



Electric Bus Feasibility Study

JUNE 2016

PREPARED BY

MARCON

Edmonton

ELECTRIC BUS FEASIBILITY STUDY FOR THE CITY OF EDMONTON

JUNE 2016



A REPORT PREPARED BY
MARCOON

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1 Executive Summary

1.1 Description of Mandate

The primary objective of this study, undertaken by MARCON, was to determine whether or not it is feasible to introduce battery electric buses (“e-buses”) in service in Edmonton. Should e-buses reliably operate in Edmonton’s winter conditions without major restrictions, then MARCON was tasked to assess the economic and environmental impacts of integrating them into the Edmonton Transit System (ETS) fleet.

The project also aimed at gauging the perceptions of the riders with regards to e-buses as well as the attitude of ETS and Fleet Services staff towards them.

Finally, MARCON examined the potential impact of e-buses on factors external to ETS: the City, its citizens and the power grid.

Based on the findings of this study, MARCON was asked to formulate recommendations for consideration by the Transportation Committee of the City regarding the adoption of electric buses in the ETS fleet.

1.2 Conclusions

Based on the information available at the time this report was prepared, MARCON predicts that electric buses used in service in Edmonton can perform as reliably as the rest of the fleet of diesel buses but will require thorough planning, training, and resources to ensure the City of Edmonton derives the full benefits of their use.

Electric buses generate environmental and potential economic benefits. An e-bus operating today will emit approximately 38-44% less CO₂^e (from the power generators) than its diesel equivalent. Although important from the start, the environmental benefits for Edmonton will increase over time, as the power used to charge the buses originates from an increasingly clean source. It is also expected that the economic benefits of using e-buses relative to using the diesel buses will grow in the future as the cost of operating diesel buses will outpace that of e-buses due to diesel fuel price increases, to rising carbon cost and to electricity prices continuing to progress at a slower pace than that of diesel, as has been the case in the past.

E-buses are a better choice for the environment than the current diesel fleet. Investment in electric vehicles improves air quality in the city, and in the atmosphere. The electric transportation modal shift is expected to accelerate as the cost of batteries decreases and electric vehicle performance improves. ETS can be a catalyst for this transition by demonstrating how electric vehicles can operate reliably in Edmonton’s winter climate, and by causing the utilities and regulators to plan for the infrastructure modifications that are required for their use.

Based on the results of the field trial conducted in Edmonton and on the experience of other Canadian transit systems' evaluations during winter months, e-buses can be

expected to operate effectively in Edmonton in winter within the operating limitations of the technology.

While electric motors have long been used in industry, batteries as a main source of energy made their entry in the transit market less than 10 years ago with the advent of diesel-electric hybrid buses. From a reliability perspective, they have performed very well. Batteries installed on diesel-electric hybrid buses have in fact exceeded industry expectations in terms of their life and degradation performances. But new battery chemistries are reaching the market, sometimes without the benefit of a proven track record. This represents a risk for ETS but at least one manufacturer has expressed a willingness to offer innovative financing terms for their buses that might make it possible to shift the risk of ownership of the energy storage system to the manufacturer.

Handling batteries in the maintenance garage or in the context of accidents requires that operators, first responders and maintenance staff know the risks associated with the battery chemistry selected when e-buses are purchased, and that all personnel be trained accordingly to mitigate such risks.

Adopting a new technology invariably presents operational risks as well. If nothing else, time is required for staff to adapt to the new vehicles. The field trial has shown that operators have quickly adapted to the test vehicles with a minimal amount of training and under conditions that were not ideal given the equipment provided by manufacturers was available for such a short period of time. The adaptation period will be longer for maintenance staff as technicians will have to learn to deal with issues currently unfamiliar to them.

The current shorter range of e-buses compared to diesel buses theoretically implies that more e-buses may be required to provide a level of service equivalent to diesel buses. However, MARCON's evaluation of current service plans shows that ETS operates a sufficient number of blocks¹ with total distance well within the range of e-buses (even with a 15% to 20% energy reserve margin) that it can place e-buses in service without concern or significant change to its operations.

Trickle-charged buses can service almost 85% of the weekday blocks but, because the blocks call for longer distances during the weekend, these same buses can be assigned to only a third of the current blocks on Saturdays and Sundays. A considerably larger proportion of the weekend blocks could be allocated to trickle-charged e-buses if the design of blocks was optimized for electric buses. Future generations of electric buses are also expected to totally mitigate this situation. As for en-route charged e-buses, they can service all the blocks currently serviced by the Westwood garage, provided en-route chargers are located at all the transit stations where the e-buses will visit.

¹ Blocks: the set of route assignments to be serviced on a single trip by a bus (from departing the garage to returning to the garage).

Although field trials revealed that e-buses are able to negotiate the steepest hills in the ETS service area without suffering an adverse impact on range, they also demonstrated that the use of diesel heaters on an e-bus provides more certainty regarding the range of the vehicle, with minimal environmental impact. The operation of electric heaters requires about 20% of the energy stored in the batteries, further reducing the effective operating range of the bus. Evidence at other Canadian transit agencies that evaluated the buses in summer indicates air conditioning has a similar negative effect on range.

Two charging technologies were appraised during this project: (rapid) en-route charging (pantographs installed at transit centres provide a quick charge to the buses - 5 minutes) and (slow) trickle charging (buses are charged at the garage overnight and/or between blocks). The use of en-route charged e-buses presents risks that are different than those of operating trickle-charged buses. With the former, the charging infrastructure required can be restrictive in terms of route planning flexibility as the cost of moving the charging equipment once in place is high. With trickle-charged buses, an electricity grid failure where the garage is located may cripple the e-bus fleet for the duration of the failure (unless a sufficiently large backup generator is installed). The current range of trickle-charged e-buses can also limit the blocks that can be assigned to those buses.

One of the benefits of using either type of e-bus is the expected increase in customer satisfaction. A large majority of current customers expressed their preference for these clean, quiet e-buses. Almost two-thirds of the survey respondents are even willing to pay a premium to ride them.

Using the latest generation of e-buses will also have an impact on the image of Edmonton as being a progressive, environmentally conscious city.

The introduction of a small fleet of e-buses at ETS can be accommodated by the current capacity of the electricity grid in Edmonton; particularly at the proposed new North East Transit Garage (NETG). However, if e-buses are introduced in large numbers, portions of the electricity grid in Edmonton may need to be upgraded to ensure there is sufficient power at the locations where the large fleet would be charged.

Electric buses used in the field trial were simply assigned to existing blocks. These blocks were created to serve ETS clientele using diesel buses. The duty cycle used for the economic calculations performed by MARCON was not optimized for e-buses. Consequently, the economic lifecycle cost forecast presented in this study must be considered conservative. The lifecycle cost associated with purchasing and operating 40 e-buses out of the new NETG is comparable to that of using the latest generation of diesel buses on the market as it falls well within the margin of error provided in this report. The net present value of the lifecycle cost of a fleet of 40 latest generation diesel, trickle charged electric, and en-route charged electric buses is respectively \$69,596,176, \$69,916,319 and \$89,859,999. There is no significant difference in the lifecycle cost of substituting diesel buses by trickle-charged e-buses. MARCON therefore concludes that it is technically and economically feasible to introduce e-buses in the ETS fleet.

1.3 Main findings

1.3.1 Customer perceptions of the e-buses

A survey of riders was undertaken to:

- Assess bus users' perceptions of electric buses
- Determine how electric bus features impact the quality and comfort of the ride
- Determine if riders would like ETS to purchase electric buses
- Ascertain rider willingness to pay more for bus service to allow for ETS to purchase electric buses.

In total, 2,825 questionnaires were collected from ETS customers riding on the electric buses that were being tested. Socio-demographic information was collected (age, employment status and number of one-way trips per typical week) to determine potential statistically significant differences by population segment.

The results of the survey are statistically significant at a confidence level of 95% with a margin of error of ± 1.8 . The results of the survey were compared to the August 2014 ETS survey "Stealth Bus Customer Survey - Interim Topline Report".

Both surveys found that Edmonton bus riders are very favourable to e-buses. E-buses were considered superior on every performance aspect evaluated by customers.

1.3.2 ETS and City Staff perceptions of the e-buses

MARCON undertook qualitative research with the staff that was involved in the field test. Focus group discussions and in-person interviews were undertaken with bus operators and with maintenance and mechanical staff, pre and post the electric bus trials.

From a staff perspective, integrating e-buses into the ETS fleet and operations will require:

- Relevant training of bus operations and mechanical, maintenance and service staff
- Preparation with unions to resolve potential issues related to compensation and responsibilities
- Bus design that reflects the needs of drivers and riders.

Adequate training will be key to ensuring staff buy-in and a smoother integration of the new technology. The staff interviewed, particularly the bus operators, are confident that with sufficient training, *"getting accustomed to this new technology will be like getting accustomed to any new bus"*. **Generally, bus operators are very positive concerning the adoption of e-buses in Edmonton as they feel it would be an improvement for their passengers and for themselves. Maintenance and service personnel remained cautious with regards to their integration in ETS' fleet.**

1.3.3 Description of the Field Trials

Two models of electric buses were evaluated during the field trials: one BYD 40-foot (40') Second Generation bus; and, one New Flyer 40' bus. The BYD bus had a 324 kWh Lithium Iron Phosphate battery and an auxiliary diesel heater to provide heat to the



passenger compartment. The New Flyer had a 200 kWh Lithium-nickel-manganese-cobalt battery and was heated with a diesel/electric heater combination. Two New Flyer Xcelsior diesel buses (model year 2013) were provided from the ETS fleet to provide a control baseline for comparison purposes. New Flyer Industries is based in Winnipeg (MB); BYD is a Chinese owned company but manufactures its e-buses for the North American market at its plant in Lancaster (CA) and, according to BYD, 68% of their components are sourced in



North America. A second BYD bus with an electric heater arrived in Edmonton at the end of January and was not a formal part of the field trial although operating data was collected by ETS. Buses from the two other manufacturers in North America, Nova Bus and Proterra, were not available for the field trials.

Despite the relatively short evaluation period of five weeks, MARCON was able to make reasonable comparisons between the buses by carefully designing the test routes and capturing operating data, along with route and weather factors for a meaningful test at ETS.

The BYD bus accumulated 3,750 km, the NFI bus 2,834 km, and the two diesel control buses 5,082 and 4,464 km respectively. The test program was designed to answer several questions, but mainly: *can e-buses perform on all routes in winter conditions in Edmonton?* Service blocks were chosen for each test route that covered both morning and afternoon peak service over the steepest hills in the network. As much as was practical, the test blocks also operated on higher capacity routes, and through the river valley up and down hills. These test routes included service on weekdays only. The test buses were operated on some weekends as operator and bus availability allowed.

Temperature and snow data for the evaluation period were recorded with observations noted twice daily on weekdays, and once on weekends at times that corresponded approximately to the middle of the selected route run times for the buses. Edmonton experienced an unseasonably warm 2015-2016 winter, and for most of the test period. Colder days were examined closely and compared to warmer days for energy use data. On board temperature data was also recorded and the e-buses all maintained temperatures above 15°C throughout their runs, even on very cold days.

The electric buses were quite reliable and operated most days at over 90% availability during the field trial. Problems were corrected within a reasonable amount of time. No electric propulsion system problems occurred during the field trials and all maintenance items were related to non-propulsion systems during the test period.

Operating range and energy use were primary factors in determining bus operating strategy and cost analysis. The BYD bus consumed less energy per km (1.04 - 1.25 kWh/km) than the NFI bus (1.25 - 1.38 kWh/km) resulting in recommended effective range for the BYD bus of 220 - 264 km and the NFI bus of 116 - 128 km (the most conservative figure was used in our economic and environmental impact calculations). The difference in range is explained by the disparity in battery size and by the technologies used for heating the interior of the buses. The diesel control buses have a maximum range of 800 km. These results were comparable to those arrived at in other trials in Canada and the US. No direct correlation was observed between energy usage and ambient outdoor temperature, which reached below -20°C on several days. However, if electric heaters are used, range could decrease between 15 and 25%.

The interior noise level for the electric buses at idle is noticeably lower than for diesel buses. Under acceleration, the noise levels are comparable. The acceleration of the NFI e-bus is marginally faster than the BYD bus and the diesel bus. However the acceleration of both the electric buses is much smoother with more torque than the diesel buses available at lower speeds. Braking distances are comparable.

1.3.4 Expected reliability of e-buses in service

E-buses have only been operating in Canada on a test basis but there are a few larger fleets in operation in the USA, in Asia, and in Europe. A review of these tests and reports and the analysis of the differences between standard diesel buses and e-buses provided a reasonable measure and qualified commentaries on the general reliability of e-buses.

During the ETS test program, there were a number of maintenance and operating problems not directly related to battery propulsion technology or its accessories that kept the buses off the road for maintenance purposes. Some downtime was attributable to technician and operator unfamiliarity or unavailability of some spare parts for the vehicles. In a larger *in-service* fleet, significant efforts would be made to specify buses in detail, arrange training for operators, service and maintenance staffs, and provide service support, parts supply, and warranty terms.

MARCON reviewed many aspects of bus reliability from numerous sources: The ETS test, other test literature, communication with manufacturers and bus properties, field meetings, personal bus maintenance and operating experience, among others. This study has found that ***battery e-bus reliability is at an acceptable level for ETS bus operations and maintenance, being at least as reliable as diesel buses.***

The other Canadian evaluations of electric buses in revenue service confirmed that the buses tested were reliable. In Winnipeg, it was concluded that battery electric transit buses perform reliably and efficiently in Manitoba's extreme cold climate. The Société de

transport de l'Outaouais (STO) and Société de transport de Montréal (STM) evaluations concluded that the performance of e-buses in terms of autonomy, operating time and regularity would allow their use over a large portion of the Montréal and Outaouais networks. The Société de transport de Laval concurred with this conclusion.

The information available regarding the reliability of e-buses tested or evaluated in the USA confirms the results obtained by Canadian transit properties. The Altoona tests of electric buses identified numerous deficiencies found with all three electric buses tested (BYD, NFI and Proterra). Of the three tests conducted, the New Flyer XE40 was found to have the fewest deficiencies. The BYD bus was found to have the most. BYD immediately designed remediation measures to correct all the deficiencies found. The latest generation of the BYD buses is expected to have far fewer reliability deficiencies as a result of these design changes.

Electrification of transit buses has been evolving for many years in various forms. Trolley buses have been operating with electrical components all over the world for decades. Hybrid buses with electrical components have been common and abundant for several years, and fuel cell in smaller demonstration fleets around the world. This experience allows rapid development of e-buses, using well-known and generally reliable technologies.

The literature review, the information obtained from other North American transit properties as well as the results from the field test in Edmonton revealed that e-buses as tested are, from an electric drive viewpoint, at least as reliable as diesel buses currently deployed at ETS.

1.3.5 Externalities

Externalities refer to costs and benefits associated with the choice to invest in e-buses that are not incurred directly by ETS but that must be considered in a broader perspective by a municipal government. A scenario of 40 e-buses assigned to the proposed new NETG was used for this purpose. One limiting factor when considering large-scale deployment of e-buses is the impact on the electrical grid, and the assessment of available power at potential charging locations.

EPCOR provided data from which MARCON was able to calculate the maximum number of buses that this power availability could service. An analysis was then conducted to determine the energy required to support service blocks operating from the NETG. From this analysis potential blocks that e-buses could service were identified. Finally, the optimal assignment of e-buses to potential blocks was determined. The state of charge (SoC) of a bus and its total battery capacity determine the charging required to supply a sufficient amount of energy to the battery so it can (minimally) service its next block assignment.

From an externalities viewpoint, there are advantages to each e-bus technology. **En-route charged buses can be dedicated to the longer blocks. This is significant because the more distance an e-bus covers, the greater financial benefit it yields** compared to its

diesel-fuelled counterpart. The most significant advantage of distributed charging strategies from a risk mitigation perspective is that there are more physical connections to the electrical grid. Consequently, there is greater redundancy in the infrastructure system. As for trickle charging, its main benefit is the lower initial investment required. Charging infrastructure would be located in the garage accommodating the e-buses. Adding charging stations to this facility will not represent a substantial investment compared to the cost of modifying eight transit centres in addition to the planned garage.

Distributing the charging process of buses throughout the city has many positive benefits for the city's electrical infrastructure, delivering EPCOR with a better distribution of the additional load over its existing power grid. This can provide opportunities for EPCOR to improve the return on their infrastructure investment.

1.3.6 Environmental impact of e-buses at ETS

The GHG intensity of Alberta's grid is expected to decrease over time as older and "dirtier" power plants are decommissioned. To project a future grid intensity, MARCON extrapolated utilization of installed capacity based on Alberta's 2014 electricity production reports and AESO's long-term outlook estimates, both future installed capacities and total demand in years 2019, 2024, and 2034. The grid intensity would be expected to drop from 0.81 tons of CO₂ equivalent per megawatt-hour (TCO₂^{e-}/MWh) in 2014 to 0.46 TCO₂^{e-}/MWh in 2034.

In 2015, the ETS fleet of 40-foot diesel buses emitted 61,230 TCO₂^{e-} from the combustion of diesel, and a further 23,300 TCO₂^{e-} from upstream emissions associated with its production. In the Edmonton field trial, the 2013 Xcelsior buses achieved an average fuel efficiency of 49 L/100 km. Data provided by ETS for calendar year 2015 indicates that these 2013 Xcelsior buses are driven an average of 49,497 km/year. At the measured consumption rate, a contemporary model diesel bus driving that distance will generate emissions of 89 TCO₂^{e-} per year or 1,781 TCO₂^{e-} in its lifetime. **Based on the 2013 Alberta grid intensity factor, an e-bus operating today will emit approximately 38-44% less CO₂^{e-} (from the power generators) than its diesel equivalent.** By 2034, the e-bus will emit 72-74% less CO₂^{e-}. When used according to the usage pattern defined by ETS (driving on average 49,450 km) a BYD will generate 684 TCO₂^{e-} and the NFI, 776 TCO₂^{e-} respectively in lifetime emissions associated with upstream emissions from power generation. On a comparative basis, the latest available model of Xcelsior diesel bus running on average 49,450 km per year for 20 years would emit 89 TCO₂^{e-}/year or 1,761 TCO₂^{e-} during its 20-year life.

MARCON also concludes that it is preferable to equip electric buses with diesel heaters rather than to lose the potential range resulting from the power consumption of electric heaters. The use of a diesel heated, BYD trickle-charged electric bus would reduce the bus' carbon footprint by 60% over 20 years of its life whilst replacing a diesel bus by a diesel heated, en-route charged NFI electric bus would reduce the GHG footprint by 56%.

1.3.7 The electric bus technology and its evolution

Although it may seem their arrival on the Canadian market was rather sudden, today's battery e-buses are the result of several generations of vehicle technology, which has been extended to include electric trains, tramways, trolley buses, diesel-electric hybrid buses and fuel cell buses. The key challenge for e-buses has always been the energy storage system (ESS), in particular, developing a battery chemistry that meets the operational requirements of e-buses. While there is certainly improvement expected with the current offering, today's batteries already allow e-buses to compete with the cost of traditional diesel buses on a lifecycle basis.

The world market for electric and hybrid-electric buses amounted to nearly 15,000 units in 2014. Sales are expected to grow at a compounded annual growth rate of 19.6% over the period 2015 - 2020. At the end of 2015, China alone was expected to operate approximately 500,000 plug-in hybrid electric and pure-electric vehicles. Nearer to Canada, the United States Department of Transportation has announced an investment of \$24.9 million (USD) for the development of zero-emission buses. A large share of this incentive will fuel the development of improved batteries.



Electric Buses 2016-2026

Forecasts, Technology Roadmap, Company Assessment

Brand new for March 2016

By Dr Peter Harrop and Mr Franco Gonzalez

The market for medium and large hybrid and pure electric buses will be over \$132 billion in 2026

Fuel cell buses are well known in Canada as two of the world leading manufacturers of hydrogen fuel cells are located in the country: Ballard Power Systems (in British Columbia) and Hydrogenics (in Ontario). More than 2,000 organizations throughout the world are actively involved in fuel cell development. Bus manufacturers, such as Daimler, are working on making these hydrogen-powered vehicles more affordable but the complexity of handling these vehicles has kept most transit properties away from them to date. With the rapid progress being achieved in battery chemistry (improvements in efficiency and cost), most experts agree that it will be challenging for hydrogen fuel cell buses to catch up to battery electric buses.

The key to a wider acceptance of EVs in general, and battery-powered e-buses in particular is battery cost and performance. Several battery manufacturers, including Bosch and BYD, are predicting the capacity of batteries currently being developed will double within 18 to 48 months (depending on the source). Reputable financial analysts project the cost of batteries will drop from their current US\$350/kWh to less than \$120/kWh on average by 2030.

There are two families of battery charging systems, both offering trickle and rapid charging options:

- Conductive
- Inductive

Conduction charging implies a physical contact between the charging system and the battery. Chargers are either installed at transit facilities such as bus barns or transit centres. Inductive charging allows for electricity to move to a battery without physical

contact. Inductive charging plates are usually located at ground level. These can be located at bus depots, bus stops and transit centres. The inductive system's main advantage is that it is easier for operators to park over a plate than to line up the bus precisely under pantographs.

1.4 The business case for e-buses in Edmonton

MARCON calculated the economic impact of shifting from diesel to electric buses using their proprietary lifecycle cost forecasting model (TLC Bu\$™) and performed a comparative analysis of diesel and electric buses relative to capital costs, facility upgrades (electrical capacity and other) costs, and operational costs including the cost of electricity and fuel, maintenance and other costs. Given the early stage of the electric bus industry, the lack of certainty related to fuel and energy costs, and the short amount of time the buses were in field trial in Edmonton, the accuracy of the business case is limited to $\pm 25\%$.

ETS and the Fleet Services branch of the City of Edmonton provided MARCON with all the information requested to establish a reference case based on the latest model of 40' diesel buses in the fleet (Xcelsior 2013 model). Whenever possible, data from Edmonton's field test with e-buses was used but, given the short duration of the test, missing data was substituted by:

- the results of evaluations conducted in other municipalities, and/or
- Altoona test results, and/or
- MARCON team members' experience with other electric buses,

in order to build a cost forecasting model reflective of Edmonton's own operating characteristics.

The Steering Committee directed MARCON to undertake its *"calculations on the feasibility of 40 buses, with details about how the study arrived at the conclusion that could be extrapolated to support decision making"*. MARCON was not required to determine the optimal size of an electric bus fleet in Edmonton within the scope of this study. The City should be aware that MARCON's conclusions, which are based on calculations for a fleet of 40 buses, may not apply to a smaller procurement of buses.

The investment required by the City was estimated on the basis of the prices provided by manufacturers for buses and charging stations. The cost of adapting the NETG to e-bus requirements was provided by an architect firm (Morrison Hershfield) and the cost of en-route charging stations was based on the recent experience at Winnipeg Transit Corporation.

The operating costs for diesel buses were provided by ETS based on its experience with the newest buses in their fleet. MARCON evaluated the detailed costs of operations for e-buses using the experience or its team members with electric vehicles and the information provided by other transit properties. Maintenance, training, tooling, and facility upgrade costs were evaluated by MARCON as well.

The current (contractual) prices of diesel fuel and electricity were provided by the City and, at the request of the City, were pegged at current levels. The announced Provincial “Carbon Levy” on transportation fuel was factored in MARCON’s calculations and therefore, the levy on diesel fuel was set at the 2018 rate of 8.03¢/litre as the procurement process for the vehicles and the construction of the new garage facility is unlikely to result in e-buses being put in service much before January 2018. As for the price of diesel, the cost of the levy was kept constant for the 20 years of the buses’ life. There was no carbon tax added to the cost of electricity as it is already built into the price.

All costs were entered in TLC Bu\$™ to arrive at the comparative life cycle costs for the diesel, trickle-charged and fast-charged e-buses.

The reference base case for the lifecycle cost of 40 standard diesel buses over a 20-year life used in regular service for 989,000 kilometres was determined to be a Net Present Value (NPV) of \$69.6 million in current (nominal) dollars².

**Table 1.1 Comparative lifecycle cost of diesel and e-bus technologies
(Net Present Value in 2016 dollars)**

Cost elements for a fleet of 40 buses	Diesel buses	Trickle-charged e-buses	En-route charged e-buses
Capital Investment Costs			
Bus acquisition & rebuild (40 units)	\$28 075 180	\$45 865 569	\$57 281 973
Building and Infrastructure cost	None required	\$750 000	\$1 154 992
Charging stations costs	None required	Included with bus	\$6 767 923
Other soft, non recurring costs	None required	\$119 843	\$126 822
Capital expenses total	\$28 075 180	\$46 861 434	\$65 331 710
Operating Costs			
Maintenance & Service Costs	\$26 201 313	\$18 260 531	\$18 064 388
Charging /Fuelling equipment maintenance	Negligible	\$66 899	\$1 131 926
Fuel & Electricity Cost	\$14 015 707	\$4 831 981	\$5 310 479
Carbon Levy	\$1 303 976	\$21 496	\$21 496
Operating Expenses total	\$41 520 996	\$23 159 937	\$24 528 289
Total NPV Lifecycle Cost	\$69 596 176	\$69 916 319	\$89 859 999
% difference with diesel buses	-	+0.46%	+29.12%

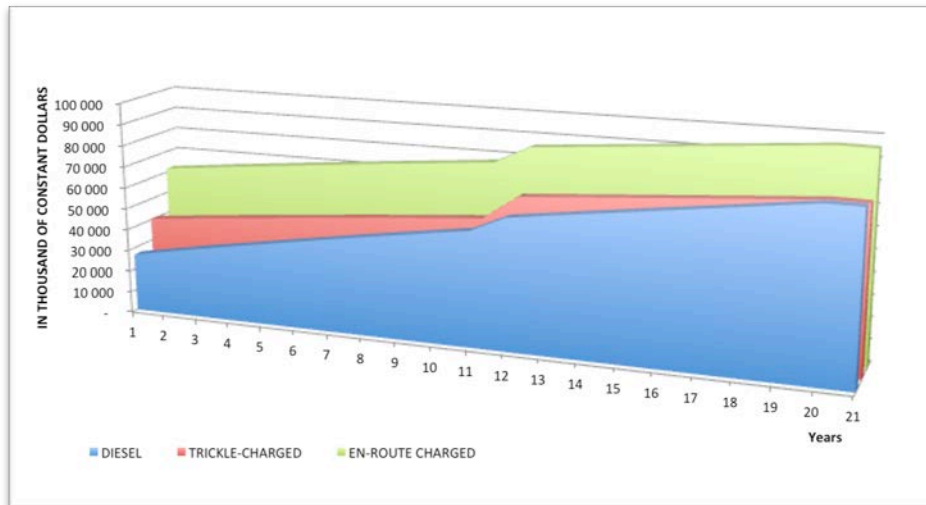
Source: MARCON, 2016.

The estimated lifecycle cost of 40 trickle-charged electric buses in Edmonton on an identical duty cycle (for a total of 989,000 km) will cost 44% less in operations, mainly due to lower fuel and maintenance costs. But the price of trickle-charged buses and of their charging stations require capital investments 67% greater than that of diesel buses, thereby offsetting the operating cost advantages of the e-bus. The resulting NPV lifecycle cost of 40 trickle-charged electric buses is \$70 million, the same as the cost of running diesel buses.

² MARCON did not take inflation into consideration for its calculations but discounted the future cash flow to obtain a net present value.

The level of precision required from MARCON for this forecast being $\pm 25\%$, the overall cost difference falls well within the margin of error and MARCON can therefore state that **there is no substantial additional cost associated with the use of trickle-charged e-buses in the ETS fleet**. The conservative approach MARCON has taken to study the business case indicates that if a more accurate assessment were undertaken, it would likely reveal that operating these electric buses would provide the City with substantial savings.

**Figure 1.1 Cumulative costs of diesel and e-buses
(In thousand of constant dollars)**



The lifecycle cost of substituting diesel buses by en-route charged e-buses amounts to \$95.6 million or, in net present value, \$89.9 million, this is 29.1% more than diesel buses. This exceeds the margin of error and indicates that a significant increase in the operating cost would occur if en-route charged buses were selected.

There are however several opportunities to reduce the cost of using e-buses. First, using innovative contractual terms regarding the e-buses’ energy storage system can mitigate their higher purchase price. Reducing the initial cash outlay requisite for their purchase by renting or leasing battery packs would generate attractive savings. Using this strategy would spread the cash flow requirements over a long period of time (possibly the life of the bus), thereby matching the additional capital cost associated with e-buses with the savings from lower energy costs.

Another way of generating savings with electric buses consists in favouring them in the daily allocation of blocks in such a way as to increase the distance the e-buses will cover each year for their entire life. The more distance an e-bus covers, the greater the savings. This is due to the higher cost of operations of diesel buses (\$1.05/km) compared to that of trickle-charged e-buses (\$0.59/km) and of en-route charged e-buses (\$0.62).

The calculations presented in this report are based on several very conservative hypotheses. For example, the price of diesel fuel is held at current contractual levels for the next 20 years, which is highly unlikely to happen. Although the price of electricity will also rise, petroleum products prices experience much greater variations and, the price

currently paid by the City results from the favourable market conditions that are unlikely to hold for the next 20 years.

1.5 Recommendations

At present, the economic benefits of adopting electric buses conservatively calculated by MARCON are slim. With time, these benefits will most likely increase and yield interesting savings. The environmental benefits associated with e-buses will also make them more attractive in the future. There are some risks associated with the introduction of e-buses to the ETS fleet, but these risks can be mitigated.

The technology associated with e-buses is continuously improving. Four North American manufacturers will have transit products of various configurations commercially available for Canadian transit fleets within the next year: New Flyer Industries, BYD, Nova Bus and Proterra. While electric bus technology is not as mature as the incumbent diesel technology, thereby presenting some risks, there is a growing consensus in the industry that electric vehicles, including buses, will likely dominate the market over the coming decades. In that context and with the results of the field trials conducted in Edmonton, **MARCON recommends that ETS procures e-buses and adds them to the service fleet in order to develop internal expertise and familiarity with this bus technology.**

Prior to procuring e-buses, **MARCON further recommends that ETS staff develop performance specifications as soon as possible.** These specifications should include diesel heaters for space heating on board each bus in order to provide more certainty in effective range for service planning. Given the amount and nature of the preparatory work required to procure these buses and integrate them in the fleet, entry in service in late 2017, or early 2018 is reasonably achievable.

The first e-buses purchased should all be located in a single garage designed or modified to accommodate them. The specific **requirements for space and equipment within that facility should be determined using a functional analysis** but must include considerations pertaining to the size of the backup generator and the clearance of the bus wash. Other items such as the possibility of using cogeneration and/or solar arrays would further improve their environmental performance.

A thorough evaluation of service blocks must be undertaken in parallel with the procurement process to identify what changes would optimize the use of e-buses and, therefore, the economic and environmental benefits of the technology. The goal will be to assign these buses to the longest blocks they can possibly handle in order to reduce their fixed cost per kilometre.

MARCON further recommends that:

- a **comprehensive engineering and maintenance fleet monitoring program be designed** prior to any electric bus fleet procurement to ensure processes are developed that will capture changes required to the current maintenance, servicing and support systems to ensure the success of the introduction of the electric bus fleet;

- **a comprehensive review of all service planning be undertaken** to ensure that service blocks are optimized for use of the electric bus fleet to achieve the best environmental, economic and system benefits; and,
- ETS work with the successful bus manufacturer and a potential third party technical training institution to **develop the necessary training packages** to ensure all staff involved with operating the electric bus fleet receives comprehensive training prior to commissioning the new buses.

If the City intends to expand the size of the electric bus fleet after a few years, it is **strongly recommended that a thorough analysis of the charging and facility upgrade requirements be carried out for each transit garage in the ETS system.** This should be undertaken in parallel with the introduction of the initial fleet of e-buses, and the facility development plan for all the operating facilities. This will ensure that the power requirements can be met and capital investment needs identified in advance of any purchases of e-buses.

It is also recommended that ETS continue to monitor other trials being conducted with e-buses at transit properties in North America and investigate sources of subsidies for procurement of clean technologies that may be available from Federal and Provincial governments.

There are a number of activities that follow:

- The City must decide whether it will proceed with the acquisition of e-buses or not; if so, it must also decide when such a purchase must take place keeping in mind the lead time required for delivery.
- ETS must resolve how the e-buses will be used in the fleet and henceforth determine what performance the e-buses are expected to achieve.
- Ideally prior to, but possibly concurrently with the procurement process, ETS must define:
 - The routes the e-buses will service
 - How the block assigning process will be modified to optimise their use
 - What their space assignment will be in the assigned garage
 - How service and maintenance procedures will be adapted to e-buses
- ETS must then develop detailed specifications for the procurement of e-buses that are compatible with the way ETS intends to operate them independently from those currently promoted by bus manufacturers
- The City must then engage in the procurement process in a way that might be different from its usual practices as negotiations with one or several suppliers willing to adapt their vehicles to ETS' specifications will be the best way to procure vehicles that will meet the City's expectations. The lowest bidder may not be the best supplier, as the lifecycle cost of the procurement should dictate the choice of supplier.
- An internal and external communications strategy must be crafted to illicit maximum collaboration from all City staff and to instil pride in the organisation on the part of all Edmonton citizens and staff members.

2 Description of mandate

2.1 Objectives of this study

The primary objective of the study was to examine the impact of adopting electric buses in the Edmonton Transit System as follows:

- a. Economic: analyze the economic impact of shifting to electric buses using MARCON's proprietary lifecycle cost forecasting model, comparing diesel and electric buses on capital costs, facility upgrades (electrical capacity and other), and operational costs including the cost of electricity, fuel, maintenance and other costs;
- b. Environment: assess the environmental impact of the adoption of electric buses;
- c. Externalities: evaluate the external impacts on the City, its citizens and the power grid;
- d. ETS Staff: assess the impacts of adopting electric buses on ETS staff;
- e. Customer Perceptions: evaluate customer perceptions;
- f. Reliability: evaluate the reliability of the buses; and,
- g. Recommendations on the feasibility and approach for adopting electric buses in the ETS fleet.

2.2 Methodology

Two electric buses from two manufacturers were evaluated during the period 7 January 2016 to 5 February 2016 - one from BYD and the other from New Flyer Industries. A second BYD bus with electric heater arrived in late January and was run after 5 February.

MARCON used a comprehensive and flexible modular approach to undertake the evaluation. Study modules reflecting the objectives listed above were established and can be used as independent documents. All modules are however interlinked in order to maximize efficiency and provide a complete picture of all the facets of introducing electric buses into service in Edmonton. While considering all sources of information available, each source was assessed independently, verified, characterized and weighted in the final analysis. Information sources included, among others:

- a. Red River College and Winnipeg Transit
- b. BC Transit
- c. Société de l'Outaouais (STO) in conjunction with the Société de gestion et d'acquisition de véhicules de transport (AVT) and the Société de transport de Montréal (STM)
- d. Pennsylvania Transportation Institute (Altoona)
- e. National Research Energy Laboratories (NREL), FTA and the US Department of Energy (DOE)
- f. OC Transpo, Société de transport de Laval (STL) and other past clients at MARCON
- g. Chicago Transit Authority (CTA) and California Air Resource Board (CARB)
- h. Bus manufacturers

The economic analysis was performed by MARCON using data provided by ETS from two sources: the field trials and ETS' historical costs. This economic data was reviewed in conjunction with information gained from other municipalities and agencies that have evaluated electric buses, as identified above, to assess and confirm performance and operational implications that were then built into the cost forecasting model.

