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Electrification of Transit in a Canadian Operating Environment

Summary of Stakeholder Experience and Consultations

Prepared for:
Transport Canada,
Environment and Climate Change Canada &
Toronto Transit Commission

By: Merrina Zhang and Isabella Jimenez
Automotive and Surface Transportation Research Centre

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Executive Summary

Canada's national greenhouse gas emissions (GHG) report indicated that "*the transportation sector accounted for 22 percent of Canada's emissions in 2021*", thus making it one of the largest sources of GHG emissions in Canada. [1]

According to the United States Environmental Protection Agency [2], there are three pathways to reducing GHG emissions from transportation, including,

- Improving vehicle efficiency
- Using lower carbon fuels
- Improving the method of travel and transport

Electrification of transit has the potential to advance all three GHG reduction pathways, since its drive cycles are well known and defined, most transit agencies own and operate their vehicles and infrastructure, and planning and route optimization can be done to benefit from the efficiencies of electric powertrains.

In Canada, many transit agencies have plans to transition away from diesel to full electric fleets.

Fleet transition to full electric comes with some uncertainties, since the technology is relatively new, and the infrastructure, operations and maintenance are different from conventional diesel fleets. In addition, long-range battery electric buses are limited in how far they can travel on a single charge, and refuel/recharge at a slower pace compared to diesel/hybrid buses.

This research was carried out to better understand the experience and perspectives of stakeholders who interact with electric buses from the policy and planning stages through to end use, since the successful uptake of any technology depends heavily on its community of users and stakeholders.

These perspectives and experiences were gathered through a range of different methods, including a series of literature scans and reviews, leveraging of project partners' internal surveys, and tours and conversations with stakeholders at electrified transit garages in Toronto, Edmonton, and Ottawa. In addition, in-depth discussions were held with a sample of key stakeholders.

The consultation process has made it clear that the electrification of transit is an important strategy in Canada's goal to fight climate change. Many municipalities have long term plans to fully convert their transit fleets to zero emission vehicles despite current technical challenges.

Feasibility studies, modelling and pilots have been recommended by multiple organizations, as tools to help transit agencies better understand their fleet operational needs, and profile routes to match the capabilities of the buses based on a variety of factors such as driving range, duty cycle, charging, and schedules.

Key procurement lessons learned from Toronto Transit Commission's (TTC) 60 electric bus trial include the need for evidence of successful completion of relevant Altoona tests, demonstrated in-service

experience of bus structure being corrosion resistant, a minimum usable battery capacity, and multi-method charging compatibilities.

With regards to charging infrastructure, many organizations emphasize the need to engage utility providers early to ensure that there is sufficient grid capacity for fleet electrification. At the time of writing, neither plug-in chargers nor pantographs have emerged as the preferred charging technology option for Canadian transits.

TTC and Edmonton Transit Service (ETS) [3] indicated it is beneficial for planning and integration to test electric buses independently of revenue service to establish energy consumption baselines through different seasons, and under controlled operating conditions.

Proper training of operations and maintenance staff is critical to the successful integration of zero emission bus fleets [4] [5] [6]. The maintenance of electric buses is sufficiently different that the initial learning curve can be quite steep, as found in TTC and ETS' experience. Due to the current demand for electric buses, it might be challenging to schedule training by OEMs and key suppliers since the trainers can be fully booked months in advance.

One of the biggest concerns identified by transit authorities throughout the literature review and consultations, is whether the range of current battery electric bus technologies is sufficient to service their existing operations, especially since most transit authorities found that their buses do not achieve the OEM advertised range. And because the range of electric buses is limited on a single charge, transit agencies, are adjusting bus dispatching to make the best use of the bus within its range limitations. As such, electric buses may not accumulate mileage as fast compared to diesels and hybrids within the same fleet.

The global supply chain shortages and inflations has impacted transit operations. It is currently unclear as to how this will impact fleet electrification in the long run.

Many TTC transit users have noticed that the electric buses provide a smoother ride, as well, people who live along bus routes have complimented on the buses being quieter. Most transit users surveyed by ETS like electric buses better than other buses within the Edmonton fleet. In Foothill California, it appears that younger riders are generally more supportive of zero emissions type of transportation solutions, while other passengers placed much more emphasis on being able to travel to their destinations faster. [7]

Glossary and Definitions

BYD	BYD Canada
DC	Direct current
CUTRIC	Canadian Urban Transit Research and Innovation Consortium
ECCC	Environment and Climate Change Canada
ETS	Edmonton Transit Service
Ft, ‘	Foot/feet
FY	Fiscal year
GHG	Greenhouse gas
HV	High voltage
HVAC	Heating, ventilation, and air conditioning
Hybrid	Hybrid diesel electric buses
kW	Kilowatt
kWh	Kilowatt-hour
km	Kilometre
MBTA	Massachusetts Bay Transportation Authority
Mpdge	Miles per diesel gallon equivalent
MW	Megawatt
NFI	New Flyer Industries
NRC	National Research Council of Canada
OEM	Original equipment manufacturer
Regen	Regenerative braking
SAE	Society of Automotive Engineers
SOC	State of charge
TC	Transport Canada
TTC	Toronto Transit Commission

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1 Introduction

Canada's national greenhouse gas emissions (GHG) report indicated that "*the transportation sector accounted for 22 percent of Canada's emissions in 2021*", thus making it one of the largest sources of GHG emissions in Canada. [1]

According to the United States Environmental Protection Agency [2], there are three pathways to reducing GHG emissions from transportation, including,

- Improving vehicle efficiency
- Using lower carbon fuels
- Improving the method of travel and transport

Electrification of transit has the potential to advance all three GHG reduction pathways, since its drive cycles are well known and defined, most transit agencies own and operate their vehicles and infrastructure, and planning and route optimization can be done to benefit from the efficiencies of electric powertrains.

In Canada, many transit agencies have plans to transition away from diesel to full electric fleets, including:

- Edmonton Transit Service (ETS)
- Calgary Transit
- Halifax Transit
- OC Transpo
- Regina Transit
- Saint John Transit
- Saskatoon Transit
- Société de transport de Laval
- Société de transport de Montréal
- Réseau de transport de la Capitale
- Réseau de transport métropolitain
- Service de transport en commun de Trois-Rivières
- Société de transport de Lévis
- Réseau de transport de Longueuil
- Société de transport de l'Outaouais
- Société de transport du Saguenay
- Société de transport de Sherbrooke
- Toronto Transit Commission (TTC) [8]
- Translink
- Winnipeg Transit
- Victoria Regional Transit

Fleet transition to full electric comes with some uncertainties, since the technology is relatively new, and the infrastructure, operations and maintenance are different from conventional diesel fleets. In addition, long-range battery electric buses are limited in how far they can travel on a single charge, and refuel/recharge at a slower pace compared to diesel/hybrid buses.

Considering the fact that the transition from diesel to electric is complex, this research was carried out to better understand the experience and perspectives of stakeholders who interact with electric buses from the policy and planning stages through to end use, since the successful uptake of any technology depends heavily on its community of users and stakeholders.

The information in this report was gathered through a range of different methods, including a series of literature scans and reviews, surveys by project partners, technical tours, and in-depth discussions with stakeholders.

2 Project Summary

2.1 Background

The Toronto Transit Commission (TTC) is Canada's largest public transit authority, serving the greater Toronto area through an extensive network of buses, subways, and streetcars. In 2019¹, TTC reported over 3.3 million daily passenger trips across all modes of transit [9].

At the time of writing, TTC operates a large fleet of over 650 hybrids within their fleet of over 2,000 buses, and is committed to 50% of their bus fleet to be zero emissions by 2028-2032, and 100% to be zero emissions by 2040 [8].

Since 2019, TTC has been operating one of the largest electric bus trials in North America, with 60 long-range electric buses from three bus manufactures, including:

- 25 from New Flyer Industries (NFI) operating out of the Arrow Road and Birchmount Garages (Figure 1)
- 25 from Proterra operating out of the Mount Dennis Garage
- 10 from BYD Canada (BYD) operating out of the Eglinton Garage

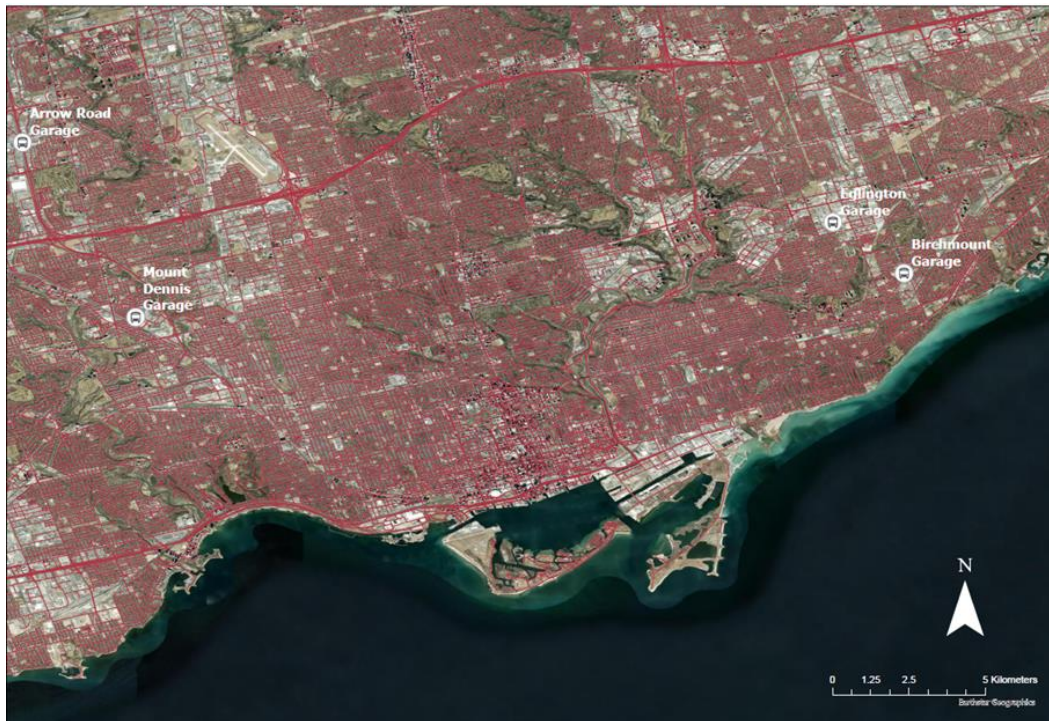


Figure 1: TTC's electrified transit garages

¹ The most recent operating year pre-COVID pandemic induced public health measures.

