For Action

TTC's Green Bus Program: Final Results of TTC's Head-to-Head eBus Evaluation

Date: April 14, 2022
To: TTC Board
From: Executive Director – Innovation and Sustainability

Summary

This report presents the final results of TTC's eBus Head-to-Head evaluation, outlines the resulting 'must have' requirements for large-scale procurements of eBuses, and seeks authority to enter into future funding contribution agreements and contracts to advance implementation of TTC's Green Bus Program.

TTC eBus Head-to-Head Evaluation

In June 2019, the TTC's first of 60 eBuses entered service. In October 2020, TTC initiated its head-to-head evaluation of the three bus types procured from BYD Canada, Proterra, and New Flyer Industries. The objective of the head-to-head evaluation was to:

1. Evaluate all three eBus types in the TTC's operating environment and leverage lessons learned to inform eBus technical and commercial specifications for future procurements; and

2. Share our findings with the broader transit community through an open and transparent exchange of best practices to assist with the planning and adoption of zero-emissions buses.

There were nine domains and dozens of metrics monitored, tracked and analyzed as part of the head-to-head evaluation. The evaluation domains were:

• System Compatibility	• Accessibility	• Customer Experience
• Operator and Maintainer Experience	• Maintainability	• Vendor Performance
• Charging System Performance	• Vehicle Performance	• Total Lifecycle Cost

As a baseline for comparison, the eBus head-to-head results have been compared to recent performance indicators of the Hybrid-Electric Vehicle/Bus (HEV) supplied by Nova Bus. The Nova HEV was introduced as a transition technology through the TTC's Green Bus Program in 2018 and has been performing with satisfactory results, or better, through all nine evaluation domains. Appendix A of this report provides the technical results of the evaluation.

The conclusion of this second and final report on TTC's head-to-head evaluation is that the battery-electric propulsion system is not a significant driver of bus performance and when it comes to the bus technology itself, there are still no 'show stoppers' to the transition towards a zero-emission bus fleet.

When reviewing this report, it is important to understand that the findings are specific to the eBus models procured, and to how those buses have performed in the TTC's operating environment. As a result, the findings of this report may not be applicable to other transit authorities or to any new buses currently supplied by the vendors listed.

'Must Have' Requirements for TTC's Next Large-Scale Procurement

TTC's next large-scale eBus procurement includes 'must have' requirements that are informed by the head-to-head evaluation and focus on ensuring longevity of the bus structure and high system reliability through a proven platform (e.g. stainless steel structure, doors, HVAC, suspension, etc.).

On April 4, 2022, the TTC issued its first large-scale eBus Request for Proposal (RFP). The RFP reflected lessons learned by TTC to-date, but also included valuable input from TTC's peers at the Ontario Public Transit Association, Metrolinx, the Canadian Urban Public Transit Association, and internationally.

The RFP, which has a base requirement of approximately 240 eBuses, represents the largest zero-emissions bus procurement in Canada; however, subject to future funding commitments, the potential of this collaborative procurement is to supply hundreds of additional buses to TTC and hundreds more to our industry peers.

Future Funding Contribution Agreements

Current approved funding enables the TTC to procure approximately 600 of the 1,826 buses required to maintain the TTC's bus fleet between 2022 and 2031. The TTC also has funding in its 2022-2031 Capital Budget and Plan of $77.6 million towards the Class 5 estimate of $656.8 million required to implement electrification infrastructure through that same period.

TTC staff is actively working with government partners to try to secure net new grant funding to support the program. The RFP in progress for TTC's first large-scale eBus procurement is targeted to conclude in Q3 2022.

This report requests approval for the TTC to enter into agreements with its government partners where applicable, to secure any new funding that may be made available toward the TTC's Green Bus Program.

Further, this report requests approval to amend the Board's April 2021 delegation of authority to the CEO, which was to enter into up to two contracts for the supply of approximately 300 eBuses, to enable the TTC to increase the eBus procurement quantity in proportion to any additional funds that may become available.

With adequate funding and primary contracts in place, including bus supply contracts and the TTC-PowerON/OPG Principle Agreement approved by the Board in February 2022 for the supply of electrification infrastructure, the TTC is positioned to begin procuring only zero-emissions buses two-years ahead of its 2025 target and achieve a zero-emissions fleet three-years ahead of the City of Toronto's Net Zero 2040 target.

Recommendations

It is recommended that the TTC Board:

1. Receive for information the results of the TTC's eBus Head-to-Head Evaluation as outlined in this report; and

2. Delegate authority to the TTC Chief Executive Officer to:

   a. Enter into contribution agreement(s), where required, with government partners to receive any net new funding / financing for the TTC's Green Bus program; and

   b. Subject to commitment of matching funds from provincial and/or federal government partners, amend existing and pending contract(s) to increase the eBus procurement quantity and associated infrastructure works in proportion to the additional funds committed.

Implementation Points

The TTC's Green Bus Program identifies a procurement strategy to transition the fleet to become zero-emissions by 2037, three years ahead of the City's Net Zero target of 2040 and three years ahead of the international target set through C40's Fossil-Fuel-Free Streets Declaration.

When the entire fleet is zero-emissions, the following benefits are expected to be realized:

1. Greenhouse gas emissions will be reduced by approximately 250,000 tonnes of CO_2 annually;

2. Diesel emissions will be eliminated from bus operations thereby improving local air quality for employees, customers, and the public;

3. Vehicle reliability and availability will have increased by an estimated 25%; and

4. Total life cycle cost of zero-emissions buses is estimated to be lower than any currently available fossil-fuel propulsion alternative.

The TTC's Green Bus Program consists of five sub-programs:

1. Clean diesel bus procurements;
2. HEV bus procurements;
3. eBus procurements;

4. Electrification infrastructure; and
5. Associated business transformation program.

HEV Bus Procurement

The TTC engaged the market through a publicly posted negotiable request for proposal (nRFP) for the supply and delivery of 336 hybrid electric buses. These buses are being procured to replace buses that have reached the end of their useful life and for fleet growth based on in-service vehicle requirements; all reflected in the approved 2021-2030 Fleet Plan.

The comprehensive negotiable request for proposal process included the following:

1. Retention of a fairness monitor to oversee the procurement process;
2. Evaluation of the technical submissions;
3. Engaging internal and external TTC stakeholders including customer focus groups to provide input into the evaluation of the bids; and
4. Best and final offer negotiations with the vendors.

On February 28, 2022, the TTC awarded the following contracts for buses to be delivered by the end of 2023.

1) Nova Bus (LFS Hybrid Platform) – 40 foot hybrid electric buses (quantity 134)
2) New Flyer (Xcelsior Hybrid Platform) – 40 foot hybrid electric buses (quantity 134)
3) New Flyer (Xcelsior Hybrid Platform) – 60 foot hybrid electric buses (quantity 68)

eBus Procurement

The TTC is engaged with other peer transit agencies in the province, including Brampton Transit, Mississauga Transit, York Region Transit, and others through the Ontario Public Transit Association on the first interagency co-operative procurement of eBuses. The aim of this collaboration is to develop a single zero-emissions bus procurement specification with the immediate benefit of reducing cost through economies of scale. The long-term benefit is through the optimization and standardization of customer experience and, operations and maintenance throughout the GTHA and beyond.

Electrification Infrastructure

At the April 2021 TTC Board meeting, staff presented a framework for agreement between the TTC, Ontario Power Generation (OPG) and Toronto Hydro-Electric System Limited (THESL) outlining the parties' mutual interest and commitment to collaboration, roles and responsibilities and associated definitive agreements.

At the February 2022 TTC Board meeting, the Board approved the proposed negotiated terms with PowerON Energy Solutions LP (a subsidiary of Ontario Power Generation Inc.) for the co-investment, ownership, design, build, operation, and maintenance of electrification infrastructure as set out in the confidential attachment

Business Transformation

The innovation that has enabled bus electrification marks a significant technological advancement. However, innovation of this type is challenging and can be disruptive. The transition from diesel to electric ‘fuel’ is transformational in scale and complexity, including:

1. Technology (e.g. vehicles, infrastructure, energy management systems, etc.).
2. Operations (e.g. route design, service plans, maintenance and service delivery).
3. Cultural changes (e.g. risk management and risk tolerance).
4. Supply Chain (e.g. industry-wide changes to support parts and service).