The environmental analysis compared the Green House Gas (GHG) emissions produced by newer (2013) diesel buses against the GHG emissions associated with the production of electricity currently used by the City of Edmonton, electricity that would eventually power the electric buses. Research was conducted to determine the current grid implications and project the future blended grid intensity of Alberta's power generation.

To determine the external impacts on the City, its citizens and power grid, research and work was undertaken with relevant partners to assess impacts outside of municipal operating costs and environmental impacts that can be projected to occur if electric buses are adopted.

Engagement with Operations and Maintenance staff was done through discussions, focus groups, and surveys to assess operational impacts associated with introducing electric buses and their perceptions of doing so. Similarly, a consultation by survey was undertaken with customers to obtain a comparative assessment of their perceptions of electric buses compared to diesel buses, and to measure their propensity to adopt such a technology, even at a premium price.

The data collected during the field trial was analysed to assess the reliability of electric bus technology and to identify maintenance issues.

2.3 Limitations of this report

Operating data, driver and customer feedback was obtained in Edmonton over the evaluation period. The evaluation presents limitations resulting from:

- The short one month period of data collection;
- Having only two of the three commercial manufacturers represented on these tests; and,
- Having only one of the only two manufacturers' bus available for the same period.

Consequently, information on **bus durability, maintainability, and energy efficiencies** collected during the field trials had to be validated using material from other sources that have conducted evaluations. However, the period when the electric buses were available for evaluation under the same operating environment provided a good basis for comparing dynamic performance, driver and customer experience of the technologies at hand.

The bus models available for the evaluation have been tested through the Altoona Bus Test Centre at the Pennsylvania Transportation Institute. Detailed test reports are available for each of the buses. The BYD e-bus is also being evaluated in service over a long term by the Société de transport de l'Outaouais (STO) in conjunction with the Société de gestion et d'acquisition de véhicules de transport (AVT) and the Société de transport de Montréal (STM). This evaluation was well underway and produced large volumes of information. The New Flyer electric bus is being evaluated in Winnipeg and in Chicago. The BYD bus has also been evaluated in California. However, the operating environment in the southern United States is not similar to the City of Edmonton in winter and so information gained from them was instructive only.

Much of the information available from other Canadian and US evaluations and testing that has been, or is being, done on the electric buses of interest, was used to confirm and validate the data gained during the field trials in Edmonton. Our approach, therefore, was to narrow the field-testing to those areas for which credible information had not already been obtained. Energy and fuel costs in Edmonton, and local environmental issues were also determined to arrive at the full life cycle costing and environmental impacts of these electric buses. In addition to the technical

portion of the evaluation, bus comparative dynamic performance on selected routes in Edmonton under similar route and climatic operating conditions, driver and maintenance personnel impressions, and customer feedback formed a portion of our evaluation program. Given the relatively short time available, this approach provided a more thorough analysis of the new electric bus technology. The budget for this assignment did not allow for a detailed analysis of the infrastructure requirements to support a fleet of electric buses, specifically as to how the proposed new North East Transit Garage would need to be modified. A provision for possible facility modifications provided by ETS architects was inserted in the financial analysis.

No attempt was made to define the implications of trades training on job classifications at ETS. The study only identifies the types and estimated costs of training that would be required to operate electric buses as it applies to operators, maintenance personnel and trainers.

As requested by the City, the accuracy of this report is within $\pm 25\%$. The one exception to this margin of error is the provision provided by the City of Edmonton for the cost of adapting its new garage facility to the presence of electric buses. The estimated marginal cost of modifying the new North East garage to allow for the service, maintenance and housing of 40 electric buses in this future facility was provided by Morrison Hershfield to an accuracy of $\pm 50\%$.

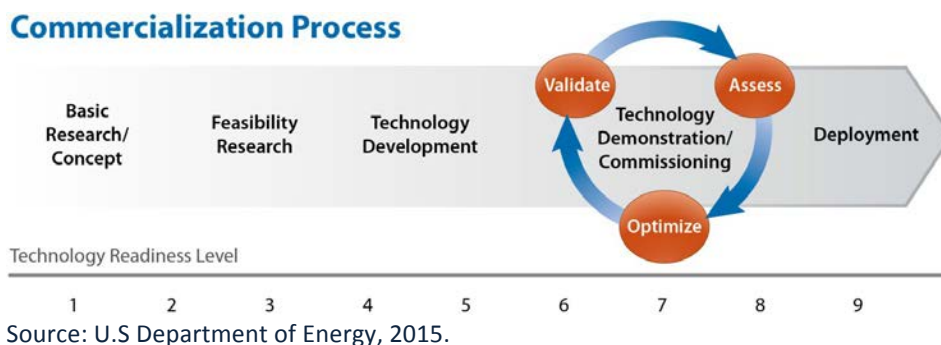
3 Description of field trials

3.1 The electric buses used for winter evaluation

There are currently three manufacturers of battery electric buses in North America that offer buses that are advertised as "commercially available": New Flyer Industries of Winnipeg (MB), BYD of Lancaster (CA) and Proterra Bus headquartered in Burlingame, CA. These buses have a reasonable amount of demonstration time, and/or have active sales in North America. They have also been through various standard bus testing protocols such as the independent "Altoona" test, conducted at the Pennsylvania Transportation Institute ³. These buses, although "commercially available" will most likely have numerous changes and improvements going forward, as battery bus technology is still evolving. This process is not uncommon as even diesel buses are still being improved today, albeit at a less frequent rate than is expected for newer vehicles such as CNG and electric buses.

In September 2011, the U.S. Department of the Environment (DOE) published a Technology Readiness Acceptance Guide⁴ for advanced technology buses that outlined nine levels of readiness. This guideline, shown below, indicates that most battery electric buses (e-buses) available today are at the 7 or 8 level of readiness. All manufacturers of e-buses are continuously improving their products.

Figure 3.1 Technology Readiness Assessment Guide - Commercialization Process



Manufacturers that are currently offering e-buses include:

- **BYD** is a publicly listed company that made its initial public offering (IPO) in July 2002. It is listed on the main board of the Stock Exchange of Hong Kong Limited, with stock code 1211.HK. The Shenzhen-based company makes rechargeable batteries, mobile phone components and solar panels. It is best known as a manufacturer of electric cars and buses, and it broadly identifies itself as a green energy firm. BYD is internationally focused. It owns an electric bus plant in California, and it has sold or test-launched electric vehicles in Colombia, Laos, Thailand, Uruguay, the Netherlands, Belgium, Finland, and Britain.

³ See: (<http://altoonabustest.psu.edu/buses/441>) BYD; (<http://altoonabustest.psu.edu/buses/458>) NFI; (<http://altoonabustest.psu.edu/buses/454>) Proterra E40.

⁴ DOE Technology Readiness Assessment Guide, G 143.3-4a, <https://www.directives.doe.gov/directives/0413.3-EGuide-04a/view>.

BYD has a robust battery technology, and a bus chassis that is rapidly improving to better match North American quality and reliability standards. They have already corrected the weaknesses identified in the Altoona testing of their prototype 40' bus and are working on several other improvements for their next generation of e-bus. Their range/charge strategy is to have higher battery capacity⁵ for longer range, with home base charging. Their latest products source 68% of components in North America. BYD has several thousands of e-buses operating in China along with a number of recent sales in the USA.



- **New Flyer Industries (NFI)** is the largest bus manufacturer in North America, with a long history of innovation and meeting North American bus quality and standardization expectations. Their range/charge strategy is to have medium battery capacity for medium range, with en-route (overhead pantograph) charging at designated stations. They can also supply an e-bus with larger battery packs for home-base charging.



- **Proterra** is a California based company focused solely on battery electric buses. It was founded in 2004 with a vision to design and manufacture world-leading, advanced technology heavy-duty vehicles powered solely by clean domestic fuels. The range/charge strategy of Proterra is to have smaller battery capacity for shorter range, with en-route (overhead pantograph) charging at designated stations. ETS was unable to obtain a Proterra test bus for evaluation during the test period.



- **Nova Bus** a Volvo subsidiary, based in Quebec, is near to completing a prototype e-bus for demonstration. The 100% electric Nova LFSe is based on the proven heavy-duty LFS platform and integrates electric propulsion technology.

- **Other European and Asian manufacturers** have battery buses, however they are not actively marketing buses in Canada. Canada's small market and Transport Canada regulations and other local regulations, plus service and parts support make selling foreign buses into Canada a large undertaking.



Two BYD and one New Flyer 40-foot e-buses were obtained by ETS for evaluation over the winter of 2015/16. Two New Flyer Xcelsior diesel buses, #4880 and #4881 (model year 2013) were provided from the ETS fleet to provide a control baseline for comparison purposes.

⁵ See lexicon in Appendix 1 for more information.

Table 3.1 Test Bus Details

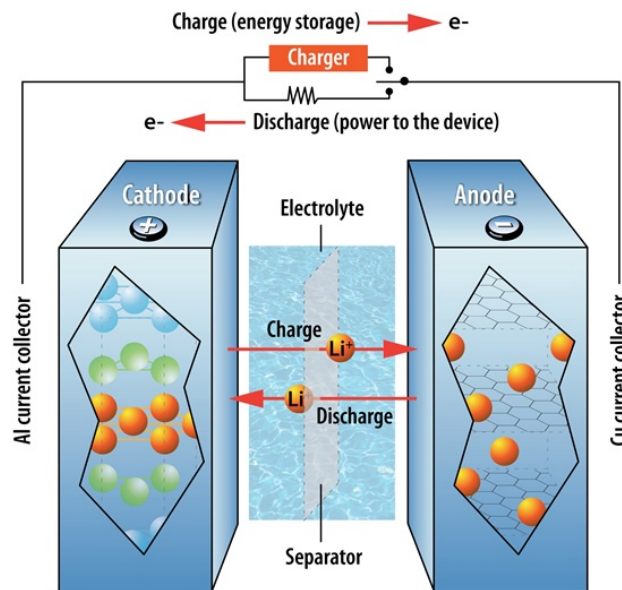
Type	Bus #	Make/Model	Year	Battery Type/Engine	Heating Type	Curb Weight (lbs)	Passenger Capacity	Estimated km
e-buses	6011	BYD 40	2014	LiFePO4 324 kWh	Diesel	32,187	70	250 *
	6012	BYD 40	2014	LiFePO4 324 kWh	Electric	32,190	70	200 *
	6013	NFI XE40	2015	Li-Ion NMC 200 kWh	Diesel/Electric	33,245	76	140 *
Diesel	4880	NFI XD40	2013	Cummins ISL	Diesel	28,000	88	800
	4881	NFI XD40	2013	Cummins ISL	Diesel	28,000	88	800

Source: Manufacturers' estimates.

It should be noted from the above table that the two BYD buses were early generation models and that they, as well as the New Flyer e-bus, are heavier than the two New Flyer diesel control buses. This heavier weight and their respective axle ratings also reduce the maximum passenger carrying capacity of the e-buses.

The two electric buses tested in Edmonton use different Lithium Ion battery technology. BYD uses its proprietary Lithium Iron Phosphate (LiFePO₄) batteries and New Flyer uses Lithium-nickel-manganese-cobalt batteries (LiNMC). Both are Lithium Ion based batteries, but use different chemistries on their cathodes. The diagram below shows the general flow within these batteries⁶:

Figure 3.2 Lithium Ion Battery Flow



The electrolyte within the batteries contains lithium ions. There is no pure lithium within the batteries meaning that the batteries are relatively safe from a toxicity point of view. However, the LiFePO₄ batteries used by BYD are more stable than the LiNMC batteries used by New Flyer. The

⁶ Source - Argonne National Laboratory, Argonne, Illinois

former is an intrinsically safer material than the latter. The Fe-P-O bond is stronger than the Co-O bond, so that when abused, (short-circuited, overheated, etc.), the oxygen atoms are much harder to remove⁷, thereby reducing the risk of combustion. Both types of battery have similar performance in providing power, but the Lithium Iron Phosphate batteries are slower to recharge and are expected to deliver a longer system life⁸ than other types of Lithium battery: 18+ years, compared to about a 12-year life for the others⁹, although both types are warranted for only 12 years.

3.2 Duration and timing of the trials

Ideally, all three test-buses would be operating at the same time to get the best available comparable test data. However, due to the limited availability of the demonstration buses, manufacturer’s delays, along with integration and commissioning issues, not all the buses operated at exactly the same times. This significantly reduced the window during which test data could be captured under similar climatic operating conditions. Carefully designing the test routes and capturing operating data, along with route and weather factors, allowed for reasonable comparisons between the buses and a meaningful test at ETS.

Table 3.2 Test Duration

Bus #	Make/Model	Formal Test Start	Formal Test Finish	Distance Operated	Notes
6011	BYD 40 diesel heat	7-Jan-2016	5-Feb-2016	3750	Shorter am/pm routes were chosen to allow comparable data to New Flyer. Some longer weekend runs were performed.
6013	NFI XE40	7-Jan-2016	5-Feb-2016	2834	
4880	NFI XD40 diesel	7-Jan-2016	5-Feb-2016	5082	
4881	NFI XD40 diesel	7-Jan-2016	5-Feb-2016	4464	

Source: MARCON, 2016.

Notes:

- Charging station problems at the beginning of the evaluation period the distance run by the NFI e-buses.
- Diesel buses operated more weekends and longer runs at the start of the test.
- 6011 was operated at ETS from November 2015 to January 7, 2016, without formally capturing test data.
- BYD bus 6012 was originally intended to be part of the comparative test, but did not arrive at ETS until Jan 28, and required several days of commissioning for ETS service. It was operating beyond the scope of the agreed test period, so 6012 detailed test results are not included in this report. However, raw data from the extended period was reviewed and it was found electric heaters consume about 20% to 25% more energy per kilometre - this is consistent with findings at other properties.

⁷ <http://www.houseofbatteries.com/articles.php?id=27>

⁸ See lexicon in Appendix 1.

⁹ Note that in the business case calculations, a battery replacement is planned after 12 years for both types of buses because the warranty of both manufacturers only extends to 12 years.

3.3 Duty cycles of the buses

The test program was designed to answer several questions, but one was key: *Can e-buses perform on all routes in winter conditions in Edmonton?*

In order to maximize the usefulness of the test, service blocks were chosen for each test route that covered both morning and afternoon peak service. As much as was practical, the test blocks also operated on higher capacity routes, and through the river valley up and down hills. These test routes included service on weekdays only. The test buses were operated on some weekends as operator and bus availability allowed.

Table 3.3 Test Route Book-out Scenario

Type of route	Type of day	Slippery roads day	Snowy roads day	Total
Flat	Extreme cold day	3	3	9
Mild hills		5	5	15
Maximum slope		5	3	11
Total		13	11	35

Source: MARCON, 2016.

Notes:

- The above table shows the types of conditions the buses should have run for the test periods.
- The above scenario was generally met by the first two test buses (6011, 6013) with few exceptions due to unavailability of the buses.
- 6011 ran 45 routes, 6013 ran 36 routes.
- There were 11 snowy days where temperatures were below -10°C.
- Routes were chosen that mostly ran through the river valleys, to ensure hilly terrain was encountered.
- Other than being a relatively mild winter, the buses did meet or exceed the operating scenario.

Table 3.4 Sample Test Book-out Detail

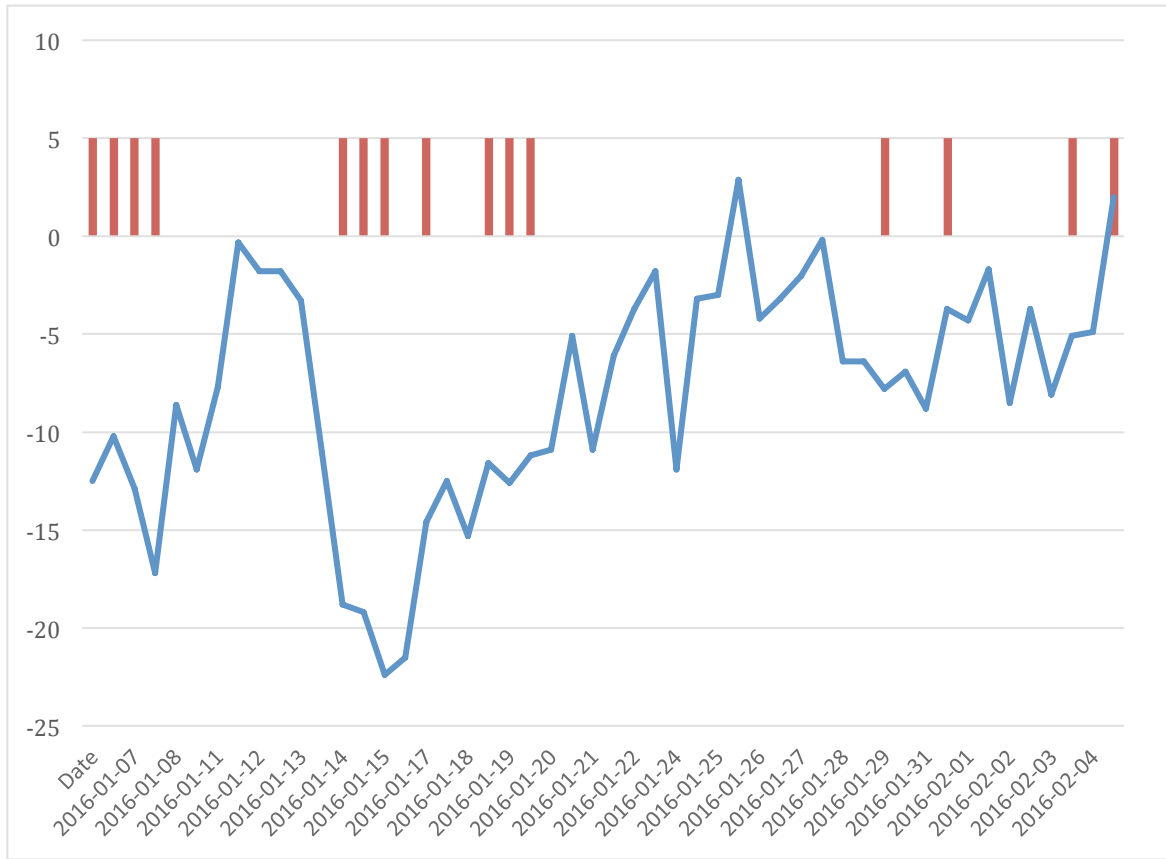
Week	Dates	Route (Block) Assignments for Each Test Bus (AM/PM)				
		Diesel heat 6011	BYD Electric heat 6012	New Flyer Electric heat 6013	New Flyer XD40 4880	New Flyer XD40 4881
1	Jan 4-8	11204/712	704/711	12808/12817	914/11208	12806/713
2	Jan 11-15	12806/713	11204/712	704/711	12808/12817	914/11208
3	Jan 18-22	914/11208	12806/713	11204/712	704/711	12808/12817
4	Jan 25-29	12808/12817	914/11208	12806/713	11204/712	704/711
5	Feb 1-5	704/711	12808/12817	914/11208	12806/713	11204/712

Note: In order to accomplish the type of operating conditions, and allow bus comparisons, an am/pm route rotation was designed. This weekly rotation allowed practical matching of operator, buses, and book out procedures, yet allowed reasonable test comparison data. Special thanks to the Operations Manager at Mitchell Garage who worked with MARCON to review available runs and design a workable test plan.

3.4 Climatic conditions during the trials

Temperature and snow data for the evaluation period were recorded from Environment Canada website¹⁰. Edmonton Blatchford was the closest station to the bus operating routes. Blatchford does not have snow data, so information from station NAMA0 located approximately 15 kilometres North of Edmonton was used to indicate snow days. Two temperatures were recorded at 0900 and 1700 on weekdays, and 0900 on weekends. These times corresponded approximately to the middle of the selected route run times.

Figure 3.3 Temperatures and Snow Day Chart



Note: The blue line indicates temperatures and the red bars, snow days.
 Source: MARCON, 2016.

Edmonton experienced an unseasonably warm 2015-2016 winter, and for most of the test period. Colder days were examined closely and compared to warmer days for energy use data.

¹⁰

http://climate.weather.gc.ca/welcome_results_e.html?txtStationName=edmonton&optLimit=specDate&selRowPerPage=25&searchType=stnName&searchMethod=contains&Year=2015&Month=11&Day=6&timeframe=1

3.5 Data collection during the field trials

In order to collect and provide data for this report, efforts were taken to review and understand the Edmonton fleet, maintenance and operations procedures and data, and work management information systems. Meetings were held at Ellerslie and Mitchell garages, and Scotia Tower offices and data was collected on MARCON designed forms and from standard reports off the maintenance management and fuel management information systems. Between these forms, the data saved by the computers on the buses and the data available on the charging stations, a good set of data was acquired. The cooperation of the Maintenance, Operations and Fleet management teams at those locations was excellent.

3.6 Availability of the buses during trials

The electric test buses had good availability during the trials. Table 3.5 was compiled using fifty (50) morning, afternoon and weekends runs.

Table 3.5 Availability Data from Jan 7 - Feb 5

Bus	# days bus operated	% days on designated route	Drive System Maintenance Events
6011 – BYD	45 = 90%	96%	Anti-Lock Braking System problems, 12 v battery draining
6013 – New Flyer	36 = 72%	90%	Charging station problems (no bus problems)
4880 – 2013 Diesel	40 = 80%	80%	None
4881 – 2013 Diesel	32 = 64%	86%	Engine, brakes, HVAC

Source: MARCON, 2016.

Note that diesel buses show a low level of availability during the test as early in the evaluation period, the two designated diesel control buses were inadvertently booked out on other routes.

The electric buses were quite reliable and operated most days at over 90% availability. Problems were corrected within a reasonable amount of time. As can be expected with any non-routine operation, effort was required to ensure these buses were a priority to operate. This is consistent with the experience at Winnipeg Transit, Foothills Transit, CA, and Chicago.

No electric propulsion system problems occurred during the field trials and all maintenance items were related to non-propulsion systems during the test period.

3.7 Extraordinary events

Considerable effort must be undertaken to conduct a test on new bus technologies, and involves many facets of the organization. Additional staff with well-defined roles and tasks as well as additional time is routinely required for test programs.

Some of the events worthy of mention are:

- Facilities – installing high capacity power cable systems to the charging stations was expensive and time consuming for staff. As some of the equipment was delivered before the holiday season, some changes to the habitual vacation policy should have been planned to ensure the equipment was in place and tested prior to the beginning of the test.

Failing this, power for the New Flyer Charging Station was not available for the charging station at the start of the test, so a diesel generator was rented for a few days. An updated software program to manage the charging was sent by NFI and was installed by ETS staff to allow charging of the bus.

- Servicing – The BYD bus did not fit into the bus wash due to its height, and had to be washed by hand.
- Towing – towing adapters were not immediately available so that one of the buses had to be flat towed.
- Operator training and familiarization for test buses is critical and efforts are required in particular to ensure safe operation. Only minimal training of two hours was provided to operators prior to the program, in many cases without the benefit of road trials. One of the manufacturers did not adequately prepare its e-buses for winter operations due to an oversight. Consequently, winter tires were installed by ETS because the acceleration/deceleration of the bus made it slip with regular tires - this problem was later corrected by an adjustment to the software controlling the ABS system.
- Operators had concerns with the reduced visibility out the curbside window of the BYD bus due to the battery pack installed there. This design issue has since been corrected by BYD on its latest generation of bus.

3.8 Analysis and Summary of trials

Analysis of the trials focused on key attributes related to ETS routes and conditions, and parameters of importance to ETS. The evaluation period ran from January 7 to February 5, 2016.

3.8.1 Range, State of Charge (SoC), Energy Usage (total test average)

Operating range, and energy use were primary factors in determining bus operating strategy, and cost analysis.

Data Collection Methodology:

- Distance driven for each charging cycle was taken from two sources – odometer readings, and documented route kilometres and deadhead kilometres
- State of Charge (in percentage) was taken from the dash readout at the start and end of each charging cycle. The energy (in kilowatt-hours) used was calculated from the battery storage capacity readings. This is an agreed upon method to track energy use. Some energy use data was obtained from the charging station and used to validate the calculated data for those incidents where the data sheets were lost.
- The estimated range takes into account the gaps and possible errors in the data due to some lost records, and to different measuring methods.

Table 3.6 Energy Consumption and Range

E-bus	Battery Storage (kWh)	Yield (Km / %SoC)	Energy Consumption (kWh / km)	Theoretical Range (km)	Recommended Range (km)
6011 – BYD	324	2.40 - 2.89	1.04 - 1.25	259 - 311	220 - 264
6013 – New Flyer	200	1.45 - 1.60	1.25 - 1.38	145 - 160	116 - 128

Diesel Bus	Fuel Capacity (litres)	Consumption L/100km	Theoretical Range (km)	Recommended Range (km)
4880 – 2013 Diesel	470	49	800	800
4881 – 2013 Diesel	470	45	800	800

Source: MARCON, 2016.

Notes:

- Battery Storage:** Rated battery energy storage capacity
- Yield:** Battery yield expressed in kilometers of range for every 1% of energy stored
- Energy consumption:** Best and worst results obtained during field trials
- Theoretical range:** Distance an e-bus can cover on a single charge using its full battery capacity
- Recommended range:** Manufactures recommend that their e-buses head back for a recharge when 80% (NFI) to 85% (BYD) of total battery storage energy is depleted¹¹.

MARCON’s block analysis of the Westwood garage in use as of February 16th, 2016 (shown in Appendix 2) demonstrates that with an appropriate deployment of charging stations at transit centres, en-route charged e-buses have no limitations and can service all the blocks out of that garage.

Based on the depletion limits recommended by the manufacturer, the trickle-charged e-buses are limited to a maximum range of 220 km. MARCON’s block analysis of the Westwood garage establishes that on that basis, these buses can service approximately 80% of all blocks. The following table shows the proportion of blocks serviced from the Westwood garage that can be serviced by a transit bus of various ranges on one charge or fuel reservoir.

Table 3.7 Bus range vs. Block Length

Westwood Garage Blocks	
Range up to (km)	% of all blocks
150	67.7
200	76.6
250	86.3
300	91.5

Source: MARCON, 2016

¹¹ An alarm sounds at 10% SoC. Below 10%, the power will very quickly de-rate until the bus is effectively reduced to “creep torque” only by the time it reaches 5%. So while it is possible to go below 10%, bus would not really achieve any effective driving. Per New Flyer e-mail dated 6 April 2016.

Range and energy use data from other sources

MARCON reviewed the information available on other tests conducted in North America in order to compare their results to those obtained in Edmonton.

Table 3.8 Energy Use Data from Other Sources

Bus	kWh / km	Estimated Range km	Notes
BYD 40'	1.26	205	Altoona test June 2014 ¹²
BYD 40'	1.2 – 1.5	240	STO Quebec 2014, no AC and with AC ¹³
BYD 40'	1.3	220	STM Quebec 2014
New Flyer 40'	1.08 – 1.30	110 - 148	Altoona test ¹⁴
New Flyer 40'	1.45	100	Winnipeg– no passengers summer/winter average ¹⁵
New Flyer 40'	1.83	140	Chicago (winter average) ¹⁶
Proterra 35'	1.08		Altoona test April 2012 ¹⁷
Proterra 35'	1.34		Foothills Transit test 2014/15 ¹⁸

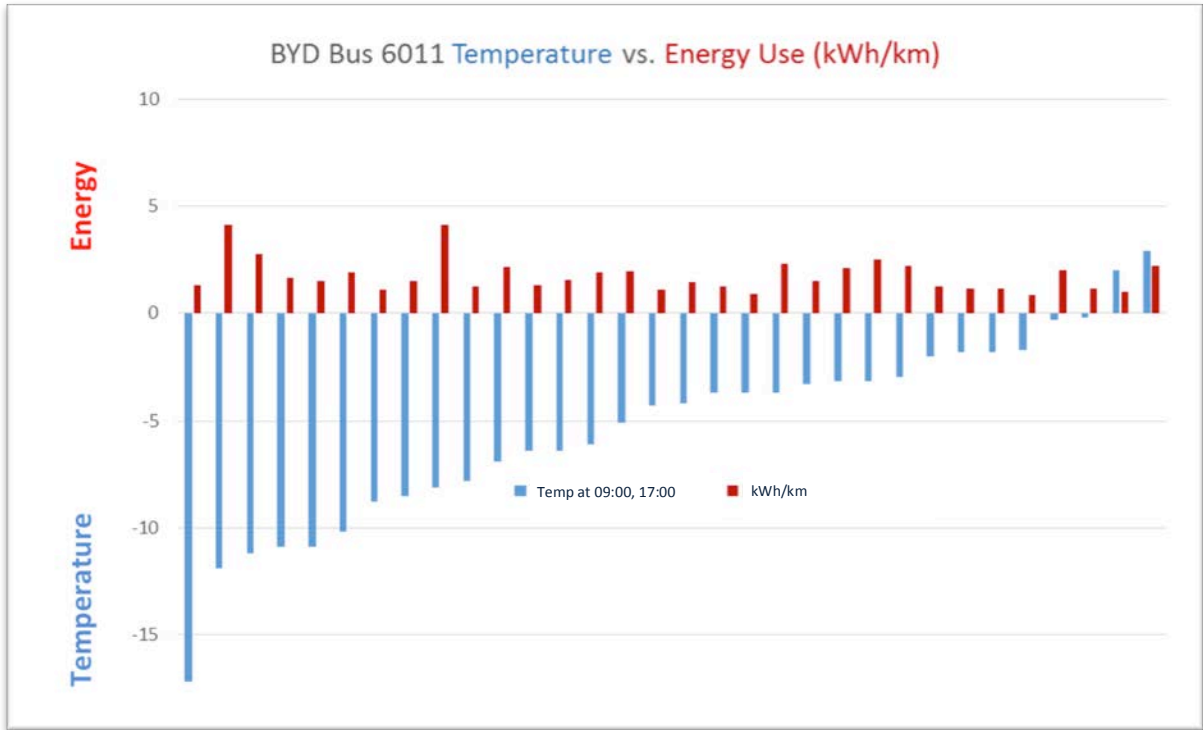
Source: MARCON, 2016.

3.8.2 Temperature and Energy Usage

The following charts show the energy usage at various outdoor temperatures as recorded by Environment Canada at 0900 hours and 1700 hours each day. These moments approximate morning and afternoon run times. Energy use was calculated using the state of charge data and route kilometres. MARCON observed no direct correlation between energy usage and ambient outdoor temperature.

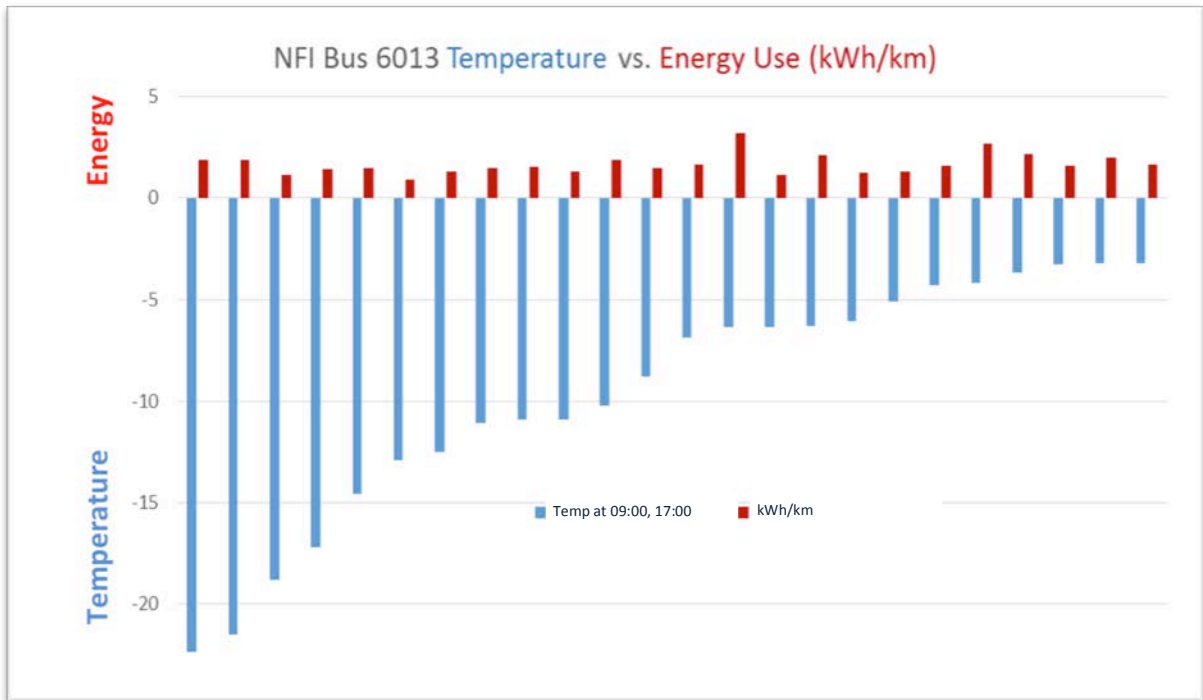
¹² Federal Transit Bus Test, BYD Electric Bus, Report LTI-BT-R1307, Pennsylvania Transportation Institute, PA, 27 June, 2014
¹³ Evaluation Report BYD's Green City Electric Bus (STO & STM), Société de gestion et d'acquisition de véhicules de transport (AVT), August 2014
¹⁴ Federal Transit Bus Test, New Flyer Electric Bus XE40, Report LTI-BT-R1405, Pennsylvania Transportation Institute, PA, 30 July, 2015
¹⁵ Manitoba Battery Electric Transit Bus Fleet Development and Demonstration Report, Red River College, Winnipeg, October 27, 2015
¹⁶ Conversation with CTA Project Manager, 8 January, 2016
¹⁷ Federal Transit Bus Test, Proterra BE-35, Report PTI-BT-R1107, Pennsylvania Transportation Institute, PA, April, 2012
¹⁸ Foothills Transit Battery Electric Bus Demonstration Report, National Renewable Energy Laboratory, Golden CO, January 2016

Figure 3.4 Temperature vs. Energy for BYD E-bus



Source: MARCON, 2016.

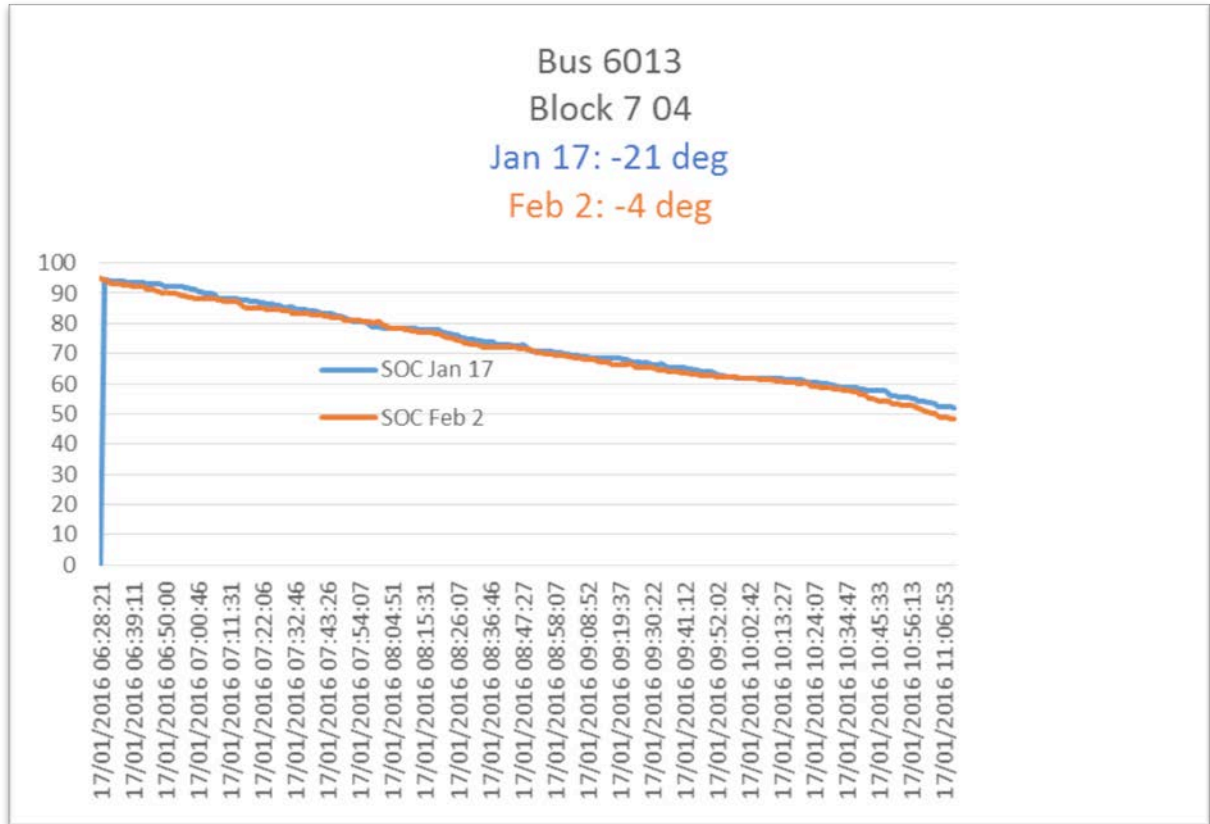
Figure 3.5 Temperature vs. Energy Use for NFI E-bus



Source: MARCON, 2016.