This research is part of a larger research collaboration between the National Research Council (NRC), TTC, Transport Canada (TC) and Environment and Climate Change Canada (ECCC) since 2020, to leverage the TTC trial to better understand the integration, operation and maintenance of electric buses within a Canadian transit environment.

2.2 Objective

The objective of this project is to better understand the experience and perspectives of stakeholders who have played a role in the policy, planning, procurement, integration, operations, and maintenance of battery electric buses, in addition to those who use transit.

Since transit electrification is still in its early stages in Canada, and the first year of this research was carried out during COVID-19 pandemic lockdowns, this research employed a variety of different methodologies to gather the information and data needed on the real-world implications of electric buses in Canadian transit environments.

2.3 Project Scope and Methodology

The activities of the research took place over 3 consecutive fiscal years (FY) from 2021 to 2024, and consisted of a series of literature scans and reviews, surveys by project partners, technical tours, and in-depth discussions with stakeholders.

2.3.1 Literature Review

Literature reviews were completed during FYs 2021-2023 as a foundation to support key activities of this project, especially the feedback and experiences of stakeholders in context with electric bus trials from around the world.

The literature scan was completed by NRC's National Science Library using various publication databases and sources, including the Conference Board of Canada, CBCA, Scopus, Lux Research, BCC Research, United States Department of Transportation, and websites of countries or cities with electric bus trials.

15 publications were identified to be relevant out of 34 during the literature scan and review process in FY 2021-2022, and 8 were identified to be relevant out of 29 in FY 2022-2023. The references from each paper were taken into consideration to expand the repertoire of related work.

The following electric bus trials were reviewed as part of the work.

- Edmonton Transit (2015-2016, [3])
- Winnipeg Transit (2014-2018, [10])
- TTC (2019-present, [8], [11])
- Foothill Transit (California, 2014-2016, [12], [13])
- King County Metro (Seattle, 2016-2017, [6])
- Massachusetts Bay Transportation Authority (2019-present, [14])

2.3.2 Surveys

TTC completed two surveys at Arrow Road, Mount Dennis and Eglinton garages to gather feedback from their operations and maintenance staff on their experience working with electric buses [11]. The first survey was carried out in March 2021 and the second one was carried out in February 2022.

The operators were asked whether they were “very satisfied”, “satisfied”, “neither satisfied or dissatisfied”, “dissatisfied”, or “very dissatisfied” about the following aspects of how the electric buses compared with hybrids:

- Noise level
- Ergonomics
- Visibility/sightlines
- Ride comfort
- Acceleration
- Steering/maneuverability
- Braking
- Night driving

Similar to the operators, the maintainers were asked whether they were “very satisfied”, “satisfied”, “neither satisfied or dissatisfied”, “dissatisfied”, or “very dissatisfied” about the following aspects of the electric bus operated out of their garage:

- Noise level
- Visibility/sightlines
- Ride comfort
- Acceleration
- Steering/maneuverability
- Diagnostic tools
- Maintenance manual content and navigation
- Parts manual content and navigation
- Layout of maintenance components

The maintainers were also asked how well the electric buses compare with diesel buses and hybrid buses.

In addition, TTC carried out online surveys of transit users on their experiences and perceptions of electric buses. According to [11], the survey was carried out from February 2021 to January 2022, with a total of 369 collected response. 87 riders responded to questions related to NFI, 166 riders for BYD, and 115 for Proterra. The transit users were asked about whether they were satisfied with the electric buses overall, electric bus design elements such as noise, ride quality, seating, as well as how they compares with the other TTC buses.

The survey results provided a good overview of the impression of key stakeholders who worked closely with electric buses throughout the first few years of electric bus integration, as well as those who were end users.

2.3.3 Technical Tours

A technical tour of TTC's Arrow Road, Mount Dennis, Eglinton and Birchmount garages was provided for members of the research team in February 2023. Team members also attended technical tours of Edmonton Transit's Kathleen Andrew's Transit garage (2022) and OC Transpo's St. Laurent Transit garage (2023) as part of Transportation Association of Canada's Conferences.

The technical tours provided the opportunity for the research team to interact with engineers, operators, and maintenance staff from the different transit agencies, in addition to gaining valuable insights into the real world challenges of electric bus integration.

Additional information of the technical tours can be found in Appendix A.

2.3.4 Virtual and In-Person Discussions

In FY 2023-2024, virtual/telephone and in person discussions with stakeholders based on the consultation plan outlined in Table 1 were completed.

This series of discussions provided the opportunity for research team members to discuss the experience of the stakeholders in more depth.

Stakeholders	Consultation Method	Consultation Completed
Environment and Climate Change Canada's Transportation Division	Virtual discussion	2023
Infrastructure Canada's Transit policy	Virtual and in person discussion	2023
Infrastructure Canada's Zero Emissions Transit Fund	Virtual discussion	2023
Infrastructure Canada's Research and Development	Virtual and in person discussion	2023
Natural Resources Canada's Office of Energy Research and Development	Virtual discussion	2023
Toronto Transit Commission's Infrastructure Procurement Team	Virtual discussion	2023
Toronto Transit Commission's Maintenance Team	Virtual discussion	2023
Toronto Transit Commission's Operations Training Team	Virtual discussion	2023
Toronto Transit Commission's Planning and Inventory Control Team	Virtual discussion	2023
Toronto Transit Commission's Technical Training Team	Virtual discussion	2023
Toronto Transit Commission's Vehicle Procurement Team	Virtual discussion	2023
Toronto Transit Commission's Vehicle Programs Team	Virtual and in person discussion	2023
Toronto Transit Commission's Vehicle Reliability Quality Assurance Team	Virtual discussion	2023

Table 1: Electric bus stakeholder consultation plan

3 Summaries of Key Findings

This section presents a consolidated summary of key findings from the literature review, survey results, technical tours, and stakeholder consultations. The information has been organized into relevant categories, including policy, planning, charging, integration, training, energy and range considerations, operations, maintenance, fleet management and transit users.

It is important to note that some elements identified are early observations by stakeholders, and since electric buses are relatively new to Canadian transit operations, there may not be sufficient data at this time for in-depth analysis of those elements. Where appropriate, those elements are identified in the report as opportunities for further research.

3.1 Policy

- Canada's 2030 Emissions reduction plan² outlines key Government of Canada's priorities, goals and activities underway.
- Electrification of transit is a solution to decarbonize transportation, since electric drives are more efficient, have no tail pipe emissions, and many Canadian jurisdictions produce clean electricity.
- Municipalities of different sizes have applied to Government of Canada's Zero Emissions Transit Fund³. Most are requesting funding for long-range, depot charged, battery electric buses.
- Canadian transit agencies are currently at different stages of readiness in terms of electrifying their fleets, with many mid-sized and small municipalities considering carrying out pilot studies first.
- Technical guidelines/manuals to provide data and reference information to help transit agencies bypass the pilot studies stage and into the implementation stage would go a long way to support transit electrification in Canada.

3.2 Planning, Procurement and Budgeting

- The long-range electric buses currently on the market may not be able to replace diesel buses on a one to one ratio.
- Infrastructure upgrades necessary for electric buses can be expensive, both for depot charging, and for on demand/rapid charging.
- Feasibility studies are recommended by CUTRIC [15] and Columbia University [16] in order to better understand the fleet operational needs and unique characteristics of cities such as route length, topography, weather conditions, ridership, etc., since these factors affect energy consumption and thus the electric bus battery sizing.