As eBus technology evolves and matures over the coming years, the TTC will need to remain flexible and nimble to manage associated changes to business assumptions, models and processes. Until full electrification is reached, the TTC will be implementing its 20-year transition program to ensure that transit services are maintained and that all benefits are realized.

Ongoing Industry Engagement

The TTC continues to work closely with stakeholders, including: bus manufacturers, peer transit agencies, Canadian Urban Transit Association (CUTA), American Public Transit Association (APTA), Canadian Urban Transit Research and Innovation Consortium (CUTRIC), Ontario Public Transit Association (OPTA), Zero Emissions Bus Resource Alliance (ZEBRA), as well as implementation partners, such as OPG and THESL.

The TTC chairs a quarterly call to discuss technical and operational challenges, including lessons learned. The call originally started with four agencies, but has grown to 29 agencies in April 2022 from 24 agencies in April 2021. Currently, the list of participants are as follows:

Toronto – TTC	Maryland - MTA	San Antonio – ViaMetro
Austin – Cap	Metrolinx – MX	San Francisco – SFMTA
Boston – MBTA	Metro Los Angeles – LA Metro	Seattle – KCM
Brampton – BT	Minneapolis – Metro	Seattle – Sound Transit
Chicago – CTA	Montreal – STM	Utah – UTA
Durham Region – DRT	New York – NYCT	Vancouver – CMBC
Edmonton – ETS	Oregon – TriMet	Washington – WMATA
Foothill, CA - FT	Ottawa – OC Transpo	Woodland, CA – YCTD
Guelph – GT	Philadelphia – SEPTA	York Region – YRT
Kingston – KT	Quebec – ATUQ	

TTC also continues to work through OPTA’s Zero-Emissions Bus Committee on joint procurement opportunities for zero-emissions buses. The goal of this collaboration is to develop a single bus procurement specification to reduce cost and standardize customer experience, operations and maintenance.

Financial Summary

This report is being provided as an update and has no additional capital financial impact beyond what has been approved in the 2022-2031 Capital Budget and Plan.

The TTC Green Bus Technology Plan, originally approved by the TTC Board in November 2017, recommended the purchase of hybrid-electric buses as a transition technology toward zero-emissions buses. This included an initial procurement of 255 hybrid buses currently in service and the procurement and delivery of 60 eBuses from the only manufactures of long-range battery electric buses: BYD, NFI, and Proterra. The TTC has been reporting on the head-to-head evaluation of these 60 eBuses to the Board, with this report as the final report.

The TTC's Green Bus Program includes the procurement of only zero-emission buses by 2024, with a target of having the whole fleet zero-emissions by 2040, which is aligned to the City of Toronto's Transform TO target of zero emissions by 2040.

Funds for this expenditure are included in the TTC's 2022-2031 Capital Budget and Plan under Program 4.11 Purchase of Buses as approved by City Council on February 17, 2022. Subject to City Council approval, the incremental carry forward adjustment of $81.2 million will revise the 10 year Capital Budget and Plan total to $688.6 million in approved funding for the procurement of approximately 600 new accessible buses, including 300 hybrid-electric buses and 300 all-electric buses, for delivery between the years 2022 and 2025. This enables the TTC to procure approximately 600 of the 1,826 buses identified in its fleet plan to be procured during this 10-year capital planning timeframe. The TTC also has funding in its 2022-2031 Capital Budget and Plan of $77.6 million towards the Class 5 estimate of $656.8 million required to implement electrification infrastructure through to 2031.

The Chief Financial Officer has reviewed this report and agrees with the financial impact information.

Equity/Accessibility Matters

A cornerstone of TTC's Corporate Plan 2018-2022 is a commitment to ensuring accessible, safe, reliable and inclusive transit services for all our customers. The TTC is also committed to promoting equitable opportunities and removing barriers within our supply chain and procurement initiatives. This section outlines recent advancements in Procurement Equity, Accessibility and Green Procurement.

Procurement Equity

A requirement that was included in the latest hybrid-electric bus procurement mandated each proponent, as part of its proposal, include a commitment to report annually on their progress with procurement equity. The successful proponent will be audited based on any claims made in its proposal with respect to areas in Procurement Equity. This approach has also been applied to the current eBus procurement.

In support of the commitment to diversity, equity, and inclusion, the Contractor must agree, as a fundamental component to the Contract, to meet the Procurement Equity Requirements, by applying a percentage of the Contract Price in respect of the Diverse Business Enterprise Requirement and a specified number and percentage, as stated in the Proposal, in respect of the Equity Hired Requirement. Details for this are set out in the Provision of Procurement Equity Requirements below:

1. Initiatives, policies and/or procedures to incorporate Diverse Business Enterprises into supply strategy.
2. The salaries of employees assigned to Diverse Business Enterprise initiatives or programs.
3. Sponsorship(s) of Diverse Business Enterprises outreach events.
4. Encouragement or requirement of first and second-tier supplier to have Diverse Business Enterprise initiatives, policies, programs and/or procedures.
5. Processes for verifying Diverse Business Enterprises.
6. Diverse Business Enterprises development and mentoring.

Certifications or certifications in progress from established supplier certification organizations such as the following entitles:

1. Canadian Aboriginal and Minority Supplier Council.
2. Canadian Council for Aboriginal Business.
3. Canadian Gay and Lesbian Chamber of Commerce.
4. Inclusive Workplace and Supply Council of Canada.
5. Minority Supplier Development in China.
6. Minority Supplier Development UK.
7. National Minority Supplier Development Council.
8. South African Supplier Diversity Council.
9. Supply Nation (Australia).
10. Women Business Enterprises Canada Council.

<u>Accessibility</u>

A reliable transit network is critical for equity-deserving groups relying on the TTC's services to get to work, school, access health services, participate in recreational and cultural services, etc.

People who have experienced barriers to accessing public services, including public transit, typically have worse economic and health prospects. Access to transit that is equitable, accessible, safe, reliable, and that grows with or ahead of the population will help improve health outcomes, economic prosperity and equality throughout the city of Toronto, regionally and nationally.

All buses, regardless of the propulsion technology, will be compliant with the Canadian Standards Association (CSA) D435 standard for accessible transit buses, which outlines requirements for safe transportation for persons with physical disabilities. All buses will also be compliant with the Accessibility for Ontarians with Disabilities Act (AODA).

The TTC strives to exceed minimum requirements and has included the Advisory Committee on Accessible Transit (ACAT) in design reviews of our bus procurements.

Through our most recent procurement of eBuses from BYD, NFI and Proterra, we have identified three different interior configurations and seating layouts that will allow for ACAT and customer focus groups to evaluate what works best and inform future bus procurements.

Green Procurement

The TTC Green Bus Program, including the Wheel-Trans eBus Program, will allow the TTC to continue providing safe and accessible services for customers, while also contributing to a reduced emissions output aligned to the City's TransformTO Net Zero Strategy for 2040.

A requirement that was included in the latest hybrid bus procurement mandated each proponent to provide the following details as part of its proposal:

1. Its environmental sustainability policy and plan;
2. Its confirmation that it practices or is working towards conflict-free mineral sourcing, which can be verified through third party accredited audits, such as Responsible Minerals Initiative's Responsible Minerals Assurance Process (RMAP); and
3. Demonstrate corporate leadership with examples of active memberships in sustainability causes, such as, but not limited to, World Business Council, Dow Jones Sustainability Index and B-Corporation.

The latest accessibility requirements and these new procurement equity and green procurement provisions will be applied to all major vehicle procurement and overhaul programs going forward.

Decision History

On November 13, 2017, the TTC Board delegated the authority to the TTC CEO to negotiate and enter into the following:

1. Up to three contracts for the supply of 30 long-range, battery electric buses with BYD, NFI and Proterra with a total project cost of up to $50 million;
2. Up to two contracts for the supply of 230 new-generation, hybrid-electric buses with Nova Bus and New Flyer with a total project cost of up to $230 million; and
3. All vehicles are to be delivered no later than March 31, 2019 to be eligible for PTIF funding.

