces both GHG emissions and harmful air pollutants. Diesel buses are major contributors to GHG emissions and release pollutants such as fine particulate matter ($PM_{2.5}$) and nitrogen oxides (NO_x), both of which are linked to serious health effects, including asthma, reduced lung function, cardiovascular disease, and premature mortality. Children are especially at risk due to their developing respiratory systems and the amount of time spent on buses.

In addition to contributing to outdoor air pollution, diesel exhaust can infiltrate bus cabins, increasing in-cabin exposure during commutes.[6] ESBs eliminate tailpipe emissions, improving both outdoor and in-cabin air quality. However, many ESBs still rely on auxiliary diesel heaters in cold weather, reintroducing localized emissions and partially offsetting the air quality benefits of electrification.

The emissions benefits of ESBs also depend on the electricity grid's composition. While tailpipe emissions are eliminated, fossil-based electricity generation can still produce GHGs and air pollutants. This shifts emissions from neighborhoods to power plants, changing the location, but not necessarily eliminating the impact. For GHGs, which have global effects, the location is less relevant. However, eliminating tailpipe emissions is especially important for children riding the bus, as it removes in-cabin exposure to diesel exhaust, one of the key health benefits of electrification.

As shown earlier in this report, the demonstration project used an auxiliary diesel heater during winter operation to reduce battery load and maintain performance. While this approach supports operational efficiency, it also introduces additional localized emissions. To understand the trade-offs of different electrification strategies, the next section compares GHG and NO_x emissions across three school bus configurations.

6 Adar, S. D., D'Souza, J., Sheppard, L., Kaufman, J. D., Hallstrand, T. S., Davey, M. E., Sullivan, J. R., Jahnke, J., Koenig, J., & Larson, T. V. (2015). Adopting clean fuels and technologies on school buses. Pollution and health impacts in children. *American Journal of Respiratory and Critical Care Medicine*, 191(12), 1413–1421.

4 Emissions Analysis

4.2 Comparative Emissions of Bus Configurations

We compared GHG and NO_x emissions over one calendar year of school bus operation for three different bus configurations through simulation[7]:

- Diesel bus with a diesel auxiliary heater (Base conditions),
- Electric bus with an electric heater
- Electric bus with a diesel auxiliary heater.

Emissions were calculated across three sources: tailpipe emissions (for diesel buses), auxiliary diesel heater emissions, and electricity generation emissions (for electric buses). For electric buses, emissions from electricity generation were estimated using Alberta's 2024 energy mix, following the province's coal-to-gas transition. As of late 2024, 81% of electricity was generated from natural gas and 19% from renewable sources.[8] Diesel bus emissions were modeled based on a 2024 vehicle equipped with modern emission controls.[9]

The simulation used consistent annual distance traveled and incorporated factors such as energy consumption rates, heater runtimes, fuel consumption, and emission intensities from electricity and diesel use. These inputs allowed us to estimate and compare the total emissions impact of each configuration based on typical school bus operations under Alberta conditions.

Figure 6 compares the GHG and NO_x emissions of the three bus types, breaking them down into tailpipe emissions, auxiliary diesel heater emissions, and electricity generation emissions. The assumptions used to generate these estimates are detailed in Appendix A. It should be noted that, in addition to the Edmonton demonstration outlined in this report, inputs were also sourced from a previous demonstration in Calgary, as well as other sources.

Greenhouse Gas (GHG) Emissions:
Figure 6 shows that total annual GHG emissions decreased from 12,526 kg CO_2e for the diesel bus to 8,981 kg CO_2e for the electric bus with a diesel heater (28% reduction) and 7,824 kg CO_2e for the electric bus with an electric heater (38% reduction). The relative contribution of the diesel auxiliary heater to GHG emissions is notably higher for the electric bus compared to the diesel bus. This is due to factors including a slightly larger heater capacity requirement and longer operating periods during cold winter days.

It is also important to note that Alberta has one of the most carbon-intensive electricity grids in Canada. As a result, the emissions reductions from electrification presented in this analysis are conservative. Greater benefits would be expected in provinces with cleaner grids. Over time, reductions in GHG emissions from electrification are expected to further improve as Alberta's electricity generation becomes cleaner. Additionally, these reductions are modeled using emissions from a new diesel bus (2024 model) and would be even greater if older diesel buses were replaced.

Nitrogen Oxide (NO_x) Emissions:
NO_x emissions decreased from 12.6 kg annually for the diesel bus to 7.5 kg for the electric bus with diesel heating (40% reduction) and 6.4 kg for the electric bus with electric heating (49% reduction). Although total NO_x emissions for both electric bus configurations are similar, the location of emissions remains critical. Tailpipe and diesel auxiliary heater emissions occur directly near students and communities, posing immediate health risks. Conversely, emissions from electricity generation are displaced to power plants. Thus, eliminating localized tailpipe and heater emissions remains an important long-term goal for community health.