² <https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/sector-overview.html#sector6>

³ <https://www.infrastructure.gc.ca/zero-emissions-trans-zero-emissions/index-eng.html>

- Winnipeg Transit recommended purchasing and deploying a trial fleet of 12 to 20 electric buses and associated infrastructure [10], while Columbia University recommended 10 electric buses from different vendors and to run them for a minimum of one year along multiple routes. They indicate that these types of trials would help determine the size of the batteries required for the fleet, as well as the types of charger and charging regimes [16].
- Massachusetts' Department of Transportation, Foothill Transit, and CUTRIC, mentioned modeling/simulation to facilitate the planning and implementation of electric buses to study different types of buses and their theoretical performance related to routes, topography, weather, schedule, asset allocations, block, and route designs [4] [5] [6]. Modelling and simulation would also help to profile routes to match the capabilities of the buses based on driving range, duty cycle, locations of charging opportunities, route schedules to accommodate charging time, schedule adjustment of each season to account for the impact on charging time, prepare for the addition of electric buses to the transit fleet, and estimate the resource required such as operational, energy, and cost.
- Advanced budget planning (possibly up to 2 years) may be needed to provide sufficient time to plan, procure and receive electric buses. This is in part due to the popularity of electric buses at the time of writing, and the global supply chain challenges.
- For the Edmonton trial, it was noted that the lead time for test buses, lease agreements, border crossings, regulatory approvals, facility modifications, and staff training were often longer than anticipated and took more coordination than expected. [3]
- Lessons learned from TTC's 60 electric bus trial include adding the following requirements to future procurement processes:
 - Successful completion of relevant Altoona tests
 - Demonstrated in-service experience of bus structure being corrosion resistant
 - A minimum usable battery capacity⁴
 - Bus size specification to fit operational requirements
 - Multi-method charging compatibility, including roof mounted pantograph charging, and dual rear-mounted charging

3.3 Charging

- It is important to engage utility providers early to ensure that there is sufficient grid capacity for fleet electrification. In the case of TTC, a close partnership with Toronto Hydro resulted in Toronto Hydro carrying out the procurement of the charging infrastructure for TTC's 60 electric bus trial.
- There are advantages and disadvantages of using plug-in chargers and pantographs. At the time of writing, neither method has emerged as the preferred option for Canadian transits.
 - Plug-in chargers are more economical to procure, install and maintain, but occupy floor (and/or wall) space, which might not always be available. In addition, the cable systems of plug-in chargers can be heavy, and need to be effectively managed to prevent damages resulting from the cables being left on the ground.

⁴ Manufacturers generally do not make 100% of the battery capacity available for use, to protect it against depletion and over charging, as well as prolong its service life. As a result, the usable battery capacity might be much less than the Manufacturer rated battery capacity.

- Pantographs are more expensive to procure, install and maintain. Training is also needed for operators to properly dock the bus with the pantograph. Both TTC and ETS have experienced Wi-Fi connectivity issues during the pantograph-bus docking process using Society of Automotive Engineers' (SAE) J-3105-1 standard. In Toronto, where the pantographs are installed outdoors, snow accumulation on the roof of the bus have caused connectivity issues. In Edmonton, where the pantographs are installed indoors, the proximity of multiple chargers are the primary causes of connectivity issues. In addition, the use of Wi-Fi has been flagged for potential cyber security concerns.
- TTC has opted to install at least 4 outdoor chargers at every electrified garage, since it is important to understand how the electric buses and charging system function in Canadian operating environments.
- Improved energy storage solutions, smart charging strategies, and local power generations may help to advance the capacity of utility grids enroute to full fleet electrification across Canada.
- Wireless charging, currently being demonstrated in Finland and Nottingham (UK) for taxis may offer a new charging solution for the future.

3.4 Integration

- Both ETS [3] and TTC indicated that it is beneficial to test electric buses independently of revenue service to establish energy consumption baselines through different seasons, and under controlled operating conditions. TTC conducted four series of head-to-head tests on approximately 40 bus routes as well as analyzed the performance of each bus model in revenue service. ETS found that it was important to allocate staff time specifically for the test, provide necessary training, and provide regular communications of testing progress to reduce test fatigue and morale that could degrade results. Support from bus manufacturers was also critical for both trials, either via on-site presence or immediate assistance, so that staff questions and concerns can be addressed with some urgency.

3.5 Training

- Both Massachusetts Department of Transportation and King County Metro believed that proper training of operators and maintenance staff is critical to the successful integration of zero emission bus fleets [4] [5] [6].
- Due to the current demand for electric buses, TTC has found it challenging to schedule training by bus manufacturers and key suppliers since the trainers can be booked months in advance.
- TTC's operation specific training for electric buses are delivered in the following manner:
 - Training for experienced operators include a review of bus features, how it differs from others within the fleet, charging procedures, and driving practices on pre-selected route(s)
 - Electric buses are integrated into the core curriculum of training for new operators
- Maintenance specific training for electric buses include elements such as technical familiarization, first responders, high voltage (HV) safety, personal protective equipment, lockout tagout, multiplex diagnosis & troubleshooting, HVAC, and doors.

- The American Public Transportation Association has developed a recommended practice for Zero-Emission bus maintenance training⁵.

3.6 Energy and Range Considerations

- Battery electric buses are powered solely by their onboard batteries, which typically have an energy rating (kWh) and a power rating (kW). [17]
- Compared to diesel buses, battery electric buses recharge at a much slower pace, and as a result, a common concern identified by transit authorities throughout the literature review and consultations was whether long-range, depot charged battery electric buses can perform within their existing operational requirements, such as the distance of their service routes, topography, and weather conditions.
- The studies and trials reviewed as per section 2.3.1, indicate that a number of factors impact energy consumption, including route ruggedness, average speeds, ridership, topography, and the number of stops and starts. The electric buses from the trials were able to achieve between 40 to 400 km in range⁶ between charges, compared to a diesel bus that can achieve between 500 and 600 km in range between fueling [15].
- In addition to general performance, Edmonton's trial also examined the impact of winter on the buses. Three electric buses were used during this trial, including two BYD 40-foot (ft) buses (a 324 kWh battery bus with diesel heating and one with electric heating) and a NFI XE40 bus (with a combination of diesel and electric heating and a 200 kWh battery). To ensure that the electric buses would experience a wide range of terrain and weather conditions, the buses were deployed in six types of weather conditions, including a mix of extreme cold days, slippery roads days/snowy days with a flat route, mild hilly route, or maximum sloped route. There were 11 snowy days where the temperatures were below -10°C and only seven days when it was very cold (-15 to -22°C). It is important to note that Edmonton experienced an unusually warm winter during the trial. For the BYD buses, the theoretical range as per the manufacturer was between 259 and 311 km. For the NFI bus, the theoretical range was between 145 and 160 km. However, both manufacturers recommend to operate the buses within 80% (NFI) to 85% (BYD) of the theoretical range, resulting in a maximum daily range of 202 to 264 km and 116 to 128 km for the BYD and NFI buses, respectively. From the test done by MARCON, the average energy consumption of BYD with diesel heating was between 1.04 and 1.25 kWh/km (2.4 to 2.98 km/%state of charge (SOC)), and the NFI bus was between 1.25 to 1.38 kWh/km (1.45 to 1.60 km/% SOC) [3]. The energy consumption for the BYD with electric heating was not calculated due to its delivery date being delayed. Contrary to all other trials, MARCON observed no direct correlation between ambient temperature and energy usage, where according to their report, the propulsion energy use and battery performance appeared unaffected by colder ambient temperatures.
- A trial in Montreal, Gatineau, and Laval in Quebec found that on extremely cold days, the power drain on the battery could be as much as 25% of its total capacity. Additionally, electric buses operating on heavy snow days with one to two inches of snow appear to use 15% more energy.

⁵ <https://www.apta.com/research-technical-resources/standards/bus-transit-systems-standards-program/apta-bts-zbt-rp-001-23/>

⁶ Depending on the size of the battery, operating scenario, and charging regime.

- Edmonton experienced 20 to 30% energy use for electric heating when it is needed. On hot days, electric air conditioning can use up to 35 kWh of energy. The amount of energy used to keep the bus at a comfortable cabin temperature depended on the outdoor temperature and the frequency of the door opening. The routes characteristics and grade also affect energy consumption. Lighter loads and flatter routes used less energy compared to the heavy morning rush, with many stops and slower speeds. During the Edmonton trial when the bus drove up hill, it consumed approximately 2% of available battery capacity. When going downhill, the regenerative braking (regen) powered the accessories, such as steering, fans, compressor, and lighting, keeping the battery at a steady SOC. The additional day-to-day variation in energy use has been attributed to driving styles by MARCON. [3]
- In the United States, King County Metro noted a higher fuel economy when the weather was colder. The fuel economy was calculated using the daily energy use and the utility bills for each charging location. The overall annual average fuel economy for the electric buses was 15.9 miles per diesel gallon equivalent (mpdge) compared to 14.7 mpdge for their trolley buses and 6.3 mpdge and 5.3 mpdge for their hybrid and diesel bus fleets, respectively. The electric buses' fuel economy was 17.6 mpdge in September 2016 and 13.3 mpdge in December 2016 [6].
- Foothill Transit's fleet had a fuel economy of between 17.47 to 19.76 mpdge for their electric buses. The vehicle subsystems that use the most of energy in the order of most to least are: powertrain, defrosting and battery thermal management, heating, ventilation, and air conditioning (HVAC) system, and small accessory loads. [10]
- The Massachusetts Department of Transportation completed a study of "Zero Emission Transit Bus and Refueling Technologies and Deployment Status in Massachusetts", and found that transit authorities within Massachusetts had challenges with electric buses, including performance issues, heat distribution within the buses, snow and freezing of overhead chargers, and equipment failures [4]. Massachusetts Bay Transportation Authority (MBTA) noted that although the advertised range of their electric buses was between 100 to 120 miles, the actual range achieved was between 60 to 110 miles. One of their biggest operational challenges was the range versus charge time dilemma, where the charging time was too long while the operating time was too short due to the short range. Their experience was that one charge a day was not enough for the electric buses to do a full service, they needed an additional midday charge, which caused electric buses to miss scheduled service [14]. This is partially due to the fact that the electric buses were equipped with an all-electric HVAC system, thus during the winter, the range was reduced by more than 40% due to cold weather and the need for the battery to supply cabin heating. This finding is in line with those from Winnipeg and Foothill Transit trials, where both have observed that cold weather has the greatest impact on long-range electric buses. Winnipeg's trial showed that a diesel heater helps to limit electric buses performance losses to 20% or less. Their diesel auxiliary heater was set to takeover if the ambient temperature dropped below freezing. In addition, Winnipeg Transit also experienced a reduction in the energy recuperated by regen during the winter from reduced road traction caused by ice or snow, or from their operators shutting off regen completely to improve bus handling. The reduced regen caused a noticeable reduction in electric bus range in the winter. Foothill noted that for their operations, on average, as much as 24% of the propulsion energy was from electric bus regen [13]. As well, battery capacity fading impacts range significantly, which is predicted to be between 20 to 30% over 6 to 12 years. To avoid capacity fade, it is recommended that actual daily range be limited to 70% of maximum range. [18]