Report:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2017/November-13/4_Green_Bus_Technology__Plan.pdf?rev=076b377ef11140ea8758901ddb0dfcd5&hash=03C7F239A060FDDDC0D41CA41C035C8B

Decision:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2017/November-13/4_Green_Bus_Technology_Plan_Decision.pdf?rev=4d9eb00ec1a442bda0aac144e0910a82&hash=C70976BB257ADFA807475196C183E52E

On June 12, 2018, TTC staff presented an update on the Green Bus Technology Plan to the TTC Board. The Board delegated the authority to the CEO to procure an additional 30 long-range, battery-electric buses with BYD, NFI and Proterra, to be delivered no later than March 31, 2020 to ensure eligibility for PTIF funding. In addition, staff were directed to begin preparations for the electrification of the TTC's first all-electric bus garage to support future procurements of battery-electric buses for a total project cost of $90 million.

Report:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2018/June-12/27_Green_Bus_Technology_Plan_Update.pdf?rev=a1c91d7b3eba4fbd8930bf89b00d2955&hash=30D094118976BA165E6412CA7F665D87

The Board also requested the following:

1. To review the operations of the 75 Sherbourne service and on other routes with similar issues (noise and air quality) to see how electric buses and other measures could minimize the impacts along the residential neighbourhoods through which they operate;

2. To report on the eBus rollout plan, including details on charging stations and infrastructure requirements, and consider the feasibility of prioritizing the use of electric buses on routes that run on local and collector roads; and

3. The TTC confirm its target for procurement of only zero-emissions propulsion technology starting in 2025 and define zero-emissions propulsion technology as fossil-fuel-free.

Minutes:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2018/June-12/27_D_Green_Bus_Technology_Plan_Update_Decision.pdf?rev=ca8415ac262644a08b0a9cbc49c59499&hash=DE9DD1F6581F23ED34833AA1AE970087

Decision:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2018/June-12/27_D_Green_Bus_Technology_Plan_Update_Decision.pdf?rev=ca8415ac262644a08b0a9cbc49c59499&hash=DE9DD1F6581F23ED34833AA1AE970087

On January 27, 2020, the TTC presented its 2020-2029 Key Capital Priorities, which included recommendations on how to allocate the recent allocation of the City's Building Fund accords TTC's state-of-good-repair backlog.

As background to this report, the TTC Board approved the allocation of:

- $686 million, representing approximately 1/3 of the estimated 10-year cost, toward procurement of 614 buses; and

- $64 million, for eBus charging system infrastructure.

Report:
https://www.toronto.ca/legdocs/mmis/2020/bu/bgrd/backgroundfile-145620.pdf

Decision:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2020/January_27/Reports/Decisions/10_TTCs_2020_2029_Key_Capital_Investment_Priorities_Subway_I.pdf?rev=00be760f369e4fb797ed39ad6293e619&hash=CCC82CEFF5F42030636D1B27D1E67DA5

On February 25, 2020, the TTC Board received the TTC Green Bus Program Update report for information and further adopted motions requesting staff to:

1. Report back on potential partnership opportunities that could advance design, procurement, construction, and enable co-investment, co-ownership, and co-maintenance of the TTC's electric vehicle charging infrastructure; and

2. Direct the TTC CEO to submit to the September 2020 TTC Board meeting a business case analysis for action on an expedited procurement plan for the 614 funded buses included in the revised 2020-2029 Capital Budget and Plan.

Report:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2020/February_25/Reports/7_TTC_Green_Bus_Program_Update.pdf?rev=0009ff98db8f44e6b0b5ec6c6bf14218&hash=6FF40BB255ADBA2C26AD05138AAEAC5D

Decision:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2020/February_25/Reports/Decisions/7_TTC_Green_Bus_Program_Update_Decision.pdf?rev=0654f772cdcd434ca17488c5154191c5&hash=CF48B99DA25B41B47DEA69E678416CBE

On October 22, 2020, staff presented a report on the TTC's Fleet Procurement Strategy and Plan, including strategies for the acceleration of transit vehicle procurements, and highlighted promising technologies from the TTC's vehicle innovation pipeline. The Board adopted motions requesting staff to:

1. Delegate authority to the TTC Chief Executive Officer to award up to two contracts for the supply and delivery of approximately 300 hybrid-electric buses for the estimated cost of approximately $390 million, inclusive of taxes and project delivery costs, based on the following:

   a. Negotiation of an acceptable agreement, satisfactory to the TTC Chief Executive Officer and General Counsel, with one or both of the only two qualified suppliers of hybrid-electric buses compliant with Transport Canada's Commercial Motor Vehicle Safety Standards; and

   b. All buses are to be delivered between 2022 and 2023.

2. Request staff to report back to the TTC Board in Q2 2021 with the first year test results of the eBus head-to-head evaluation and the resulting technical requirements for the supply and delivery of approximately 300 all-electric, long-range buses commencing in 2023 through 2025.

Report:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2020/October_22/Reports/5_TTC_Fleet_Procurement_Strategy_and_Plan.pdf?rev=ed6e2828628c484daf919cc64b83b111&hash=32DE90249784BB0438C9B4E266C1D718

Presentation:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2020/October_22/Reports/5_Staff_Presentation_TTC_Fleet_Procurement_Strategy_and_Plan.pdf?rev=75b9872828074ed3a28d42b13df2bc2a&hash=2F7C490A3796CA429A996777BD97452D

Decision:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2020/October_22/Reports/Decisions/2047_5_TTC_Fleet_Procurement_Strategy_and_Plan_Decision.pdf?rev=9d10a7d0ba0b49839a2915072b9b0fd8&hash=0535C87A4FF1C266805F715C6765D13D

On April 14, 2021, staff provided a report summarizing preliminary results of the TTC's head-to-head evaluation of long-range, battery-electric accessible buses (eBuses). The Board recommended that:

1. The Board delegate authority to the TTC CEO to undertake a public procurement through issuance of a negotiated Request for Proposal (nRFP) and enter into up to two contracts for the supply of approximately 300 long-range, battery-electric buses (eBuses), based on the following:

a. Limit the total contract award amount, including all applicable taxes, and project delivery costs to within the approved funding of approximately $300 million;

b. Apply lessons learned through the TTC's eBus Head-to-Head Evaluation to prequalify potential suppliers based on demonstrated compliance with system compatibility requirements and Transport Canada's Motor Vehicle Safety Standards;

c. All 300 eBuses to be delivered between Q1 2023 and Q1 2025; and

d. Negotiation of an acceptable agreement that is satisfactory to the TTC General Counsel

Report:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2021/April_14/6_TTCs_Green_Bus_Program_Preliminary_Results_of_TTCs_Head_to_Head_eBus_Evaluation.pdf?rev=5c348c81e8504ef0b83735556437f7ec&hash=E6789DA35DB0E6CA426A2D391FD426AB

Decision:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2021/April_14/2052_6_TTCs_Green_Bus_Program_Preliminary_Results_of_TTCs_Head_to_Head_eBus_Evaluation_Decision.pdf?rev=37ee30a88a954826b9ba5e257e09a107&hash=682B892BE7D3885383A17B5C2F2F60D7

On February 10, 2022, staff provided a report containing information about the position, plan, procedure, criterion or instruction to be applied to negotiations carried on or to be carried on by or on behalf of the TTC for the Principal Agreement between the TTC and PowerON for EV charging systems infrastructure. The Board adopted the following recommendations:

1. Approve the proposed negotiated terms with PowerON Energy Solutions LP (a subsidiary of Ontario Power Generation Inc.) for the co-investment, ownership, design, build, operation, and maintenance of electrification infrastructure as set out in the confidential attachment.

2. Delegate authority to the CEO to enter into the TTC-PowerON Principal Agreement with PowerON Energy Solutions LP (a subsidiary of Ontario Power Generation Inc.), i) with an upset limit amount of $69.8 million in Canadian funds, inclusive of all taxes, for implementation of fleet electrification infrastructure; ii) subject to the receipt of further funding commitments by TTC towards remaining fleet electrification infrastructure, to amend the TTC-PowerON Principal Agreement upset limit up to $591 million in Canadian funds, inclusive of all taxes; and iii) subject to terms and conditions satisfactory to the TTC's General Counsel.