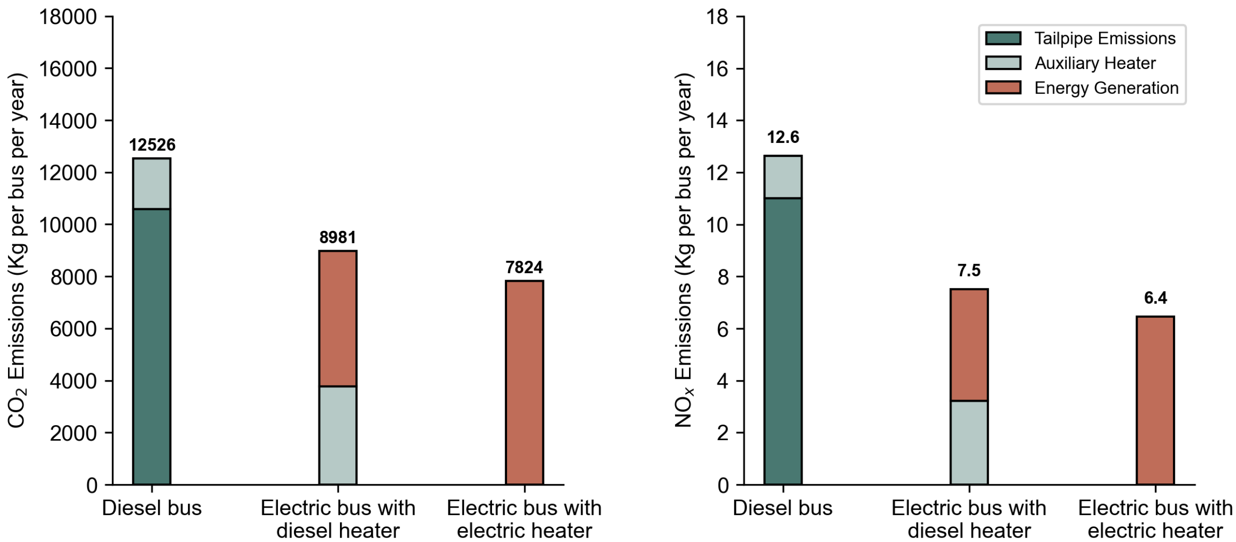
7 A school year was estimated to be equivalent to 16,300 km travelled

8 This energy mix corresponds to CO_2-equivalent emissions of 400 g/kWh and NO_x emissions of 0.33 g/kWh.

9 Emission factors were extracted from the U.S Argonne National Lab Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool.

4 Emissions Analysis

Figure 6. Annual CO_2 and NO_x emissions (kg per bus per year) for diesel and electric buses, broken down by source: tailpipe emissions, auxiliary heating, and energy generation.



These results highlight key trade-offs between energy efficiency, total emissions, and local air quality impacts. In Alberta's fossil-fuel-dominated electricity context, using a diesel auxiliary heater provides comparable total emissions reductions to fully electric heating when deploying an electric school bus. However, fully electric systems deliver significantly greater localized air-quality benefits. Therefore, phasing out diesel-based cabin heating remains crucial to maximizing both the health and environmental advantages of electrifying school buses over the long term. These findings also underscore the importance of accelerating electricity grid decarbonization to fully unlock the climate benefits of electrification.

Lessons Learned

This demonstration provided valuable insights into the real-world operational performance and emissions trade-offs associated with ESBs operating under cold-climate conditions. Building on prior studies, it offers actionable insights for fleet operators, vehicle manufacturers, and policymakers working to successfully scale up ESB deployment in Canada and similar regions.

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PHOTO: CHANOOK PHOTOGRAPHY/GETTY IMAGES

5.1 Cold Weather Operational Strategies

Winter operation can be viable.
The demonstration confirmed that ESBs can reliably operate throughout harsh winter conditions under the operational conditions evaluated. By incorporating an auxiliary diesel heater, the ESB maintained cabin comfort without significantly compromising battery range or vehicle performance. This highlights a practical and proven interim strategy, ensuring reliable operations while battery technologies continue to evolve.

Energy intensity remains sensitive to cold temperatures, even without electric heating.
While auxiliary diesel heaters relieved the battery of cabin heating loads, energy consumption still rose notably during colder months due to increased battery resistance and reduced energy conversion efficiency. Fleet operators should anticipate seasonal variation in energy consumption and plan accordingly, ensuring sufficient charging opportunities and scheduling flexibility during winter.

Auxiliary heating currently improves ESB operational viability but introduces trade-offs.
The diesel heater ensured consistent vehicle performance during extreme cold conditions, but it also introduced localized emissions. Fleet operators and policymakers should consider auxiliary heaters as a transitional solution while battery and thermal management technologies continue to improve, with the ultimate goal of achieving complete electrification, including heating systems.