- Cleveland State University evaluated the effects of changing weather on zero emissions bus performance. While they did not attempt to identify the cause of loss in efficiency⁷, the most apparent cause seems to be the need to maintain a comfortable cabin temperature for the bus. The study concluded that electric buses lose around 32.1% “fuel” efficiency when the temperature drops from 10 to 15°C to 0 to -5°C. On the other hand, when the temperature rises from 10 to 15°C to 21 to 25°C, electric buses only lose around 6.4% “fuel” efficiency. The electric buses lose a driving range of 37.8% when temperatures drop from 10°C to -5°C. An additional cause of loss in the winter could also be due to the added power required to overcome two types of forces that are higher at sub-freezing temperatures, including aerodynamic drag and the friction between the tires and the road. [19]
- MARCON observed that energy consumption is greatly affected by driving styles, frequency of stops and starts, acceleration rate, etc. Therefore training programs for operators could potentially extend the range and improve the energy efficiency of the electric buses. [3]
- One of the strategies implemented by TTC to better manage electric bus range is to establish alerts. For example, the 1st level alert is set at 12% SOC (approximately 20-25 km range), while the 2nd level alert is set at 7% SOC (approximately 10-15km range). The alerts are sent via short message service (SMS) and emails to transit management, bus maintenance, and engineering simultaneously.

3.7 Operations

- For the TTC trial, each electric bus model has its unique design features and operating characteristics, including ergonomics, line of sight, blind spot, ride quality, steering and maneuverability, regenerative braking, ease of charging, and passenger accessibility. TTC’s internal survey results indicate that operators have a preference for the hybrid buses within the TTC fleet when electric buses are compared directly to hybrids. However, they do prefer the quietness of electric buses and their ability to accelerate over hybrid buses. And depending on the electric bus model, operators also like the steering, braking and ride comfort aspect of its design.
- For TTC, as long as routes are designed to be within electric bus range limitations, operators don’t seem to have range anxieties.
- ETS’ trial found that it was important to keep staff informed of the city goals and plans, and ensuring that the buses are assigned to duty cycles and routes they were planned for. By doing so, usage of buses would be optimized to the largest distance they can travel, as their cost advantage grows with every kilometre they are on the road [3]. In addition, during winter operations, it was recommended to park electric buses in heated parking facilities to prevent drops in performance. Moreover, a cleaning and washing should be scheduled regularly to prevent road salt build-up on bus components. [3] The respondents of Edmonton’s post-trial survey expressed that the smoothness of the ride and the acceleration were positive points, while skidding on ice, brake sensitivities, instability and sluggish performance in accelerating uphill, and complexities in charging are areas of improvement. The biggest concern for the operators was

⁷ Gallons of diesel equivalency per 100 miles.

whether the actual range of the electric buses would be sufficient for a 14-16 hour day. Despite the technical challenges, in general, the operators felt that ETS was ready for more electric buses as long as operators can receive the training necessary.

- King County Metro found that the on route fast charger's availability is important for the operation of a fast-charge electric bus fleet since any failure would interrupt fleet operation.

3.8 Maintenance

- In order to support electric bus operations, ideally there is a sufficient number of trained staff to cover for every working shift.
- For TTC,
 - When buses are under warranty, maintenance activities primarily involve preventative maintenance and diagnosis, since repairs are done by manufacturers on site, or parts are sent out for repairs.
 - When buses come off warranty, maintenance activities involve a combination of preventative maintenance and repairs.
 - Similar to the experience of other transit authorities operating electric buses, there were some initial staff hesitations to work on electric buses due to the presence of HV. Training has been effective in reducing people's fear, and many bus maintenance staff were interested in being early adopters.
 - The maintenance of the charging system and infrastructure is contracted to an outside entity.
 - Having experience with hybrid buses has been a helpful transition to full electric, since the tooling, HV systems, and work process can be similar.
- TTC is currently using an alert system for battery health and safety, including setting temperature thresholds.
- For TTC maintainers at the Arrow Road garage, the survey indicated that they are generally satisfied with the maintenance element of the NFI buses. For TTC maintainers at the other two garages, the maintainers are more satisfied with elements related to operations, such as steering, acceleration, ride comfort, visibility, and noise than with maintenance related survey elements.
- The mechanical, maintenance and service staff of the ETS electric bus trial felt that in general, despite the training received, they were not as prepared to address many of the issues and challenges they experienced. They did indicate they were more familiar with the NFI electric bus, since ETS was using diesel NFI buses. They recommended adding an audible alarm to the silent vehicles for the garage personnel safety, and adding special lifts and equipment to change batteries and equipment. The staff expected that in time, electric buses will become easier to maintain compared to diesel buses since they have fewer parts, less fluids and the components are larger. [3]

3.9 Fleet Management

- Since the range of the 60 electric buses under trial is proving to be less than the original equipment manufacturer's (OEM) advertised range, TTC has made adjustments to bus

dispatching. As such, the electric buses are not necessarily accumulating as much mileage compared to diesels and hybrids within the fleet.

- Vehicle telematics has been a key enabling technology for transit fleet management, operations and maintenance.
- King County has found, along with many transit agencies deploying electric bus, parts availability is a common issue, and recommends transit agencies to keep more spare parts on hand [6].
- The global supply chain shortages have impacted transit operations in the following manners:
 - Shortages of raw materials have increased the lead time for electrical components and cabling.
 - The electronic chip shortage has impacted all bus types including electric and diesel/hybrid buses⁸.
 - The lead time for parts has improved since the COVID-19 pandemic lockdowns, but has not recovered to 2019 levels.
 - Though electric buses have fewer parts, electric specific parts can be more expensive and require longer lead time (i.e. electrical component, HV cabling), especially since the electric bus market is currently very small. [7]
 - Longer lead times can keep buses out of service longer.
- Inflation has impacted transit operations, since budgets are put together based on costs when supply contracts are negotiated (1-3 years in advance). The price volatility has been challenging for both transit agencies and suppliers.
- For TTC, it typically takes 1 year to establish a supply program for consumable spares for a brand-new vehicle platform. This lines up with the operations and maintenance programs, where it takes about a year to get to know the buses, better understand what parts fail and how often, and the quantities of components needed.

3.10 Transit Users

- Many TTC transit users have noticed that the electric buses provide a smoother ride. People who live along bus routes have complimented on the buses being quieter as well.
- The feedback from TTC's transit users survey were generally positive,
 - 91% were satisfied with NFI buses (85% liked electric buses better than other TTC buses)
 - 83% were satisfied with BYD buses (83% liked electric buses better than other TTC buses)
 - 79% were satisfied with Proterra buses (69% liked electric buses better than other TTC buses)
- During the electric bus trial in Edmonton (2015-2016), a survey of the transit customers was completed as well. The survey of transit riders was intended to better understand the users' perception of electric buses, determine the quality and comfort of the ride, whether there was public support for ETS to purchase more electric buses, and whether there was willingness to pay more in fares for the electric buses [3]. A total of 2,825 surveys were collected:
 - 57% of users rode the NFI bus and 41% rode the BYD bus

⁸ Used in engine controllers.

- 92% noticed that the design of the bus was different from other types of ETS buses
- 78% would like ETS to purchase electric buses
- 64% were willing to pay more for electric bus service
- 73% said that the electric buses were better (43%) or much better (30%) in noise compared to other types of ETS buses
- 72% considered the electric buses as being better (38%) or much better (34%) with respect to fumes compared to other types of ETS buses
- 66% said that the smoothness of ride was better (40%) or much better (26%) compared to other types of ETS buses
- 80% rated the temperature on the electric buses as “comfortable”
- Transit user experience was also reported for the Foothill Transit electric bus trial. According to [7], it appears that younger riders are generally more supportive of zero emissions type of transportation solutions, while other passengers placed much more emphasis on being able to travel to their destinations faster. Foothill Transit also reported that the automated bus docking at charging stations often confused riders and pedestrians. Since passengers associate buses stopping with the ability to embark and disembark. Some became frustrated when the automated docking process takes over, even if it was only for a few minutes.