3. Request regular reporting back to the Board on the performance of PowerON Energy Solutions LP through staff's updates on the TTC's Green Bus Program.

4. Subject to the mutual agreement of the TTC and PowerON Energy Solutions LP (a subsidiary of Ontario Power Generation Inc.), the TTC to make public the executed TTC-PowerON Principal Agreement.

Report:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2022/February-10/Reports/5PrincipalAgreementwithPowerONEnergySolutionsLPOPGtoDecarbon.pdf?rev=d600618c340a4bd0b6b4221186fdea69&hash=193AD0F656AF4F94DA51D8E9F359048E

Decision:
https://ttc-cdn.azureedge.net/-/media/Project/TTC/DevProto/Documents/Home/Public-Meetings/Board/2022/February-10/Decisions/20625Principal-AgreementwithPowerONEnergySolutionsLPOPG-to.pdf?rev=82f2f1a5d10b45379e44671e23e2ee07&hash=8115D02904BBBF5072A06FCD5A93683A

Issue Background

At the November 2017 Board meeting, TTC staff was authorized to purchase 30 eBuses for a pilot program. The TTC entered into negotiated procurement with three different manufacturers of eBuses (BYD, NFI and Proterra). Subsequently, in June 2018, the TTC was authorized to purchase an additional 30 eBuses to increase the procurement quantity to 60 eBuses.

As part of the eBus pilot program, the intention was to have the three eBus vendors participate in the TTC head-to-head evaluation.

The objective of the head-to-head evaluation is to:

1. Evaluate all three eBus types in the TTC’s operating environment and leverage lessons learned to inform eBus technical and commercial specifications for future procurements; and

2. Share our findings with the broader transit community through an open exchange of best practices to assist with eBus planning and adoption.

This report provides the final results of the TTC’s head-to-head evaluation of long-range, battery-electric buses.

Comments

This report presents the final results of TTC’s eBus Head-to-Head evaluation, outlines the resulting ‘must have’ requirements for large-scale procurements of eBuses, and seeks authority to enter into future funding contribution agreements and contracts to advance implementation of TTC’s Green Bus Program.

TTC eBus Head-to-Head Evaluation

This section of the report is more technical in nature than a typical Board report, however, a certain level of technical detail is required to inform future bus procurements and to share with the transit industry our learnings through the TTC's eBus head-to-head evaluation.

When reviewing this report, it is important to understand that the findings are specific to the eBus models procured and to how those buses have performed in the TTC's operating environment. As a result, the findings of this report may not be applicable to other transit authorities. In the last year, advances by eBus original equipment manufacturers (OEMs) have been made resulting in improvements to vehicle and vendor performance. It is expected that the industry will continue to optimize eBus offerings as more in-service experience is accumulated.

The TTC's first 60 eBuses were procured from BYD, NFI and Proterra. Prior to the delivery of these eBuses, three garages (Arrow Rd, Mt Dennis and Eglinton Garages) were retrofitted with depot charging systems to accommodate charging up to 25 eBuses per location. All 60 eBuses procured have now been in-service between one to 2.5 years at the TTC with more than 2.5 million kilometres driven, and have reduced GHG emissions by 3.3 million metric tonnes.

The table below is a summary of the three eBus vendors, battery capacity, mileage accumulated and emissions reductions as of December 31, 2021:

			
Make	BYD	New Flyer	Proterra
Model	K9M	XE40	E2
Length	40'	40'	42'6"
Battery Capacity [kWh]	360	400	440
Quantity	10	10	10 ProDrive
		15*	15 DuoPower*
1st Bus In-Service [mm/dd/yy]	9/8/2020	6/3/2019	10/26/2019
Mileage LTD [km]	302,894	1,511,592	729,238
GHG Reduction [Tonnes]	453,487	1,885,646	994,430

*Overhead Charge Capable

Table 1: TTC eBus Fleet Summary

The TTC tracked the performance of the buses from the time they were delivered, commissioned and placed in service. The head-to-head evaluation is based on nine domains listed below:

• System Compatibility	• Vendor Performance	• Customer Experience
• Operator and Maintainer Experience	• Maintainability	• Accessibility
• Charging System Performance	• Vehicle Performance	• Total Life Cycle Cost

While final results against all domains are detailed in Appendix A of this report, there are four domains that will largely inform our next eBus procurement: System Compatibility; Accessibility; Vehicle Performance; and Vendor Performance.

The Nova hybrid-electric bus (HEV) is referenced throughout this report as a benchmark for comparison to eBus performance. The Nova HEV is similar in age and propulsion technology to that of the existing eBus fleet.

System Compatibility

The system compatibility domain considers constraints that all transit authorities have in the form of 'must have' requirements for the procurement of buses. For the TTC, these include physical compatibility with existing garages, proven charging technology that is interoperable with other manufactures, and a proven corrosion resistant frame structure. There have been no changes to this domain since reported in April 2021.

- **Physical Compatibility:** The industry standard bus length is 40-feet (12 metres). This standard was used to design storage facilities in the TTC's existing bus garages.

  The Nova HEV, BYD, and NFI buses meet this standard. Proterra buses are 42.5 feet long, but also offers the highest seating and standee capacity. Based on our bus garage layout, procurement of additional Proterra buses would result in a loss of storage capacity of approximately 10% at four of eight garages. The remaining four bus garages could accommodate this additional length. However, this would impose a significant operational constraint that would prevent movement of buses between garages.

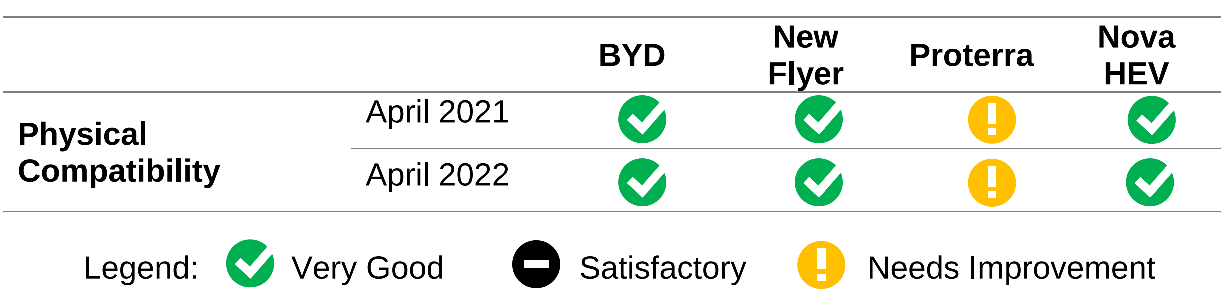

Figure 1 – Dashboard Final Results for Physical Compatibility

- **Charging Technology Interoperability:** The industry has adopted Society of Automotive Engineers (SAE) standards for charging system interoperability to ensure that buses from different manufactures are compatible with common infrastructure.

  NFI and Proterra buses meet this standard. The BYD buses procured by the TTC have a proprietary charging system technology. However, it is important to note that BYD Canada and Nova Bus are now both offering a long-range battery-electric bus meets this standard.

		BYD	New Flyer	Proterra	Nova HEV
Charging Technology Interoperability	April 2021	❗	✅	✅	N/A
	April 2022	❗	✅	✅	N/A

Figure 2 – Dashboard Final Results for Charging Technology Interoperability

- **Corrosion Resistant Frame Structure:** The standard practice for transit agencies operating in cold climates and whose vehicles are exposed to de-icing agents is to specify a corrosion resistant frame structure. Historically, the TTC's bus fleet has been constructed with a stainless steel frame that has proven to last the life of the asset.

  The Nova HEV, NFI, and Proterra meet this requirement. Both Nova and NFI use a stainless steel frame. Proterra's bus is a fiberglass composite, which like stainless steel is inherently corrosion resistant. BYD uses a carbon steel frame construction and employs an annual rust proofing program. While Proterra and BYD have novel solutions to mitigate the risk of corrosion, both introduce long-term risk given they have not been proven in service over the lifetime of a bus.