Figure 3.13 is offered as a demonstration of how little impact outdoor ambient temperature has on the energy consumption of e-buses. It shows the state of charge (SoC) of the battery pack throughout the morning run of the same bus on the same route on two different days: one with cold and the other with much milder temperatures on record. Notice there is little difference in the SoC plot given the 17°C difference in ambient temperature. A review of data for other days when the temperature was between the highs and lows in the chart confirmed this rather linear depletion of the SoC, irrespective of the outdoor temperature. This finding is corroborated by the STO and STM evaluations¹⁹.

Figure 3.6 Temperature vs. State of Charge Bus #6013



Source: MARCON, 2016.

Energy usage for bus propulsion is not affected by outdoor/ambient temperature to the same degree as consumer EVs. Several reasons explain this:

- The buses use diesel fired heaters (consumer cars use energy from the battery).
- Buses are parked in a heated barn so batteries and bus components are warm at start of route.
- The battery compartment on board e-buses is equipped with a temperature management system that maintains its temperature at an optimal level at all times.

¹⁹ Evaluation Report BYD's Green City Electric Bus (STO & STM), Société de gestion et d'acquisition de véhicules de transport (AVT), August 2014.

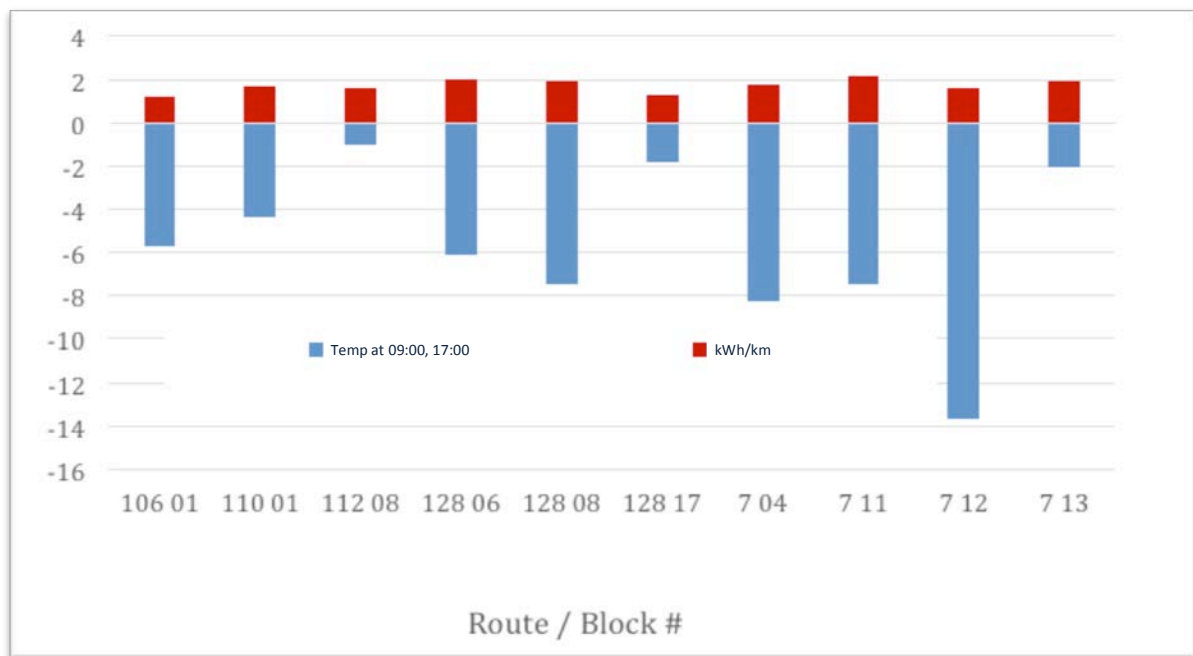
- Outside data suggest a decrease in 15-25% range if electric heaters are used (outside temperature dependent). Data reviewed from BYD bus 6012 collected after 5 Feb 16 confirms this reduction in range when electric heaters are used.

This is good news for Edmonton battery bus operations. Range can be reliably calculated based on battery storage capacity, if diesel heaters are used.

3.8.3 Route Analysis

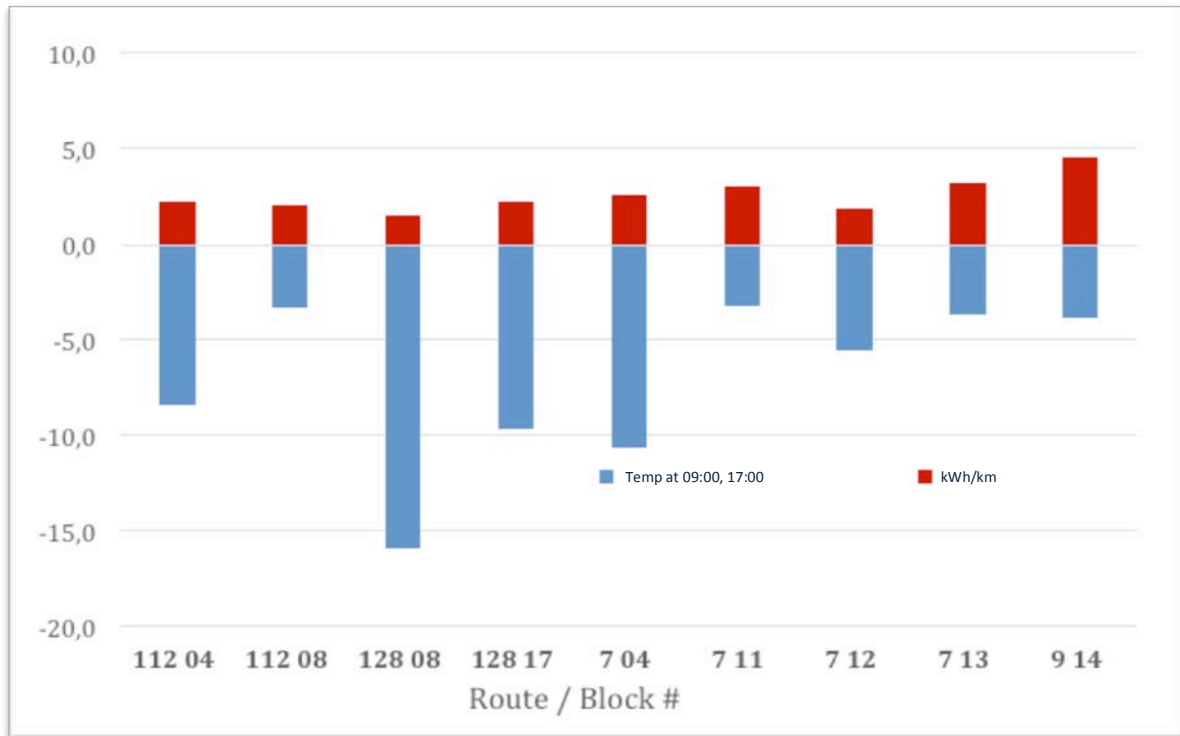
An analysis was also performed to compare the effect of temperature on the route driven. The following charts show energy use by route, and the average temperature on the routes. While one can see there is a variation in energy use by route, there is no direct correlation between temperature and energy use.

Figure 3.7 Energy Use by Route at Temperature Bus #6011



Source: MARCON, 2016.

Figure 3.8 Energy Use by Route at Temperature Bus #6013



Source: MARCON, 2016.

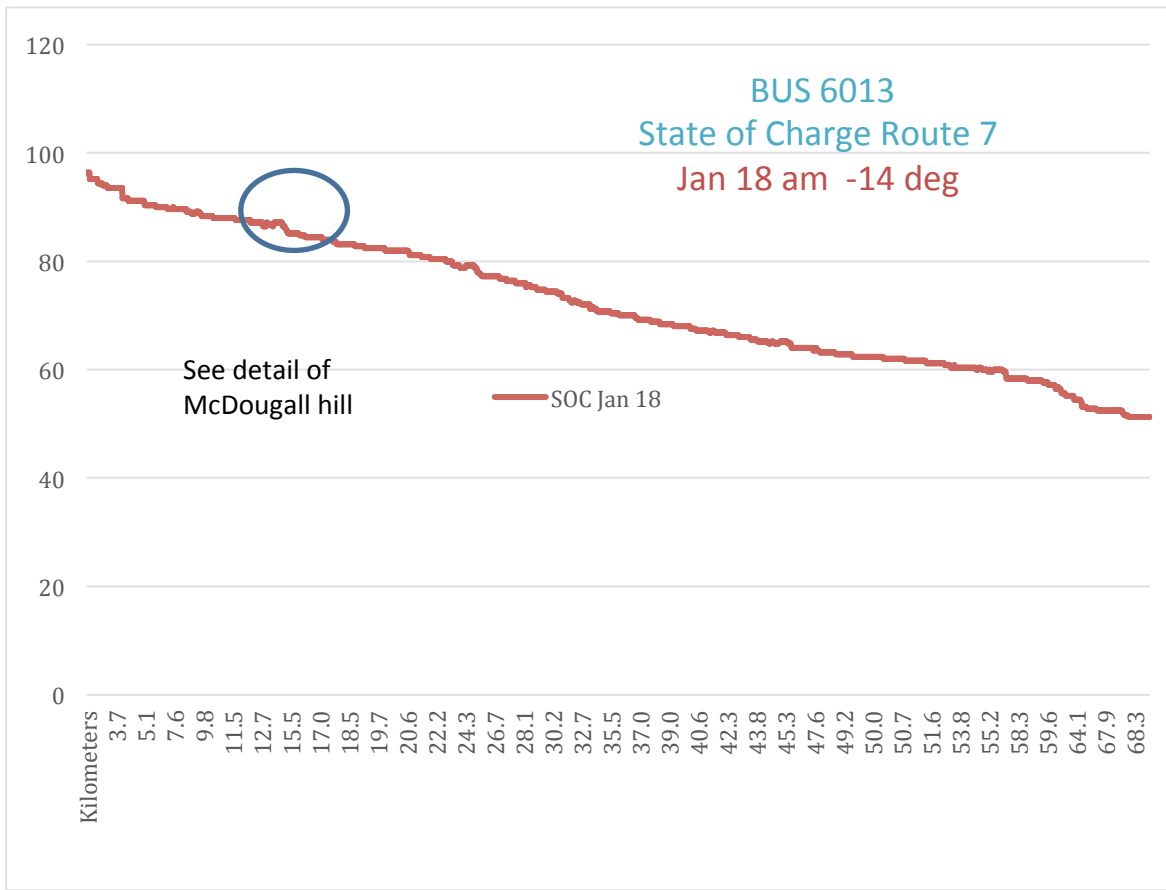
By comparing the data in figures 3.14 and 3.15, MARCON concludes that there is variance in energy use on similar routes and that therefore, temperature has little to no effect on energy consumption. Note that route 106 was a 180 km run on a Saturday, lighter loads and easier route showed less energy use. (West Edmonton Mall to University) while route 914 is a heavy morning rush, with many stops, slower speeds (Southgate to NAIT), which explains higher energy use.

3.8.4 Impact of Slope on Energy Consumption

Several ETS routes comprise steep hills. As one of the key objectives of the testing program was to establish whether or not e-buses could be used in all Edmonton conditions, the test program included runs that covered the most challenging hills ETS is required to climb.

Discharge (and recharge) rates of batteries have been examined for ETS routes that include steep hills and are illustrated in the following figures.

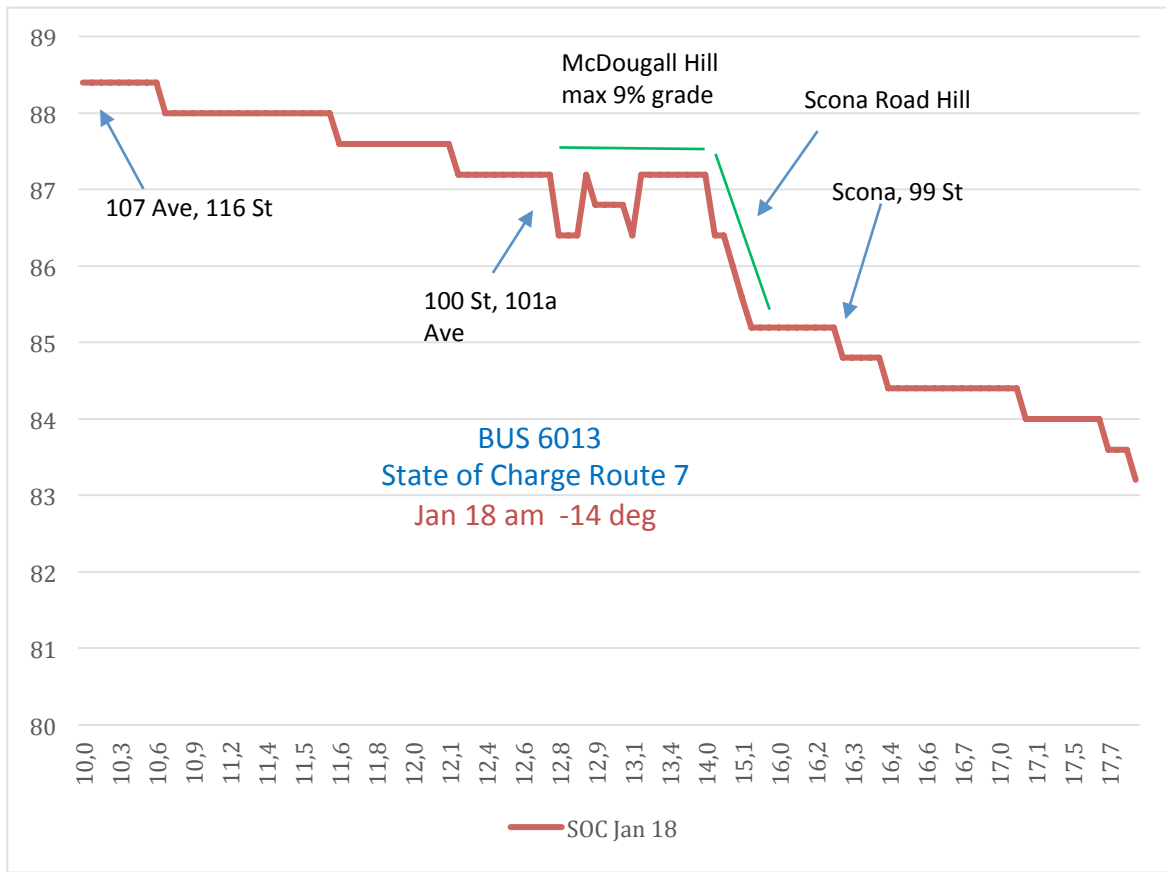
Figure 3.9 Bus #6013 State of Charge Route 7



Source: MARCON, 2016.

Note that the State of Charge declines quite steadily throughout the 68 km run. 51.2% at end of run. A closer look at the downtown, McDougall hill, Scona Road hill portion of Route 7 is shown below.

Figure 3.10 Bus #6013 State of Charge on Hills - Route 7

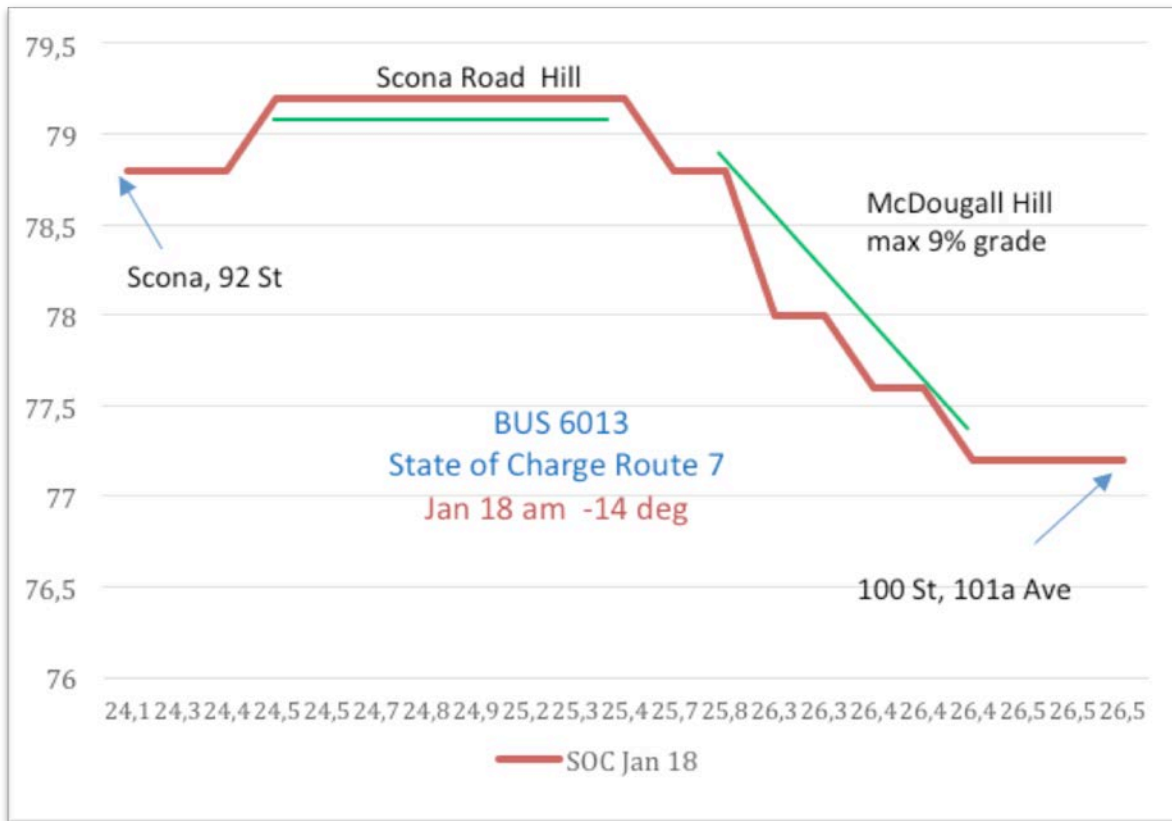


Source: MARCON, 2016.

Discharge on level route to downtown is steady. The regeneration on McDougall hill keeps the battery at a steady state of charge. In fact, energy from the regenerative braking is powering the steering, fans, compressor, lighting, etc. There is then a fairly steep discharge rate as the bus heads up Scona Road Hill, consuming approximately 2% of available battery capacity.

The following figure shows the return portion of the previous graph. Energy is obtained from regeneration while the bus heads down Scona Road Hill, and is depleted going up McDougall hill. Again approximately 2% of available battery capacity is consumed to climb McDougall hill.

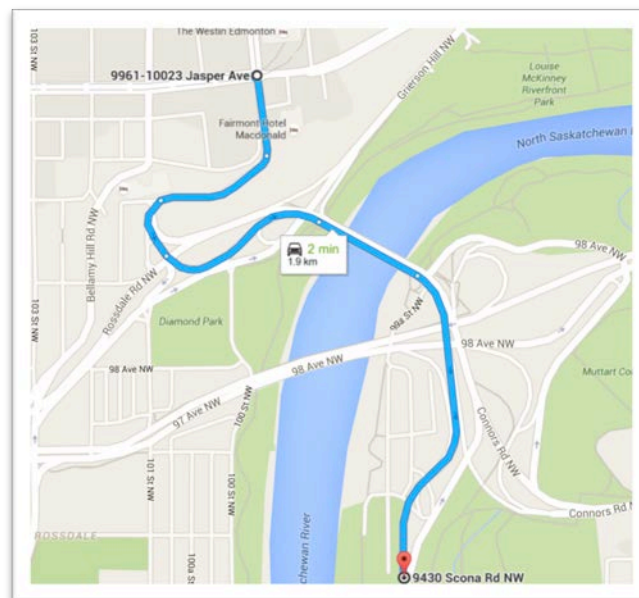
Figure 3.11 Bus # 6013 State of Charge Uphill



Source: MARCON, 2016.

The map below shows Route 7 in the McDougall - Scona Road hill area.

Figure 3.12 Map of Route 7



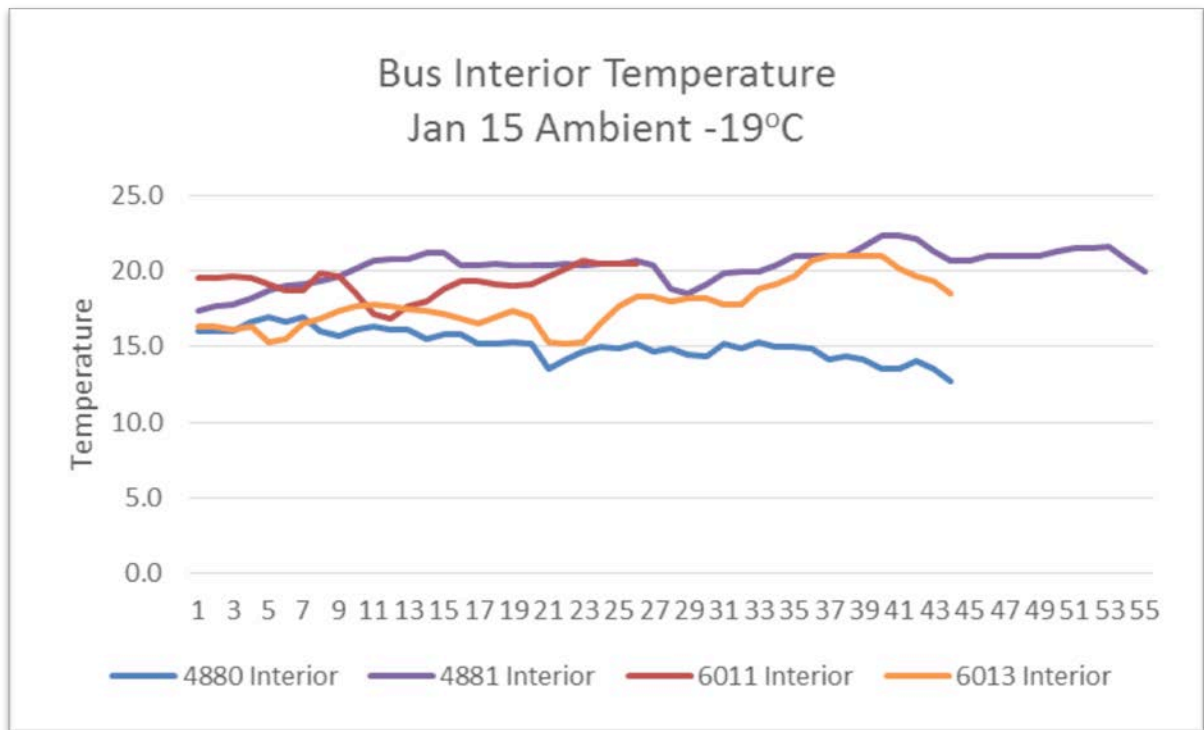
Source: Google, 2016.

3.8.5 Interior Bus Temperature Analysis

Temperature data loggers were installed in the test buses (6011 & 6013 electric, and 4880 & 4881 diesel). Loggers were attached to the underside of driver’s seat, middle seat, rear seat, and inside an exterior body panel.

The chart below records the average bus interior temperature on a cold day, in this case -19° C.

Figure 3.13 Interior Bus Temperature on Cold Day

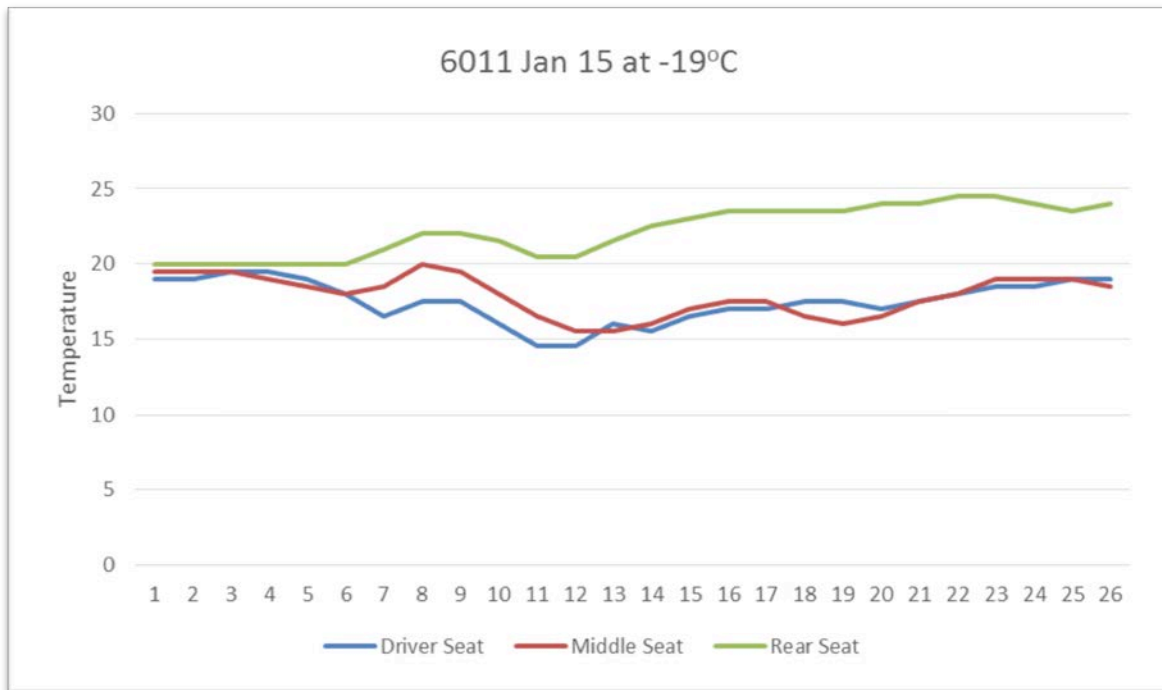


Source: MARCON, 2016.

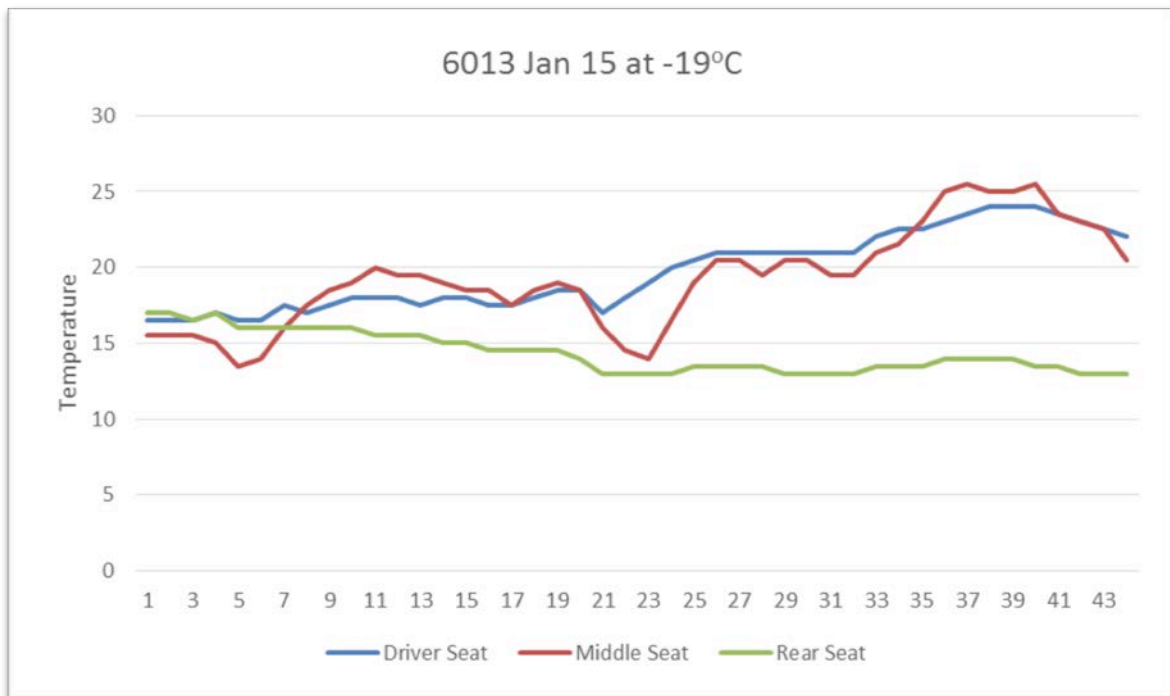
The electric buses maintained temperatures above 15°C throughout their runs. It is unknown why the diesel bus 4880 had cooler interior temperatures, probably due to the thermostat setting.

The following figures show the same run for each bus, with the individual temperature logger data taken from locations under the driver's seat, under a middle seat and under a rear seat. The electric buses had comfortable temperatures, although there was a difference in the interior locations due to heating airflow, and cold air entering. The location of the data loggers (under the seats) affected the readings as they received cold drafts from door openings while the heater forced air mainly from the roof area.

Figure 3.14 Diesel Heated Bus #6011* and Diesel & Electric Heated #6013 Interior Temperature

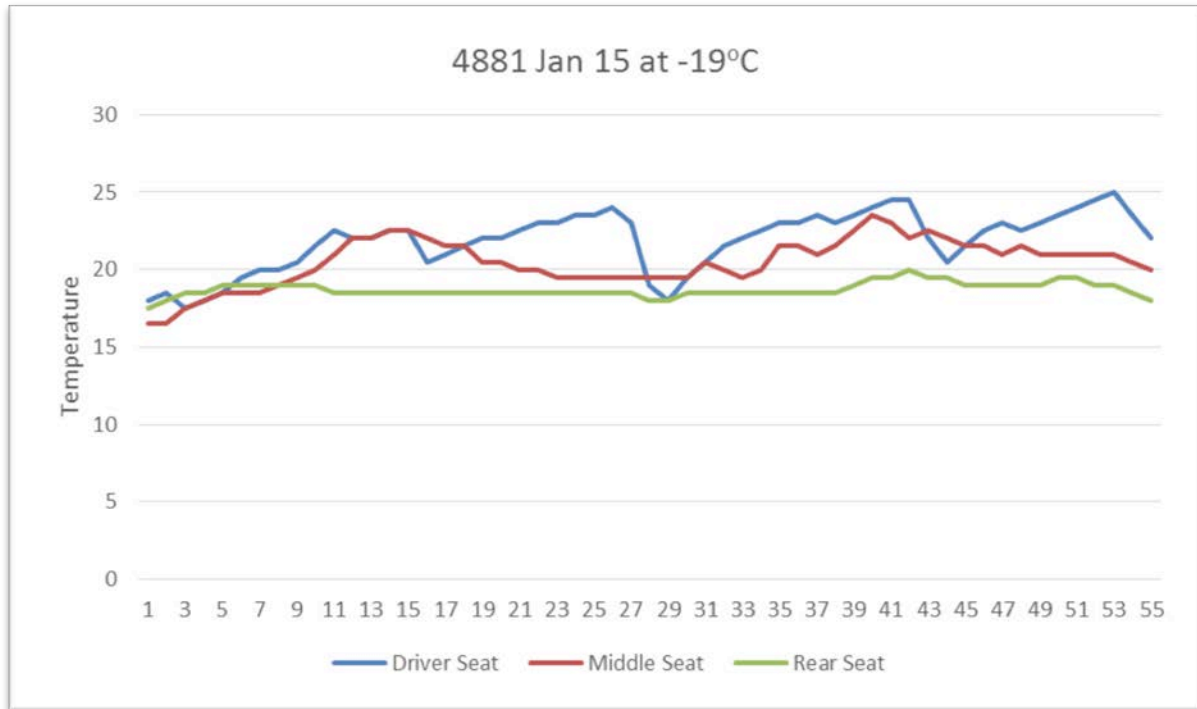


Note: Bus 6011 was fitted with both, an electric and a diesel space heaters
 Source: MARCON, 2016.



Source: MARCON, 2016.

Figure 3.15 Bus #4881 Interior Temperature



Source: MARCON, 2016.

Data was also analyzed for the five-week test period, and no sustained cold interior temperatures were recorded. In addition, there were no maintenance events or reports related to cold interior.

3.8.6 Other Performance Parameters

Other performance parameters that are of interest in operating transit buses are interior and exterior noise levels, acceleration and braking. While these were not measured during the ETS evaluation, a comparison was obtained from the Altoona testing reports. These tests are conducted under very controlled conditions. The results for the New Flyer diesel XD40, the BYD electric and New Flyer electric XE40, are shown in the table below. Noise levels are measured with all accessories on.

Table 3.9 Other Performance Parameters - Comparison

Performance Parameter	NFI XD40	BYD	NFI XE40
Interior Noise at Idle, dBa	54.9	47.2	46.5
Exterior Noise at Idle, dBa	58.5	49.0	49.3
Exterior Noise under Acceleration to 60 km/h, dBa	69.3	68.3	69.3
Acceleration to 50 km/h, seconds	14.27	16.19	13.71
Braking Distance from 50 km/h, feet	66.78	65.41	67.96

Source: MARCON, 2016

As can be seen, the interior noise level for the electric buses at idle is noticeably lower than for the diesel buses. However, under acceleration the noise levels are comparable. The acceleration of the NFI e-bus is marginally faster than the equivalent diesel and almost 2.5 seconds faster than the

BYD bus. However the acceleration of both the electric buses is much smoother and there is much more torque than the diesel buses available at lower speeds. Braking distances are comparable.

3.9 Key findings

The electric buses tested in Edmonton's winter trials proved to be reliable, operating at over 90% availability. There were no problems with the **electric propulsion system** (motor and batteries).

There are however some maintenance/design issues with the electric buses that needed extra attention to maintain this high availability rate. Manufacturers tell us that they will need to be addressed in production buses. For example, early generations of BYD buses were equipped with an awkward bus charging connector design. This issue has since been resolved.

Figure 3.16 New Location of BYD Bus Charger Receptacle - Front Right of Bus



The NFI connector is heavy and normally, an operating garage would be supplied with a connector support that was not available for the ETS test program.

Unfortunately, the test program duration was too short to gain enough maintenance and reliability data for direct comparison of battery electric to diesel.