4 Gaps and Opportunities for Electric Buses

This section presents a consolidated summary of gaps and opportunities identified from the literature review, survey results, technical tours, and consultations.

4.1 Gaps

- Both CUTRIC and Massachusetts' Department of Transportation emphasized the importance for transit agencies that have trialed and integrated electric buses to share their experience and information, which will go a long way to reducing risks and unknowns for the entire transit community [15] [4].
- Since electric buses are more expensive to buy, some procurement decisions have been made based on potential cost savings. TTC's experience indicated that, to date:
 - Depending on the charging strategy (depot charging versus on route charging), diesel fuel cost, efficiencies of the charging regime for the fleet, along with the complexities of electricity rate makes it difficult to determine the potential cost savings from fuel offset.
 - Not enough data has been collected to determine whether there are/will be significant savings in maintenance for electric buses (such as brake wear), or more wear (such as faster tire degradation due to electric buses being heavier). It is also important to note that electric buses generally do not accumulate mileage as fast as diesel buses since their range is limited.
 - There are expected savings from the Clean Fuel Regulation⁹, but this is a relatively new process for transits.
- Since electric buses are relatively new to the market, TTC's experience indicate that, to date:
 - Not enough data has been collected to determine the service life of charging systems, though the plug-in chargers at TTC's Arrow Road transit garage have been operating reliably since 2019.
 - Not enough data has been collected to determine the service life cycle of electric buses and components. It is expected that since the 60 electric buses under trial are early OEM bus generations, the components may not perform as well in Canadian operating environments.
 - The industry (OEMs and critical parts suppliers) is still developing electric bus specific procedures, such as, detailed de-energizing processes, service and inspection intervals, detailed maintenance manuals with fault code libraries and diagnosis trees, optimized spare parts list, etc.
- Transit agencies would like to see longer term battery warranties as battery life and degradation is very much unknown at this time.
- In terms of availability, electric bus trials reviewed to date have not provided sufficient data to shed light on this topic in a long term setting in North America [20].

⁹ <https://www.canada.ca/en/environment-climate-change/services/managing-pollution/energy-production/fuel-regulations/clean-fuel-regulations/compliance.html>

- Diesel fuel is still used for auxiliary heaters of busses, typically with no emissions controls.

4.2 Opportunities

1. Modelling tools to support planning and procurement, such as range predictions, route planning, charging methods, life cycle cost analysis, and electricity rates. According to [7], a number of transit agencies surveyed indicated that these types of advanced tools would be beneficial. TTC also indicated that there is a need to have better insight and more accurate tools to better understand energy consumption. [11]
2. Develop standard methods to measure range, in a more real-world setting [17], [20]. Since electric bus range is affected by many factors, such as capacity, age, climate and operational scenarios, the actual ranges generally fall short of advertised ranges from OEMs. The current Altoona efficiencies testing method could be augmented with more real-world operating scenarios.
3. Research to better understand battery health and degradation. According to [20], as with range, battery health, usable capacity, and state of charge can be complex and affected by a multitude of factors. Since batteries are critical for electric buses, and especially since over time, the electric buses in service will be experiencing capacity fade [10], more insight is needed to monitor, measure, and track degradation issues, to better plan for operations, maintenance, and warranty.
4. Technologies to better manage charging. [20] indicated that there is value in automated solutions that optimize the charging of fleets to minimize electricity costs.
5. Autonomous driving systems [20], such as blind spot warning, lane assist and automated braking features that are already commonly available in light duty vehicles. While automation in transit might be a long-term process, there are many potential short-term opportunities, such as garage management, automated parking, and docking with chargers.
6. Standardized methods to assess service life cycle costs, especially in the procurement phases [7]. Considering the technology is relatively new, there is a need for data and experience from current electric bus trials underway to inform future policies and standards in this regard. In addition, service life cycle considerations needs to take a more holistic approach of incorporating the cost and benefits of displacing GHG emissions and air pollutants.
7. When managing large fleets such as transit fleets, standardization becomes important. Industry wide, there is an opportunity for OEMs and critical parts suppliers to work together to standardize specifications, components, and procedures, where possible.
8. Telematics data that is collected as part of trials and operations could be better leveraged by OEMs and parts suppliers for maintenance, vehicle self diagnosis, and the scheduling of predicative maintenance activities.

5 Conclusions

The objective of this project is to better understand the experience and perspectives of stakeholders who have played a role in the policy, planning, procurement, integration, operations, and maintenance of battery electric buses, in addition to those who use transit.

These perspectives and experiences were gathered through a range of different methods, including a series of literature scans and reviews, leveraging of TTC's internal surveys, and tours and conversations with stakeholders at electrified transit garages in Toronto, Edmonton, and Ottawa. In addition, in-depth discussions were held with stakeholders as per the stakeholder consultation plan in Table 1.

The consultation process has made it clear that the electrification of transit is an important strategy in Canada's goal to fight climate change. Many municipalities have long term plans to fully convert their transit fleet to zero emission vehicles despite current technical challenges, and that the long-range electric buses currently on the market may not be able to replace diesel buses on a one-to-one ratio.

Feasibility studies, modelling and pilots have been recommended by multiple organizations, as tools to help transit agencies better understand their fleet operational needs, and profile routes to match the capabilities of the buses based on a variety of factors such as driving range, duty cycle, charging, and schedules.

Key procurement lessons learned from TTC's 60 electric bus trial include the need for evidence of successful completion of relevant Altoona tests, demonstrated in-service experience of bus structure being corrosion resistant, a minimum usable battery capacity, and multi-method charging compatibilities.

With regards to charging infrastructure, many organizations emphasize the need to engage utility providers early to ensure that there is sufficient grid capacity for fleet electrification. At the time of writing, neither plug-in chargers nor pantographs have emerged as the preferred charging technology option for Canadian transits.

TTC and ETS [3] indicated it is beneficial for planning and integration to test electric buses independently of revenue service to establish energy consumption baselines through different seasons, and under controlled operating conditions.

Proper training of operations and maintenance staff is critical to the successful integration of zero emission bus fleets [4] [5] [6]. Due to the current demand for electric buses, it might be challenging to schedule training by OEMs and key suppliers since the trainers can be fully booked months in advance.

Multiple transit agencies have found that there were initial hesitations from maintenance staff to work on electric buses due to the presence of HV. TTC has found that training has been effective in reducing people's fear, and on the flip side, many bus maintenance staff were interested in becoming early adopters.

One of the biggest concerns identified by transit authorities throughout the literature review and consultations, was whether the range of current battery electric bus offerings is sufficient to service their

existing operations. The data presented in recent electric bus trials in North America on battery electric bus range has been somewhat conflicting. For example, while most transit trials observed a decrease in electric bus range/performance in cold weather, MARCON did not observe a correlation during the Edmonton trial. Nevertheless, how far an electric bus can travel on a single charge remains one of the key concerns for transits, especially since most transit authorities found that their buses do not achieve the OEM advertised range.

TTC's internal survey results indicated that operators have a preference for the hybrid buses within the TTC fleet when electric buses are compared directly with hybrids. This may be due to the fact that the operators are more familiar with the hybrid buses within the fleet. However, operators do prefer the quietness of electric buses and their ability to accelerate over hybrid buses. And depending on the electric bus model, operators also like the steering, braking and ride comfort aspect of its design.

The maintenance of electric buses is sufficiently different that the initial learning curve can be quite steep, as found in TTC and ETS' experience. For ETS, the mechanical, maintenance and service staff during the electric bus trial felt that in general, despite the training received, they were not as prepared to address many of the issues and challenges they experienced. [3]

Vehicle telematics has been a key enabling technology for transit fleet management, operations and maintenance.

Because the range of electric buses is limited on a single charge, transit authorities such as TTC adjust bus dispatching to make the best use of the buses within their range limitations. As such, electric buses may not accumulate mileage as fast compared to diesels and hybrids within the same fleet.

The global supply chain shortages and inflations has impacted transit operations. It is currently unclear as to how this will impact fleet electrification in the long run.

Many TTC transit users have noticed that the electric buses provide a smoother ride, as well, people who live along bus routes have complimented on the buses being quieter. Most transit users surveyed by ETS like electric buses better than other buses within the Edmonton fleet. In Foothill California, it appears that younger riders are generally more supportive of zero emissions type of transportation solutions, while other passengers placed much more emphasis on being able to travel to their destinations faster. [7]

6 Recommendations

This section presents a consolidated list of recommendations for future research.

1. Develop standard methods to help transit agencies better forecast charging costs.
2. Develop methods/technologies to help transit agencies better manage the simultaneous charging of large fleets, to minimize cost and impact to utility grid.
3. Gather and analyze data from long term and large-scale electric bus trials to examine maintenance data to determine savings in maintenance for electric buses, in context with their operational use (or mileage), and the service life cycle of electric buses and components.
4. Gather and analyze data from long-term and large-scale electric bus trials to examine availability data to determine their long-term performance.
5. Examine alternative and cleaner technologies for cold weather auxiliary heating of buses.
6. Develop advance modelling tools to support planning and procurement, such as range predictions, route planning, charging methods, life cycle cost analysis, and electricity rates.
7. Develop standard methods to measure electric bus range, in a more real-world setting.
8. Perform research to better understand battery health and degradation.
9. Adapt autonomous driving systems [\[20\]](#) to electric buses, such as blind spot warning, lane assist, automated braking features that are already commonly available in light duty vehicles.
10. Develop autonomous assistance features, such as garage management, automated parking, and docking with chargers.