		BYD	New Flyer	Proterra	Nova HEV
Corrosion Resistant Frame Structure	April 2021	⛔	✅	⛔	✅
	April 2022	⛔	✅	⛔	✅

Figure 3 – Dashboard Final Results for Corrosion Resistant Frame Structure

Lessons Learned and Next Steps:

1. A maximum bus length specification of 40 feet is required in order to preserve bus storage density at existing maintenance facilities;

2. Bus specifications to require DC charging capability using SAE interface and communication standards to allow for maximum charge rates, competitive procurement, and interoperability between buses and chargers across all maintenance facilities; and

3. Stainless steel frame structure negates the need for, and associated risks of, annual rust-proofing maintenance programs.

Updates:

1. A maximum bus length has been specified as part of the procurement pre-qualification criteria;

2. DC charging capability using SAE interface and communication standards has been specified as part of the procurement pre-qualification criteria; and

3. A stainless steel frame structure with a minimum of six years of in-service experience has been specified as part of the procurement pre-qualification criteria.

Accessibility

All three bus manufactures are compliant with the Canadian Standards Association (CSA) D435 standard for accessible transit buses and the Accessibility for Ontarians with Disabilities Act (AODA).

The TTC strives to exceed these minimum requirements and has engaged the Advisory Committee on Accessible Transit (ACAT) through various stages of the procurement process

		BYD	**New Flyer**	**Proterra**	**Nova HEV**
Accessibility	April 2021	✓	✓	✓	✓
	April 2022	✓	✓	✓	✓

Figure 4 – Dashboard Final Results for Accessibility

Vehicle Performance

The vehicle performance domain measures the in-service performance from the time the vehicles entered service. The primary metrics of concern in terms of vehicle performance include vehicle reliability and fleet availability, both of which are detailed below. Appendix A includes results from additional vehicle performance metrics.

Vehicle Reliability

Reliability is measured by calculating the Mean Distance Between Failures (MDBF). The TTC's target for eBus MDBF is 30,000 km.

NFI has achieved an MDBF of 70,000 km, which is an increase of 30,000 km since April 2021. BYD is currently performing at 35,000 km and meeting the target but trending negatively. Proterra has occasionally met the target but is currently achieving 25,000 km and also trending negatively. By way of comparison, the Nova HEV continues to achieve an MDBF greater than 70,000 km.

The following chart reports the life-to-date reliability performance of the eBus fleet, including the Nova HEV fleet as a comparator.

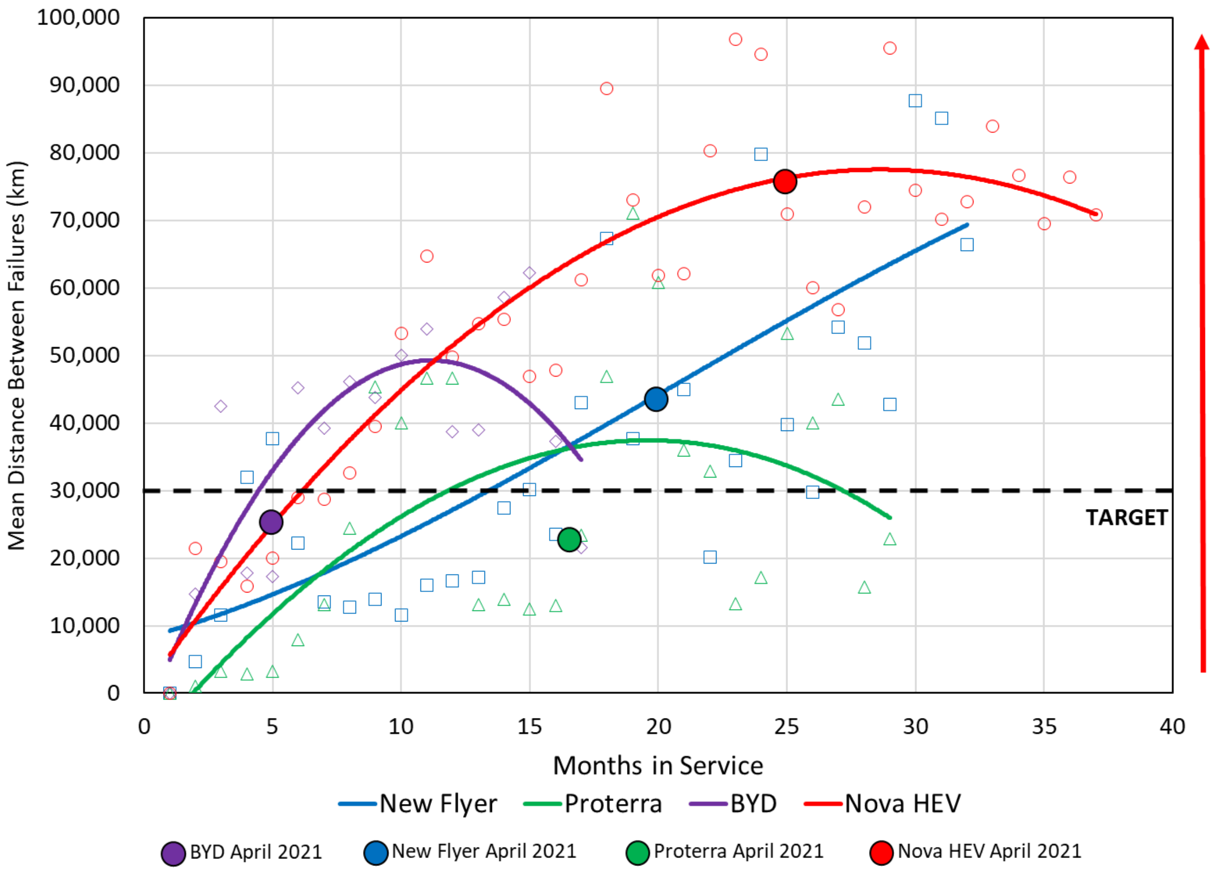

Chart 1: eBus vs. HEV Mean Distance Between Failures (MDBF)

		BYD	New Flyer	Proterra	Nova HEV
Vehicle Reliability MDBF	April 2021	!	✓	!	✓
	April 2022	−	✓	!	✓

Figure 5 – Dashboard Final Results for Reliability

Fleet Availability

Bus fleet availability is a measure of how well a bus fleet performs in terms of being available for use when needed. Availability is reported as a percentage and should be as close to 100% as possible so that all fleet assets are available when needed. A target of 80% fleet availability was established for the eBus program.

The following chart reports the life to date Fleet Availability achievement of the eBus fleet in comparison to the Nova HEV fleet.