5 Lessons Learned

5.2 Charging and Infrastructure Considerations

Level 2 charging was sufficient for daily school bus operations.
With predictable routes, moderate daily distances (~55 km per trip), and sufficient time parked between trips, a lower-cost 19 kW Level 2 AC charger proved to be practical and reliable. Fleet operators with similarly structured routes and operational conditions can confidently utilize Level 2 infrastructure, avoiding more expensive DC fast chargers.

Cold weather had minimal impact on charging performance.
Charging power output remained stable throughout most of the demonstration, even during extreme cold periods (-20°C to -30°C). Only a minor reduction (~10%) was observed during these conditions. This stability indicates that standard charging infrastructure is robust enough to maintain reliable operations through harsh winters.

Routine charging schedules simplified vehicle management.
In this single-bus demonstration, the consistent practice of plugging in the ESB after each morning and afternoon route streamlined daily operations and helped ensure reliable vehicle availability. This simple, predictable routine was effective given the depot setup and route schedule. As fleets expand beyond one or two vehicles, however, charging coordination may require more deliberate planning to maintain similar levels of operational and cost efficiency.

5.3 Environmental Trade-offs and Emissions

Electric school buses substantially reduce overall GHG and NO_x emissions.
Transitioning from diesel to electric buses significantly reduced greenhouse gases by approximately 28-38% and nitrogen oxides by around 40-49% under Alberta's current energy grid mix. These results demonstrate that even in regions with fossil-fuel-heavy grids, electrification yields significant environmental benefits. These reductions, modeled using emissions from a new diesel bus (2024 model), would be even greater if older diesel buses were replaced.

Fully electric heating provides the lowest emissions, though diesel heaters remain a viable transitional option. An electric bus with fully electric heating achieved the greatest emissions reduction. However, using an auxiliary diesel heater still provided substantial emissions reductions compared to diesel buses and currently offers practical reliability advantages in cold climates. With continued advancements in battery and thermal management technology, the performance gap between diesel and fully electric heating is expected to narrow further, reinforcing the long-term potential for full electrification of heating systems.

Emission location remains critical for community health.
Although total NO_x emissions were broadly similar between the two electric bus configurations, diesel auxiliary heaters emit pollutants directly around schools and neighborhoods. Eliminating these localized emissions remains essential for improving air quality and protecting public health, underscoring the importance of transitioning toward fully electric cabin heating solutions over the long term.

5 Lessons Learned

5.4 From Pilot to Scaling: Awareness and Funding

Clear, timely funding processes are critical for scaling. Operator experiences highlighted that uncertainty and delays in accessing federal funding significantly impacted their ability to expand ESB fleets. Clearer timelines, faster approvals, and potentially tiered funding (i.e. higher incentives initially, then reduced incentives as fleet sizes grow) could help operators effectively plan their long-term transition to ESBs.

Community awareness accelerates adoption. Proactive engagement by early ESB adopters through community events, expos, and public demonstrations has successfully increased local awareness and industry confidence in electric buses. Continued visibility and knowledge-sharing are essential for maintaining momentum and fostering broader adoption, particularly in regions where ESBs remain relatively unfamiliar.

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Appendix A
Emissions Calculation Assumptions

The following inputs were used to estimate annual GHG and NO_x emissions for each school bus configuration presented in **Figure 6**. These assumptions are based on data from the demonstration project, previous pilot studies, and published emission factors (EFs).

Table A1. Input Assumptions and Sources

Variable	Value	Unit	Source / Note
Total distance traveled per year	16,300	km	From demonstration data
Auxiliary heater operating days per year	119	days	Based on observed fleet operator usage.
Diesel tailpipe EF (GHG)	650	g CO_2e/km	AFLEET[10]
Diesel tailpipe EF (NO_x)	0.65	g/km	AFLEET
Diesel heater fuel consumption for diesel vehicle	3	L/h	Propulsion Québec[11]/ Pettinen et al., 2023[12]
Diesel heater fuel consumption for electric	3.9	L/h	Propulsion Québec / Pettinen et al., 2023
Diesel heater runtime for diesel vehicle	2	h/day	Based on observed fleet operator usage.
Diesel heater runtime for electric vehicle	3	h/day	Based on observed fleet operator usage.
Diesel heater EF (GHG)	2.7	kg CO_2e/L	NRCan Factsheet 9[13]
Diesel heater EF (NO_x)	2.3	g/L	NRCan Factsheet 9
Alberta grid EF (GHG)	400	g CO_2e/ kWh	ECCC, 2024[14]
Alberta grid EF (NO_x)	0.33	g/kWh	CASA, 2017[15] (weighted average for gas/renewable mix)
ESB energy use (with diesel heater)	0.8	kWh/km	From demonstration data
ESB energy use (with electric heater)	1.2	kWh/km	Calgary demonstration; weighted average based on observed trips

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