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A-1 TTC's Arrow Road Transit Garage

The Arrow Road transit garage is the home garage of fifteen New Flyer electric buses (Figure 2).



Figure 2: A New Flyer electric bus (left) and operator dash board (right)

The garage has both indoor and outdoor parking, and is equipped with direct current (DC) indoor and outdoor chargers as shown in Figure 3. At Arrow Road, there are 4 outdoor chargers installed, even though electric buses primarily use indoor parking and charging facilities.

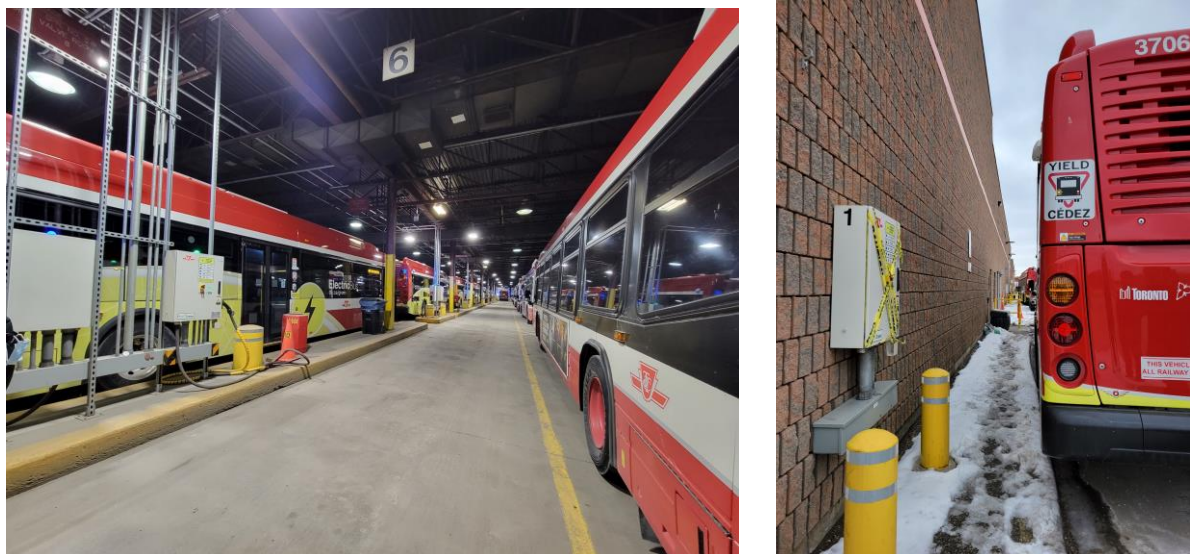


Figure 3: Arrow Road garage electric bus chargers (left: floor mounted, right: wall mounted)

Charging infrastructure can take up a great deal of space as shown in Figure 4, and since land in Toronto is very expensive, charging equipment footprint is a major design consideration at TTC.



Figure 4: Example rectifiers¹⁰ (left) and charging equipment panel (right)

The Arrow Road facility is also equipped with a 6 Megawatt (MW) capacity compressed natural gas backup generator and a 4 MW battery energy storage system as shown in Figure 5.



Figure 5: Arrow Road garage backup system (left: natural gas generators, right: batter energy storage system)

Other than special electric bus parking zones within the garage, electric buses are generally serviced and maintained within the same facilities as other buses within the TTC fleet, as shown in Figure 6.

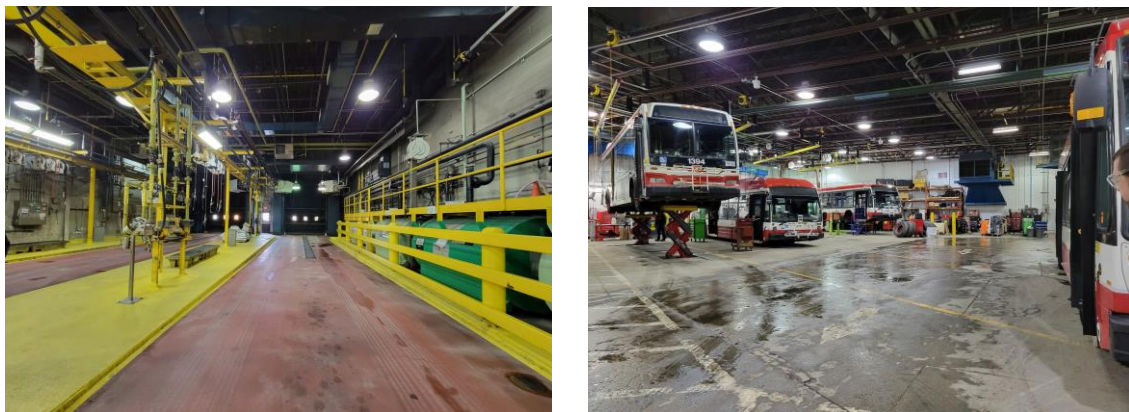


Figure 6: Arrow Road garage facilities (left: bus service bay, right: bus maintenance bay)

¹⁰ One is needed for every 2 chargers.

A-2 TTC's Mount Dennis Transit Garage

The Mount Dennis garage is the home garage of Proterra electric buses (Figure 7).



Figure 7: A Proterra electric bus (left) and operator dash board (right)

Similar to the Arrow Road garage, Mount Dennis has both indoor and outdoor bus parking, and is equipped with DC indoor (Figure 8) and outdoor chargers. At Mount Dennis, there are 4 outdoor chargers installed, even though electric buses primarily use indoor parking and charging facilities.

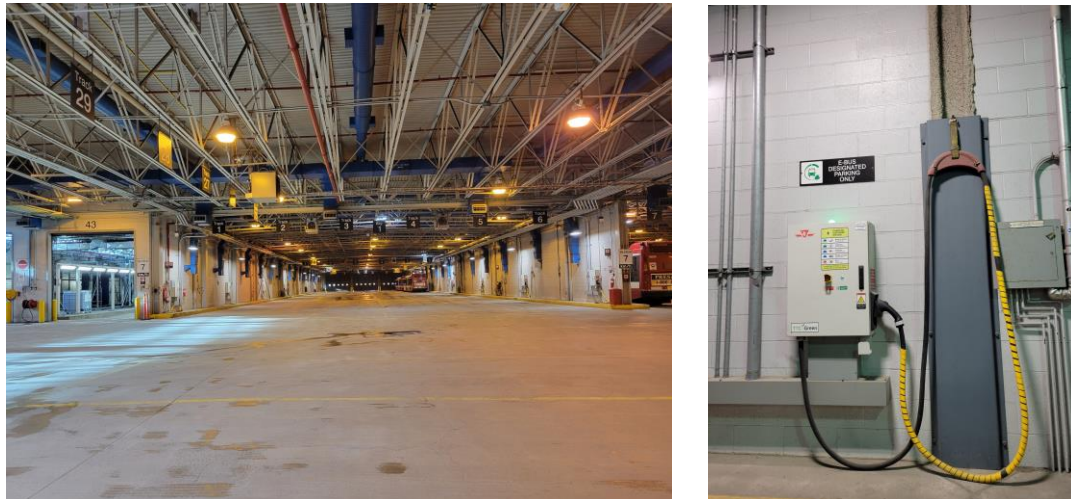


Figure 8: Mount Dennis garage (left: indoor bus parking, right: electric bus wall mounted charger)

Other than special electric bus parking zones within the garage (due to the locations of chargers), electric buses are generally serviced and maintained within the same facilities as other buses within the TTC fleet, as shown in Figure 9.

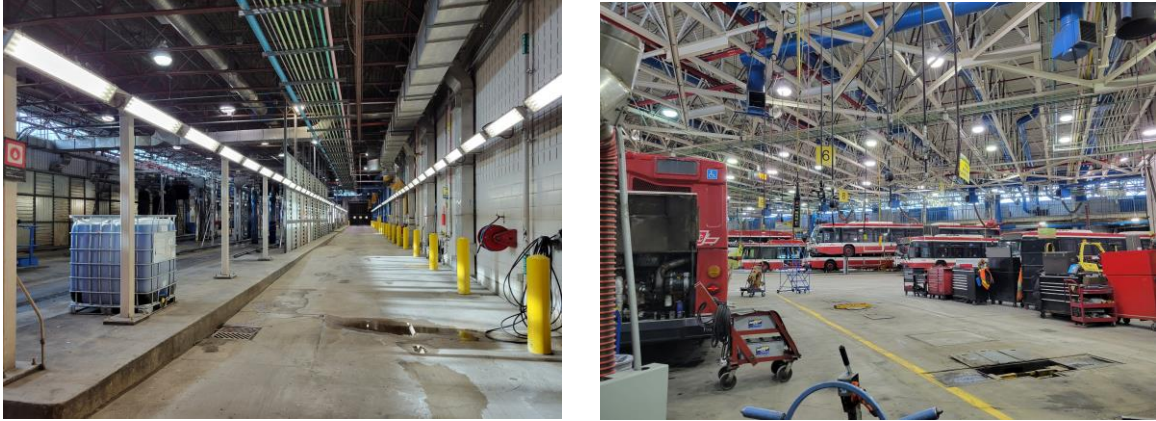


Figure 9: Mount Dennis garage facilities (left: bus service bay, right: bus maintenance bay)

The Mount Dennis garage is also equipped with a 4 MW battery energy storage system

A-3 TTC's Eglinton Transit Garage

The Eglinton garage is the home garage of BYD electric buses (Figure 10).