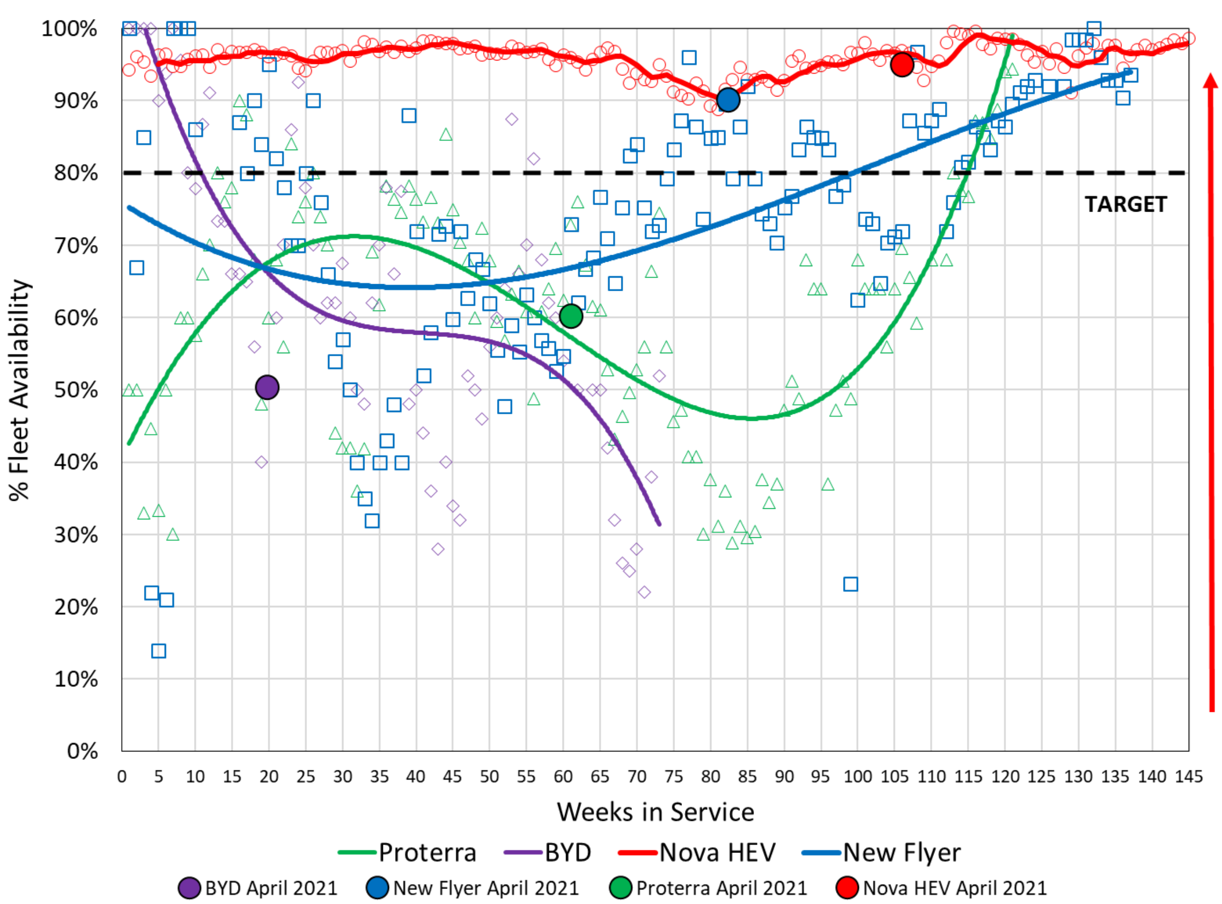

Chart 2: eBus vs. HEV Fleet Availability

NFI achieved 95%, which is an increase of 6% since April 2021. BYD achieved 30% which is a reduction of 22% since April 2021 and is trending downward. Proterra achieved 95% which is an increase 33%. By comparison, the benchmark Nova HEVs continue to perform consistently at above 95% availability.

Challenges impacting vehicle availability with respect to BYD buses continue to be parts unavailability and long lead-times, lengthy bus retrofit campaign work and complex propulsion system faults with insufficient engineering support. For example, it took BYD 73 days to deliver a replacement rear axle reducer gear and 63 days to deliver a V2G module.

		BYD	New Flyer	Proterra	Nova HEV
Fleet Availability	April 2021	!	✓	!	✓
	April 2022	!	✓	✓	✓

Figure 6 – Dashboard Final Results for Fleet Availability

Lessons Learned and Next Steps:

1. Continue to monitor eBus availability performance, mature product with vendors and prioritize retrofit campaigns that will yield reliability and availability improvements.

2. BYD to hire a second field service technician in Q2 2021.

3. Include availability metrics to be achieved by the eBus OEM in future procurement contracts. Failure to meet the availability targets will result in liquidated damages.

Updates:

1. Second field service technician for BYD fleet support started working in Q3-2021; however, fleet availability continues to trend downward.

1. A minimum fleet availability target with associated liquidated damages has been incorporated into the next bus procurement contracts.

Vendor Performance

The vendor performance domain is used to monitor the performance of vendors' quality and contractual requirements. Throughout the execution of the contracts with the three eBus vendors, the TTC has been monitoring the following metrics to track vendor performance, including:

- Compliance to the vehicle delivery schedule;
- Manufacturing facility quality audit;
- Quality defects (snags);
- Duration to final acceptance;
- 30-day reliability;
- Contract deliverables;
- Canadian content review; and
- Training.

It should be noted that since the preliminary report, the only sections of this domain that have been updated are the following; Duration to final acceptance; 30-day reliability and Training. However, all the areas related to the Vendor Performance domain are detailed in Appendix A.

Duration to Final Acceptance

This measures the average time taken from delivery of the vehicle until the bus receives the final acceptance certificate (FAC) and is deemed ready for service. The FAC is issued to the vendor when all the quality defects identified during the commissioning of the bus are repaired to the satisfaction of the TTC.

Nova required on average of 50 days to achieve FAC. BYD took on average 242 days with the delays largely attributed to excessive lead-time for parts and lack of local resources to repair buses. Proterra took on average 136 days, with the delays generally a result of insufficient resources on site due to COVID-19. NFI took on average 94 days, with the delays partially attributed to charging defects.

		BYD	**New Flyer**	**Proterra**	**Nova HEV**
Duration to Final Acceptance	April 2021				
	April 2022				

Figure 7 – Dashboard Final Results for Duration to Final Acceptance

Lessons Learned and Next Steps:

1. Through a comprehensive review of commercial terms against industry peers and across modes (i.e. bus, subway and streetcar), the TTC is restructuring its milestone payments. Included in this restructure is a higher milestone payment percentage due at FAC in order to motivate vendors to improve quality and responsiveness during the acceptance process.

Updates:

1. The TTC has restructured its milestone payments for the next bus procurements as an approach to provide greater incentive for successful/on-time issuance of Final Acceptance Certificates. For the hybrid-electric bus procurement, TTC has moved away from a high percentage due upon delivery (75%) to the following:
   i. From 0% to 20% upon Contract Award (notice to proceed)
   ii. From 75% to 10% upon Preliminary Acceptance Certificate (PAC)
   iii. From 20% to 50% at Final Acceptance Certificate (FAC)
   iv. From 5% to 20% upon achieving the 30-Day Reliability requirement

30-Day Reliability

As part of the contract requirements, the final milestone payment (5%) for each bus is contingent on the bus operating reliably for a period of 30 consecutive days from the time it first enters service. If the bus experiences an in-service failure as a result of a warrantable defect during these first 30 days, the clock resets until 30 consecutive days of no defects is achieved. Listed below is the average number of days taken for each bus vendor to achieve this 30-day reliability target.

- Nova required 38 days;
- NFI required 64 days;
- Proterra required 131 days (increase of 18 days from April 2021); and
- BYD required 244 days (increase of 84 days from April 2021).

		BYD	New Flyer	Proterra	Nova HEV
30-Day Reliability	April 2021	!	–	!	✓
	April 2022	!	–	!	✓

Figure 8 – Dashboard Final Results for 30-Day Reliability

The length of time required to obtain the 30-Day Reliability metric generally reflects the manufacturing quality of the bus vendor and is an early indicator of bus reliability. As with the longer-term reliability measure of Mean Distance Between Failures, failures within this 30-day contractual period negatively impact customers.

Lessons Learned and Next Steps:

1. The TTC is restructuring its milestone payments. Included in this restructure is a larger percentage due upon achievement of the 30-Day Reliably requirement.

Updates:

1. The TTC has restructured its milestone payments for the next bus procurements. The percentage due upon achievement of the 30-Day Reliability requirement has been increased to 20% from 5%.

<u>Training</u>

The TTC has experience with hybrid-electric buses that have a similar drivetrain and propulsion controls to that of a battery-electric bus. However, additional training was required for the three new eBuses on some of the new systems found on this bus, such as plug-slide doors on the Proterra or ThermoKing HVAC on the NFI bus. To date, a total of 3,983 employees have been trained on eBus specific courses. Below is a table summarizing eBus training courses available and the number of employees trained thus far for each:

Course	BYD	New Flyer	Proterra
Operation & Familiarization - Operators	1096	1198	1089
Operation & Familiarization - Maintainers	93	56	47
Technical Familiarization	Pending	104	37
High Voltage Safety	Pending	41	52
Multiplex & Schematics	Pending	29	13
Maintenance 1	Pending	45	19
Maintenance 2	N/A	N/A	31
Doors	N/A	N/A	12
HVAC	Pending	18	3

Table 2: eBus Training Completion Status

In 2021, COVID-19 restrictions continued to impact training which resulted in additional OEM train-the-trainer courses being conducted virtually. The TTC's Operations Training Centre has delivered operator training to more than 3,383 operators and 196 maintainers.