Findings re energy consumption:

- The kWh / km and range numbers obtained during the test program are similar to other recent test data obtained from the other sources identified earlier and fall well within the ranges advertised by the manufacturers. This validates the Edmonton testing protocols as having been reasonably accurate.
- MARCON observed a wide day-to-day variation in energy use. Although the data at MARCON's disposal does not explain these differences, they are not uncommon in field-testing conducted elsewhere, irrespective of the technology being tested. These variances are probably attributable to driving habits, as careful driving using slower acceleration and more braking regeneration can have a dramatic positive effect on energy use. However, this variation is not unique to electric buses as similar variations in energy use caused by driving habits are found for any vehicle.

- MARCON was unable to observe significant differences in energy usage between *dry* and snow days as too many other factors define the impact of the snow on energy consumption. Nevertheless, Winnipeg anecdotally reports up to 15% more energy use on heavy snow days with 1-2" on roads.
- The NFI bus (#6013) used more energy than the BYD bus (#6011) during the testing phase. The New Flyer has a 10kW supplementary electric heater that may account for some more energy use. However, there are too many variables in the test (routes, passenger loads, driving habits, etc.) to make any well-founded comparisons on overall energy efficiency between the buses. Using controlled testing parameters and identical protocols, the Altoona tests of these two buses reveal that the BYD e-bus uses slightly more energy per km than the New Flyer one (1.26kWh/km compared to 1.16 kWh/km).

New York Metropolitan Transit Authority evaluated a BYD electric bus between 25 August 2013 and 25 October 2015. During this evaluation 1,481 miles were accumulated in revenue service in heavy traffic and with full passenger loads. Energy use averaged 1.46 kWh/km²⁰ on the days the bus was in service. The operating conditions in NYC were more severe than can be expected in Edmonton and explain the higher energy usage. This observation was also supported by STO and STM in their evaluation that demonstrated energy consumption can vary by 15% depending on the number of passengers on board the buses²¹.

²⁰ BYD and New York Metropolitan Transit Authority press release dated 9 January 2014.

²¹ Evaluation Report: BYD's Green City Electric Bus (STO & STM), Société de gestion et d'acquisition de véhicules de transport (AVT), August 2014.

4 Customer perceptions of the e-buses

The perceptions of customers concerning electric propulsion technology for buses were measured through the use of a self-administered questionnaire. The methodology and survey results are discussed in this section of the report.

4.1 Methodology

A survey of riders was undertaken to ...

- Assess bus users’ perceptions of electric buses
- Determine how electric bus features impact the quality and comfort of the ride
- Determine if riders would like ETS to purchase electric buses
- Ascertain rider willingness to pay more for bus service to allow for ETS to purchase electric buses.

Socio-demographic information was collected (age, employment status and number of one-way trips per typical week) to determine potential statistically significant differences by population segment.

A survey questionnaire was prepared, tested on board the electric buses on January 11th and finalized for distribution.

Figure 4.1 Rider survey questionnaire

ETS Rider Survey
Please take a moment to answer these questions

1. When you boarded the bus today, did you notice the design was different from other ETS buses?
 Yes No

2. Thinking about this particular bus compared to other ETS buses you may have rode on, how does this bus compare with respect to the following features?

This bus compared to other ETS buses	MUCH WORSE	WORSE	SAME	BETTER	MUCH BETTER
Noise	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fumes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Smoothness of ride	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3. The temperature on this bus is ...
 Much too cold Somewhat cold Comfortable Somewhat warm Much too hot

4. This is an electric bus. Would you like ETS to purchase electric buses?
 Yes No Don't know / Don't care

5. Electric buses are more expensive to purchase than diesel buses. Would you be willing to pay more for bus service in order to allow for ETS to purchase electric buses?
 Yes No
 How much more?
 Maximum 5% more
 Maximum 10% more
 Maximum 15% more
 Maximum 20% more

6. How many one-way trips (a one-way trip includes transfers) do you make in a typical week?

7. What is your age?

8. Which of the following best describes your status?
 Employed full time Employed part time Unemployed
 Retired Student Homemaker

Once completed, please place the questionnaire in the container located at the back of the bus. If you were provided with a pencil, please also place in box. ETS thanks you for your kind cooperation!

Hard copies of the questionnaire were made available to a team of ETS personnel²² that were responsible for ...

- Boarding the electric buses;
- Distributing the questionnaires to passengers as they boarded;
- Collecting the completed questionnaires from disembarking passengers.

ETS personnel were tasked with completing the left-hand portion of the questionnaire identifying

- The model of electric bus (BYD with electric heating, BYD with diesel heating or New Flyer²³);
- The time of day (morning peak, afternoon peak or other) the ride was undertaken
- The route²⁴;
- The date.

Survey data was collected on weekdays between January 18th and February 5th inclusively. This was a completely random sampling.

In total, 2,825 questionnaires were collected from ETS customers²⁵ riding on the electric buses that were being tested. The results of the survey are statistically significant at a confidence level of 95% with a margin of error of ± 1.8 .

4.2 E-bus rider perceptions (as measured during trials)

4.2.1 Bus model

Of the 2,825 surveys completed, 57% were by riders on the New Flyer electric bus while 41% were by riders on one of the two BYD electric buses²⁶.

4.2.2 Noticed a different design of ETS bus

Overall, 92% of respondents noticed that the design of the bus they boarded was different from other ETS buses. This percentage was higher among those aged under 30 compared to those aged 31 years or older.

4.2.3 Respondent profile

Riders participating in the survey provided some information about themselves that allows the reader to better understand the respondent profile:

- The number of one-way trips²⁷ in a typical week;
- The age;
- The employment status.

²² ETS personnel were provided with a training session prior to survey start to ensure uniformity in methodology. Personnel distributing and collecting completed questionnaires were told not to provide information to respondents in order to minimize bias.

To minimize bias, ETS personnel was also instructed to stop a promotional video from playing on the New Flyer electric bus.

²³ ETS personnel identified only if the bus was a BYD or a New Flyer. No distinction was made between the two BYD models.

²⁴ On 79% of the questionnaires, route data was not provided.

²⁵ 15 years of age or older.

²⁶ On a minority (2%) of self-administered questionnaires, ETS staff did not identify the bus model.

²⁷ "One-way trips" includes transfers.

On average, the ETS customers surveyed stated that they undertake just over 9 one-way trips per week. The breakdown is presented in Table 4.1. under “Relative importance”.

With the exception of the group that did not provide information regarding the number of trips they take each week, over 70% of all readers in all frequency groups are in favour of ETS adopting e-buses.

Table 4.1 Opinion of riders regarding the purchase of e-buses by ETS

# of trips per week	Relative Importance		Should ETS buy electric buses?		
	# of respondents	% of total	Yes	No	Don't know
1 to 5	718	25.4%	77.7%	5.7%	16.6%
6 to 9	374	13.2%	78.1%	2.9%	19.0%
10 to 15	1200	42.5%	81.0%	3.0%	16.0%
16 to 30	186	6.6%	83.3%	5.9%	10.8%
>30	21	0.7%	71.4%	9.5%	19.0%
No answer	326	11.5%	65.3%	6.4%	28.2%
Total	2825	100%	78.1%	4.3%	17.6%

Source: MARCON, 2016

The employment profile of respondents indicates a strong representation of students (47%). This likely reflects the routes selected for testing the electric buses. The rest of the respondents are full-time employees (37%), retired (3%) and unemployed (2%).

Table 4.2 Employment status of respondents

Multiple-response	Overall
Employed full time	37%
Employed part time	13%
Unemployed	2%
Retired	3%
Student	47%
Other	2%
No answer	3%

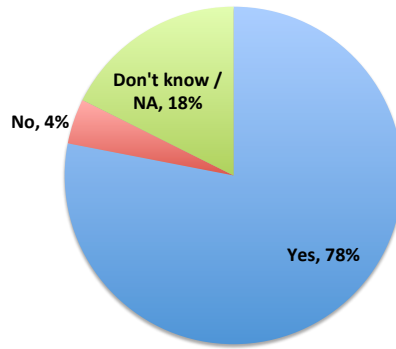
Source: MARCON, 2016

4.2.4 Interest in ETS buying electric buses

Riders participating in the survey were asked whether they would like ETS to purchase electric buses. Overall, 78% of respondents would like ETS to purchase electric buses. Interest in buying electric buses is significantly higher among younger age groups (15-22 year olds: 81%, 23-30 year olds: 80%, 31-59 years olds: 81%) than among those aged 60 and over (64%). Similarly, individuals who are categorized as employed and students are more favourable²⁸ to ETS purchasing E-buses than those who are unemployed or retired (73%).

²⁸ 79% among those who are employed full time and 81% among students.

Figure 4.2 Should ETS purchase electric buses?



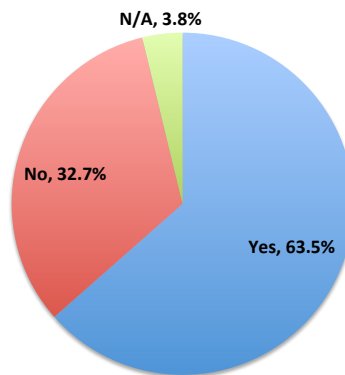
Source: MARCON, 2016

There is no statistically significant difference in interest for ETS to purchase electric buses by frequency of travel²⁹.

4.2.5 Willingness to pay more for bus service to allow ETS to purchase electric buses

Overall, 64% of respondents indicated a willingness to pay more for bus service to allow ETS to purchase electric buses that cost more than their diesel counterparts.

Figure 4.3 Willingness to pay more for bus service to allow ETS to purchase electric buses



Source: MARCON, 2016

Only those indicating that ETS should buy electric buses were targeted for a follow up question concerning if, and how much of an increase they would be willing to pay. Despite this, some of those stating no interest for ETS to purchase E-buses answered the additional question, and demonstrated some interest in paying extra for bus service to allow for ETS to acquire electric propulsion technology buses. In fact, 25% of those “not in favour of e-buses” would still be willing to pay more to ride them.

Table 4.3 Willingness to pay more for e-buses

	ETS should buy E-buses		
	Yes	No	Don't know
Yes	73.4%	13.1%	32.3%
No	25.0%	82.8%	54.2%
N/A	1.6%	4.1%	13.5%

Source: MARCON, 2016

²⁹ Number of one-way trips in a typical week.

Willingness to pay more is also higher (73%) among respondents who are favourable towards ETS purchasing electric buses than among their counterparts who are not favourable towards the purchase of E-buses (13%).

As indicated in Table 4.4, willingness to pay more for bus service to enable ETS to purchase electric buses decreases with age (69% of 15-22 year old respondents, 66% of 23-30 year old respondents, 63% of 31-59 year old respondents and 61% of respondents aged 60 years or older).

Table 4.4 Willingness to pay more for bus service (Overall, by interest to buy E-buses, by age category)

	Age category			
	15-22	23-30	31-59	60+
Yes	69.2%	65.8%	62.8%	50.7%
No	29.4%	33.0%	34.1%	43.3%
N/A	1.5%	1.2%	3.1%	6.0%

Source: MARCON, 2016

Among respondents who indicate a willingness to pay more for bus service to allow for ETS to purchase electric buses:

- 46% indicated that they would be willing to pay 5% more
- 35% stated that they would be willing to pay 10% more
- 8% claimed that they would be willing to pay 15% more
- 7.5% stated that they would be willing to pay 20% more

The breakdown by age category is provided in the following table.

The average increase of those favourable to paying more to allow ETS to purchase electric buses is 8.8%. No statistically significant differences by age category, by employment status or by frequency of bus use were identified.

Table 4.5 Willingness to pay more for bus service by size of increase by age category

	% of all respondents	Age			
		15-22	23-30	31-59	60+
5% more	46.3%	44.3%	49.0%	47.9%	38.2%
10% more	35.4%	40.7%	33.2%	31.3%	36.8%
15% more	7.9%	7.9%	8.0%	8.5%	3.9%
20% more	7.5%	5.9%	8.0%	8.1%	11.8%
Not sure	0.1%	-	0.2%	-	1.3%
No answer	2.8%	1.2%	1.7%	4.1%	7.9%
Average increase in price	8.8	8.8	8.7	8.8	9.4

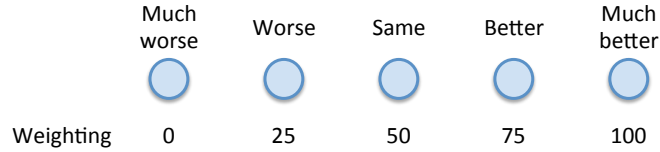
Source: MARCON, 2016

4.2.6 Evaluation of electric bus experienced

Respondents were asked to evaluate the electric bus they had experienced compared with other ETS buses with respect to ...

- Noise
- Fumes
- Smoothness of the ride

Respondents were asked to provide their evaluations using a five-point scale:



The weighting is a means to develop averages for statistical evaluation purposes.

Noise comparison

From a noise perspective, 73% of respondents evaluated the electric bus as being better (43%) or much better (30%) than the other ETS buses they are familiar with. Those who responded that they would like ETS to purchase electric buses had a more favourable evaluation of the noise of electric buses. The remainder³⁰ (19%) considered the noise level to be equivalent to that of diesel buses.

Table 4.6 Noise comparison

NOISE	Much worse	Worse	Same	Better	Much better	N/A	Weighted average
Overall	0.7%	2.7%	19.1%	43.1%	30.1%	4.2%	75.9
Buy E-buses	Yes	0.5%	2.1%	17.1%	43.8%	33.9%	77.9
	No	5.7%	4.9%	34.4%	34.4%	16.4%	63.2

 statistically significantly higher than overall statistically significantly lower than overall

Source: MARCON, 2016

Fumes

Overall, 73% of respondents considered the electric bus as being better (38%) or much better (34%) than other ETS buses with respect to fumes. Again, respondents indicating that they would like ETS to purchase electric buses rated e-buses more favourably on fumes than respondents who stated they would not like ETS to purchase electric buses.

Table 4.7 Fumes comparison

FUMES	Much worse	Worse	Same	Better	Much better	N/A	Weighted average
Overall	0.5%	1.0%	16.6%	38.4%	34.3%	9.1%	78.9
Buy E-buses	Yes	0.5%	0.7%	14.2%	39.3%	38.5%	80.8
	No	1.6%	2.5%	28.7%	31.1%	20.5%	69.7

 statistically significantly higher than overall statistically significantly lower than overall

Source: MARCON, 2016

Smoothness of ride

When comparing the smoothness of ride between electric buses and non-electric ETS buses they are familiar with, 66% of respondents evaluated the electric bus as better (40%) or much better (26%). As with the previous two features evaluated, respondents who stated they would like ETS to purchase electric buses rated smoothness of the ride higher.

³⁰ 4% did not provide an answer.

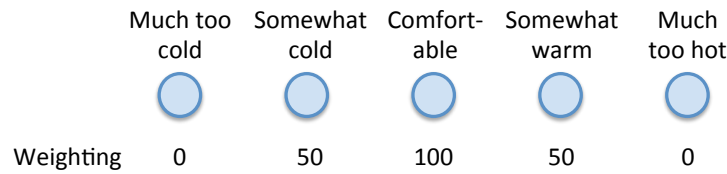
Table 4.8 Smoothness of ride comparison

SMOOTHNESS	Much worse	Worse	Same	Better	Much better	N/A	Weighted average	
Overall	1.0%	1.6%	24.8%	39.9%	25.7%	7.0%	73.6	
Buy E-buses	Yes	0.5%	0.9%	22.2%	42.4%	28.6%	5.4%	75.8
	No	4.1%	6.6%	45.9%	16.4%	18.0%	9.0%	60.4

 statistically significantly higher than overall  statistically significantly lower than overall
 Source: MARCON, 2016

4.2.7 Temperature evaluation

Respondents were also asked about the temperature on the bus using a five-point scale:



The weighting is a means to develop quantitative averages for statistical evaluation purposes.

As indicated in the following table, over 80% of respondents rated the temperature on the electric buses as “comfortable”, with an additional 13% stating that they found the temperature “somewhat warm”. As with the features evaluated (noise, fumes and ride smoothness), respondents interested in having ETS purchase electric buses rated the comfort level higher than their counterparts who would not like the transit system to purchase electric buses.

Table 4.9 Temperature on bus

TEMPERATURE	Much too cold	Somewhat cold	Comfortable	Somewhat warm	Much too hot	N/A	
Overall	0.2%	2.8%	80.5%	13.4%	1.1%	2.0%	
Buy E-buses	Yes	0.2%	2.3%	82.5%	13.7%	0.7%	0.6%
	No	1.6%	4.1%	70.5%	15.6%	5.7%	2.5%

 statistically significantly higher than overall  statistically significantly lower than overall
 Source: MARCON, 2016

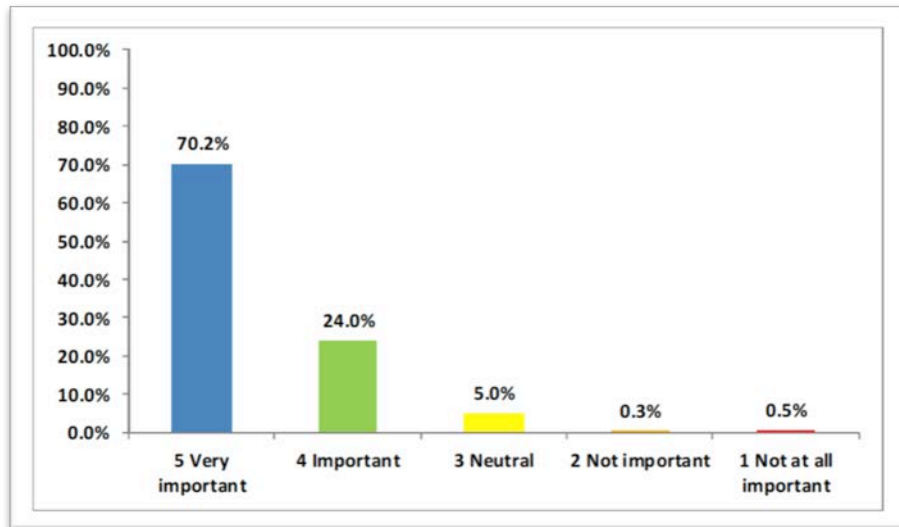
4.3 Pre-trial perceptions (ETS research)

In August 2014, ETS Staff produced a report entitled “Stealth Bus Customer Survey – Interim Topline Report”³¹. According to this document, the study was “conducted to gather customer’s insight regarding their comfort and some other aspects of newly designed Stealth bus”³². On page 4 of the document, the reader understands that the “Stealth bus” is an all-electric.

³¹ MARCON is informed that no report followed the Interim Topline Report. This report is therefore considered the Stealth Bus Customer Survey final report. Results based on 996 completed surveys.
³² “Stealth Bus Customer Survey – Interim Topline Report”, 2014, page 2.

The results of this 2014 research are similar to the results of the customer research undertaken in the context of this study with 94% of respondents indicating that it is important (24%) or very important (70%) to them that ETS pursue green technology that is more environmentally friendly.

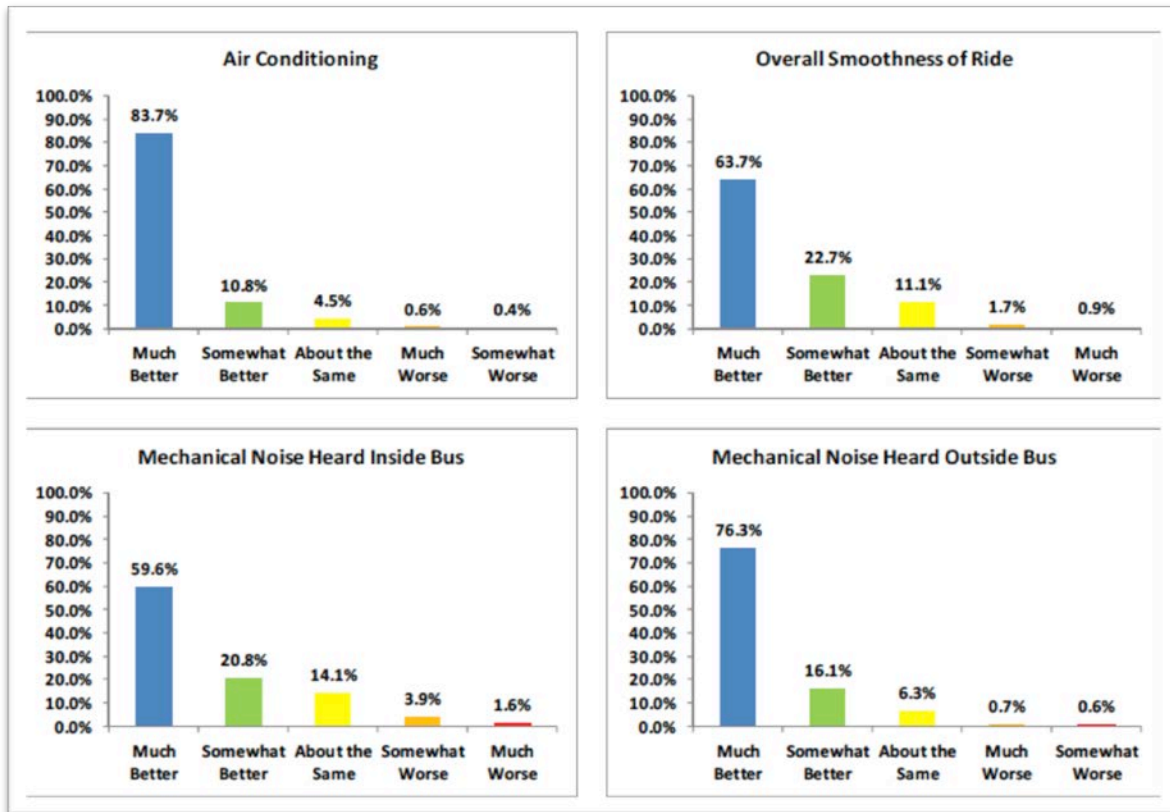
Figure 4.4 Importance of Green Focus³³



Further, on all the features tested (general seat comfort, seat leg room, air conditioning, overall smoothness of ride, mechanical noise heard inside the bus, mechanical noise heard outside the bus), ETS customers participating in the survey rated the electric bus somewhat or much better than other ETS buses. These results are consistent with the favourable customer results gathered in January – February 2016 with respect to noise, fumes, smoothness of ride and temperature comfort.

³³ "Stealth Bus Customer Survey – Interim Topline Report", 2014, page 4.

Figure 4.5 Customer evaluation of electric bus features compared to other ETS buses³⁴



4.4 Key findings

The results of the MARCON survey are statistically significant at a high confidence level (95%) with a small margin of error (± 1.8). With 996 respondents, the 2014 Stealth Bus Customer Survey is also a very reliable source of information.

Both surveys have found that Edmonton bus riders are very favourable to e-buses. So much so that almost two thirds of them would be willing to pay a premium in order to help ETS acquire them. E-buses are considered superior on every performance aspect evaluated by customers.

³⁴ "Stealth Bus Customer Survey – Interim Topline Report", 2014, page 3.

5 ETS and City Staff perceptions of the e-buses

MARCON undertook qualitative research with the staff³⁵ that came into contact with the electric buses trialled³⁶. Following is a discussion of the research methodology employed as well as the results of the research.

5.1 Methodology

Focus group discussions were undertaken with bus operators³⁷ pre and post the electric bus trials. In addition, interviews were undertaken with maintenance and mechanical staff pre and post trials.

Table 5.1 Pre and post trial qualitative research with staff

	Pre-trial	Post-trial
Bus operators	10 participants in focus group	5 participants in focus group
Mechanical, maintenance and service staff	4 people interviewed	5 people interviewed

Source: MARCON, 2016

Few staff members participated in both the pre and post research activities undertaken.

5.2 Pre-trial perceptions of operators and maintenance staff

At the time of the pre-trial interviews (December 2015), training had already been provided to staff using the 2nd generation BYD bus. Training from New Flyer personnel to operators and maintenance and mechanical staff was expected to take place on January 4th 2016.

5.2.1 Bus operators

MARCON asked ETS to invite all bus drivers that were trained to drive the electric buses to a discussion intended to provide insights regarding the perceptions that operators have of E-buses prior to driving them in the context of regular transit service.

With the exception of one operator, all drivers³⁸ participating in the pre-trial group were selected by superiors to drive the electric buses. Consequently, they were not driving the electric buses because of a positive predisposition to them.

Participants believed that ETS was interested in testing electric buses in order *“to be ahead of the game”*, *“to cut fuel costs”* and *“to be green”*. All the participants perceived the testing of the buses to be a good idea and several spontaneously suggested that deploying electric buses would be positive for the image of ETS.

³⁵ Interviews and focus groups were undertaken with the drivers and mechanical and maintenance staff that were informed and made the effort to meet with researchers.

³⁶ Some members of the staff came into contact with one of the three models while others came into contact with all three.

³⁷ All drivers participating in the pre-trial focus group had received some training on the electric buses prior to the discussion.

³⁸ All indicated being spare board shift.

When questioned whether they considered electric buses to be ready to be put in service, participants stated that they are likely ready for summer-climate operation but, given their lack of experience with driving these buses in winter conditions, questioned whether they are ready for such conditions. The participants also questioned whether the duration of the trial would be sufficiently long to enable ETS to gain a true appreciation for the ability of electric buses to meet the winter needs of the transit system.

Participants also stated that they expected the driving experience with electric buses to be superior to that of driving with diesels. The reasons provided:

- Noise reduction
- Reduction in pollution (no fumes)
- Smoother ride (including excellent braking)
- Availability of air conditioning
- More comfortable seating

Based on the training provided on the BYD bus, participants noted certain design features that did not appeal to them. Most of these features had little to do with the fact that the buses tested were electric, with the exception of...

- Lower passenger capacity,
- Lack of ABS (not yet installed),
- Regenerating brakes resulting in buses sliding in snow³⁹, and
- Significant noise at the back of the bus (cooling fan).

The participants generally did not anticipate difficulties getting accustomed to electric buses although one did mention that turning corners would require *“getting used to”*.

In the pre-trial discussion, participating operators generally welcomed the change and stated that they perceived the electric buses to be better equipped than their diesel counterparts. They, however, were not certain that electric buses, despite being easier to maintain, would make lifetime economic sense for ETS given their relatively higher acquisition cost. One of the participants expressed serious concern with their purchase price and questioned whether citizens, in an economic downturn, would be willing to pay more for transit access or accept cutbacks in other municipal expenditures allowing the City to invest in electric buses.

5.2.2 Mechanical and maintenance staff⁴⁰

Personnel interviewed prior to the trials were of the opinion that ETS was testing electric buses given the interest of citizens and Edmonton City Council in cleaner vehicular technologies. They expected the tests were required to prove the *“viability and performance of the technology in ETS’s climatic and operating conditions”*.

Much like the bus operators, the maintenance and mechanical staff interviewed considered the trial period as extremely limited. In the latter’s opinion, the buses should be tested for approximately one year to gain a better appreciation for their capabilities and potential limitations. One of the issues identified early in the experiences with the BYD 2nd generation bus and shared during the interviews is the bus’ perceived inability to drive in winter conditions without winter tires.

³⁹ This was also reported by operators to the maintenance staff for the NFI bus.

⁴⁰ Service staff was not interviewed during pre-trial interviews.

Asked if they expected any differences in maintenance between the electric buses and their standard diesel counterparts, personnel interviewed expected approximately the same amount of work, although different issues given the dissimilarities in technology. Some of the members of the mechanical and maintenance staff stated that they had read the Altoona evaluations of the BYD bus and were therefore concerned about the quality of manufacturing. The general perception of the maintenance staff interviewed was that the BYD quality is poor. In contrast, personnel generally viewed the New Flyer bus favourably.

Additional challenges expected by the maintenance and mechanical staff prior to trials, particularly in a context where electric buses are integrated into the ETS fleet included:

- Towing: *“ETS is not equipped to tow electric buses”*,
- Lack of qualified personnel,
- Access to spare parts and procurement logistics that may need to be modified to meet the needs of electric buses,
- Inability to fit the electric buses in the washing area,
- Lack of understanding of how electric buses need to be treated from a safety perspective,
- Bus range: *“Can we get 350 km range in the winter? It has operating implications.”*
- Charging infrastructure: the staff questioned whether the garages can be equipped with the charging infrastructure required to charge the electric buses
- Hoist training will be required to handle the batteries

Asked if they considered that ETS should purchase electric buses, maintenance and mechanical personnel interviewed believed *“the technology may be ten years out”* and that given the economic downturn, questioned whether the timing for purchasing electric buses was ideal.

In short, contrary to operators, maintenance and service personnel displayed a rather negative attitude towards e-buses ahead of the field trials.

5.3 Post-trial perceptions of operators and maintenance staff

5.3.1 Bus operators

All bus operators participating in the post-trial focus group claimed to have driven both the BYD and NFI e-buses, although the experiences of some were predominantly with one model and consequently, operators' comments were very model-specific.

Table 5.2 Positive and negative perceptions of Operators⁴¹

Content reflects operator language	BYD	NEW FLYER
Perceived positives	Good acceleration	Good acceleration
	Smooth ride ("don't feel every pothole")	Smooth ride ("don't feel every pothole")
	Quiet	Very quiet
	Great heating	Even better heating than BYD
	Good lighting	Even better lighting than BYD ("blue lights reduce the glare on the windshield")
Perceived negatives	Sensitive braking	Antilock braking issues: "When I applied brake, the ABS grabbed and let go and then it skid"
	Difficulty accelerating uphill: "rolled 16 inches before accelerating"	Difficulty accelerating uphill ("the New Flyer performed better. If the load was lighter, the New Flyer climbed the hill with no problem")
	Camera on the BYD looking outside is focused too low	
	On turns, bus tilts to one side	On turns, bus tilts to one side
	Rocking side to side	Door stays open while driving. Requires interlock
	Skidding on ice	Rocking side to side due to battery weight on top of bus (greater than with BYD)

Source: MARCON, 2016

Bus operators participating in the discussion expressed concern about the range of the electric buses (*"We run the buses 14-16 hours per day. We need the juice to continue driving them."*) as well as the economics associated with purchasing and installing charging stations. Further, they indicated that the silence of electric buses (*"you don't hear them coming"*) may pose a safety issue for people walking in their vicinity.

Asked if the adoption of electric buses will require any changes to operations, bus operators offered the thoughts expressed in Table 5.3.

⁴¹ Bus operators made several comments regarding the design elements of the buses. These are not reflected in the table as they are not specific to the performance of electric propulsion buses.

Table 5.3 Perceived changes to operations required to enable adoption of electric buses

Perceived changes required	
Operating procedures	A change in scheduling may be required: "Currently, buses arrive at transit centers at the same time. If you have to charge the bus at these centers, we need to figure out how to charge at the same time or pace their arrivals."
Shift lengths	Buses may be required to return to the garage after every shift.
Other	Depending on the range of the vehicles and the charging strategy implemented, drivers participating in the groups question whether more buses will be required to meet ETS's operational needs if the buses are electric.

Source: MARCON, 2016

Despite the issues raised, the ETS bus operators that participated in the focus group generally felt that electric buses are ready to be placed in service as long as the charging infrastructure is available to meet the operating needs of ETS. Moreover, they stated that the public *"is becoming more environmentally aware and ETS should be setting the example"*.

Before electric buses can be integrated in the ETS fleet, the drivers need proper training and education⁴². They would like to receive a driver's manual describing the vehicle's capabilities, its specifications, its hazards (if any) as well as what to do in emergency circumstances or *"when something goes wrong"*.

5.3.2 Mechanical, maintenance and service staff

Generally, the mechanical, maintenance and service staff interviewed, which were exposed to all three electric bus models, felt that they were ill prepared to service them during the field trials even though they received some manufacturer training.

The personnel interviewed felt that they experienced *"several bumps that could have been eliminated"* had they received the manuals and proper training: *"we didn't even have any computer programs to communicate with the bus"*. In fact, the general perception among those interviewed is that with the appropriate training, most of the issues and challenges experienced would have been removed. However, both BYD and NFI under their bus use contracts were responsible for all maintenance issues other than running repairs.

In general, the mechanical, maintenance and service staff interviewed felt a greater level of familiarity with the New Flyer electric bus given the similarities between this bus and the New Flyer diesel buses currently used in the ETS fleet.

⁴² Drivers participating in the focus group felt that training received was insufficient: *"even 30 minutes on the road would have been useful", "we were self-taught", "too many people showed up at the training session and I was in the back, unable to see what was being demonstrated"*).

Maintenance and service staff involved with the field trails felt that a longer trial period is required to truly evaluate the electric buses: *“We had them for a short period so we had minor issues. We would need more time in order to evaluate the maintenance and mechanical side of the buses. We would need some major failures to evaluate them. We never got into any of the electrical components.”* A trial of two years was suggested as a required period to evaluate the technology and its viability for ETS. The individuals interviewed also stated that a period of two years would be required for them to *“get used to the electric buses”*.

Table 5.4 Positive and negative perceptions of M&S Staff

Content reflects personnel language	BYD	NEW FLYER
Perceived positives	Relatively simple charging compared with New Flyer	Perceived as a superior product: "just the way it's put together" Winter ready
	Smoothness of ride	Smoothness of ride
	Good acceleration	Good acceleration
		Can fit through the washer
Perceived negatives	Sensitive acceleration	
	Perceived poor quality of manufacturing of the vehicle	
	Instability of performance in snow: "Even with the first layer of snow, it would dog track. It would slide from side to side."	
	Braking issues: "As soon as you hit break, you lost steering control."	Charging procedure is long with too many steps: "When they asked us to reprogram the charger, it took us 2-3 days before we got it to charge the buses"
	Stability issues despite changing the tires	
	The bus has one extremely large windshield that is heated. ETS changes several windshields per week given that rocks hit them and create damage. Changing these windshields would prove extremely challenging.	Diesel heater on the 2nd generation bus defeats the purpose of having an electric bus as it produces raw pollutants.
	Diesel heater on the 2nd generation bus defeats the purpose of having an electric bus as it produces raw pollutants.	

Source: MARCON, 2016

The mechanical, maintenance and service staff interviewed questioned the cost-effectiveness of electric buses: *“You need to consider personnel training, mechanical failures that would multiply. Plus I read that the frame of the [BYD] buses have failed⁴³. In our weather conditions, it wouldn't last long”*. Despite these questions, they expect that it would be easier for them to maintain electric buses as they have *“fewer parts, less fluids so fewer leaks, components are larger and*

⁴³ In the absence of information and education from the manufacturers, several members of mechanical, maintenance and service staff interviewed stated that they undertook Internet research and discovered the Altoona report where BYD electric buses received unfavourable evaluations: “From Altoona testing results, we understand that we would have more problems with the BYD than with the New Flyer. It was scary looking at these results. Major components were said to be coming off the vehicle. It does put doubts in your mind regarding the quality of BYD.”

probably rebuildable". They also expect savings because *"we wouldn't be going through oil like crazy"*.

Moreover, they raised the issues of the changes that would have to be implemented if the electric buses were deployed at ETS:

- Additional space in the garages would need to be allocated to charging stations and the charging area. Consequently, the garages would need to make physical adjustments to accommodate these buses.
- The wash rack would need to be changed, particularly if the BYD bus is used.
- Given the silence of the vehicles, they would need to be equipped with an audible alarm for the safety of garage personnel.
- Special lifts would be required to change batteries or other components.
- Special equipment or procedures would be required to change the BYD windshields when necessary.

5.4 Key findings

From a staff perspective, integrating electric buses into the ETS fleet and operations will require ...

- Relevant training of bus operations and mechanical, maintenance and service staff
- Preparation of unions to eliminate potential issues related to compensation and responsibilities
- Bus design that reflects the needs of drivers and riders.

Adequate training will be key to ensuring staff buy-in and a smoother integration of the new technology.