Figure 10: A BYD electric bus (left) and operator dash board (right)

Bus parking at Eglinton is primarily outdoors (Figure 11), though electric buses have dedicated indoor parking. The chargers installed at Eglinton are AC chargers from BYD. Similar to Arrow Road and Mount Dennis, there are 4 chargers installed outdoors.

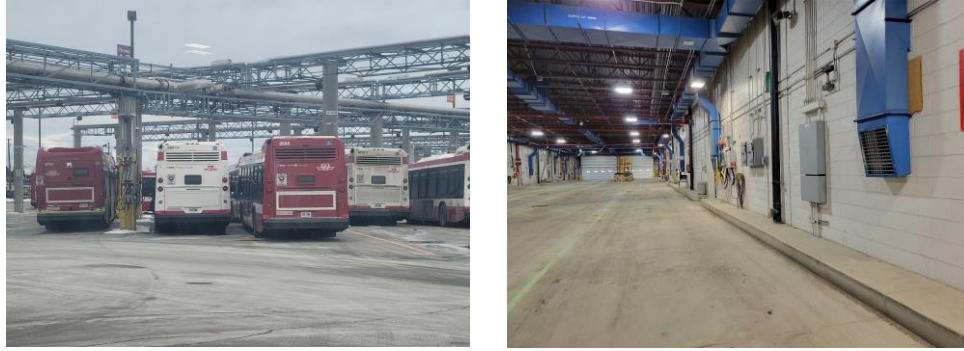


Figure 11: Eglinton garage (left: outdoor bus parking, right: indoor electric bus parking with wall mounted chargers)

Again, similar to the Arrow Road garage, other than special electric bus parking zones within the garage, electric bus are generally serviced and maintained within the facilities as other buses within the TTC fleet, as shown in Figure 12.

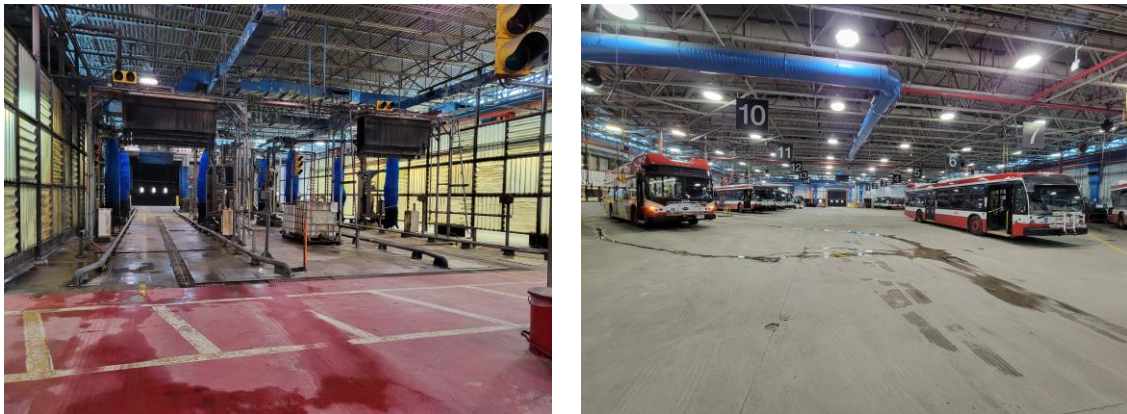


Figure 12: Eglinton garage facilities (left: bus service bay, right: bus maintenance bay)

The Eglinton garage is equipped with a 4 MW battery energy storage system

A-4 TTC's Birchmount Transit Garage

The Birchmount transit garage is the home garage of ten New Flyer electric buses. The garage has only outdoor parking, and has been fitted with pantograph charging systems at dedicated electric bus parking zones as shown in Figure 13.



Figure 13: Birchmount garage pantograph chargers

Similar to other garages, electric buses are generally serviced and maintained within the same facilities as other buses within the TTC fleet.

A-5 ETS' Kathleen Andrews Transit Garage

ETS' Kathleen Andrews transit garage, a LEED Silver certified (Figure 14) facility, houses 30 of Edmonton's 40 Proterra electric buses (Figure 15).

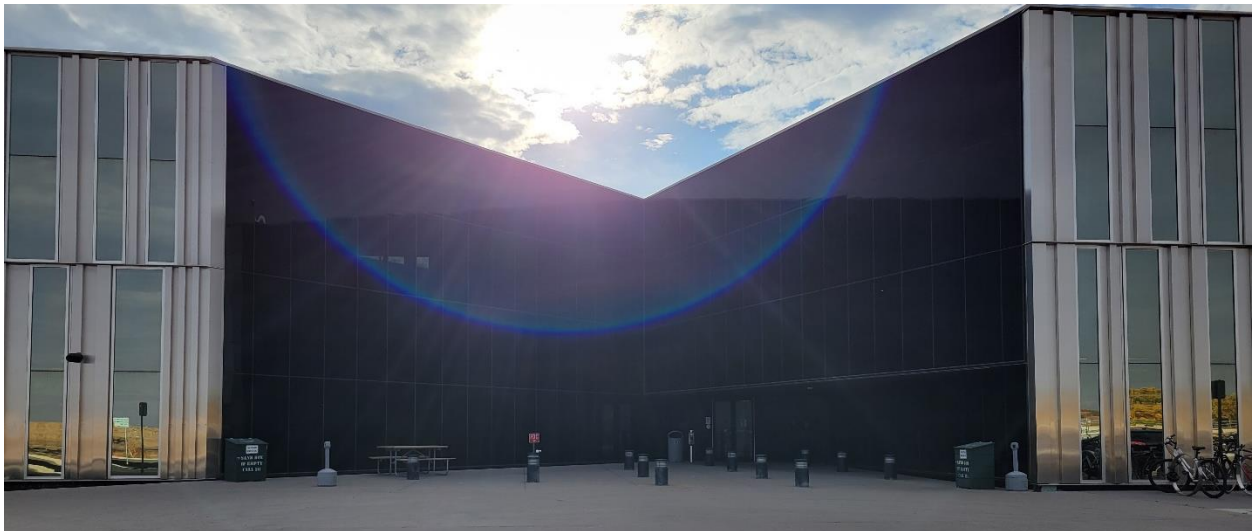


Figure 14: ETS' Kathleen Andrews transit garage



Figure 15: ETS' Proterra electric bus

At ETS, after each shift, the buses arrive in the garage and gets pre-rinsed in the bay as shown in Figure 16.

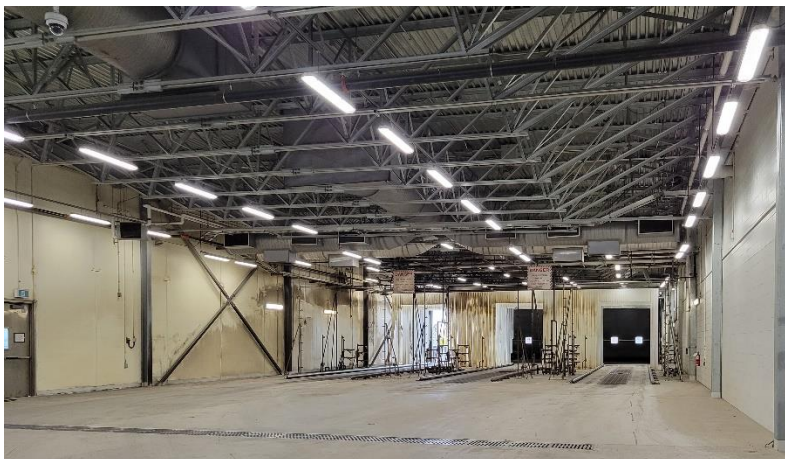


Figure 16: Bus pre-rinse bay

Since the Proterra electric buses are a bit wider compared to the rest of the fleet, the buses require careful maneuvering through the guided wheel tracks. Bus sizing is a consideration for many transits with fixed infrastructure already in place.

The buses then navigate through to the vehicle wash bay as shown in Figure 17.



Figure 17: Bus wash bay

Electric buses are parked indoors in the underground garage, fitted with overhead pantographs charging systems. Electric buses drive in along the red or yellow lines as shown in Figure 18 (left). The WIFI system on the bus connects with the Wi-Fi system on the charger as seen in Figure 18 (right). Once the wireless connection is made, the charger would lower the pantograph to dock with the bus and initiate charging.