		BYD	**New Flyer**	**Proterra**	**Nova HEV**
Training	April 2021	✓	✓	✓	N/A
	April 2022	✓	✓	✓	N/A

Figure 9 – Dashboard Final Results for Training

In conclusion, all manufacturers continue to demonstrate a commitment to improving reliability and availability of our existing fleet through the implementation of product improvement campaigns and applying lessons learned to their next generation of long-range, battery-electric buses. TTC's lessons learned to date have been applied to the technical and commercial terms of the TTC's next eBus procurement of approximately 300 buses to be delivered starting in 2023 as TTC progresses towards full-fleet electrification.

<u>'Must Have' Requirements for TTC's Next Large-Scale Procurement</u>

TTC's next large-scale eBus procurement includes 'must have' requirements that are informed by the head-to-head evaluation and focus on ensuring longevity of the bus structure and high system reliability through a proven platform (e.g. stainless steel structure, doors, HVAC, suspension, etc.).

Based on the lessons learned over the past two years, the TTC has identified technical 'must have' criteria for its next eBus procurement as follows:

1. Altoona and shaker table testing has been successfully completed;

2. A full stainless steel structure with a minimum of six years of in service experience;

3. A minimum usable battery capacity of 400 kWh;

4. A maximum overall bus length of 12.8 m (42 ft.) including a stowed bike rack;

5. A maximum overall height of 340 cm (134 in.) including any roof-mounted equipment;

6. Ability to charge via roof mounted pantograph charging interface, capable of accepting a minimum charge rate of 300kW (400 ADC) at 750 VDC or greater via SAE J3105/1; and

7. Two rear-mounted charging ports capable of accepting a minimum charging rate of 150 kW (200 ADC) at 750 VDC or greater via SAE J1772.

On April 4, 2022, the TTC issued its first large-scale eBus Request for Proposal (RFP). The RFP reflected lessons learned by TTC to-date, but also included valuable input from TTC's peers at the Ontario Public Transit Association, Metrolinx, the Canadian Urban Public Transit Association, and internationally.

The RFP, which has a base requirement of approximately 240 eBuses, represents the largest zero-emission bus procurement in Canada; however, subject to future funding commitments, the potential of this collaborative procurement is to supply hundreds of additional buses to TTC and hundreds more to our industry peers.

Future Funding Contribution Agreements

Current approved funding enables the TTC to procure approximately 600 of the 1,826 buses required to maintain the TTC's bus fleet between 2022 and 2031. The TTC also has funding in its 2022-2031 Capital Budget and Plan of $77.6 million towards the Class 5 estimate of $656.8 million required to implement electrification infrastructure through that same period.

TTC staff is actively working with government partners to try to secure net new grant funding towards the program. The RFP in progress for TTC's first large-scale eBus procurement is targeted to conclude in Q3 2022.

This report requests approval for the TTC to enter into agreements with its government partners where applicable, to secure any new funding that may be made available toward the TTC's Green Bus Program.

Further, this report requests approval to amend the Board's April 2021 delegation of authority to the CEO, which was to enter into up to two contracts for the supply of approximately 300 eBuses, to enable the TTC to increase the eBus procurement quantity in proportion to any additional funds that may become available.

With adequate funding and primary contracts in place, including bus supply contracts and the TTC-PowerON/OPG Principle Agreement approved by the Board in February 2022 for the supply of electrification infrastructure, the TTC is positioned to begin procuring only zero-emissions buses two-years ahead of its 2025 target and achieve a zero-emissions fleet three-years ahead of the City of Toronto's Net Zero 2040 target.

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Attachments

Appendix A – Head-to-Head Evaluation All Domain Results
Appendix B - eBus Procurement Schedule vs Charging Infrastructure Availability
Appendix C - eBus Life Cycle Cost Estimates (Operating)

Appendix A

This report is primarily technical in nature and the information presented here are the final results of the Head-to-Head evaluation of the eBuses, part of the Green Bus Program update based on the TTC's experience with operating battery-electric buses in our operating environment and service network. The performance results reported are therefore specific to the TTC and not necessarily applicable to other transit agencies.

To recap, the objective of the head-to-head evaluation is ultimately to:

1. Evaluate all three eBus types in the TTC's operating environment and leverage lessons learned to inform eBus technical and commercial specifications for future procurements; and

2. Share our findings with the broader transit community through an open exchange of best practices to assist with eBus planning and adoption.

There are nine domains and dozens of metrics that were monitored, tracked and analyzed as part of the head-to-head evaluation. This report provides the final results in each of the evaluation domains. They are:

• System Compatibility	• Accessibility	• Customer Experience
• Operator and Maintainer Experience	• Maintainability	• Vendor Performance
• Charging System Performance	• Vehicle Performance	• Total Lifecycle Cost

For completeness, this Appendix includes the complete head-to-head evaluation results for all domains.

As per the April 2021 preliminary report, the Nova hybrid-electric bus (HEV) is referenced throughout this report as a benchmark for comparison to eBus performance. The Nova HEV is similar in age and propulsion technology to that of the pilot eBus fleet.

System Compatibility

The system compatibility domain considers constraints that all transit authorities have in the form of 'must have' requirements for the procurement of buses. For the TTC, these include physical compatibility with existing garages, proven charging technology that is interoperable with other manufactures, and a proven corrosion-resistant frame structure.

- Physical Compatibility: The industry standard bus length is 40 feet (12 metres). This standard was used to design storage facilities in the TTC's existing bus garages.

  BYD and NFI buses meet this standard. Proterra buses are 42.5 feet long, but also offer the highest seating and standee capacity. Based on our bus garage layout, procurement of additional Proterra buses would result in a loss of storage capacity of approximately 10% at four of eight garages. The remaining four bus garages could accommodate this additional length. However, this would impose a significant operational constraint that would prevent movement of buses between garages. Physical Compatibility results have not changed since the April 2021 report.

		BYD	New Flyer	Proterra	Nova HEV
Physical Compatibility	April 2021	✔	✔	❗	✔
	April 2022	✔	✔	❗	✔

Legend: ✔ Very Good ⊖ Satisfactory ❗ Needs Improvement

Figure 1 – Dashboard Final Results for Physical Compatibility

- Charging Technology Interoperability: The industry has adopted Society of Automotive Engineers (SAE) standards for charging system interoperability to ensure that buses from different manufactures are compatible with common infrastructure.

  NFI and Proterra buses meet this standard. The BYD buses procured by the TTC have a proprietary charging system technology. However, BYD has recently developed a bus that meets this standard, but there is insufficient service history. Charging Technology Interoperability results have not changed since the April 2021 report.

		BYD	New Flyer	Proterra	Nova HEV
Charging Technology Interoperability	April 2021	❗	✔	✔	N/A
	April 2022	❗	✔	✔	N/A

Figure 2 – Dashboard Final Results for Charging Technology Interoperability

- Corrosion Resistant Frame Structure: The standard practice for transit agencies operating in cold climates and whose vehicles are exposed to de-icing agents is to specify a corrosion resistant frame structure. Historically, the TTC's bus fleet has been constructed with a stainless steel frame and proven to last the life of the asset.

  While NFI uses a stainless steel frame, Proterra and BYD both offer alternative solutions to address corrosion resistance. Proterra's bus is a fiberglass composite, which is inherently corrosion resistant, and BYD uses a carbon steel frame construction that requires an annual rust proofing program. While all three vendors meet the criteria for corrosion resistance, the solutions proposed by Proterra and BYD have introduced new challenges.

  The composite body used by Proterra is susceptible to cracking. The majority of cracks to-date have been superficial at the outer gelcoat layer. However, there have been instances where more significant cracks have breached the structural laminate layers. As no tools exist today to measure the depth of body cracks, material must be removed for evaluation and composite repair processes are complex and require significant time.

The annual rust proofing program required by BYD has resulted in dripping of the corrosion inhibitor oil used several days after initial application. The oil residue creates slip hazards in the bus storage track areas.

As a consequence of these findings, the Corrosion Resistant Frame Structure results have not changed since the April 2021 report.

		BYD	**New Flyer**	**Proterra**	**Nova HEV**
Corrosion Resistant Frame Structure	April 2021	⊖	✓	⊖	✓
	April 2022	⊖	✓	⊖	✓

Figure 3 – Dashboard Final Results for Corrosion Resistant Frame Structure

Lessons Learned and Next Steps:

1. A maximum bus length specification of 40 feet is required in order to preserve bus storage density at existing maintenance facilities; and

2. Bus specifications to require DC charging capability using SAE communication standards to allow for maximum charge rates, competitive procurement, and interoperability between buses and chargers and maintenance facilities.