The staff interviewed, particularly the bus operators, are confident that with sufficient training, *"getting accustomed to this new technology will be like getting accustomed to any new bus"*.

Generally, bus operators are very positive concerning the adoption of e-buses in Edmonton as they feel it would be an improvement for their passengers and for themselves. Maintenance and service personnel somewhat warmed up to e-buses in the course of the field trials, but still remained cautious with regards to their integration in ETS' fleet.

6 Expected reliability of e-buses in service

6.1 Methodology

Electric buses have only been operating in Canada on a test basis but there are a few larger fleets in operation in the USA, in Asia, and in Europe. Fleet reliability statistics can be usually compared without major data investigations for North American fleets. Other countries often used different metrics that require detailed analysis beyond the scope of this report (agencies such as the International Bus Benchmarking Group provide such comparisons).

In North America, battery electric buses are still an emerging technology. Maintenance and reliability data available does not usually originate from a *standard in-service fleet* operating environment, making it difficult to compare e-buses performance to those of standard diesel or CNG buses. Foothills Transit and National Renewable Energy Laboratory, however, have recently published a detailed comparative report⁴⁴ that evaluates 35ft Proterra buses against a control fleet of CNG buses; details of which were used as part of this analysis.

The STL (Laval, QC) and the WTC (Winnipeg, MB) have 2 buses in service each⁴⁵, but they are still considered test vehicles and therefore receive “*special treatment*”, which makes it unfair to compare them directly to the rest of the fleet. But nevertheless, ETS bus testing and a variety of test reports from various sources (Transit properties, Altoona tests, etc.) offer a wealth of reliability information. A review of these tests and reports and the analysis of the differences between standard diesel buses and electric buses can provide a reasonable measure and qualified commentaries on the general reliability of battery electric buses⁴⁶.

This module focuses on the reliability of battery electric bus technology. During the ETS test program, there were a number of maintenance and operating problems not directly related to battery propulsion technology or its accessories; other problems related to the brand of bus, or lack of training/service support were also observed. It must be cautioned that during the very short test program at ETS, the e-buses in use were at various development stages (from advanced prototypes to early commercialization). Some of the downtime of the buses for maintenance purposes was attributable to technician and operator unfamiliarity or unavailability of some spare parts for the vehicles. In a larger *in-service* fleet, significant efforts would be taken to specify buses in detail, arrange training for operators, service and maintenance staffs, and provide service support, parts supply, and warranty terms.

In addition to the very short evaluation period at ETS, the planning for the evaluation was done too quickly, resulting in buses being made available that did not represent the latest generations of buses offered by the manufacturers. The short lead-time to procure buses resulted in not allowing manufacturers sufficient time to react resulting in one manufacturer not being able to provide a bus and another for only a very short period of time. Both BYD buses were an early generation bus and did not include all the design modifications that had been done as a result of other testing in Canada. The short lead-time and delivery of the buses over the Christmas period

⁴⁴ Foothill Transit Battery Electric Bus Demonstration Results, Leslie Eudy, Robert Prohaska, Kenneth Kelly, and Matthew Post, National Renewable Energy Laboratory, January 2016.

⁴⁵ The STL operates one DesignLine and one BYD bus. WTC operates two (and soon three) NFI electric Excelsior buses.

⁴⁶ The reader is reminded that this report’s level of precision is contractually limited to $\pm 25\%$.

also resulted in insufficient training being made available to staff even though manufacturers had the capability to provide the training.

6.2 Reliability of e-buses in other systems

6.2.1 Battery Electric Bus Reliability, Canada

MARCON has reviewed many aspects of bus reliability from numerous sources. The ETS test, other test literature, communication with manufacturers and bus properties, field meetings, personal bus maintenance and operating experience, among others. This study has found that ***battery e-bus reliability is at an acceptable level for ETS bus operations and maintenance, being at least as reliable as diesel buses.***

However, there are some caveats to the above statement:

- There is a general consensus in the industry that the future of transit buses lies on the electric path (battery or fuel cell powered). Bus manufacturers are therefore aggressively developing and improving their e-bus product line. This is confirmed by the rapid development of this new technology, by the positive and rapid way manufacturers are reacting to the formal “Altoona” tests and to transit properties' recommendations. In fact, the technology progresses at such a rate that MARCON expects the few weaknesses observed during the ETS field trial to be corrected by the time ETS is ready to place an order for what will be a new generation of battery electric buses.
- ETS staff experienced numerous issues with the test buses from maintenance to operating complaints. Most of these problems that are not attributable to the inexperience or lack of training of the ETS staff have been or are currently being improved and incorporated on newer generation buses.
- Much of the maintenance complaints relate to technician unfamiliarity, and reaction time of the bus manufacturer. This might not have occurred if a more careful test plan had been prepared at the outset. But, this situation would most likely not occur if a bus purchase project with appropriate purchase conditions, training, tooling and parts supply is followed.
- Some of the maintenance issues are related to additional staff time and handling of the buses, during the busy peak book out and servicing times, and weekends. More appropriate planning would have foreseen the need for additional resources for such a test program.
- Operator complaints often are related to safety conditions. In a test fleet some “safety” complaints can't be addressed with urgency. This can lead to miscommunication of the problem, delayed troubleshooting, and reduced confidence in the bus. New battery electric buses would need concentrated efforts to train Operators and deal with problems promptly. Timely manufacturer support and changes in programming could alleviate many problems.
- It is clear that purchasing a fleet of battery electric buses will require a change in maintenance staff support. Some reduction of running maintenance and preventive maintenance activities could be re-allocated to e-bus complex troubleshooting, and ongoing servicing activities. A more thorough analysis of tasks, skills, time and motions would be required to fully understand the impact.

Both of the other Canadian evaluations of electric buses in revenue service confirmed that the buses tested were reliable. In Winnipeg, it was concluded that battery electric transit buses perform reliably and efficiently in Manitoba's extreme cold⁴⁷ climate. The STO and STM evaluations concluded that for e-buses performance in terms of autonomy, operating time and regularity would allow their use over a large portion of the Montréal and Outaouais networks. The lack of significant variations in performance based on operating conditions (temperature, driving style, passenger load, charge time, etc.) justified this conclusion. Because of its predictable and stable performance, the use of e-buses does not add any major operational constraints other than those of time, space and electrical supply required for charging⁴⁸.

The Winnipeg evaluation was a long-term cooperative effort between the manufacturer, Winnipeg Transit and Red River College, and allowed technical improvements to be made to the bus before the formal evaluation phase. The STO and STM evaluations of the BYD bus conducted by AVT identified many issues with the design of the bus. These were forwarded to BYD and BYD responded addressing each of the 57 items and confirming what action was taken to remedy the deficiencies⁴⁹. These corrective actions were incorporated in subsequent design modifications to the bus. The ETS evaluated an early generation of the BYD bus, a version that preceded the improvements suggested by the STM and STO. Therefore, ETS identified many of the same deficiencies noted by AVT that have now been addressed in the commercially available version of the bus.

6.2.2 Battery Electric Bus Reliability, USA

The information available regarding the reliability of electric buses tested or evaluated in the USA confirms the results obtained by Canadian transit properties. The Altoona tests of all electric buses identified numerous deficiencies found with all three electric buses tested (BYD, NFI and Proterra)⁵⁰. Of the three tests conducted, the New Flyer XE40 was found to have the fewest deficiencies. The BYD bus was found to have the most. BYD learned from the test results and immediately designed remediation measures to correct all the deficiencies found⁵¹. A visit to the BYD manufacturing plant in early February 2016 confirmed that the design changes identified were being incorporated into the latest BYD buses being assembled. The latest generation of the BYD buses is expected to have far fewer reliability deficiencies as a result of these design changes.

MTA's (Chicago, IL) experience with the NFI XE40 electric bus has mirrored that of Winnipeg, confirming the good reliability of the bus⁵².

Foothills Transit evaluated the Proterra electric buses from April 2014 to July 2015, accumulating approximately 600,000 km on the 12 electric buses used in revenue service. Their performance was compared to a control fleet of CNG buses. The bus availability target for this transit system is 85%, higher than that of ETS. During the reporting period, the average availability was 90% for the E-buses and 94% for the CNG buses. Bus-related maintenance issues not associated with the drive

⁴⁷ Manitoba Battery Electric Transit Bus Fleet Development and Demonstration Report, Red River College, Winnipeg, October 2015.

⁴⁸ Evaluation Report: BYD's Green City Electric Bus (STO & STM), Société de gestion et d'acquisition de véhicules de transport (AVT), August 2014.

⁴⁹ Letter from BYD to AVT dated 5 August 2015.

⁵⁰ The results of the Altoona test of NovaBus new LFS-e were not yet available at the time of MARCON's analysis.

⁵¹ K9M Altoona Test Findings Corrective Actions Applied, 2015.

⁵² Conversation with CTA Project Manager, 8 January, 2016.

components explained the higher percentage of unavailability for the E-buses⁵³. The evaluation concluded that the E-buses have proved to be very reliable. Bus Mileage Between Road Calls (MBRC) for the data period was more than 9,000 miles; propulsion-related MBRC was more than 25,000 miles.

King County Metro in Seattle evaluated the Proterra Catalyst 40' electric bus from 17 October 2015 to 31 January 2016. The bus was operated 24/7 over a period of 106 days to simulate a full year's worth of operating time. The bus accumulated over 52,000 km in controlled testing with a full-simulated passenger load, and underwent over 1,750 charging cycles. It experienced no unforeseen maintenance issues and was available for 98% of the 106 days. The 2% unavailability was due to regular routine maintenance inspections⁵⁴.

6.3 Reliability experience in winter field trials in Edmonton

The following figure shows propulsion system and other related events for electric buses 6011 and 6013. The 6011 BYD bus operated before and after the official test period and is shown here for reference purposes only.

Table 6.1 Maintenance Events - Electric Buses

Unit No	Date Completed	Job Description	Labor Hours	Unit No	Date Completed	Job Description	Labor Hours
				N6013	04-01-2016	REPAIR Decals	3.5
N6011	25-01-2016	TOWING/BOOST Total Vehicle	1.0	N6013	11-01-2016	DIAGNOS E Smartbus Suite	0.0
N6011	25-01-2016	TOWING/BOOST Total Vehicle	0.5	N6013	12-01-2016	REPAIR Destination Sign	0.5
				N6013	17-01-2016	CHANGE OVER Total Vehicle	0.8
				N6013	20-01-2016	DIAGNOS E Farebox	0.4
				N6013	24-01-2016	CHANGE OVER Total Vehicle	1.3
				N6013	28-01-2016	DIAGNOS E Destination Sign	1.7
				N6013	31-01-2016	CHANGE OVER Total Vehicle	0.8
				N6013	03-02-2016	REPAIR Panels - Exterior	6.0

Events during the field trials period:

- Extra maintenance and operating staff effort was required to ensure the electric buses operated most days during the test period.
- There were few propulsion related problems with either bus during the test period. The BYD 6011 bus had one propulsion related issue and the NFI 6013 had no propulsion related issues. In fact, most of the maintenance items experienced once the buses were in Edmonton were unrelated to the battery/propulsion system. For example, mirrors, doors, destination sign maintenance is common to any type of bus.
- 6011 Towing/Boost was related to the problem of 12V bus body batteries draining (possibly due to an ETS added Smartbus system).
- 6013 had Sunday changeovers during the test period. This is because the Sunday routes are approximately 360 km, so 6013 was changed out after approximately 90 km.
- BYD buses 6011 and 6012 also operated outside of the Jan 7 – Feb 5 formal test period. Issues outside of the test period are also noted below.

⁵³ Foothill Transit Battery Electric Bus Demonstration Results, Leslie Eudy, Robert Prohaska, Kenneth Kelly, and Matthew Post, National Renewable Energy Laboratory, January 2016.

⁵⁴ Fresh Energy Video Report dated 29 March 2016, <http://fresh-energy.org/2016/03/seattles-experience-with-electric-buses/>.

Table 6.2 Other Maintenance or Design Issues - ETS Electric Buses

BYD Buses (6011, 6012)	New Flyer
<p>Connecting the charger is an awkward two-handed operation. <i>BYD has moved the location to front side on new buses – more convenient with only a single action required to insert the charger.</i></p>	<p>Bus has considerable body roll due to rooftop batteries and components. <i>A front sway bar would improve this situation.</i></p>
<p>Battery pack on front right wheel well restricts driver vision for right hand turns. Some routes and/or drivers have issue with this. <i>BYD has moved this battery pack on its new generation of buses.</i></p>	<p>New Flyer charging connector is heavy. <i>An optional available lifting arm is required for fleet service to reduce likelihood of connector damage or strains.</i></p>
<p>ABS problems early on kept the bus out of service. <i>Software issue, corrected by BYD service staff.</i></p>	<p>Bus power must be cycled on/off 30% of the time to connect to overhead charger.</p>
<p>Front door re-opening after closing. <i>A sensor was out of adjustment and repaired.</i></p>	
<p>12V bus body batteries draining when parked. <i>ETS Smartbus system could be draining power.</i></p>	
<p>Wiring harnesses poor weatherproof seals noted but did not cause issues during the test program. <i>Being improved on new buses.</i></p>	
<p>BYD bus acceleration and deceleration is more aggressive than what operators are used to due to high torque of electric drive. <i>Winter tires required in ETS winter. BYD can re-program the regenerative braking but it may impact energy consumption.</i></p>	
<p>BYD bus too high for existing bus wash. <i>Bus wash in new facility needs to be specified accordingly.</i></p>	

Source: MARCON, 2016

Electrification of transit buses has been evolving for many years in various forms. Trolley buses have been operating with electrical components all over the world for decades. Hybrid buses with electrical components have been common and abundant for several years, and fuel cell in smaller demonstration fleets around the world. This experience allows rapid development of battery buses, using well-known and generally reliable technologies. More of a challenge is the integration of these various components and logic controls to network. Table 6.3 indicates the relative reliability of the various components used in electric buses based on our experience. The non-electric drive components have warranties similar to those for diesel buses.

Table 6.3 Battery Electric bus Components and Attributes

Component	Notes	Expected Reliability / Warranty Period
Bus Chassis and component layout	Battery buses have very similar chassis layout and attributes to standard diesel, CNG, hybrid or Trolley buses. The main differences, other than Batteries/Motor to drive the bus, is electrical operated accessories. A summary of these battery bus attribute difference is listed below.	
Battery Pack Lithium Ion	Technology also used in Hybrid buses and Trolley buses, and recent fuel cell buses.	Good reliability. 6-12+ years life up for debate. Warranty - NFI and BYD have offered 12 year warranty.
Battery Pack and Component Cooling	Cooling for batteries, motor, inverters required. Technology also used in Hybrid buses and Trolley buses.	Good reliability. Simple cooling loop using electric fan/radiators.
Voltage Inverters, Power Modules	Similar technology used in Hybrid, Trolley, Fuel Cell buses.	Improving reliability. Lessons learned from hybrid and fuel cell buses. Warranty from 2-6 years.
Drive motor(s) Single or dual wheel motors	Technology used in Hybrid, Trolley, Fuel cell buses.	Good reliability. Usually European technology. Warranty from 2-6 years.
Electric bus rear axle	Standard production axles available	Good reliability, standard axles. Special drive shaft must be used. Warranty 5-6 years.
Power Steering	Similar technology used in Hybrid, Trolley, Fuel Cell buses.	Good reliability. Warranty covered under 1-2 year bumper to bumper.
Air Compressor	Similar technology used in Hybrid, Trolley, Fuel Cell buses.	Excellent reliability – direct drive scroll compressors often used. Warranty covered under 1-2 year bumper-bumper.
Body Heating	Diesel heaters used in most diesel buses since 2007. Electric heating evolving.	Fair reliability. Diesel heaters have often been problematic in buses with smoking and maintenance problems.
Air Conditioning	Technology used in Hybrid, Trolley, Fuel cell buses.	Excellent reliability. Electric driven air compressors common and standard availability.
Electrical Integration	Communication and Logic between electrical components is critical.	Good-Fair reliability. Some manufacturers have more robust experience in integrating various electrical components than others. Technicians must have training and experience.
High Voltage Wiring	Similar technology used in hybrid buses, trolley buses and Fuel Cell buses.	Good reliability. Some manufacturers have more robust experience in quality control and installation methods.

Source: MARCON, 2016.

6.4 Impact of winter performance of e-buses on ETS's

6.4.1 Temperature

Considering Edmonton is one of the coldest cities in North America, temperature is of particular importance to ETS. A detailed analysis of the test results obtained during the test program was conducted to determine the impact of temperature on performance. The AVT report on the STO/STM trials in Quebec was also taken into account⁵⁵. Although there were only seven very cold (-15 to -22 °C) days during the Edmonton test period, MARCON is confident⁵⁶ that the conclusions of this test program can be reliably extrapolated to colder temperatures:

- **Propulsion energy use:** Propulsion energy use and battery performance is unaffected by colder ambient temperatures. Refer to Section 3.8.2 for further information.
- **Interior bus heat:** Empirical measurements show that a comfortable temperature was maintained during the test program inside all e-buses, with or without the diesel heater. However ...
 - Electric heat – rigorous testing in Quebec by AVT has concluded that diesel heat is required in very cold temperatures⁵⁷. Up to 50% of battery power could be used to heat the bus with electric heaters. Of course this depends on outside temperature, and door opening frequency. Anecdotal experience shows typically 20-30% energy use for electric heating. This can be easily calculated – a typical Spheros 300 diesel heater can produce 30 kW/hour (100,000 BTU) of maximum heating energy. ETS tests showed 15-20 kWh/hour of propulsion energy use.
 - Conversely, electric air conditioning can consume up to 35 kW of energy. On extremely hot days with frequent door openings, this could limit the buses' operating range.

Customer perceptions of the indoor temperature in e-buses (see section 4.2.7) indicate that all e-buses performed adequately and, if anything, were a little warmer than preferred.

6.4.2 Servicing

Several servicing issues were identified during this study:

- Battery electric buses must be parked in the heated parking barn when not operating. This is normal for ETS operations, but critical for battery buses. A White Paper from CALSTART⁵⁸ showed Lithium-Ion battery performance drops off sharply below 0°C. However, when vehicles are kept warm when not in use, the heat management system on board the buses is well able to prevent this drop in performance by keeping the batteries at their optimal temperature under all conditions.
- Diesel usage for space heaters normally increases in cold temperatures. A diesel fill schedule should be designed to ensure the tank has sufficient fuel for a day's operation.
- Bus washing. Battery electric buses have much more wiring, connectors, electronic controls and components than standard diesel buses. Melting snow on roof and salt

⁵⁵ Evaluation Report: BYD's Green City Electric Bus (STO & STM), Société de gestion et d'acquisition de véhicules de transport (AVT), August 2014.

⁵⁶ Certainly within the contractual level of precision of this assignment.

⁵⁷ Ibid 55.

⁵⁸ E-truck Performance in Cold Weather, CALSTART, Pasadena, CA, June 2014.

intrusion onto components can cause electrical problems. A cleaning and washing schedule may have to be designed depending on road salt build-up on bus components.

6.4.3 Bus Driving

Several operating issues were identified during the field trials:

- Battery electric buses have regenerative braking. When the accelerator pedal is released, the system uses the motor as an alternator, thereby automatically converting the kinetic energy from the movement of the bus into electric energy that is being sent back to the battery pack. The use of the motor in that manner causes the bus to slowdown. This can cause rear wheel slip, or ABS events, in very slippery conditions by having less direct control over rear wheel braking. BYD recommends turning off the regeneration in extremely slippery conditions (icy roads).
- Electric motors can have a lot of torque and so, electric buses can accelerate relatively rapidly, depending on how the drive system has been programmed. Rapid acceleration can also cause rear wheel slip. To a certain extent, operators need appropriate training and must get used to this added power. Snow tires can be installed in the winter to help them better control the bus but acceleration and deceleration programming can be adjusted by the manufacturer if necessary. Reducing the regeneration rate on braking will however decrease the amount of energy that can be recovered and reused by the batteries.
- In any vehicle, energy use is greatly affected by driving habits. Driver training programs are strongly recommended to maximize the benefit of using battery electric buses if ETS elects to electrify its fleet.
- Similar to other technologies (hybrid, trolley, fuel cell) battery buses have different warning lights and alarms, and safety protocols. Again focused driver training is required.
- Winnipeg Transit has noted up to 15% more energy usage on heavy snow days (2" on road or more). This should be temporary in operation as it is hoped road clearing and traffic will reduce the snow load.

6.5 Lessons Learned

Lessons learned and conclusions regarding the ETS field test and this investigation into e-Bus reliability are summarized below.

The literature review as well as the results from the field test in Edmonton revealed that e-buses as tested are, from an electric drive viewpoint, at least as reliable as diesel buses currently deployed at ETS. Of course, the quantity of data at our disposal was somewhat limited by the short duration of Edmonton's field test and by the newness of the technology itself. But given the fact that:

- almost all other bus components are akin to those currently being used;
- electric motors are simple, well known and have proven to be reliable in many applications; and,
- batteries are evolving rapidly but have so far demonstrated their robustness.

It should be noted that WTC has been experiencing issues with its en-route charging system. This should be investigated further in order to correct any potential problem if this technology is to be adopted by ETS.

7 Externalities and related costs

7.1 Methodology

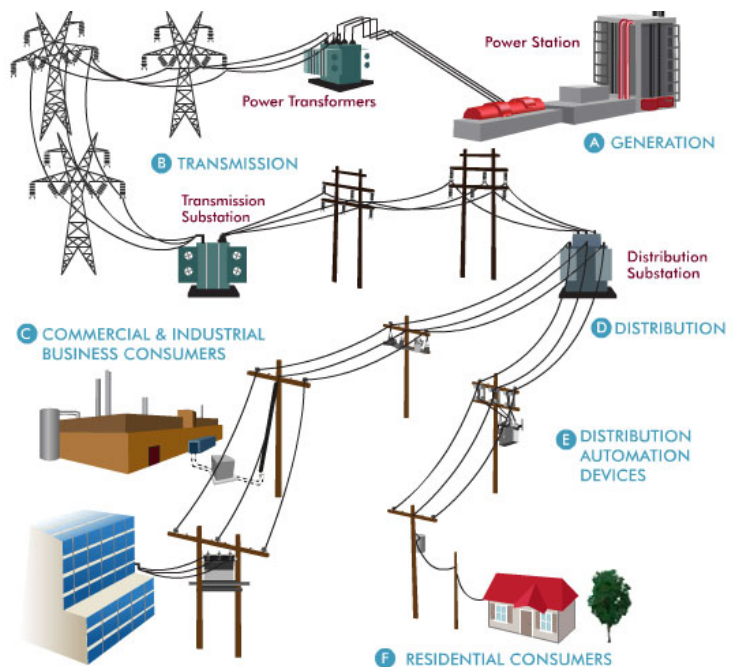
Externalities refer to costs and benefits associated with the choice to invest in e-buses that are not incurred directly by ETS but that must be considered in a broader perspective by a municipal government.

In order to determine some of these costs, the ETS Steering Committee directed MARCON to work from a single scenario: 40 e-buses assigned to a new facility still in planning, the North East Transit Garage (NETG). Calculations described in this section are based on this scenario but calculations first had to be performed to determine whether the grid could handle the additional electric load, and if the buses could handle the usage prescribed by the Steering Committee.

7.1.1 Methodology used to analyze grid impacts

One limiting factor when considering large-scale deployment of e-buses is the impact to the electrical grid, and the assessment of available power at potential charging locations. Power availability can always be increased by adding infrastructure, but potentially at great cost. In Figure 7.1, electricity created at a power station is delivered to an end customer through a series of infrastructure items including step-up transformers, high voltage transmission lines, step-down transformer substations, lower voltage local transmission lines, and customer location transformers. Any of these infrastructure pieces can be capacity challenged based on the local demand.

Figure 7.1 - Key Components of an electrical grid



In Edmonton, the local distribution utility is EPCOR, and it is their responsibility to anticipate the power needs of their territory and plan the installation of equipment that the customers will require to satisfy demand. Either the customer or the utility can install equipment on the customer-side of a distribution substation without regulatory approvals. The Alberta Electric System Operator (AESO) is the regulator that provides approvals to the utilities to install major equipment (substations) that connects directly to the grid. An AESO regulated approval is lengthy and costly as the process includes mandatory public engagement, front-end engineering, and could take up to two years for final approvals. In the business case presented in section 9, MARCON assumes that no new substations would be built as EPCOR did not raise this possibility when presented with the parameters of the study. Substation capacity at peak load is thus one of the most significant limiting infrastructure items in the study, and the charging strategies described below reflect different approaches to delivering electricity to e-buses.

In order to establish the amount of power available for charging at various locations, MARCON connected with EPCOR and requested a current and forward-looking assessment of available power at each transit garage. EPCOR provided data from which MARCON was able to calculate the maximum number of buses that this power availability could service.

The energy required on a daily basis by each of the 40 e-buses was determined by making a detailed analysis of all the blocks served by the fleet posted at the Westwood facility, (Westwood Garage). Potential blocks that e-buses can service were then identified. Finally, the optimal assignment of e-buses to potential blocks was determined.

A battery depletion simulation developed by MARCON was then used to predict the state-of-charge (SoC) of buses returning to the garage. The SoC of a bus and its total battery capacity dictate how many minutes of charging are required to supply a sufficient amount energy to the battery so it can (minimally) service its next block assignment, and ideally be fully charged.

Despite their rating, charging station performance is ultimately limited by the chemistry of the battery on the bus. Many bus vendors are using a mixture of third party and proprietary battery technology; some operational constraints limit their deployment. The scope of this project did not include a complete review of all charging options available on the market. For the purposes of this report, MARCON based its calculations on the equipment provided by the vendors that participated in this test program.

Only two charging technologies were considered: Trickle-charging and en-route charging.

BYD offers trickle-charging, conductive charging units. Power specifications allow for a BYD 12m bus to get a full charge from empty in 3.5 to 5½ hours, depending on unit used.

Although a conductive system is available from this supplier, New Flyer offers an en-route rapid charger that was used for our calculations in Edmonton. Based on a mature technology from the rail industry, this charger offers up to 300kW of output power from a 600VAC 3-phase nominal voltage input. It is available in both Nema Type 1 (Indoor) and Nema Type 3R (Outdoor) enclosures.

The two charging methods are fundamentally different in how they interact with the grid, and the externalities associated with each are discussed later in this section. Ultimately, the environmental externalities are influenced by the technology constraints of each charging method, because the utilization potential of the buses determines the amount of diesel being displaced.

Figure 7.2 Winnipeg's en-route charging equipment with a New Flyer bus



7.2 Battery depletion and fuel-use

The battery of an electric bus is analogous to its fuel tank. Theoretically, the range of a bus is determined by its battery capacity and its fuel efficiency (often related to its curb weight). Practically, other factors such as its payload, the driving habits of the operator and road conditions have substantial impact of its performance.

**Table 7.1 BYD
Battery Discharge**

Hour#	Time	Charge (kWh)
0	5:00	324
1	6:00	299
2	7:00	274
3	8:00	249
4	9:00	224
5	10:00	199
6	11:00	259
7	12:00	319
8	13:00	324
9	14:00	299
10	15:00	274
11	16:00	249
12	17:00	224
13	18:00	199
14	19:00	174
15	20:00	49
16	21:00	124
17	22:00	184
18	23:00	244
19	0:00	304
20	1:00	324
21	2:00	324
22	3:00	324
23	4:00	324
24	5:00	324

Source: MARCON, 2016.

In the ETS field tests, the BYD buses were equipped with 324 kWh battery, and the New Flyer had a 200 kWh battery. Both vendors offer alternative battery capacities, but 324 kWh is one of the largest capacity commercially available today.

In a conservative way, MARCON selected the worst fuel-efficiency performances observed during the field trials to calculate the single-charge range potential of both e-bus types. This represented electricity consumption rate of 1.25 kWh/km for the BYD bus. The manufacturer recommends that at SoC of 15%, the bus returns to the Garage (warning lights appear on the console). BYD can therefore handle a run of 220 km before it heads back to the garage for a recharge. Table 7.1 demonstrates a battery depletion model for a BYD bus. The cells marked in green represent time in which the bus is recharging. Note that the minimum SoC in this example never reaches below 15%.

In this example, the bus consumes approximately 22.5 kWh of electricity per hour of use, and recharges at a rate of 60 kW/hour. The best use for a trickle-charged bus is therefore in “*peaker*” capacity (2 blocks assigned per day) as it enables its owner to maximize the

service the bus will thereby procure.

In the case of an NFI bus, the electricity consumption rate was measured a 1.38 kWh/km. The bus can therefore cover 116 km on a full charge of its 200 kWh battery⁶⁰. NFI’s e-bus operating in Winnipeg recharges en-route with the rapid charging conductive system described earlier. It is located where the bus has a scheduled layover at the end of each run. This allows the bus to *top-up* for a few minutes each hour. This charging technology can eradicate concerns with range limitations, provided that a sufficient amount of strategically located chargers are available along its route⁶¹.

**Table 7.2 – NFI
Battery Discharge**

Hour #	Time	Charge ⁵⁹ (kWh)
0	5:00	160
1	6:00	157
2	7:00	155
3	8:00	152
4	9:00	150
5	10:00	147
6	11:00	144
7	12:00	142
8	13:00	139
9	14:00	137
10	15:00	134
11	16:00	131
12	17:00	129
13	18:00	126
14	19:00	124
15	20:00	121
16	21:00	118
17	22:00	116
18	23:00	113
19	0:00	111
20	1:00	108
21	2:00	160
22	3:00	160
23	4:00	160
24	5:00	200

Source: MARCON, 2016.

⁵⁹ Rapid chargers do not recharge batteries as fast past 80% of their nominal capacity. MARCON therefore uses 80% of nominal capacity as the maximum SoC in its model. See discussion on round trip efficiency in the Appendix 1 lexicon.

⁶⁰ While NFI can also deploy a 300 kWh battery bus, BYD was used to model the trickle-charging scenario because it is more efficient.

⁶¹ It should be noted that while the WTC has a 100 kW charger at their garage facility, it has rarely been used because the rapid-charger located en-route provides sufficient opportunities to keep the battery fully charged.

Table 7.2 demonstrates a battery discharge model of en-route charging for a 200 kWh NFI bus using a rapid conductive charger, as is the case in Winnipeg. In this example, the e-bus uses approximately 27.5 kWh of electricity per hour, and the bus receives 5 minutes per hour of charging using a 300 kW (25 kWh) charging station. It can be observed that the battery depletes throughout the day, but the minimum recommended SoC (20%) that would require the bus to come out of service is never reached. Thus there is no range limitation using this technology.

While the average ETS diesel fleet fuel efficiency is approximately 54 L/100 km, the 2013 Xcelisior diesel buses used as baseline comparative vehicles for the field trials running along the electric buses consumed only 49 L/100 km.

7.2.1 Space heating and its impact of energy efficiency

In a diesel bus, heat for passenger comfort is harvested from the engine's cooling system that would otherwise vent this energy. Space heating therefore has no impact on diesel bus energy efficiency. In an e-bus however, the discharge of the battery pack does not generate a sufficient amount of heat⁶² to maintain the interior of the bus at a comfortable temperature at all times. Heating loads therefore represent an additional drain on batteries unless e-buses are equipped with heaters fed by another energy source. The most common way is to fit the bus with an auxiliary diesel-fuelled heater.

Using electric space heating reduces the efficiency of an e-bus significantly. In our field test, both manufacturers supplied an e-bus equipped with a diesel heater and one bus had an electric heater as well.⁶³ Data from other field trials⁶⁴ performed in Quebec (Montreal, Gatineau and Laval) show that on extremely cold days, electric heaters create a power drain on batteries can be as much as 25%⁶⁵ of its total capacity. The energy consumption of buses using an electric heaters increases substantially on these very cold days, decreasing the range of buses proportionately. This can potentially limit the blocks that the e-bus can service on occasion.

When using electric space heating, there are no externalities associated with upstream electricity generation as the amount of energy used by the buses remains the same. But using auxiliary diesel heaters increases both GHG emissions and its associated cost. The diesel heaters used in field trials consumed an average of approximately 2 litres of diesel per 100 km.

Using diesel space heaters would also change the way that e-buses could be characterized and marketed to customers. For instance, the bus could (technically) no longer be described as entirely "*tailpipe emission free*", and whilst this diesel consumption is marginal (approximately 4% of a standard diesel bus), the odour of diesel combustion might still be noticeable to customers.

⁶² The operation of any battery generates heat due to the I^2R losses as current flows through the internal resistance of the battery whether it is being charged or discharged. This is also known as Joule heating. In the case of discharging, the total energy within the system is fixed and the temperature rise will be limited by the available energy.

Battery designers strive to keep the internal resistance of the cells as low as possible to minimise the heat losses or heat generation within the battery but even with cell resistances as low as 1milliOhm the heating can be substantial. See Effects of Internal Impedance for examples.

⁶³ Note that data from the BYD bus equipped with an electric heater is considered unreliable because that bus was put in service late in the test period and yielded sporadic results.

⁶⁴ Evaluation Report: BYD's Green City Electric Bus (STO & STM), Société de gestion et d'acquisition de véhicules de transport (AVT), August 2014.

⁶⁵ It should also be noted that severe weather conditions (below -25C) were not encountered during the trial, thus colder days than those encountered would likely decrease the efficiency and range of the buses even further.

7.3 Assignment of 40 e-buses from Westwood

7.3.1 Blocks and Routes

The Westwood garage (and therefore its replacement, the NETG) has 395 weekday blocks, 95 Saturday blocks, and 66 Sunday blocks. To create a 40-bus scenario for each charging method, there needs to be a match between the range capabilities of the technologies and the character of the block.

Based on the block schedule in effect on February 16th, 2016, weekday blocks vary in length from 430 km to 12 km. Saturday and Sunday blocks do not include ‘*peaking*’ services thus the average block distance is considerably longer, 263 km and 275 km respectively, compared to 110 km for weekdays.

Trickle-charged e-buses

An e-bus equipped with a 324 kWh energy storage system and consuming 1.25kWh per kilometre as measured in the field trials can cover a block of 220 km before reaching the recommended 15% SoC limit. But taking into account a spare ratio of 20%, the average yearly distance ascribed to e-buses by Steering Committee (see figure 9.1) can easily be exceeded, as the maximum potential of these e-buses is 57,850 km. In year 2, the usage pattern calls for 59,000 km. This is feasible as the buses, in their early life, will experience less downtime for maintenance

Based on the battery depletion models described in table 7.1, trickle-charged e-buses can service 334 weekday blocks, but only 33 on Saturday and 22 on Sunday. It is even possible to create more weekend block opportunities for these buses by splitting some of the longer blocks into portions that the technology is capable of servicing, but the redesign of blocks is beyond the scope of this project.

En-route charged e-buses potential

En-route charging enables buses to stay on the road much longer. There are less than 10 Blocks out of the Westwood Garage that an en-route charged bus could not complete based on the infrastructure scenario described in section 7.3.6.

7.3.2 Interlining

Interlining is used to make the overall fleet utilization more efficient by having a bus cover more than one route during its block. Interlining is irrelevant to the trickle-charged buses, as they do not require any infrastructure on the road. But charging stations for en-route charged e-buses are usually positioned at transit centres, therefore requiring block assignments to be done with the limitations of the vehicles in mind, as certain routes may not be serviceable by trickle-charged buses.

In this analysis, a block is considered a viable assignment for an en-route charged bus only when all of the routes on that block have a Transit Centre equipped with a charging station.

7.3.3 Block Assignment Strategy and Duty Cycle

During the field trial, both BYD and New Flyer were tested by the city’s toughest hills fully loaded, and in winter conditions. Neither bus showed perceptible difficulty climbing these hills. Given this performance, MARCON concludes that there is no route in the city that e-buses are incapable of driving, nor is there a likelihood that such a route will be designed in the future.