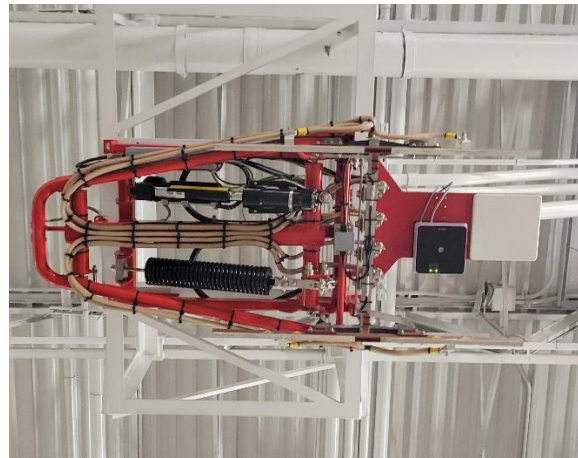
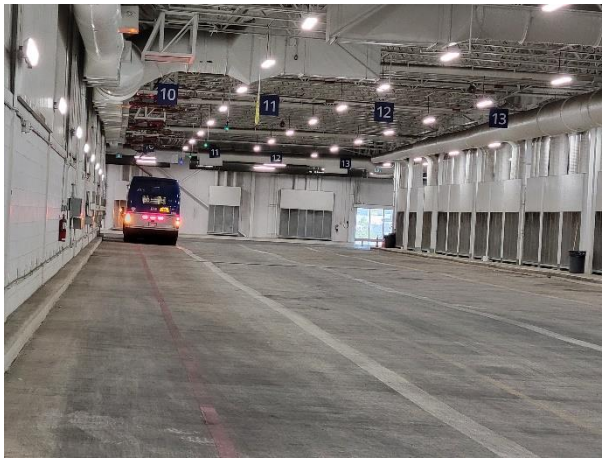


Figure 18: Electric bus parking and charging bay

ETS staff indicated that the Wi-Fi connections can be problematic, since so many chargers are in close proximity that the buses sometimes have a hard time connecting with the charger that it has parked directly under. Some staff didn't think that the pantograph set up is necessary, since simple chargers mounted overhead with long cords may be a cheaper alternative.

The vehicle maintenance bay is located on the main level of the garage as shown in Figure 19. It is set up to provide maintenance to all ETS bus fleet types as shown in Figure 20.



Figure 19: Bus maintenance bay

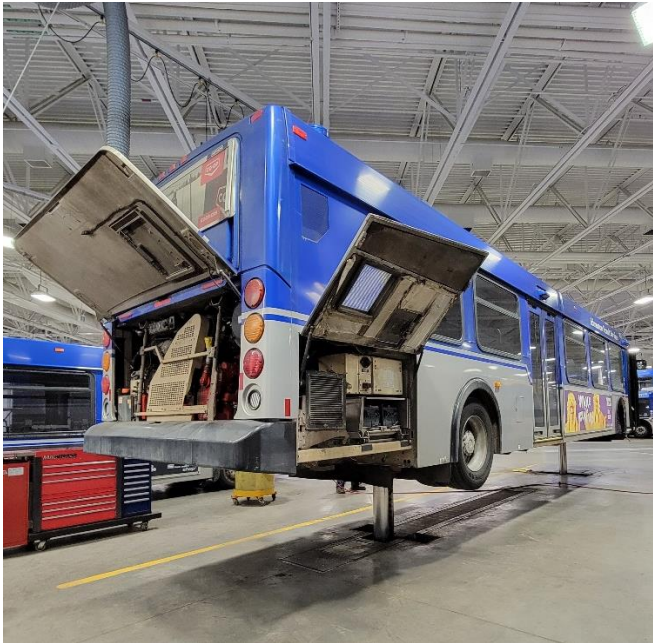
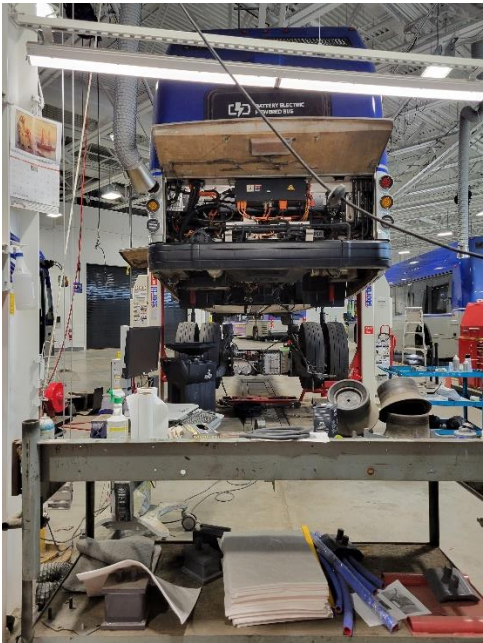


Figure 20: Maintenance being done on an electric bus (left) and conventional bus (right)

Multiple work stations are set up for electric bus maintenance, as shown in Figure 21, complete with slower bus chargers.

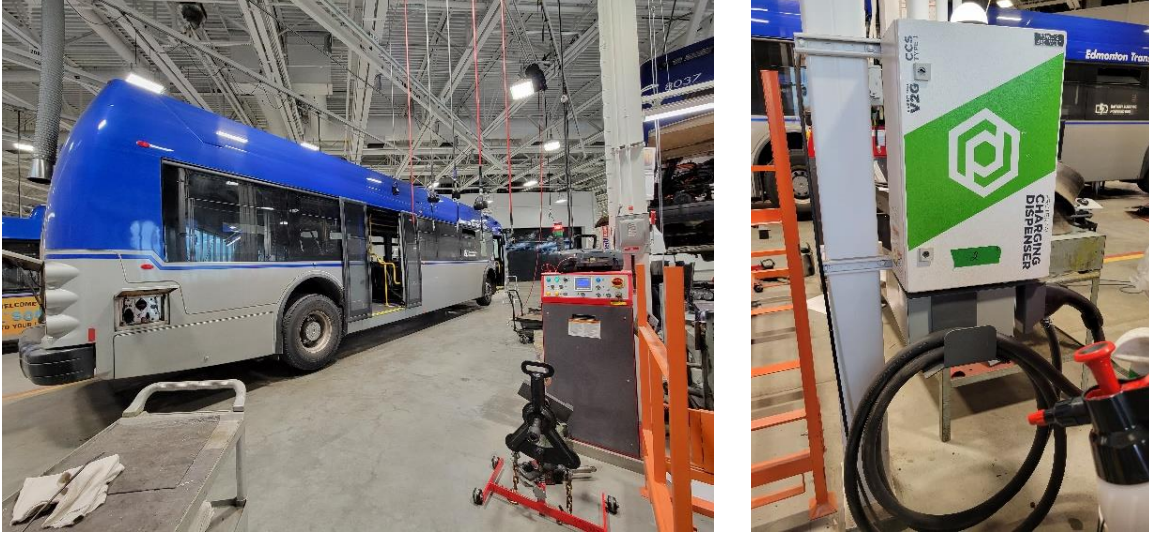


Figure 21: Electric bus maintenance station with slower charger

ETS staff indicated that there has been a very large learning curve with maintaining electric buses, but in time, it will get easier. Electric buses have fewer moving parts, but the global supply chain issues have made it hard to keep enough spare parts readily available. Operations have not been impacted, but it has been very challenging. Diesel bus spare parts are impacted in the same manner.

A-6 OC Transpo’s St. Laurent Transit Garage

OC Transpo’s St. Laurent transit garage is the home garage of four 40 ft New Flyer XE40 electric buses (Figure 22), which are part of OC Transpo’s zero emission bus pilot project launched in 2022. The garage has been outfitted with two different types of floor mounted plug-in chargers (Figure 23, left and middle), in addition to a pantograph charging system (Figure 23, right).

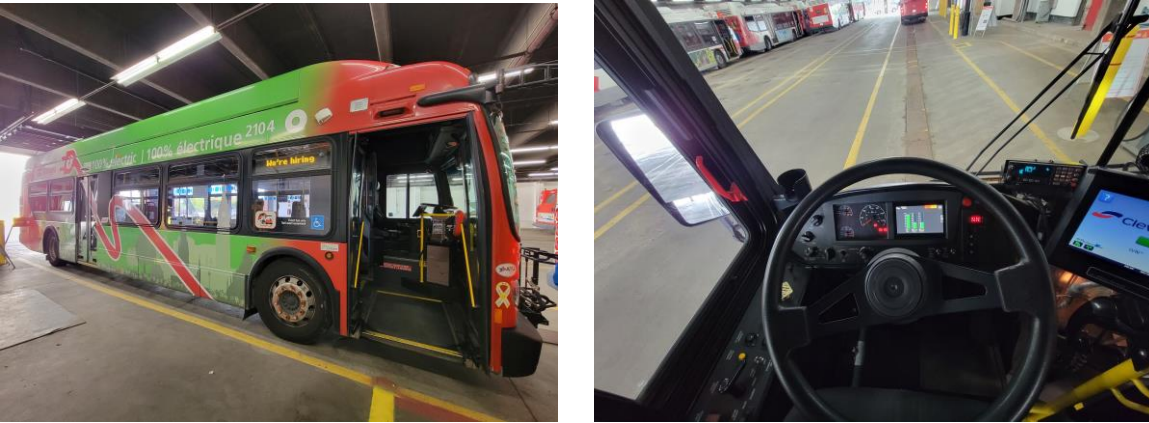


Figure 22: OC Transpo’s New Flyer electric bus and operator’s dash



Figure 23: OC Transpo's electric bus Charging Systems

OC Transpo's long term plan is to add 26 zero emission buses in 2024, and the entire fleet to be zero emissions by 2036.