As e-buses can deliver significant operational cost savings compared to diesel buses (Section 9), it is advantageous to assign e-buses to the longest blocks that their ranges are capable of servicing. Our analysis of each Westwood garage serviced block, of the number of kilometres driven and the time at which the buses leave and return to the garage is known (Appendix 2). Based on the results of the field trials, MARCON calculated:

- The amount of diesel fuel required by the latest model diesel buses in service;
- The amount of electricity required by both types of e-buses;
- A baseline for GHG emissions from the diesel buses;
- The amount of GHG emissions attributable to the electricity consumed by e-buses;
- The return to garage SoC; and,
- The amount of time available to replenish trickle-charged e-buses at the garage.

Trickle-charged e-buses

In order to establish the maximum in-service range of these vehicles, the longest 40 morning blocks and the longest 40 afternoon blocks the trickle-charged e-buses could handle were assigned. MARCON's selection of blocks was based on the amount of time returning e-buses assigned to morning blocks would have for recharging before being sent on their afternoon runs. The morning blocks selected in this model commonly leave the Westwood garage around 06:00 hours, and return around 09:20 hours. The afternoon blocks generally depart around 15:15 hours to return at approximately 21:30 hours.

On average, these assignments provide the opportunity for about 360 minutes of charging after the morning run, and approximately 500 minutes of charging at night. Using a dedicated 60 kW charger for each bus, there is sufficient charging time both between the morning and afternoon blocks (83 charging minutes required) and overnight (178 charging minutes required) for the buses to leave the garage fully charged every day on all assigned blocks.

Using the targeted blocks, each trickle-charged bus could maximally drive up to 57,800 km/year. The usage pattern supplied by ETS calls for up to 59,000 km of service in year 2. This will be achievable with trickle-charged e-buses as the downtime required for maintenance in the buses' early life is no more than 15%.

7.3.4 Externalities associated with the use of trickle-charged buses

EPCOR provided MARCON with estimates of current (2015) and future (2020 and 2025) load for all of the ETS garages. Table 7.3 describes the substation assigned the new Westwood facility and the estimate of available power that could be dedicated to charging stations. The estimate includes a project that will add another 100 amps of available capacity to the site at 600 Volts. Available current suggests that up to 44 concurrent charging stations can operate under this condition, and if an automated switchgear was installed to take advantage of the charging equipment availability ratio, up to 121 buses can be potentially charged under perfect conditions per night.

**Table 7.3
Substation capacity limitations**

Division	Circuit Limit	2015 Summer Peak Loading	Available Amps	2020 Summer Peak Loading	Available Amps	2015 BYD 60 kW Charging Stations	2020 # BYD 60 kW Charging Stations
New Westwood Garage (as planned)	316	176	140	184	132	47	44

Source: EPCOR, 2016.

7.3.5 Externalities associated with the use of en-route charged e-buses

The Winnipeg Transit Corporation has been using two New Flyer en-route charged e-buses operating on the downtown-airport run for the past 16 months. The configuration of the technology deployed in Winnipeg has been used in the calculations of this study’s battery depletion and block analysis for lack of this equipment in the ETS field trial. The bus performances used for our calculations are however from the NFI e-bus tested in Edmonton.

The technical constraint limiting the maximum number of buses utilizing en-route charging is the number of charging stations that can reasonably be deployed for this task and how efficiently they can be utilized without affecting service delivery. Our calculations are based on the assumptions that each bus will benefit from a 5-minute charge at a rapid charging station. MARCON assumed a utilization rate of only 75%, resulting in no more than 8 buses per hour having access per charger.

The influence on time-of-day availability of charging stations associated with interlining was not studied as it exceeds the scope of this study. In order to charge 40 e-buses in service at any given time, 8 en-route rapid charging stations are required. They would be located⁶⁶ at:

- 1 station – Jasper Place TC
- 1 station – Coliseum TC
- 1 station – Belvedere TC
- 1 station – East Clareview TC
- 1 station – West Clareview TC
- 1 station – Northgate TC
- 1 station – Eaux Claires TC
- 1 station – Castle Downs TC

The en-route charging strategy as suggested above permits most of the longest blocks out of the garage to be assigned to e-buses. Each bus does, however, require access to a charger for on

⁶⁶ The scope of this study does not provide for an analysis of the feasibility of installing rapid charging stations at the locations indicated herein.

average 4-6 minutes per hour. Conveniently, this time requirement is largely built into the Block schedule, with layovers at a transit centre of approximately the same frequency and duration already built into each route. Interlining can also have the added benefit of an extended layover as a bus shifts from route-to-route depending on the block, thereby providing additional charger availability.

The analysis of Westwood’s blocks suggests that using this rapid charging equipment, ETS could deploy more than 40 e-buses assigned to the majority of the longest blocks out of the garage. If the utilization rate of en-route charging stations reached 75%, the same en-route charging infrastructure could service an additional 16 buses.

Assuming that when e-buses return to the garage, their average SoC is 69%, topping up each e-bus to 80% of its battery nominal capacity would require a little less than 5 minutes. A single rapid charger can theoretically perform this task, but equipping the garage with a second unit would allow the service crew to use the same routine as with the diesel buses. Alternatively, these e-buses could be topped up at the first transit centres they encounter on their block by simply adding 5 minutes to the blocks. This would have less than a 1% impact on the average assigned block length (1034 minutes). In this case, a trickle charger will be required at the garage to handle cases of self-depletion (see lexicon in Appendix 1).

EPCOR also provided forward-looking power capacity and power utilisation estimates for the Transit Centre locations. All identified locations have sufficient power available to install at least two 300 kWh rapid charging stations as East and West Clareview would draw power from the West Clareview TC. This analysis suggests that no additional substations would be required to be built to satisfy the implementation of this technology, and that there is significant opportunity to expand beyond 40 buses in the future.

Table 7.4 Transit Centre charging potential

Division	Circuit Limit	2015 Summer Peak Loading	Available Amps	2020 Summer Peak Loading	Available Amps	# New Flyer 300 kW Charging Station
Northgate Transit Centre	380	333	47	346	34	3.9
Coliseum Transit Centre	380	319	61	305	75	5.0
Belvedere Transit Centre	310	145	165	250	60	4.0
East Clareview Transit Centre						0.0
West Clareview Transit Centre	380	345	35	279	101	6.7
Eaux Claires Transit Centre	380	262	118	272	108	7.2
Castle Downs Transit Centre	380	332	48	345	35	2.3
Jasper Place Transit Centre	380	225	155	234	146	9.7

Source: EPCOR, 2016.

This capability does come at a capital cost as shown in section 9.2.2. While the price of a BYD e-bus includes its trickle charging system, transit properties must purchase rapid-charging stations separately. En-route charging systems serve multiple buses (5-12 each).

7.4 Other externalities

In its 2016 budget, the Federal Government announced its intention to invest in transit infrastructure. In total, this budget committed \$347 M to the province of Alberta and Edmonton will likely receive a large share of these funds as they are allotted on the basis of ridership.

Funding has been earmarked for projects that increased rider density, and benefit the environment. ETS's Valley Line LRT project satisfies these requirements, as potentially would an electric bus deployment. One advantage of an e-bus proposal is that ETS has a natural procurement cycle planned in 2017 for new buses, and diesel buses will not likely qualify for this federal funding opportunity.

Despite this favourable situation, the business case presented in section 9 does not take any contribution to the implementation project from either the federal or other source.

7.5 Key findings

Externalities associated with charging principally concern the amount of power available at specific locations at both the garages and transit centres where charging equipment will be located. To determine how a bus will functionally operate within ETS's existing block structure, every block assigned out of the garage was evaluated to determine whether an e-bus would be capable of completing the block. Suitable blocks were ranked by distance with the preferred assignment ranked by the longest distance travelled.

From an externalities viewpoint, there are advantages to each e-bus technology. En-route charged buses can be dedicated to the longer blocks. This is significant because the more distance an e-bus covers, the greater financial benefit it yields compared to its diesel fuelled counterpart. The most significant advantage of distributed charging strategies from a risk mitigation perspective is that there are more physical connections to the electrical grid, thus there is greater redundancy in the infrastructure system. For instance, if a single substation were to fail in a distributed network, an en-route charged bus would still most often have 2-3 other Transit Centres to charge at. Interlining actually reduces risk in an en-route scenario. However, if the substation upstream of the Garage was to fail, everything dependent upon it does as well.

As for trickle charging, its main benefit is the lower initial investment required. Charging infrastructure would be located in one facility. Adding charging stations to this facility will not represent a substantial investment compared to the cost of modifying eight transit centres in addition to the planned garage. Trickle charging at a single location will also minimize the disruption of traffic in the city that will inevitably result from the modification of the transit centres.

Also, distributing the charging process of buses throughout the city has many positive benefits for the city's electrical infrastructure, delivering EPCOR with a better distribution of the additional load over its existing power grid. This can provide opportunities for EPCOR to improve the return on their infrastructure investment.

Creating additional demand for electricity might also spur the renewal of energy production equipment, and potentially the installation of greater capacity within the city.

Alberta has not experienced a significant deployment of electric vehicles. Utilities and AESO have therefore not developed projects or modified their demand forecasts with electric vehicles (EVs)

in mind. ETS could be the catalyst for a transportation electrification strategy citywide. EPCOR and the City should work collaboratively to develop a policy and infrastructure plans that anticipate how electrical energy demand will grow in response to emerging EV technologies, and a rise in consumer confidence in how an electric vehicle can meet their transportation needs. By creating these plans, there will be more opportunity for capacity building within the rate base, which will reduce project specific costs. Consumer comfort with EVs will also potentially ease stakeholder concerns when regulated projects work their way through the approval process.

Finally, the adoption of EVs by their municipal government sends a strong and positive signal to citizens regarding this technology. It will encourage the population to consider, and eventually adopt EVs in a wider fashion. This will have a measurable impact on the carbon footprint of Edmonton.

8 Environmental impact of e-buses at ETS

8.1 Methodology

The GHG intensity of Alberta’s grid is expected to decrease over time as older and “dirtier” power plants are decommissioned. To project a future grid intensity, MARCON extrapolated utilization of installed capacity based on Alberta’s 2014 electricity production reports⁶⁷ and AESO’s long term outlook⁶⁸ estimates, both future installed capacities and total demand in years 2019, 2024, and 2034.

AESO also projects power generation scenarios that include Main Growth, Low Growth, Environmental Shift and Energy Transformation. Using the main outlook AESO scenario, the grid intensity would be expected to drop from 0.81 TCO₂^e/MWh in 2014 to 0.46 TCO₂^e/MWh in 2034. This anticipated improvement would have resulted mainly from the 2012 Federal regulation regarding coal-fired power plants that decrees the decommissioning of coal-fired plants no later than 45 years from their commissioning date. In addition, the use of renewable energy, cogeneration and gas-fired power plants by utilities, oil sands companies and petroleum refining industries will also contribute to reducing the grid’s intensity.

Table 8.1 Year 2013 grid intensity

	Installed Capacity (MW)	% of total capacity	GHG t/MWh	Utilisation rate	Production (MWh/year)	GHG (TCO ₂ e/year)
Coal	6 271	42%	1.20	81%	44 441 574	53 329 888
Cogeneration	4 245	28%	0.42	61%	22 683 582	9 527 104
Combined Cycle	843	6%	0.42	43%	3 175 412	1 333 673
Simple Cycle	804	5%	0.55	33%	2 288 988	1 258 943
Hydro	894	6%	-	24%	1 840 388	-
Wind	1 459	10%	-	27%	3 476 388	-
Other	423	3%	-	66%	2 430 795	-
Total	14 939		0.81		80 337 128	65 449 609

Source: AESO 2014 Long-Term Outlook, Government of Alberta Electricity Statistics.

In November 2015, the Provincial Government indicated that Alberta will ban coal power plants completely by 2030. The policy will force coal-generating units that were still operating in the AESO model in 2030 to close “prematurely”. The Province also indicated its intention to have up to 30% renewable installed capacity. To model the impact of this policy, MARCON used a combination of AESO’s Environmental Shift and Transformative scenarios (described in Figure 8.2). In this model, coal has been decommissioned and production of electricity has shifted to natural gas and renewable forms of energy. Utilization rates of renewables are expected to remain the same because they are limited by nature, whilst gas generation is increased to make up for the lost coal capacity. The net result of this policy is a further grid intensity reduction to approximately 0.37 TCO₂^e/MWh by 2034.

⁶⁷ <http://www.energy.alberta.ca/electricity/682.asp> .

⁶⁸ Source : AESO 2014 long-term outlook, AESO, 2014.

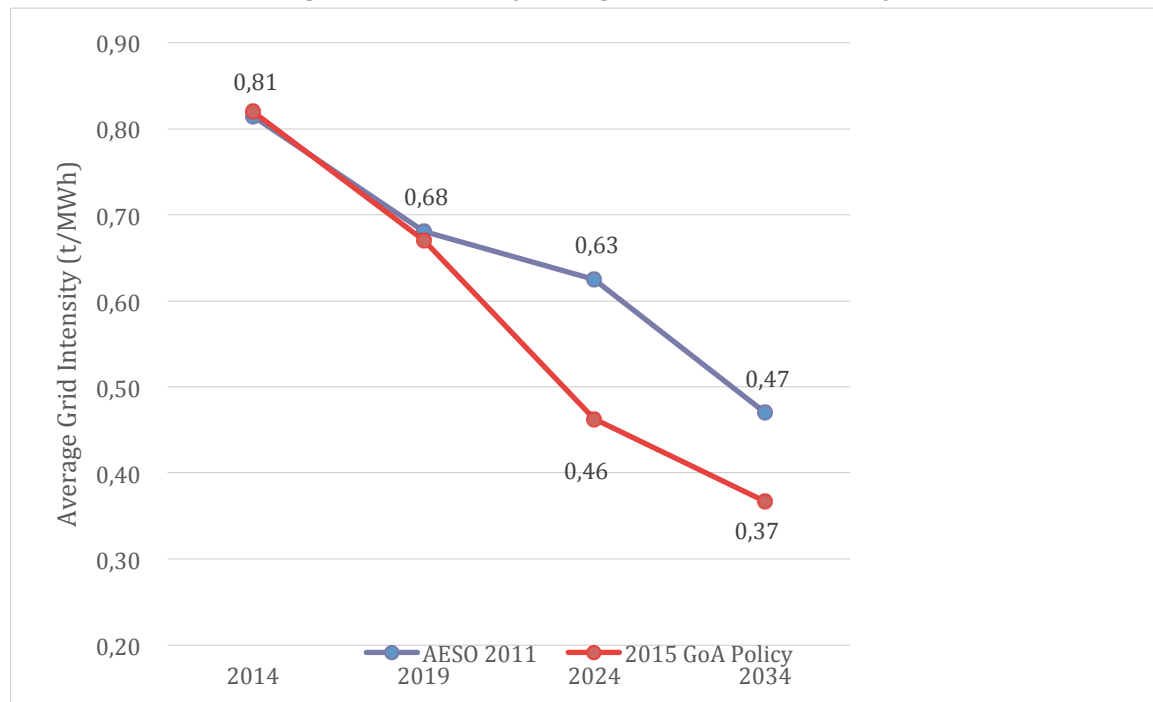
Table 8.2 Projected 2034 grid intensity (without coal)

	Installed Capacity (MW)	% of total capacity	GHG t/MWh	Utilisation rate	Production (MWh/year)	GHG (TCO2e/year)
Coal	0	0%	1.05	0%	-	-
Cogeneration Combined Cycle	7527	30%	0.42	80%	52 749 216	22 154 671
Simple Cycle	7471	30%	0.42	70%	45 812 172	19 241 112
Hydro	2939	12%	0.55	50%	12 872 820	7 080 051
Wind	1894	8%	-	24%	3 981 946	-
Other	3777	15%	-	27%	8 933 360	-
	1343	5%	-	66%	7 764 689	-
Total	24951	MW	0.37		132 114 203	48 475 834

Source: MARCON calculations based on AESO data from AESO 2014 Long-Term Outlook, and GoA Policy announced in Nov. 2015.

There is therefore a marked difference between the current status, the currently regulated shutdown schedule and the new (yet to be enacted) policy as figure 8.2 shows.

Figure 8.1 Alberta power grid forecasted intensity



Source: AESO 2014 Long-Term Outlook and MARCON, 2016.

8.2 Carbon footprint of diesel buses

In determining the emission factor of diesel fuel both direct combustion and upstream emissions from the extraction, refinement, and storage of petroleum to make diesel fuel are considered. The Specified Gas Emitters Regulation (SGER) protocol⁶⁹ states that the emission factor to use for diesel combustion is 2.7171 kg CO₂^e/litre⁷⁰, and upstream emissions is 0.9579 kg CO₂^e/litre⁷¹, thereby taking into consideration the use of biodiesel. Combined emissions from all sources are equal to 3.675 kg CO₂^e/litre.

In 2015, the ETS fleet of 40-foot diesel buses drove 42 million kilometres, thereby consuming almost 23 million litres of diesel fuel. The resulting average fuel efficiency for the whole 40-foot bus fleet is 54.6 L/100 km.

Consequently the ETS 40-foot bus fleet (841 buses) emitted 61,230 TCO₂^e from the combustion of diesel, and a further 23,300 TCO₂^e from upstream emissions associated with its production. Unless a greater amount of biodiesel is mixed into the diesel fuel purchased by ETS, the fuel will likely have the same approximate emission factor 20 years from now as it does today. As there has been no indication in government policy announcements in the past three years to increase the current federal mandate of 2% biodiesel, it has been assumed that today's emission factor for diesel will remain the same.

In the Edmonton field trial, the 2013 Xcelsior buses achieved an average fuel efficiency of 49 L/100 km. Data provided by ETS for calendar year 2015 indicates that these 2013 Xcelsior buses are driven an average of 49,497 km/year.

For comparative purposes, the Steering Committee supplied MARCON with the 20-year usage pattern shown in table 8.3 and figure 9.1 later. This usage pattern results in an average distance of 49,450 km/year for comparative purposes. At the measured consumption rate, a contemporary model diesel bus driving that distance will generate emissions of 89 TCO₂^e per year or 1,781 TCO₂^e in its lifetime.

8.3 Carbon footprint of electric buses

Because the GHG intensity of Alberta's grid will decrease progressively until 2030, the carbon footprint of electric buses will diminish over time as well. Based on the 2013 Alberta grid intensity factor, an e-bus operating today will emit approximately 38-44% less CO₂^e (from the power generators) than its diesel equivalent. By 2034, the e-bus will emit 72-74% less CO₂^e.

The following table shows the yearly emissions of both trickle-charged and en-route charged buses based on the usage pattern provided by ETS. Yearly electricity consumption of both types of e-buses is also displayed along with the emissions resulting from electricity usage and diesel fuel usage for space heating.

⁶⁹ <http://open.alberta.ca/dataset/c1c50abd-c082-4b2f-a119-0fc0a3b1caa7/resource/31b488e3-1ee8-463d-91aa-fb7df765c1d6/download/2013-02-ProtocolFuelSwitchingMobile.pdf>

⁷⁰ Idem, page 79.

⁷¹ Idem, page 78.

Table 8.3 Total life GHG Emissions of e-buses

Year	km/year	kWh	BYD			NFI			
			T CO ₂ ^{e-} /kWh	Electricity T CO ₂ ^{e-}	Diesel T CO ₂ ^{e-}	kWh	T CO ₂ ^{e-} /kWh	Electricity T CO ₂ ^{e-}	Diesel T CO ₂ ^{e-}
2017	57,000	71,250	0.00081	57.7	103	78,660	0.00081	63.7	103
2018	59,000	73,750	0.00081	59.7	106	81,420	0.00081	66.0	106
2019	58,000	72,500	0.00081	58.7	104	80,040	0.00081	64.8	104
2020	54,000	67,500	0.00068	45.9	97	74,520	0.00068	50.7	97
2021	54,000	67,500	0.00068	45.9	97	74,520	0.00068	50.7	97
2022	54,000	67,500	0.00068	45.9	97	74,520	0.00068	50.7	97
2023	54,000	67,500	0.00068	45.9	97	74,520	0.00068	50.7	97
2024	52,000	65,000	0.00068	44.2	94	71,760	0.00068	48.8	94
2025	50,000	62,500	0.00046	28.8	90	69,000	0.00046	31.7	90
2026	50,000	62,500	0.00046	28.8	90	69,000	0.00046	31.7	90
2027	48,000	60,000	0.00046	27.6	86	66,240	0.00046	30.5	86
2028	45,000	56,250	0.00046	25.9	81	62,100	0.00046	28.6	81
2029	45,000	56,250	0.00046	25.9	81	62,100	0.00046	28.6	81
2030	45,000	56,250	0.00037	20.8	81	62,100	0.00046	28.6	81
2031	44,000	55,000	0.00037	20.4	79	60,720	0.00046	27.9	79
2032	44,000	55,000	0.00037	20.4	79	60,720	0.00046	27.9	79
2033	44,000	55,000	0.00037	20.4	79	60,720	0.00046	27.9	79
2034	44,000	55,000	0.00037	20.4	79	60,720	0.00037	22.5	79
2035	44,000	55,000	0.00037	20.4	79	60,720	0.00037	22.5	79
2036	44,000	55,000	0.00037	20.4	79	60,720	0.00037	22.5	79
Avge	49,450	61,813	0.000536	34.2	89	68,241	0.000536	38.8	89
TLC	989,000	1,236,250		684	1,781	1,364,820		776.8	1781

Source: MARCON. 2016

When used according to the usage pattern defined by ETS (driving on average 49,450 km) a BYD will generate 684 TCO₂^{e-} and the NFI, 776 TCO₂^{e-} respectively in lifetime emissions associated with upstream emissions from power generation.

8.4 Carbon footprint reduction

On a comparative basis, the latest available model of Xcelsior diesel bus running on average 49,450 km per year for 20 years would emit 89 TCO₂^{e-}/year or 1,761 TCO₂^{e-} during its 20-year life.

As diesel heaters are preferable on e-buses, the fuel consumption of these heaters reported in the trial was approximately 2 litres per 100 km. If it was assumed that this average consumption would apply to the months of December and January, but 75% of that average was used for the months of November and February and 50% for the months of October March, and April, As a result, e-buses would burn 412 litres of diesel per year and therefore produce emissions of 1.51 TCO₂^{e-}/year.

So, using a diesel heated BYD bus to replace a diesel bus would reduce the bus' carbon footprint by 60% over 20 years whilst replacing a diesel bus by a NFI would reduce the GHG footprint by 56% respectively.

8.5 Carbon Levy

Although the price of carbon is market driven, there is a regulated ceiling price of emissions in Alberta. Between 2007 and 2015, this ceiling price was set at \$15/tonne. The ceiling price changed to \$20 as of January 1, 2016, and to \$30 as of January 1, 2017.

Consequently, the carbon levy imposed by the Province of Alberta on diesel fuel has been set at 5.35¢/litre for 2017 and 8.03¢/litre for 2018⁷².

Calculations of the financial impact of the carbon levy are provided in section 9.

8.6 Other environmental externalities

There are many other environmental opportunities that are quantifiable, but considered beyond the scope of this project. For instance, accidental discharges of diesel and oil, due to equipment failure and regular use, deposits petroleum product onto the surface of city roads. These chemicals eventually make their way to the Saskatchewan River via the storm sewer network, and there is an impact to the environment. An electric bus would not leak these fluids, but there is no financial cost savings to the City because there isn't a remediation program for this pollutant.

The tailpipe emissions from diesel buses have been improving but still include smog generating NO_x and SO_x, as well as particulate matters that are harmful to people. These chemicals and other elements in diesel exhaust also produce noxious odours that are unpleasant but challenging to attribute a societal economic cost. The transit rider surveys (Section 4) demonstrated that approximately 80% of the riders surveyed indicated that they perceived the e-bus to be better or much better than a diesel bus.

Upstream emissions that originate at coal-fired power plants have considerable negative health effects to those within their air-shed, which includes the western edges of Edmonton that are downwind of the power plants in the Wabamum area. The Province's commitment to close down coal-fired power by 2030 is partly motivated by the intention to end these health-harming sources of emissions.

Finally, the noise pollution created by diesel engines is reduced considerably when using e-buses.

8.7 Key findings

Electricity in Alberta is considered to have the highest GHG intensity in Canada, but it will get better over time. An e-bus is currently 38% to 44% better than its diesel equivalent, and is expected to become 72% to 74% better by 2034. The current policy to end coal-fired power in 2030, greater dependency on gas electrical generation, and the goal to have up to one third of Alberta's power being renewable are responsible for this gain.

The use of diesel heaters on board e-buses will use 4% of the diesel fuel currently consumed by diesel buses at most, irrespective of which e-bus is equipped with these heaters. Considering the

⁷² Source : Government of Alberta, <http://www.alberta.ca/climate-carbon-pricing.cfm>, 2016.

range reduction implications of an electrically heated bus, diesel heated buses are considered more desirable despite their small impact on the environment.

Whether upstream emissions, or those from the tailpipe, e-buses are a better choice for the environment than the current diesel fleet. Investment in electric vehicles improves air quality in the city, and in the atmosphere. The electric transportation modal shift is expected to accelerate as the cost of batteries decreases even further and EV performance improves even more. ETS can be a catalyst for this transition by demonstrating how electric vehicles can operate in Edmonton's winter climate, and by causing the utilities and regulators to plan for the infrastructure modifications that are required for their use.

9 The business case for e-buses in Edmonton

MARCON was required to “analyze the economic impact of shifting to electric buses using their proprietary lifecycle cost forecasting model. The analysis will compare diesel and electric buses on capital costs, facility upgrades (electrical capacity and other), and operational costs including the cost of electricity and fuel, maintenance and other costs.”[1]

The level of precision in business case calculations depends on the quality of the working hypotheses provided to the model used. Given the early stage of the electric bus industry, lack of certainty related to fuel and energy costs, and a short amount of time the buses were in field trial in Edmonton, the business case accuracy is limited to $\pm 25\%$. In some instances, input was provided directly by the Steering Committee members as noted in the source references provided. For example, the analysis considered acquiring and operating 40 buses based out of the new North East Garage, comparing the cost related to electric buses with the latest model of diesel buses in the ETS fleet (New Flyer Industry, Xcelsior 2013 model). Forty buses were selected as this represents the present schedule for bus replacements in both 2017 and 2018.

9.1 Methodology

ETS and the Fleet Services branch of the City of Edmonton provided MARCON with all the information requested to establish a reference case based on the latest model of 40' diesel buses in the fleet (Xcelsior 2013 model). Whenever possible, data from Edmonton's field test with e-buses was used but, given the short duration of the test, missing data was substituted by:

- the results of evaluations conducted in other municipalities, and/or
- Altoona test results, and/or
- MARCON's team members experience with other electric buses,

in order to build a cost forecasting model reflective of Edmonton's own operating characteristics.

The Steering Committee directed MARCON to make its “calculations on the feasibility of 40 buses, with details about how the study arrived at the conclusion that could be extrapolated to support decision-making”. MARCON was further instructed to use the new NETG (that was designed as a direct replacement building of the Westwood Garage) as the facility that would host the 40 e-buses. Although that building has not been designed to house electric buses, ETS used a local architect firm⁷³ to appraise the cost of adapting this facility, but without the benefit of a complete functional analysis.

The calculations were undertaken using MARCON's proprietary lifecycle cost model TLC Bu\$™.

As the goal of this assignment consists of comparing the three technologies (diesel, en-route charge e-buses and trickle-charged e-buses), costs that are identical for all three technologies are not taken into consideration. For example, inflation is the same for all, year after year. There is no point in considering this factor in a comparative mode. Another example is the lease cost of tires, which is the same for all types of buses. On the other hand, the interest rate used for discounting was taken into consideration, as the timing of expenses is different for the three technologies, e-buses requiring a more intense initial investment than diesel buses.

⁷³ Source: Morrison Hershfield, 2016.

9.2 Assumptions – Capital costs

9.2.1 Bus prices forecast (electric and diesel)

The prices for buses, as well as the price of key components such as the replacement the energy storage system, used in our calculations were provided by bus manufacturers for the most part.

Table 9.1 Cost of buses

	Diesel Buses	Trickle-charged Buses	En-route charged Buses
Gross price of buses (in CAD)	\$600 000	\$949 200	\$1 300 000
Mid-life rebuild	\$128 755	\$248 627	\$169 075
Residual value at life’s end – buses (% of original cost)	0.5%	0.5%	0.5%

Sources: ETS, BYD, New Flyer Industries, ETS and MARCON, 2016.

The costs of rebuilding diesel buses at mid-life are well documented by ETS and historically amount to a total of \$128 755. This amount comprises of engine and transmission rebuild or replacement (including turbo compressor) at \$64 534 and bodywork at \$64 221. The amount of bodywork to be performed on all buses (diesel and electric) will remain the same, regardless of their power train. At the end of 2015, ETS implemented a new rebuilding policy whereby certain parts are no longer replaced as a preventive measure. This will result in a smaller capital cost but may increase the cost of maintenance in the second half of the bus life as some failing parts will need replacement. MARCON conservatively elected to rely on historical data rather than expected outcomes from this new policy for its calculations.

The cost of rebuilding e-buses at mid-life is not available from any source no e-bus has reached that stage of life yet (prototypes excepted). The cost has therefore been calculated by MARCON based on a long experience with trolley buses and using a differential approach. This means that the detailed cost of rebuilding a diesel power train was used as a starting point and various components and tasks were added or subtracted for each of the two e-bus models work as required by their respective designs. Detailed calculations are shown in Appendix 3. The final result shows a cost of \$184 406 for trickle-charged buses and \$104 854 for en-route charged buses in addition to the cost of bodywork.

These estimates were developed considering that one manufacturer (BYD) suggests that their battery pack will last 20 years with only 1% degradation per year of service. MARCON has conservatively estimated that the battery pack would be replaced at the end of its warranty (12 years). No revenue was considered for the potential sale or reuse of battery packs, nor did any expense enter the calculations to take a possible cost of disposal into account.

9.2.2 Facilities

Housing the reference fleet of 40 diesel buses at the NETG will not affect the current cost estimate for the new facility as it has been designed for this very purpose.

Table 9.2 Cost of facilities upgrade (inclusive of charging stations)

	Diesel Buses	Trickle-charged Buses	En-route charged Buses
Facilities upgrade cost (in CAD)	\$ 0	\$750 000	\$1 154 992

Sources: Morrison Hershfield (BYD) and MARCON (NFI), 2016.

According to the architect retained by the City of Edmonton, the estimated cost to add the required electric capacity and components to house 40 e-buses at this facility is \$750,000. The cost of the trickle-chargers is included in the price of the bus quoted by the manufacturer while adding a fast-charger to the NETG would add approximately \$405 thousand to the cost of the facility. A charging station should be installed at the NETG to recharge units coming out of maintenance⁷⁴ or to top up units if the need arises⁷⁵.

These trickle-charged units being very simple, MARCON budgeted only \$100/year per unit for their maintenance. For en-route charged vehicles (where charging would occur at pantograph charging stations located at transit stations), the cost of maintaining the fast charging stations is higher.

Additional investments are required for en-route charged buses. In order to service the 40 e-buses in this case study, eight (8) transit stations will require rapid chargers. Since the NFI e-bus was used as the reference in this case simulation, the NFI fast charger installed in Winnipeg recently was used as a base case for estimating how much these stations would cost the City of Edmonton. Table 9.3 provides the cost breakdown of a single charging station costing \$845 990, installation included.

Table 9.3 Estimated cost of en-route charging stations

	In Cdn \$
Charger (USD \$320 000)	\$404 992
Transformer	\$40 000
Cabling	\$80 000
Civil works	\$180 000
Engineering & Project management	\$140 998

Source: MARCON based on Winnipeg Transit Corporation information, 2016.

Charging station maintenance has been evaluated at 1% of their initial value per year and, in our calculations, conservatively remains constant for the duration of the planning horizon. Note that if the battery technology selected allows, a trickle charger could replace the fast charger planned for the NETG at less than half the cost of a rapid charger.

A functional analysis of the transit centres was not included in the scope of this study. Some or all of them may not lend themselves easily to the addition of a charging infrastructure in their current configuration. It is likely that some modifications will be required to all transit centres to improve the flow of a mixed fleet of buses in and out of these areas.

9.3 Assumptions – Operating costs

ETS requested that MARCON forecast the cost of operating e-buses using the current practices applied to the diesel fleet. These are not optimized for e-buses and therefore result in a very conservative scenario for an electric fleet.

⁷⁴ E-buses that are left unused experience self-discharge. See Appendix 1 for more information.

⁷⁵ The cost of that station could be avoided if a transit station equipped with a rapid charger was located very near the garage.

9.3.1 Routes

Despite the fact that e-buses can technically operate on all the current routes served by ETS, the choice of routes is limited by several factors:

- a. Each garage services specific routes and with all 40 electric buses assigned to a specific garage, the e-bus fleet is thereby limited to the routes serviced out of that garage.
- b. The en-route charged buses require a charging infrastructure that is usually located at transit stations. Assignment of these e-buses is therefore constrained by the availability of charging stations on their routes at their planned time of arrival.
- c. Although not requiring en-route infrastructure, trickle-charged buses have a shorter autonomy (range) than diesel buses. In the current block structure, they cannot be assigned to routes or blocks that exceed their safe operating range.

The optimization of ETS's block structure is beyond the scope of MARCON's assignment and calculations are performed on the basis of the current bloc structure without any changes over the 20-year life of the bus to make a fair comparison between the three technologies. ETS would likely adjust scheduling to better align with the capabilities of the assets.

9.3.2 Duty cycle and operating conditions

Duty cycle has an important impact on the performance of all buses. For example, heavy traffic forces buses to stop and go very often. As a large quantity of energy is required to overcome inertia, this type of duty cycle (low speed, many stops) causes the fuel consumption of diesel buses to increase significantly. On the other hand, electric buses are equipped with a kinetic energy recovery system that regenerates energy from braking. The efficiency⁷⁶ of such systems can reach over 65%⁷⁷ and can result in extending the range of batteries by almost 40%⁷⁸. E-buses are therefore much less affected by a similar duty cycle. Given the short period of the field test, few routes and duty cycles were tested. Data from the field test and other sources does not allow for a conclusive quantitative analysis of the impact of duty cycle on bus performance.

The design and curb weight of the buses tested result in a reduction of maximum passenger capacity at crush loads compared to diesel buses. Theoretically, this could mean that more electric buses would be required to provide the same level of service during peak service hours. After carrying out an analysis, ETS concluded that the maximum capacity of e-buses in terms of number of passengers and weight restrictions will not be a significant issue. Furthermore, battery manufacturers are improving their products at a very fast rate and they believe that the weight capacity limitations will be eliminated in future generations of electric buses.

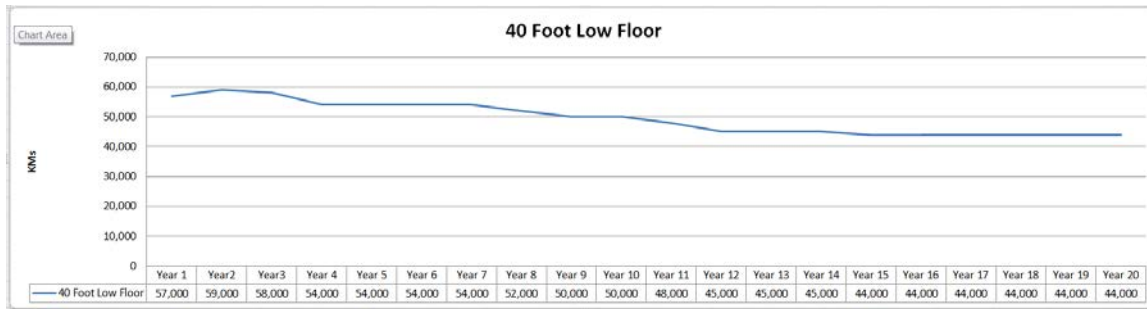
The annual distances to be assigned to e-buses were determined by the City and ETS based on the actual performance of diesel busses based on historical averages for the ETS fleet. The reference distances per year were provided as follows:

⁷⁶ Defined as the ratio of the actual regenerated energy to the total kinetic energy that can be regenerated.

⁷⁷ Source: Regenerative Braking System for Series Hybrid Electric City Bus, Junzhi Zhang, Xin Lu, Junliang Xue and Bos Li, The World Electric Vehicle Journal, Vol 2, Issue 4.

⁷⁸ Source: Analysis of regenerative braking effect to improve fuel economy for E-REV bus based on simulation, Jongdai Choi, Jongryeol Jeong1, Yeong-il Park, Suk Won Cha, Proceedings of EVS28, 2015.

Figure 9.1 Yearly Reference Distance forecasted for Diesel Buses in Edmonton



Source: ETS, 2016.

The total distance for a transit bus in service in Edmonton is forecasted to be 989,000 km or 49,450 km per year. This is comparable to ETS’s historical data showing that 40’ buses are running an average of 49,947 km per year.

9.3.3 Cost of energy (electricity and diesel)

Given that the development of a forecasting model for the price of diesel and electricity is beyond the scope of this study, the prices of diesel and electricity were maintained at the current level for the 20-year forecasting period. Both prices were provided by the City of Edmonton:

- Electricity: 11¢ per kWh and
- Diesel fuel: \$0.8631 per litre.

9.3.4 Energy consumption

From a business case perspective, the main contribution of the field trial to the business case is the energy consumption data. This information was gathered in winter, where conditions are particularly difficult for transit buses of all types. MARCON selected the worst fuel-efficiency performance observed during the field trials to build Edmonton’s business case. Despite the lack of extremely cold weather during the field test period, the use of the energy consumption data obtained at that time of year represents a very conservative estimate of the performance a fleet of e-buses will achieve during the rest of the year when climate conditions are more favourable.

The energy consumption by e-buses during Edmonton’s field trials is described in section 7: 1.25 kWh/km for the trickle-charged BYD e-bus and 1.38 kWh/km for the New Flyer e-bus.

The diesel buses used for comparative purposes consumed 45 to 49L/100 km, compared to the average of 48.53L/100km for the fleet of 2013 Excelsior Diesel buses purchased in the same year. That average performance is used in our forecasts, as the 40 new buses ETS would purchase (if diesel fuelled) would perform at least as well.

9.3.5 Environmental cost

The announced Provincial “Carbon Levy” on transportation fuel is factored in MARCON’s calculations. The Province of Alberta set at 5.35¢/litre (for 2017) and 8.03¢/litre (for 2018)⁷⁹ levy on diesel fuel. In the projections, MARCON uses that latter amount as the procurement process

⁷⁹ Source : Government of Alberta, <http://www.alberta.ca/climate-carbon-pricing.cfm>, 2016.

for the vehicles and the construction of the new garage facility is unlikely to result in e-buses being put in service much before January 2018. As with the cost of fuel, the cost of the Carbon Levy is kept constant for the 20 years of the forecast.

There is no carbon tax added to the cost of electricity as it is already built in the price but e-buses will be consuming a small quantity of diesel fuel for space heating purposes. A modest cost of \$25 thousand will be incurred by both types of e-buses for that purpose.

9.3.6 Maintenance and service (M&S) costs

M&S costs include three categories of costs: preventive maintenance, routine (or running) maintenance and servicing the buses on a daily basis. The cost of exceptional repairs (accidents, vandalism, etc.) is excluded from our calculations. The cost of maintaining Edmonton’s entire fleet in 2015 is used as the basis for our calculations. While the latest buses may be more reliable, they will age and their cost of maintenance will increase with time. Using all 40’ buses provides a long history of maintenance data to the business case. M&S costs for e-buses are calculated as a variation from the diesel fleet, adding and subtracting items to the current list of running maintenance.

The cost per kilometre is therefore based on the average distance run by a 40’ bus in the course of the year as described in table 9.3.

Table 9.4 Maintenance and service cost for 40’ buses in Edmonton

Preventive maintenance	Diesel Bus	E-Bus	
	(40’ fleet average)	Trickle-charged	En-route charged
Total / km	\$0.125	\$0.094	\$0.094
Running maintenance			
Total / km	\$0.613	\$0.407	\$0.401
Servicing			
Total / km	\$0.045	\$0.045	\$0.045
Total maintenance & servicing			
Total \$/ km	\$0.783	\$0.546	\$0.540

Sources: ETS (for diesel buses), 2015, and MARCON (for e-buses), 2016

Numbers in the above table have been rounded to 1/10th of a cent precision and a detailed list of how MARCON determined the maintenance costs of e-buses is provided in Appendix 4.

9.3.7 Financial hypotheses

Working hypotheses regarding the financial aspects of acquiring new buses are common to all three types of buses.

Table 9.5 Miscellaneous assumptions

Financial	
Discount factor / interest rate (%)	1.9%*
Exchange rate (USD 1 to CAD) (as of April 19):	\$1.2656
Bus life (years)	20*
Mid-life overhaul after (years)	12*
Inflation rate	Ignored

*Source: ETS, 2016.

9.3.8 Training costs

Training is an essential part of the process for introducing new bus technologies into revenue service. Bus operators, mechanics, service persons and trainers need to be thoroughly trained before a new fleet is placed in service. This training can be provided through the selected bus manufacturer to train all employees affected by the new technology, including operator and mechanical trainers in the company. A third party technical training institution can also provide it. Bus manufacturers also provide operating and maintenance manuals, usually provided as part of the contract.

New Flyer Industries confirmed that the majority of its standard Xcelsior courses apply to the electric buses. They also offer OEM training on the electric propulsion system and batteries, which isn't totally defined as of yet. Student hand-out materials are provided with each course. Generally, the price of training is included in the cost of the bus and it would be subject to the terms in the RFP and the negotiated contract. The length of training would depend on the scope of training and since most of the non-electric components on electric buses are very similar to those found on standard diesel buses, it is estimated training designed for ETS mechanics would take 40 to 60 hours. Similarly, ETS trainers could be trained who could then train mechanics. Operator familiarization with electric buses could take about eight hours.

BYD will provide training to clients and it also is part of the price of the bus. Their training packages cater to operators, mechanics and trainers. BYD is prepared to provide as much time as necessary to ensure the client personnel are properly trained to operate their equipment and will also provide all the training materials and manuals required⁸⁰. No information is available at BYD regarding the length of training for operators, service personnel and maintenance staff. Therefore, the cost of training used in MARCON's forecasts is nearly identical for both types of buses, some additional time having been provided for training operators to used overhead charging stations on en-route charged buses.

NAIT has a history of providing technical training courses to ETS, the most recent being in 2013 when training was provided for Electronics Technicians who were to work on the Edmonton LRT system. In discussions with the NAIT Continuing Education Department it was confirmed that NAIT would be happy to set up a training program to give mechanics certification on high voltage electric bus systems⁸¹. Any course would be developed jointly between NAIT, ETS and, of necessity, the selected bus manufacturer. The course would be tailored to the specific model of bus purchased and is estimated to be between 40 and 60 hours long. The cost to develop this specialized course would be an additional one-time cost and would take between 80 and 100 hours of course development time, estimated to cost about \$10,000 - \$15,000. Actual training could cost about \$2,000 per student, depending on its length. Definitive costs could not be provided at the time of writing this report.

⁸⁰ Source: BYD's Vice-President of Sales, 10 February 2016.

⁸¹ Source: NAIT Department of Continuing Education, March 2016.

Table 9.6 Training costs

	Trickle-charged buses	En-route charged buses
Course preparation - operators	Provided by mfr.	Provided by mfr.
Course delivery - operator hours	\$6 979	\$13 958
Course preparation - service	Provided by mfr.	Provided by mfr.
Course delivery - service personnel hours	\$544	\$544
Course preparation - maintenance (flat fee)	\$15 000	\$15 000
Course delivery - maintenance (per student fee)	\$16 000	\$16 000
Course delivery - maintenance personnel (hours)	\$37 320	\$37 320
TOTAL	\$75 843	\$82 822

Source: MARCON, 2016

In addition to the actual cost of training, overtime costs would likely be incurred by ETS unless collective agreements have other provisions. Estimating these costs was beyond the scope of the assignment given to MARCON.

In addition to the training required for ETS personnel, it is very important that familiarity training be provided for emergency first responders in the City of Edmonton. In the case of an accident involving an electric bus, they will need to know where the emergency high voltage power shut-off switch is located. If there is a fire, they will need to know that respirators will be needed because if batteries are ruptured there may be noxious fumes. Here again, estimating these costs was beyond the scope of the assignment given to MARCON.

9.3.9 Tooling and related costs

The bulk of tools required to maintain electric buses is very similar to those required to maintain diesel buses. However, there are some unique tools and testing equipment that will be required to maintain the electric buses as they have battery packs, inverters and electric drive systems. A non-exhaustive list of these specialist tools, based on experience with hybrid electric buses and trolley buses is as follows:

- Propulsion service kit approximately \$5,000 which will include diagnostic interface/cables, high impedance multi-meter, battery protection tools, high voltage gloves, and motor bearing re&re tools
- Accessories tools approximately \$5,000 which will include special tools for electric accessories – HVAC, air compressor, steering, and cooling
- Battery pack and Inverter lifting jigs approximately \$2,000.
- Other bus tools approximately \$10,000, depending on make/model of bus axles, brakes, PLC, body, etc

An overhead crane, or jib crane for lifting rooftop battery packs or other components will be required and MARCON assumed it would be available in the new NETG facility. Again, based on trolley and hybrid experience battery packs can be made to last a long time with proper heat/voltage monitoring, and selected cell replacement later in life. A forklift should be able to remove smaller roof components such as inverters, and HVAC units.

Gantry platforms or probably rolling scaffold platforms will be required for roof access. Fall protection anchors will also be required for maintainers working on the roofs of the electric buses. A rolling scaffold similar to the one in the picture below should be used.

Depending on the ETS maintenance model – an electrical “lab” may be needed for electronic component repair/troubleshooting, or, this function can be outsourced.

The increase in complex electrical troubleshooting / maintenance that will be needed to maintain electric buses may need an Electrical / Electronics Engineer or technical electrical supervisor on staff.

Table 9.7 Cost breakdown of tooling required

	# required	Unit Price	Total
Propulsion service kit	2	\$5 000	\$10 000
Battery pack and Inverter lifting jigs	2	\$2 000	\$4 000
Rolling scaffold	1	\$20 000	\$20 000
Other bus tools	1	\$10 000	\$10 000
Total cost of tooling			\$44 000

Source: MARCON, 2016

9.4 Lifecycle cost of diesel buses in Edmonton (reference case)

The lifecycle cost of diesel buses presented in this report is not intended to be complete. It is proposed as a fair basis for comparing the overall cost of running diesel versus electric buses. Some cost categories are, and will remain identical for both types of buses and were therefore excluded from our calculations.

For example, the cost of tire leasing will not vary from one type of bus to the other. Management overhead cost belong to this same category of “invariable” costs that can be ignored for the purpose of comparing different technologies.

Table 9.4 summarizes the base case for comparative purposes using diesel buses as follows: the acquisition costs are based on the latest NFI Xcelsior buses as are the fuel costs. The maintenance costs are based on the average 40’ diesel fleet data.

Figure 9.2 Example of Rolling Scaffold

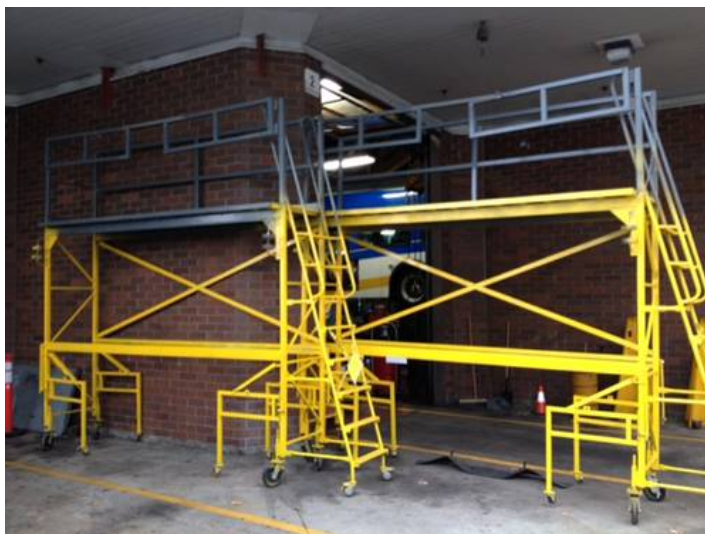


Table 9.8 Reference case: 40' diesel buses

	Discounted total	Total
Capital Investment Costs		
Bus acquisition & rebuild (40 units)	\$28 075 180	\$29 030 200
Building and Infrastructure cost	None required	
Other soft, non recurring costs	None required	
Operating Costs		
M&S Costs	\$26 201 313	\$30 976 741
Fuelling equipment maintenance	Negligible	
Fuel & Electricity Cost*	\$14 015 707	\$16 570 707
Carbon Levy	\$ 1 303 976	\$ 1 541 637
Total Cost	\$69 596 175	\$78 118 776

Source: MARCON, 2016

Table 9.8 shows that operating 40 new generation 40' diesel buses in regular service for 989,000 km at ETS will roughly cost the City of Edmonton \$78.0 million over its 20 year life if the cost of facilities, management overhead and other smaller components that are excluded from calculations as explained earlier. Not accounting for inflation and on a net present value (“NPV”) basis, this represents \$69.6 million in 2016 dollars. These are our reference numbers.

9.5 Lifecycle cost of trickle-charged electric buses in Edmonton

Using a trickle-charged, 40' electric bus on an identical duty cycle and for the same 989,000 km will cost 68% less in fuel and 42% less maintenance and service as itemized in Appendix 4. But the price of trickle-charged buses and of their charging stations require an initial investment 58% greater than that of diesel buses, thereby offsetting the operating cost advantages of the e-bus. The total original investment required by trickle-charged e-buses is 62% higher than for diesel buses.

Table 9.9 provides the breakdown of the total \$76 million (\$70 M NPV) forecasted cost of operating a fleet of 40' trickle-charged buses in Edmonton.

Table 9.9 Trickle-charged e-buses, lifecycle cost

	Discounted total	Total
Capital Investment Costs		
Bus acquisition & rebuild (incl. ESS replacement)	\$45 865 569	\$47 723 240
Building and Infrastructure cost	\$750 000	\$750 000
Other soft, non recurring costs	\$119 843	\$119 843
Operating Costs		
M&S Costs	\$18 260 531	\$21 588 679
Charging station maintenance	\$66 899	\$80 000
Fuel / Electricity Cost	\$4 831 981	\$5 712 654
Carbon Levy	\$21 496	\$25 413
Total Cost	\$69 916 319	\$75 999 829

Source: MARCON, 2016

In terms of net present value, the total cost of operating diesel buses and trickle charged e-buses is essentially identical.

9.6 Lifecycle cost of en-route charged electric buses in Edmonton

Using en-route charged buses presents the additional cost of building a network of fast chargers at transit stations. This cost alone was evaluated at nearly \$846,000 per unit and, to meet the 989,000 km target set by ETS, eight (8) stations must be installed at transit stations and one more at the new NETG. At \$1.3 M per unit, en-route charged e-buses are expensive as well. Their low energy and maintenance costs cannot compensate for the additional 150% initial investment required compared to diesel buses.

As a result, the lifecycle cost of replacing diesel buses by en-route charged e-buses amounts to \$95.6 million. With a net present value of \$89.9 million, this is 28.5 % more than diesel buses. This exceeds the margin of error set for this evaluation and indicates that a significant increase in the operating cost of the fleet would occur if this technology were selected. Table 9.10 provides additional information for each cost category.

Table 9.10 En-route charged e-buses, lifecycle cost

	Discounted total	Total
Capital Investment Costs		
Bus acquisition & rebuild (incl. ESS replacement)	\$57 281 973	\$58 503 000
Building and Infrastructure cost	\$1 154 992	\$1 154 992
Charging stations costs	\$6 767 923	\$6 767 923
Other soft, non recurring costs	\$126 822	\$126 822
Operating Costs		
M&S Costs	\$18 064 388	\$21 356 787
Charging station maintenance	\$1 131 926	\$1 353 585
Fuel / Electricity Cost	\$5 310 479	\$6 278 362
Carbon Tax (on diesel fuel for heaters)	\$21 496	\$25 413
Total Cost	\$89 859 998	\$95 566 884

Source: MARCON, 2016

9.7 Key findings

With the 40-bus scenario, our calculations indicate that the cost of using trickle-charged e-buses will be comparable to that of using new diesel buses in Edmonton. En-route charged buses would however cost significantly more than trickle charged e-buses and diesel buses. These calculations are based on operating e-buses in the same manner as diesel buses are currently used. This is not optimal for e-buses and, if ETS adapts to this new technology, the use of trickle-charged electric buses could be lower than that of diesel buses if service planning and operating changes are made.

10 The electric bus technology and its evolution

Several organisations have been working on electric buses for years. Although it may seem their arrival on the Canadian market was rather sudden, today's battery electric buses (e-buses) are the result of several generations of vehicle technology, which has been extended to include electric trains, tramways, trolley buses, diesel-electric hybrid buses and fuel cell buses.

With such an ancestry, why did e-buses take so long to reach the commercial stage? The short answer is: Battery chemistry. Technology continues to evolve in order to deliver a reliable product that:

- Stores a reasonable amount of energy
- Is compact
- Can be operated safely
- Weighs as little as possible
- Can be discharged and recharged often
- And quickly
- Does not degrade much or rapidly; and,
- Is available at an affordable price.

While there is certainly still improvement expected with the current offering, today's batteries already allow e-buses to compete with the cost of traditional diesel buses on a lifecycle basis. Many battery manufacturers are staking their future on e-buses.

The world market for electric and hybrid-electric buses amounted to nearly 15,000 units in 2014. According to a recent report⁸², sales are expected to grow at a compounded annual growth rate of 19.6% over the period 2015 - 2020. At the end of 2015, China alone was expected to operate approximately 500,000 plug-in hybrid electric and pure-electric vehicles.

Nearer to Canada, the United States Department of Transportation has announced an investment of \$24.9 million (USD) for the development of zero-emission buses. A large share of this incentive will fuel the development of improved batteries.

There are still relatively few electric bus manufacturers and some have a global presence: **AB Volvo** (Canada's NovaBus parent company from Sweden) and **BYD Company Limited** (China) are operating across all major markets. Globally, **YUTONG GROUP** (China) is the largest player in the electric bus market. The company holds the largest market share of the world's biggest market, China. AB Volvo with its broader regional presence across all the major electric bus markets holds the second position in global electric bus sales, and is the largest electric bus manufacturer in Europe.

Solaris Bus and Coach S.A. (Poland) launched its articulated electric bus 'Urbino 18', in September 2014. **EBUSCO** (Netherlands) offers EBUSCO 2.0, a new product under the company's electric bus portfolio. Other major players operating in the electric bus market include **Irizar** (Spain), **Shenzhen Wuzhoulong Motors Co. Ltd.** (China), **FAW Group Corporation** (China), **King Long United Automotive Industry Co. Ltd.** (China), **Daimler AG** (Germany), **Alexander Dennis Limited** (United Kingdom), **Ashok Leyland Ltd** (India), **New Flyer Industries** (Canada), and **Proterra Inc.** (USA).

⁸² Global Electric Bus Market Size, Share, Development, Growth and Demand Forecast to 2020, P&S Market Research, October 2015.

Four manufacturers offer their e-buses in Canada: NFI, BYD, Proterra and soon Novabus.

10.1 Fuel cell electric buses

Fuel cell buses are well known in Canada as two of the world leading manufacturers of hydrogen fuel cells are located in the country: Ballard Power Systems (in British Columbia) and Hydrogenics (in Ontario). Hydrogen fuel cell buses (H₂FC) are equipped with a hydrogen reservoir (mostly high pressure gaseous but possibly liquid) that provides them with flexibility and range that are similar to those of a diesel bus. However, the infrastructure required to refuel a H₂FC bus is significantly more expensive and complex than a diesel fuel pump, or a simple electric charger. In addition to the H₂ fuelling equipment, the garages, depots and barns of a transit system must be equipped to handle lighter than air explosive gases. This entails the installation of ventilation, lighting, electrical and safety systems that are also more expensive than regular equipment.

Figure 10.1 Hydrogen fuel cell bus



Unless it is the by-product of another industrial process and can be recuperated in sufficient quantities, large H₂ production involves using either electricity (water electrolysis) or natural gas (steam methane reforming). Both processes suffer from significant quantities of energy lost or used for production and in the following steps of compression or liquefaction of the gas as well as transportation. It becomes difficult to justify H₂ in a world where electric and natural gas buses are already commercially available.

In almost all cases, H₂ fuel must be trucked over to the transit facility and stored on site. When transit garages are located in densely populated areas, fire marshals are hesitant to grant permits for such installations as the fire codes are not very specific regarding the use of industrial hydrogen in filling stations and, whenever they do, they require security systems that add significant cost to the operation.

More than 2,000 organizations throughout the world are actively involved in fuel cell development⁸³. Bus manufacturers, such as Daimler, are working on making these hydrogen-powered vehicles more affordable but the complexity of handling these vehicles has kept most

⁸³ Source : http://batteryuniversity.com/learn/article/the_future_battery.

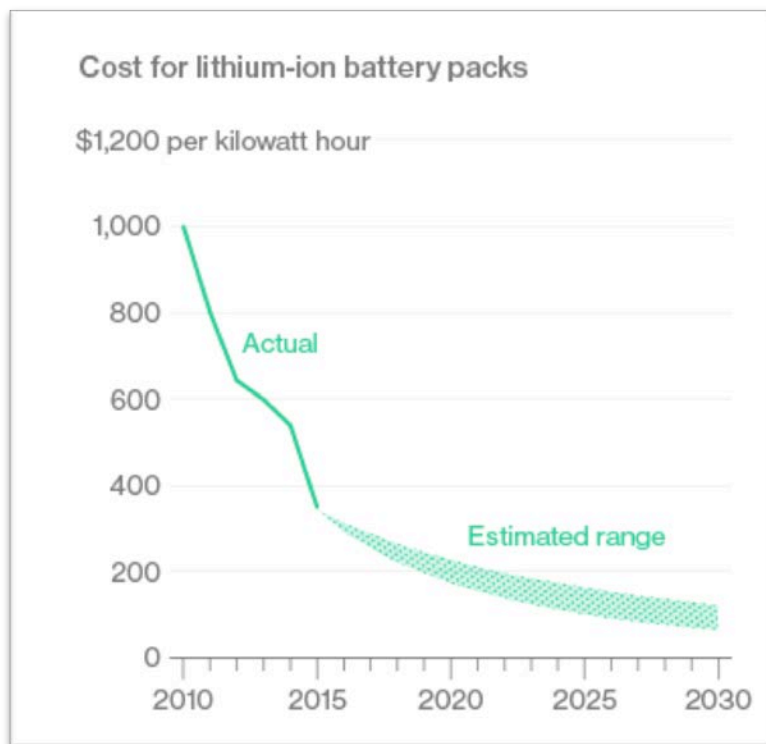
transit properties away from them to date. With the rapid progress being achieved in battery chemistry (improvements in efficiency and cost), most experts agree that it will be challenging for hydrogen fuel cell buses to catch up to battery electric buses⁸⁴.

10.2 Batteries

The key to a wider acceptance of EVs in general, and battery-powered e-buses in particular is battery cost and performance.

Several battery manufacturers, including Bosch⁸⁵ and BYD⁸⁶, are predicting the capacity of batteries currently being developed will double within 18 to 48 months (depending on the source). While some claim their price will not increase, others claim it will actually decrease by virtue of two well know phenomena, the learning curve and the economies of scale. Reputable financial analysts project the cost of batteries will drop from their current US\$350/kWh to less than \$120 on average by 2030 as figure 10.6 shows.

Figure 10.2 Cost of Li-Ion batteries 2010-2030



Source: Bloomberg New Energy Finance, 2015.

Lithium-Ion is the basic *ingredient* in many battery chemistries, but it is not the only one. Currently research is dedicated to cheaper materials. Canada’s IREQ (Institut de recherche en électricité du Québec) is one of several prominent players in that field, developing a generation of batteries that

⁸⁴ Two of the writers of this report have cumulated over 25 years of experience with hydrogen and hydrogen buses (H2buses). They have co-authored the only roadmap in existence in Canada for the development of H2buses and their implementation in transit systems.

⁸⁵ Source : <http://ecomento.com/2015/10/13/bosch-developing-electric-car-battery-of-the-future/>, October 2015.

⁸⁶ Source : Wang Chuanfu, CEO of BYD, in a presentation to his staff at their California plant, February 2016.

will succeed lithium-ion batteries in transportation electrification. The work performed on this *Solid State Battery* technology is innovative in two ways: first, it uses a solid electrolyte; and, second the anode is made of metallic lithium with a specially treated surface. This is expected to yield a more stable, safer but yet cheaper battery⁸⁷.

Although this research is promising, it is one of many projects expected to yield power packs that will be both denser (energy-wise) and cheaper.

10.3 Other charging methods

Recently, major electric bus manufacturers, namely Irizar, Solaris, VDL and Volvo, concluded an agreement⁸⁸ with numerous suppliers of charging technologies that will allow them all to use the same open interface between bus and charger. This agreement is seen as a vital step towards finding a common standard that will apply to all technologies.

Although only the three main suppliers of charging technology (ABB, Heliox and Siemens) have signed this agreement, the open interface will be accessible to everyone in hope that all manufacturers will adopt the new standard. The European body CEN-CENELEC⁸⁹ is working with the international standardization body ISO/IEC on the development of European and international standards. These standards are not expected until 2019.

There are two families of charging systems, both offer trickle and rapid charging options:

- Conductive
- Inductive

10.3.1 Conductive charging

Conductive charging implies a physical contact between the charging system and the battery. Using wires is the oldest and most common form of powering electric transit. The ETS trolley buses that operated for decades in Edmonton are an example of this technology. In this case, a pole connector from the bus engages overhead wires⁹⁰.

Charging battery electric buses is rarely performed on the road on a continuous basis. Rather, chargers are either installed at transit facilities such as bus barns or transit centres. In the former case, it is most common to find an electric cable running from a trickle charger to each e-bus in the garage. Alternatively, rapid-chargers are used at transit centres and/or garages. Figures 10.1 and 10.2 illustrate the two most common systems. In figure 10.3, a mobile arm on each bus reaches to an overhead charging plate while in figure 10.4, the mobile arm is attached to the overhead apparatus (called a pantograph) and it reaches down to the e-bus.

There are two common types of pantograph: a mobile apparatus located on the top of e-buses reaches up to **fixed pantographs** to reach a contact head. Alternatively, a mobile arm reaches down from **mobile pantographs** to make contact with contact bars. In both cases, physical contact is required.

⁸⁷ Source : New Lithium Metal Polymer Solid State Battery for an Ultrahigh Energy: Nano C-LiFePO₄ versus Nano Li_{1.2}V₃O₈, Nano Letters, February 2015, pp 2671–2678.

⁸⁸ See <http://www.abb.com/cawp/seitp202/ab11e1c9cedfc92d44257f79004b0f5c.aspx> .

⁸⁹ European Committee for Electro-technical Standardization (see <http://www.cencenelec.eu>) .

⁹⁰ Edmonton abandoned its overhead wires in 2009, and decommissioned its aging wire and associated transformer infrastructure.

Figure 10.3 Fixed Pantograph



Figure 10.4 Mobile Pantograph



While there are less well-known pantograph systems, with the agreement recently concluded in Europe, they are unlikely to progress past the prototype stage. It should, however, be noted a wide variety of presentations of these two types of pantographs exist; and many of them are aesthetically appealing, enabling City planners to integrate them with other street furniture.

In addition to the apparent section of the charging station, hidden components can be housed underground or in a separate enclosure. The size of this equipment depends on several factors such as the rated power⁹¹ of the equipment, the equipment manufacturer and the need for additional equipment such as step-up or step-down transformers.

10.3.2 Inductive charging

Induction allows for electricity to move to a battery without physical contact. Inductive charging plates are usually located at ground level and, here again, the bus either lowers itself as near to the induction plate as possible or a mechanism moves the plate up to the bus. Figures 10.3 and 10.4 illustrate both technologies.

Figure 10.5 Fixed Induction Plate

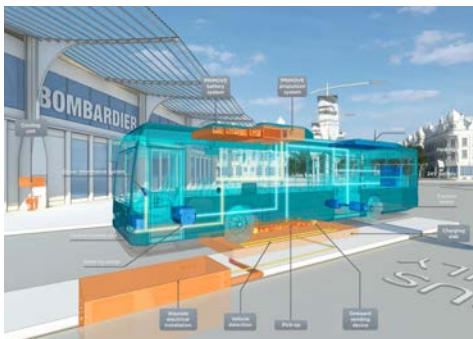


Figure 10.6 Mobile Induction Plate



A Canadian company, Bombardier, offers an inductive charging system that is already commercially used for both buses and trains in Europe.

Again, as with conductive charging, the systems can either trickle charge the bus (usually at the bus depot or in its parking lot) or rapid charge en-route at bus stops and transit centres. In

⁹¹ See lexicon in Appendix 1 for more information.

In addition to the induction plate, there are also components that can be located under or above ground.

The inductive system's main advantage is that it is easier for operators to park over a plate than to line up the bus precisely under pantographs. There are however concerns regarding the efficiency of the technology as the amount of energy transferred to the bus' energy storage system diminishes with the distance between the plates and the batteries. The quantity of snow and ice can increase the distance between the induction plate and the receiving component. Such conditions therefore have an impact on charging efficiencies, and the time required to recharge buses.

As was the case for the conductive charging systems, there are alternative systems that have not been very successful to date, mainly due to the cost of the infrastructure required. For example, an induction wire can be embedded in the road along the whole (or at least a large portion) of a bus route. This type of charging, which would benefit from almost continuous charging, would allow for a relatively smaller battery on-board the e-bus. However, it would limit the routes for buses to streets equipped with these underground cables, thereby requiring long-term commitment to the routes where they are installed, which is a consideration for evolving municipalities or those that adjust routes to meet evolving rider needs and ridership trends.

10.3.3 Boost charging

It was once believed that providing smaller amounts of electricity on a more frequent basis to a bus would be the best way to accelerate the adoption of e-buses by transit systems. By doing so, the size of the battery on board the buses could be kept to a minimum, thereby reducing curb weight, increasing payload and improving fuel efficiency.

With the rapid advancements already made by battery manufacturers, and with the anticipated improvements in the coming months and years, market trends favour keeping investments in infrastructure to a minimum, making boost charging rather unpopular at the moment.

11 Conclusions and other considerations

Based on the information available at the time this report was prepared, **MARCON predicts that electric buses used in service in Edmonton can perform as reliably as the rest of the fleet of diesel buses** but will require thorough planning, training, and resources to ensure the City of Edmonton derives the full benefits of their use.

Electric buses offer environmental and potential economic benefits. Although important from the start, the environmental benefits for Edmonton will increase over time, as the source of energy used to charge the buses gets cleaner. It is also expected that the economic benefits of using e-buses relative to using the diesel buses will improve in the future as the cost of operating diesel buses will outpace that of e-buses due to diesel fuel price increases, the rising carbon cost and the price of electricity continuing to progress at a slower pace as has been the case in the past.

MARCON concludes that it is feasible to introduce e-buses in the ETS fleet.

11.1 Limitations of the scaling up of the reports in this study

The road trials of e-buses in Edmonton were conducted during a very short period of time, in January 2016. That period was not markedly cold by Edmonton standards, nor were there many snow days. The buses were therefore not tested under very severe climate conditions and their performance in extreme cold weather cannot be predicted accurately. Based on the results of the trial and experience of other Canadian transit evaluations during winter months, e-buses can be expected to operate effectively in Edmonton in winter within the operating limitations of the technology.

The accuracy of the data provided in this report is $\pm 25\%$. One exception to this level of accuracy: the cost of modifying the new garage facility to accommodate e-buses, which is estimated at \$750,000 within $\pm 50\%$ by a third party selected by the City of Edmonton⁹².

MARCON used its proprietary model, TLC Bu\$™, to predict the lifecycle cost of operating e-buses in Edmonton. As instructed by the Steering Committee, the calculations are based on 40 buses only. Using this relatively small fleet makes the fixed cost of infrastructure (garage, tooling, charging stations, etc.) relatively high as a proportion of the total cost of adopting e-buses in the fleet. Increasing the size of the e-bus fleet would yield savings for ETS in the future.

The cost of diesel fuel and electricity are maintained constant for the 20-year life of the analysis. The price history of both energy sources indicates that future price increases for diesel should, on average, outpace the expected rise in the cost of electricity, making the business case for electric buses more attractive.

Timeliness of data is also important. The financial projections are made with the information provided to MARCON in the course of winter 2015-2016. Large elements of cost and performance are expected to change substantially over time. For example, the price of electric buses is expected to decrease as suppliers gain both sales volume and manufacturing experience. Battery performance is improving rapidly. As a result, the same energy stored on board with a smaller and

⁹² Morrison Hershfield.

lighter battery and a lower cost of batteries can reasonably be expected. Both have an important impact on lifecycle cost.

Batteries installed on diesel-electric hybrid buses have exceeded industry expectations in terms of their life and degradation performance. But new battery chemistries are reaching the market, sometimes without the benefit of a proven track record. This represents a risk for ETS but at least one manufacturer has expressed a willingness to offer innovative terms for the sale of its buses. In an informal proposal discussed with MARCON, the manufacturer offered to lease their battery pack for twelve years (the length of the warranty) or to rent them for as long as ETS owns the buses. This overture shows that it might be possible to shift the risk of ownership of the batteries over to the bus supplier selected by ETS, thereby easing the cash flow requirements for the purchase of e-buses over time and matching the higher capital cost of e-buses with the energy savings they procure.

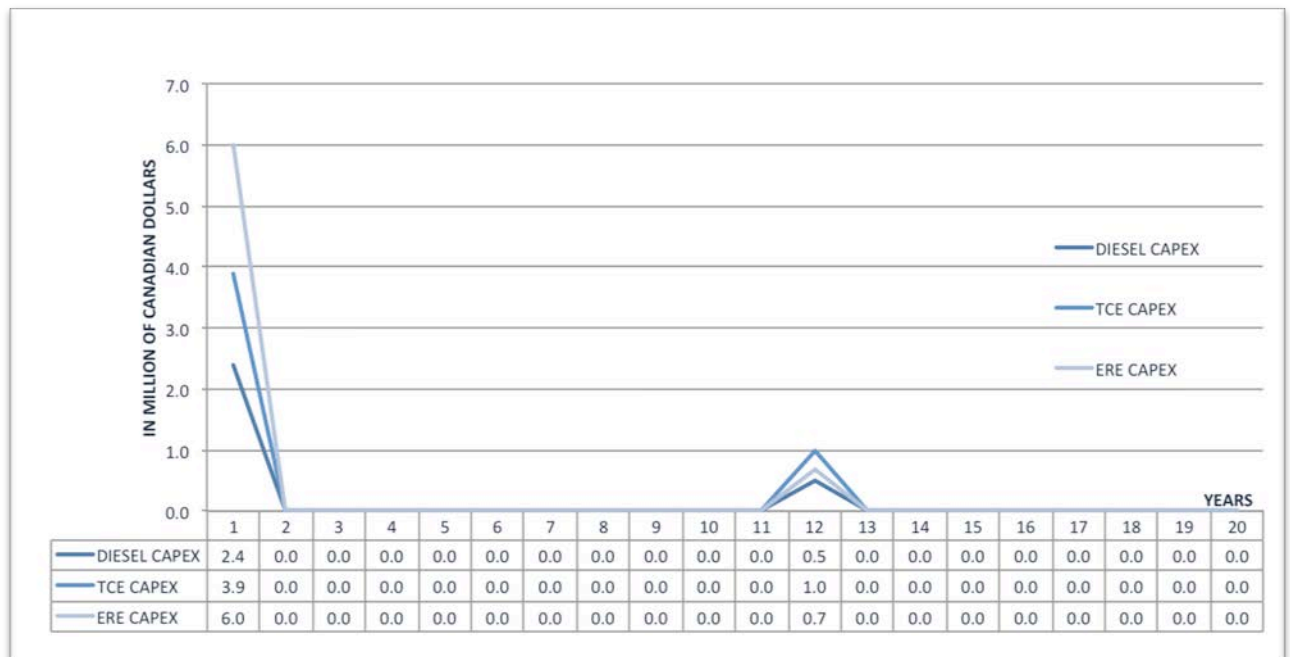
It should be noted that the financial data provided in this report is not intended as a prediction of the full cost of bus ownership over the next 20 years. Rather, the evaluation was conducted to provide a fair comparison between three technologies: diesel, trickle-charged buses and en-route charged buses.

Finally, the current ETS duty cycle of diesel buses was used to establish a basis for comparison between diesel and electric buses. This duty cycle is not optimal for e-buses. Adapting ETS procedures and practices to accommodate the capabilities of e-buses will undoubtedly provide better results for e-buses.

11.2 Expected financial impact of using 40 electric buses in Edmonton

Using a standard procurement practice, the initial and mid-life rebuild capital expenses (CAPEX) of e-buses are noticeably higher than the cost of diesel buses as shown in the following figure.

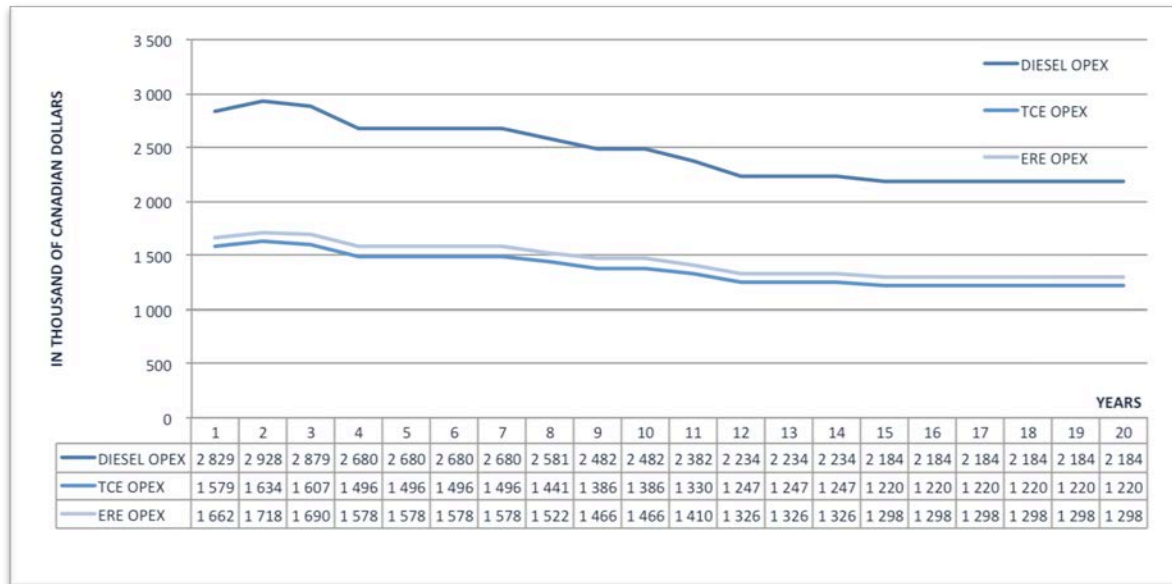
Figure 11.1 Capital expenses (CAPEX) for diesel and e-buses (20 years life)



Source: MARCON, 2016.

However, the operating expenses (OPEX) expenses of e-buses are, for their part, only approximately 56% to 59% of the cost of running diesel buses. This calculation assumes that the price of diesel fuel will remain at its current level for the next 20 years, which is highly unlikely.

Figure 11.2 Operating expenses (OPEX) for diesel and e-buses (20 years life)



Source: MARCON, 2016

Given the duty cycle used for the economic calculations performed and the hypotheses related to the cost of energy and the price of the carbon levy, the economic forecast is very conservative.

And on that basis, **the lifecycle cost associated with purchasing and operating 40 trickle-charged e-buses out of the new NETG is comparable to that of using the latest generation of diesel buses on the market.**

Despite the fact that almost two-thirds of ETS customers surveyed expressed a willingness to pay more in order to ride e-buses, no additional revenue is factored into MARCON’s calculations. In fact, no increases are foreseen for the fares over the 20-year period used in MARCON’s analysis. All the hypotheses used in MARCON’s calculations are selected in a similarly moderate way.

There are several opportunities to further improve the business case for e-buses. For example, leasing or renting the e-buses’ energy storage system can mitigate their higher purchase price. Favouring the e-bus in the daily block allocation in such a way as to increase the distance the e-buses will cover each year for their entire life will also produce savings as the cost of operations of diesel buses (\$1.05/km) is higher than that of trickle-charged e-buses (\$0.59/km).

The calculations presented in this report are based on several very conservative hypotheses. For example, the price of energy, diesel fuel included, is held at current contractual levels for the 20 years life of the buses. Although the price of electricity will rise, petroleum products prices have historically experienced much greater variations and the price of diesel is currently low.

11.3 Expected environmental impact of using 40 electric buses in Edmonton

The use of e-buses in Edmonton would generate GHG saving of 38% to 44% compared to diesel buses used in the same way. These savings will reach 72% to 74% by 2034 as the Alberta electricity supply base gets cleaner with the progressive phasing out of coal-fired power generation.

The use of diesel heaters on board e-buses will use 4% of the diesel fuel currently consumed by diesel buses, irrespective of which e-bus is equipped with these heaters. Considering the range reduction implications of heating e-buses electrically, equipping e-buses with diesel heaters is considered more desirable despite the small impact of diesel heating on the environment.

Whether upstream emissions, or those from the tailpipe, **e-buses are a better choice for the environment than the current diesel fleet.** ETS can further decrease its environmental footprint by many other ways: sourcing renewable power for the buses, co-generating heat and electricity in the new facility that will host the buses, installing solar arrays on that same building, etc.

11.4 Risks associated with the use of electric buses at ETS

Adopting a new technology invariably presents risks. If nothing else, time is required for staff to adapt to the new vehicles. **The field trial has shown that operators have quickly adapted** to the test vehicles with a minimal amount of training and under conditions that were not ideal as the equipment provided by manufacturers was available for only a short period of time. The adaptation period will be longer for maintenance staff as technicians will have to learn to deal with unfamiliar issues but operators will get used to driving e-buses very quickly.

While electric motors have long been used in industry, batteries made their entry in the transit market as a main source of energy less than 10 years ago with the advent of diesel-electric hybrid buses. From a reliability perspective, they have performed very well. This issue and its associated risks have already been discussed but additionally, handling batteries in the maintenance garage or accidents requires that operators, first responders and maintenance staff know the risks associated with the battery chemistry selected when e-buses are purchased, and that all personnel be trained accordingly to mitigate such risks.

The current shorter range of e-buses compared to diesel buses also presents a risk that more e-buses may be required than diesel buses to provide an equivalent level of service. However, MARCON's evaluation of ETS service plans shows that **the property operates a sufficient number of blocks with total distance well within the range of e-buses** (even with a 15 to 20% energy reserve margin). ETS can therefore place 40 e-buses in service without having to worry about this issue. Also, upcoming generations of e-buses are expected to totally mitigate this risk. MARCON also observed that e-buses are able to negotiate the steepest hills in the ETS service area without experiencing an adverse impact on range.

The field trial also demonstrated that the use of diesel heaters on an e-bus provides more certainty regarding the range of the vehicle, with minimal environmental impact. Approximately 20% of energy stored on board the e-bus is required to operate electric heaters. In extreme cold this could be higher, further reducing the effective operating range of the bus. Evidence at other Canadian transit agencies that evaluated the buses in summer indicates air conditioning has a similar negative effect on range.

The use of en-route charged e-buses presents risks that are different than those of operating trickle-charged buses. With the former, the charging infrastructure required can be restrictive in terms of route planning flexibility as the cost of moving the charging equipment from one station to another will be high. With trickle-charged buses, an electricity grid failure affecting the garage where e-buses are charged can hamper e-bus fleet operations if the electricity supply failure occurs when e-buses are scheduled for a charge (unless a sufficiently large backup generator is installed). The range of the current generation of trickle-charged e-buses also limits the portion of the blocks that can be assigned to these buses.

11.5 Other risks and benefits associated with the use of e-buses at ETS

One of the important benefits of using e-buses is the **expected increase in customer satisfaction**. A large majority of current customers expressed their preference for these clean buses. Almost two-thirds of them expressed a willingness to pay a premium to ride them. And despite residents along the routes not being surveyed on that topic, it is fair to assume that most will prefer a quiet bus to a noisy one in their neighbourhood.

Using the latest generation of e-buses will also have an impact on the image of Edmonton as being a progressive, environmentally conscious city.

The introduction of e-buses at ETS can be accommodated by the current capacity of the electricity grid in Edmonton, particularly at the proposed new North East Transit Garage. However, if e-buses are introduced in large numbers, the electricity grid in Edmonton may need to be upgraded in some areas to ensure there is sufficient power at the locations where large fleet would be charged.

11.6 Key success factors for the use of electric buses by ETS

There are several key success factors to the implementation of e-buses in Edmonton. MARCON has identified them in a time sequence as follows:

1. Clearly determining what performance the e-buses are expected to achieve
2. Making the right e-bus technology choice for the intended use
3. Prior to the procurement process, defining exactly:
 - a. The routes the e-buses will service
 - b. How the block assignment process will be modified to optimise their use
 - c. What their space assignment will be in the assigned garage
 - d. How service and maintenance procedures will be adapted to e-buses
 - e. What design changes must be made to the assigned garage to accommodate e-buses with minimal impact on operations
4. Developing specifications for the procurement of e-buses that are compatible with the way ETS intends to operate them and not the brand of buses available
5. Engaging in a procurement process that will involve negotiations with one or several suppliers willing to adapt their vehicles to the specifications ETS has developed
6. Obtaining favourable terms (ex. battery rental or leasing) from the selected supplier as ETS will likely be showcased by the bus manufacturer in future promotions of their product
7. Keeping all ETS staff informed of the goals of the City with regards to e-buses and developing a detailed plan of the process ETS will use to bring them into service
8. After delivery of the buses, ensuring the buses are assigned to the duty cycle and routes they were originally intended for

9. Optimize the use of the buses to the maximum distance they can deliver as their cost advantage increases with every kilometre in service
10. Ensuring the deployment location of e-buses can be supported by the electricity grid at that location.

12 Recommendations

12.1 Risks and benefits for the e-bus case in Edmonton

While there are risks associated with the introduction of e-buses to the ETS fleet, these risks can be mitigated. In the long run, the environmental benefits associated with e-buses will make them more attractive. The cost of operating trickle-charged e-buses is already comparable to that of operating a diesel bus fleet (within the level of precision required from MARCON's calculations herein). The business case for e-buses will keep improving with time as cheaper energy storage systems introduced by manufacturers.

Therefore, the addition of e-buses to the ETS fleet is recommended.

12.2 E-bus technology

Two charging technologies were evaluated in the course of this project. **The trickle-charged buses proved to be more economical to operate** with some limitations in terms of service delivery to riders. Buses that can be recharged at a central location can serve a reasonable block length while providing almost the same flexibility as the current diesel buses in terms of their route assignments. With the expected improvements in energy storage systems announced by the industry, range limitation issues will become irrelevant for trickle-charged buses within a few years. ETS is therefore less restricted when deploying these e-buses than they would be with en-route charged buses that must necessarily run from one charging station to the next in order to maintain their range.

While they do not experience range limitations because they can quickly replenish their batteries, en-route charged buses require a charging infrastructure that pushes their lifecycle cost beyond what could be considered comparable to that of diesel buses, outside the $\pm 25\%$ margin of error.

For these reasons, if the City of Edmonton chooses to add e-buses to its fleet, **MARCON recommends that trickle-charged e-buses be adopted.**

The technology associated with e-buses is continuously improving, with four manufacturers that will have transit products of different configurations available in the next year or two - New Flyer, BYD, Nova Bus and Proterra. The maturity of the technology in the development cycle is such that MARCON supports the procurement of e-buses by ETS.

A procurement of a limited number e-buses will not necessarily optimize the required capital cost of facility upgrades, charging infrastructure, specialized tooling and other initial soft costs. While a smaller fleet than the one evaluated in this report would damage the business case for e-buses, a small procurement will provide ETS with a good opportunity to evaluate all the facets of operating an e-bus fleet, and to optimize the operational processes required should a further expansion of the electric bus fleet be desired.

12.3 Timing, number and rate for the introduction of e-buses at ETS

Electric bus technology is not as mature as the incumbent diesel technology and so, adopting electric buses does present the risks identified in chapter 11. But at this time, there is a growing consensus in the industry: electric vehicles will most likely dominate over the next few decades.

In that context and with the results of the field trials conducted in Edmonton, **MARCON recommends that ETS's next bus procurement comprise of a limited number of trickle-charged electric buses.** Putting e-buses in service in Edmonton will represent a credible and conclusive first step in greening Edmonton's transit bus fleet.

Given the amount and nature of the preparatory work required to procure these buses and integrate them in the fleet, **it would be reasonable to expect their entry in service in late 2017, or early 2018.**

12.4 Changes required for a successful transformation of ETS

12.4.1 Essential changes

In order to minimize the cost of infrastructure and operations, **MARCON recommends deploying these e-buses to a single garage designed or modified to accommodate them.** Their specific requirements should be determined using a functional analysis but must include considerations pertaining to the size of the backup generator and the clearance of the bus wash. Other items such as the possibility of using cogeneration and/or solar arrays would improve further their environmental performance.

In procuring the modest fleet of e-buses, **MARCON further recommends that ETS staff develop a performance specification as soon as possible.** These specifications should include diesel heaters for space heating on board each bus in order to provide more certainty in effective range for service planning. Due to the drain on the batteries the use of air conditioning is not recommended.

A thorough evaluation of service blocks must be undertaken in parallel with the procurement process to identify what changes would optimize the use of e-buses and, therefore, the economic and environmental benefits of the technology. The goal will be to assign these buses to the longest blocks they can possibly handle in order to reduce their fixed cost per kilometre.

12.4.2 Important changes

MARCON recommends that:

- **A comprehensive engineering and maintenance fleet monitoring program be designed** prior to any e-bus fleet procurement to ensure processes are developed that will capture changes required to the current maintenance, servicing and support systems to ensure the success of the introduction of the e-bus fleet
- **A comprehensive review of all service planning be undertaken** to ensure that service blocks are optimized for use of the e-bus fleet to achieve the best environmental and economic benefits
- ETS work with the successful bus manufacturer and potential third party technical training institution to **develop the necessary training packages** to ensure all staff involved with operating the e-bus fleet receive comprehensive training prior to commissioning the new buses

If it is intended to expand the size of the e-bus fleet after a few years of experience with the modest fleet identified above, **it is strongly recommended that a thorough analysis of the charging and facility upgrade requirements be carried out for each transit depot in the ETS system.** This should be carried out in parallel with the introduction of the initial fleet of e-buses,

and the facility development plan for all the operating depots. This will ensure that the power requirements can be met and capital investment needs identified in advance of any purchases of e-buses.

It is also recommended that **ETS continue to monitor other trials being conducted with e-buses at transit properties in North America and investigate sources of subsidies for procurement of clean technologies that may be available from Federal and Provincial governments.**

12.4.3 Preferable changes

It is possible to reduce the GHG intensity of the electricity the City purchases to zero through the purchase or production of renewable energy. There are currently many opportunities to acquire renewable energy from certified sources around the province. Edmonton currently purchases some renewable energy credits (RECs), but the representative of Edmonton's Office of Energy Management confirmed to MARCON that the City prefers conducting energy efficiency projects rather than to purchase offsets to reduce its carbon footprint.

Considering the preference of the City of Edmonton for energy efficiency over the purchase of RECs, ETS should explore cogeneration potential where boilers currently specified to heat the building are replaced by cogeneration units that simultaneously produce heat and power using abundant and cheap natural gas as well as solar arrays on the garage roof where the buses will be housed. The Office of Energy Management indicated that it is mandated to explore the business cases of modernization and renewable energy investment, and they are interested in exploring this potential prior to the building being constructed.

12.5 Other recommendations

Standard government sourcing processes are generally ill suited to the adoption of new technologies because the usual "low cost bidder" approach does not allow the organisation to select an ensemble of suppliers that will minimize the overall cost of the implementation. The procurement process at the City of Edmonton was not examined but, based on this general observation, MARCON suggests that a special task force be selected to oversee the arrival of the e-bus fleet, from design and procurement to the ribbon-cutting ceremony.

At least one bus manufacturer has expressed much flexibility in providing a contractual arrangement for the provision of its vehicles that would allow ETS to lease or rent the energy storage systems for the e-buses. The economic analysis and resulting lifecycle cost analysis show that the initial high capital cost of purchasing e-buses is most damaging to the e-bus business case.

The possibility of using this procurement of e-buses and the possibility of further procurements from the same supplier as leverage for economic development in the Edmonton area should also be taken into consideration as one manufacturer has expressed an interest in performing at least part of its e-bus assembly in Canada.

Finally, if ETS ever conducts field-testing of new technologies in the future, MARCON recommends that the "*lessons learned from the field trials*" presented in Appendix 5 be considered.

12.6 Next steps

The activities to be undertaken if the City decides to introduce e-buses in the ETS fleet are:

- ETS must resolve how the e-buses will be used in the fleet and henceforth determine what performance the e-buses are expected to achieve.
- Ideally prior to, but possibly concurrently with the procurement process, ETS must define:
 - The routes the e-buses will service
 - How the block assignment process will be modified to optimise their use
 - What their space assignment will be in the assigned garage
 - How service and maintenance procedures will be adapted to e-buses
- ETS must then develop detailed specifications for the procurement of e-buses that are compatible with the way ETS intends to operate them independently from those currently promoted by bus manufacturers
- The City must then engage in the procurement process in a way that might be different from its usual practices as negotiations with one or several suppliers willing to adapt their vehicles to ETS' specifications will be the best way to procure vehicles that will meet the City's expectations. The lowest bidder may not be the best supplier as the lifecycle cost of the procurement should dictate the choice of supplier.
- An internal and external communications strategy must be crafted to illicit maximum collaboration from all City staff and to instil pride in the organisation on the part of all Edmonton citizens and staff members.

Appendix 1: Lexicon and other useful information

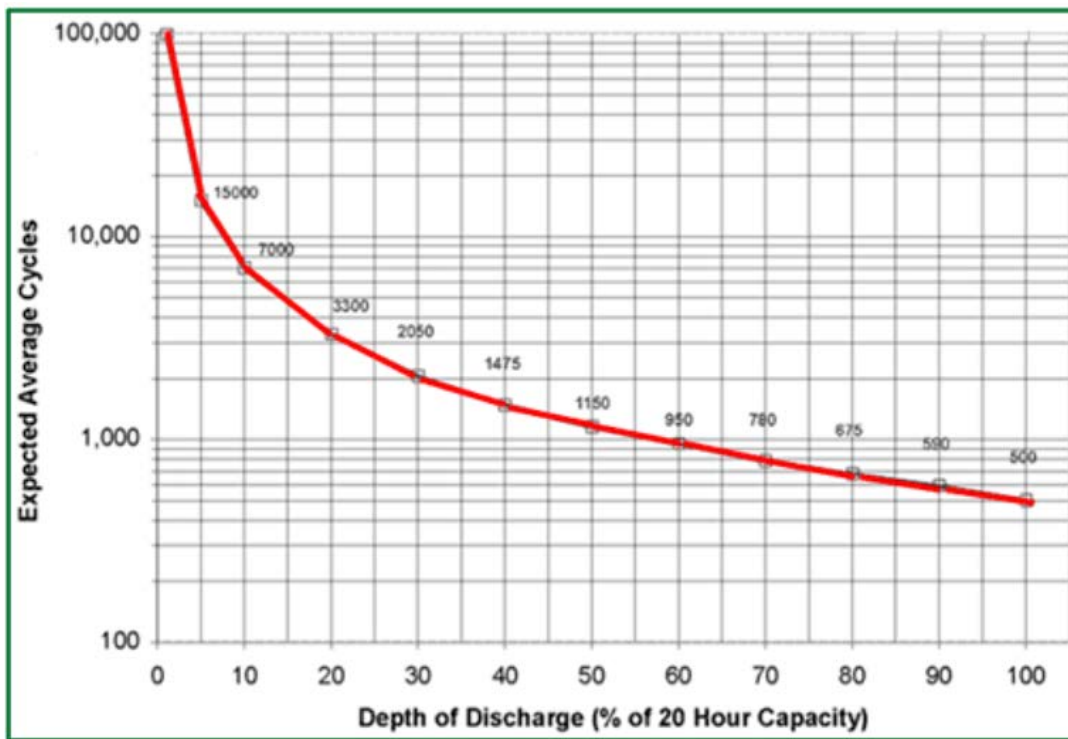
Cycle Life

This is the number of times an energy storage system can be discharged and recharged before end-of-life.

Cycle life may vary with depth of discharge (DOD) and/or discharge rate. It is usually specified as a number of cycles to a certain depth-of-discharge (e.g. 5,000 cycles to 80% DOD), or even as a table or graph. A sample is provided in Figure 1.

Cycle life may also vary based on the charge rate.

Figure 1 - Sample Cycle Life vs. Depth-of-Discharge Graph



Energy Capacity

This is the amount of energy that can be stored in the device for delivery to a load and is described in kilowatt-hour (kWh) or megawatt-hour (MWh).

It is important here to note the difference between direct current (DC) and alternating current (AC) ratings, and between the “rated capacity” and the “useable capacity.” Many energy storage devices (especially those called “batteries”) are rated in DC, while an energy storage “system” – which interacts with the electric grid – is rated in AC. So, it is important to note which one is being discussed by specifying “kWh-DC” or “kWh-AC”.

It is also important to note whether this is the “nameplate rating” or the “useable capacity.” Some technologies (e.g. lead-acid and lithium) have a theoretical rating based on 100% discharge. However, using this capacity repeatedly would cause physical damage to the battery, so manufacturers recommend using only some percentage (i.e., 50% or 80%) of the nameplate

rating. There are other energy storage systems, especially flow batteries; that can do 100% depth of discharge (DOD) without physical damage to the battery.

Power Rating

This is the amount of power which can be delivered from the energy storage system, and is measured in kilowatts (kW) or megawatts (MW).

This must also be specified as DC (if discussing the battery alone) or AC (if discussing an energy storage system).

This rating is a function of the battery itself and of the power electronics (inverter), which are used to convert the battery energy into AC power. The most common specification is for continuous power, but different devices may also be rated for short-term or “surge” power. The power rating is usually the same for both discharge and recharge, but it can be different in special circumstances, especially when discussing the battery alone.

Round Trip Efficiency

This is the ratio of the amount of energy, which can be discharged from the energy storage system to the amount of energy it takes to recharge to the initial state. It is usually abbreviated as RTE, which must be specified as DC (if discussing the battery alone) or AC (if discussing an energy storage system).

$$ACRTE = DCRTE * \text{inverter efficiency} * \text{charger efficiency}$$

Round-trip efficiency may vary based on charge / discharge rate.

Note that all energy storage systems have a round-trip efficiency of less than 100%.

Actual DCRTE can be between 65% and 95%, depending on the battery technology.

System Life

This is the number of years that the system is expected to operate within specified parameters. For example, some systems may be specified to operate for five or ten years and then be replaced / recycled, while others may be specified to operate for 25 years, assuming certain maintenance and component replacements along the way.

Inverters and pumps/motor drives and flow-battery membranes are examples of components that may need refurbishing and/or replacement over the life of the system.

There are also other specifications which may be described on a datasheet, including:

Degradation

Some energy storage systems (especially electrochemical) will experience a reduction in capacity over their life. Such systems are often rated using terminology such as “5,000 cycles to 80% final capacity.”

Note – this is the reason why people are looking at selling used electric vehicle (EV) batteries for home energy storage after they have outlived their specified life in the vehicle.

Self-Discharge

This is the rate at which an energy system will lose capacity if left unconnected to a charging source.

It important to note that some technologies (lead acid, lithium, flow batteries) are suitable to standby use (long periods of inactivity followed by use), while others (sodium nickel chloride, liquid metal batteries) are designed to be used continuously, since their “losses” help provide the heating for the high temperature elements of the battery.

Appendix 3: Mid-life cost rebuild – detailed costs

	Diesel Xcel­sior 2014-2015	Diesel 40' Buses 2012-2015	Excelsior E-Bus	BYD E-Bus	Notes
Rebuild / Overhaul / Midlife Costs eBus only (thick border)					
Energy storage life expectancy (years)			12	12	1
Energy Storage replacement (per bus) (parts only)*			\$244 000	\$156 542	2
Energy Storage replacement (per bus) (parts only)*			\$63 000	\$85 000	3
ESS replacement (labour)			\$1 500	\$1 500	4
Annual preventive maintenance (power pack)			\$0	\$0	5
Energy Storage System disposal costs (per bus)					6
Power Inverter Module (PIM) (parts only)			\$15 000	\$0	7
PIM Labour			\$750	\$0	8
Power train (Incl: turbo compressor)					
Engine or Motor rebuild/replacement	N/A	N/A	\$23 104	\$30 806	9
eBus Motor replacement labour			\$1 500	\$2 250	10
Transmission rebuild/replacement	N/A	N/A	N/A	\$61 100	11
BYD reduction gears labour				\$3 750	12
Combined Engine & Transmission rebuild/replacement	\$64 534	\$64 534	N/A	N/A	
Body Midlife	\$64 221	\$64 221	\$64 221	\$64 221	13

NOTES

- Both NFI and BYD offered 12 year battery warranty on recent RFP
- BYD = C\$156,542 NFI= 4x\$61,000 (61,000 for 50 kW, 200 kW total) Re: Sales quoted costs
- Alternate **future** cost analysis using CARB report*
- Estimate 2 days (replacement and testing labour)
- Included in PM Inspections noted below
- Future costs unknown. Recycling probable.
- BYD - included in Battery system. NFI-\$15,000 aux inverter (assume motor, charger inverter included with components)
- 1 day replacement and testing labour
- BYD motor replacement cost (2). NFI-no price obtained assume BYD*1.5 (single larger motor)
- Replacement and testing labour (2 days NFI, 3 days BYD-2 motors)
- BYD reduction gear set @\$1.30
- 5 days axles re&re and rebuild
- Assume same as diesel (BYD unknown as it's a new production bus)

Appendix 4: Detailed maintenance costs

	Diesel Xcelsior 2014-2015	Diesel 40' Buses 2012-2015	Excelsior E-Bus	BYD E- Bus	Notes
MAINTENANCE COSTS					1
Running Maintenance					
Brake maintenance (annual per bus)	\$3 032	\$5 225	\$1 516	\$1 516	2
Body/Cab Interior/Exterior (annual per bus)	\$2 923	\$3 952	\$3 952	\$4 348	3
Preventative Maintenance Inspections (annual per bus)	\$6 251	\$6 251	\$4 689	\$4 689	4
General Engine work (annual per bus)	\$914	\$2 836	\$0	\$0	
Transfer Case (annual per bus)	\$0	\$0	\$0	\$0	
Suspension (annual per bus)	\$701	\$1 819	\$1 819	\$1 819	
Hvac System (annual per bus)	\$968	\$1 664	\$1 664	\$1 664	5
General Transmission work (annual per bus)	\$340	\$1 504	\$0	\$0	
Cooling System (annual per bus)	\$546	\$1 437	\$546	\$273	6
Steering (annual per bus)	\$166	\$1 237	\$1 361	\$1 361	7
Fuel System (annual per bus)	\$34	\$1 102	\$0	\$0	8
Air Compressor System (annual per bus)	\$185	\$726	\$653	\$653	9
Wheels, Rims, Hubs & Bearings (annual per bus)	\$739	\$663	\$663	\$663	10
Exhaust System (annual per bus)	\$226	\$648	\$0	\$0	
Cranking System (annual per bus)	\$284	\$625	\$0	\$0	
Supplemental Information Devices (annual per bus)	\$23	\$549	\$549	\$549	11
Lighting System (annual per bus)	\$178	\$414	\$178	\$178	12
Charging System (annual per bus)	\$17	\$399	\$0	\$0	13
Air Intake System (annual per bus)	\$5	\$375	\$200	\$200	14
Instruments, Gauges, Meters & Warning (annual per bus)	\$174	\$323	\$258	\$258	15
Electrical System (annual per bus)	\$14	\$266	\$266	\$320	16
Electrical Accessories (annual per bus)	\$117	\$200	\$401	\$401	17
Axles (annual per bus)	\$0	\$150	\$150	\$150	18
Hydraulic Systems - Multi-Function (annual per bus)	\$0	\$149	\$0	\$0	
Modules/Relays/Wiring - Electrical (annual per bus)	\$63	\$132	\$264	\$264	19
Drive Shafts (annual per bus)	\$11	\$130	\$156		20
Frame (annual per bus)	\$0	\$46	\$46	\$46	
Ignition System (annual per bus)	\$5	\$14	\$0	\$0	
Oil changes (annual per bus)	\$0	\$0	\$0	\$0	21
Misc. Other Systems (annual per bus)	\$107	\$48	\$1 500	\$1 800	22
Tires, Tubes, Liners & Valves (annual per bus)	\$26	\$5	\$26	\$26	23
Total Running Maintenance	\$18 048	\$32 891	\$20 859	\$21 178	

- 1) In general, used 2012-2015 as the average Battery bus comparison-starting point as 2014-15 Xcelsiors are too new for long-term average cost. Use Xcelsior cost for specific new technology on new buses (e.g. disk brakes). Differences in NFI and BYD generalized as this is not a "purchase" analysis, and bus details may change in future.
- 2) 50% less brake maintenance - hybrid and trolley examples with regenerative braking
- 3) XE40-same as 2012-15 average. BYD add 10% for less "refined" body, less standard sourcing
- 4) PM annual average cost, calculated over a 140,000 km cycle
- 5) Slightly less electric AC maintenance, but add for diesel heater (same cost)
- 6) NFI - same as XD40, multiple cooling systems. BYD - 50% of XD, simpler cooling system
- 7) Add 10% for more costly power steering motor
- 8) Diesel heater fuel included in HVAC cost
- 9) Deduct 10% from diesel (for oil-less scroll compressor, no belt direct drive)
- 10) Same as diesel
- 11) Same as diesel 2012-15
- 12) Use XD40 costs, for LED lighting
- 13) No alternator on battery bus
- 14) Some air filters on e-buses
- 15) 20% less, no engine/transmission gauges
- 16) Same basic body electrical as diesel (BYD add 20% - ETS experience)
- 17) Double the electrical accessories as diesel
- 18) Same as diesel
- 19) Double the electrical wiring as diesel
- 20) 20% more - more costly drive shaft on battery bus
- 21) Oil changes are included in the PM cycle numbers
- 22) Estimate for other electrical systems on bus compared to diesel (2 days work) BYD 20% more due to more complicated system (ETS experience)
- 23) XD40 costs used (should be higher - 3 tires/year)

Appendix 5: Lessons learned from the field trials

The field trial conducted in the winter of 2015-2016 in Edmonton provided an opportunity to learn and improve. Should the occasion arise to conduct another field trial regarding a new bus technology, the following comments may be helpful:

- A good understanding of the electric bus market, test bus availability, and status of e-buses commercial availability should be acquired before starting field trials to ensure that the objectives of such a test program can be met as efficiently as possible and that the timing for the test is optimal.
- An overall project scheme, anchored by a detailed test plan, is necessary to ensure all program components are considered and that a detailed plan is prepared for the field test. This should be completed well ahead of acquiring the buses to be evaluated. Lead times to obtain test buses, lease agreements, border crossing and regulatory approvals, facility modifications, technician training, driver training, and support personnel are key to the winter testing. Lead times are often longer than anticipated and take much coordination than originally expected.
- A detailed test plan, organized prior to putting buses in service is highly recommended. This plan should include a test design that will achieve the objectives and procure the data required to make meaningful conclusions, even if it means testing the buses independently of revenue service to obtain specific technical objectives under identical operating conditions before evaluating them in revenue service.
- A great number of variables can affect the performance of vehicles being tested. Ideally, all factors should be controlled while only one varies in order to assess the impact of the latter on bus performance. For example, running buses without passengers but loaded to capacity on the identical route for several days allows for the best possible measurement of weather conditions on bus performance.
- In general, staff will be under pressure to accommodate a test of this magnitude. There are many additional tasks, work routines, and trouble calls for maintenance, operating, and management staff. To successfully operate such a field test, it is recommended to allocate staff time specifically to the test. Ideally a test coordinator would be available to deal daily with ongoing planning and issues. In addition, in this test, a consulting firm with experience in field tests can perform much of the planning and coordination tasks, but still needs assistance from garage staff for daily running tasks.
- Staff motivation to be a part of the test, to put in the extra effort, and to understand the rationale and benefits of all this extra work should be considered a key success factor. Senior management should communicate the project at an early stage, and follow up during the test to champion the cause. Test fatigue and morale can degrade the test results, and affect staff appreciation of future electric bus decisions.
- Training and matching operators to test buses and blocks of work is a complicated effort. Union and work rules create constraints and limit the availability of operator/bus/block matchups. Training must be organized, and operator complaints must be addressed with some urgency. Drivability, ergonomics, visibility, and bus familiarity should be pre-tested and worked out with operators, bus supplier, management, and training/safety before evaluation commences.
- Data collection during the field test is key. Specific bus data is required to be recorded by hand. Brief forms with instructions must be communicated to staff, and followed up quickly if data is not recorded correctly or in a timely manner. Much data can be obtained from existing computer systems from maintenance and operations. It is

recommended this data be collected frequently (twice per week or more), to be able to monitor and react to problems in a timely manner.

- Technicians will often struggle to troubleshoot test buses, especially when the technology is unfamiliar to them and when insufficient training is provided. Battery buses have many unfamiliar systems compared to a diesel fleet, and extensive training/familiarization time is required. Support from bus manufacturers is key, with an agreement for either on-site specialist to do the work, or at the very least, prompt personal help.
- Analyzing electric bus test data is a significant undertaking as well, and requires good data collection and validation. In this test (see Section 3), ETS test data is reported in categories that are meaningful to ETS. In addition, other tests and bus operating data is required to validate the ETS test conclusions due to the short length of the field test.
- Whenever the opinion of the public is required as an input in the analysis, the general conditions of the data collection environment (in this case, the bus itself) should be made to match those of “*usual conditions*” as much as possible. The bus should be painted the same way as others in the fleet and as few things as possible should distinguish it from the rest of the fleet. Publicizing the test is not recommended. It will invariably attract those who are the most in favour or against new technologies, thereby creating a bias in the sample of customers surveyed.



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