Updates:

1. A maximum bus length specification of 42 feet including a stowed bike rack has been specified for the next battery electric bus procurement; and

2. Overhead and plug-in DC charging capability using SAE J3105 and J1772 communication standards has been specified for the next battery-electric bus procurement.

Accessibility

This domain ensures accessibility features meet industry standards and legislative requirements.

All three bus manufactures continue to be compliant with the Canadian Standards Association (CSA) D435 standard for accessible transit buses and the Accessibility for Ontarians with Disabilities Act (AODA). The TTC strives to exceed these minimum requirements and has engaged the Advisory Committee on Accessible Transit (ACAT) through various stages of the procurement process. Accessibility results have not changed since the April 2021 report.

		BYD	New Flyer	Proterra	Nova HEV
Accessibility	April 2021	✓	✓	✓	✓
	April 2022	✓	✓	✓	✓

Figure 4 – Dashboard Final Results for Accessibility

New Accessibility features adopted by the current eBus fleet include:

1. Companion seat next to the two personal mobility device (PMD) positions;
2. Under seat priority stop request buttons; and
3. Yellow guide stripe down the centre of the wheelchair ramp.

Update:

As a result of follow-up meetings with ACAT, the following improvements have been incorporated into the hybrid bus and eBus procurement technical specifications:

1. Optimal stop request button size;
2. Optimal priority stop request button size and location; and
3. Removal of securement equipment in PMD floor area.

Vehicle Performance

The vehicle performance domain measures the in-service performance from the time the vehicles have entered service. This includes the following key performance indicators: reliability, distance between repairs, and fleet availability.

<u>Reliability</u>

Reliability is measured by calculating the Mean Distance Between Failures (MDBF). The TTC's target for eBus MDBF is 30,000 km.

NFI has achieved an MDBF of 70,000 km, which is an increase of 30,000 km since April 2021. BYD is currently performing at 35,000 km and meeting target but trending negatively. Proterra has occasionally met target, but is currently achieving 25,000 km and also trending negatively. By way of comparison, Nova HEV continues to achieve an MDBF greater than 70,000 km.

The following chart reports the life-to-date reliability performance of the eBus fleet, including the Nova HEV fleet as a comparator.

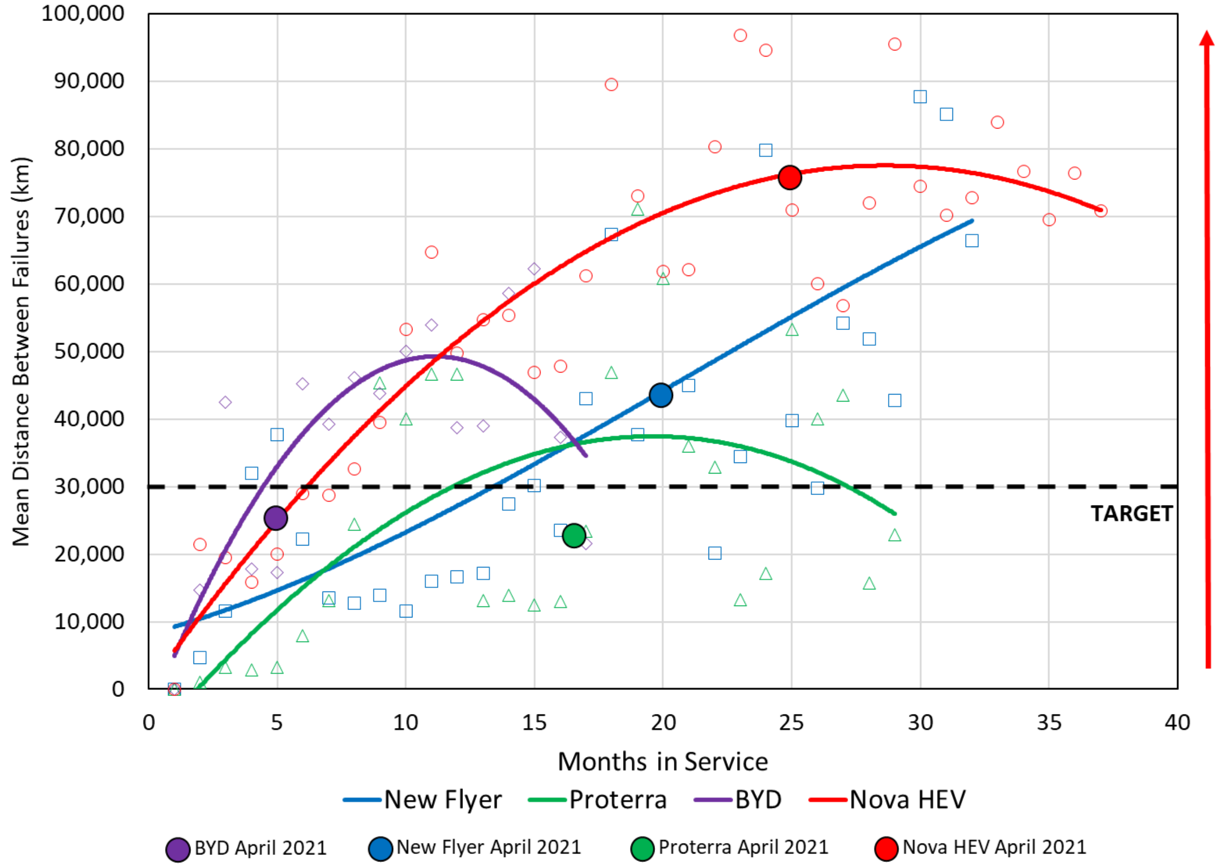

Chart 1: eBus vs. HEV Mean Distance Between Failures (MDBF)

		BYD	New Flyer	Proterra	Nova HEV
Vehicle Reliability MDBF	April 2021				
	April 2022				

Figure 5 – Dashboard Final Results for Reliability

<u>Distance Between Repairs</u>

The Distance Between Repairs (DBR) is calculated by summing the distance travelled by a bus fleet and dividing it by the number of defect repairs over a defined period of time. DBR accounts for all minor faults identified during service or end of service that increase maintenance backlog or asset down time. A higher DBR allows the bus to be in service more often.

The Nova HEV continues to achieve the greatest distance between repairs at 811 km although this has reduced 17% since April 2021. BYD is still achieving the least at 323 km but has improved by 30%. NFI has improved by 7% achieving 527 km while Proterra improved by 4% achieving 375 km.

		BYD	New Flyer	Proterra	Nova HEV
Distance Between Repairs DBR	April 2021				
	April 2022				

Figure 6 – Dashboard Final Results for Distance Between Repairs

When looking at DBR, it is also important to consider the average time a defect repair requires. For the April 2021 report, all eBuses and Nova HEV were still under a two-year bumper to bumper warranty. As a result, the majority of defect repairs were performed by the bus vendor. As these fleets now surpass two years, average repair time has increased. The BYD is averaging 9.03 hours which is an increase of 8% since April 2021. Proterra is averaging 7.49 hours which is an increase of 20%. NFI was the only bus to experience a decrease of 8% with an average of 3.79 hours. By way of comparison, the Nova HEV increased by 41.5% but is still achieving a very low average of 1.84 hours.

Lessons Learned and Next Steps:

1. Continue to monitor eBus reliability performance, mature product with vendors and prioritize retrofit campaigns that will yield reliability improvements.
2. Include reliability metrics to be achieved by the eBus OEM in future procurement contracts. Failure to meet the reliability targets will result in liquidated damages.

Updates:

1. A minimum MDBF reliability target to be achieved by the eBus OEM coupled with liquidated damages has been incorporated into the next bus procurement contracts.

<u>Fleet Availability</u>

Bus fleet availability is a measure of how well a bus fleet performs in terms of being available for use when needed. Availability is reported as a percentage and should be as close to 100% as possible so that all fleet assets are available when needed. A target of 80% fleet availability was established for the eBus program.

The following chart reports the life to date Fleet Availability achievement of the eBus fleet in comparison to the Nova HEV fleet.

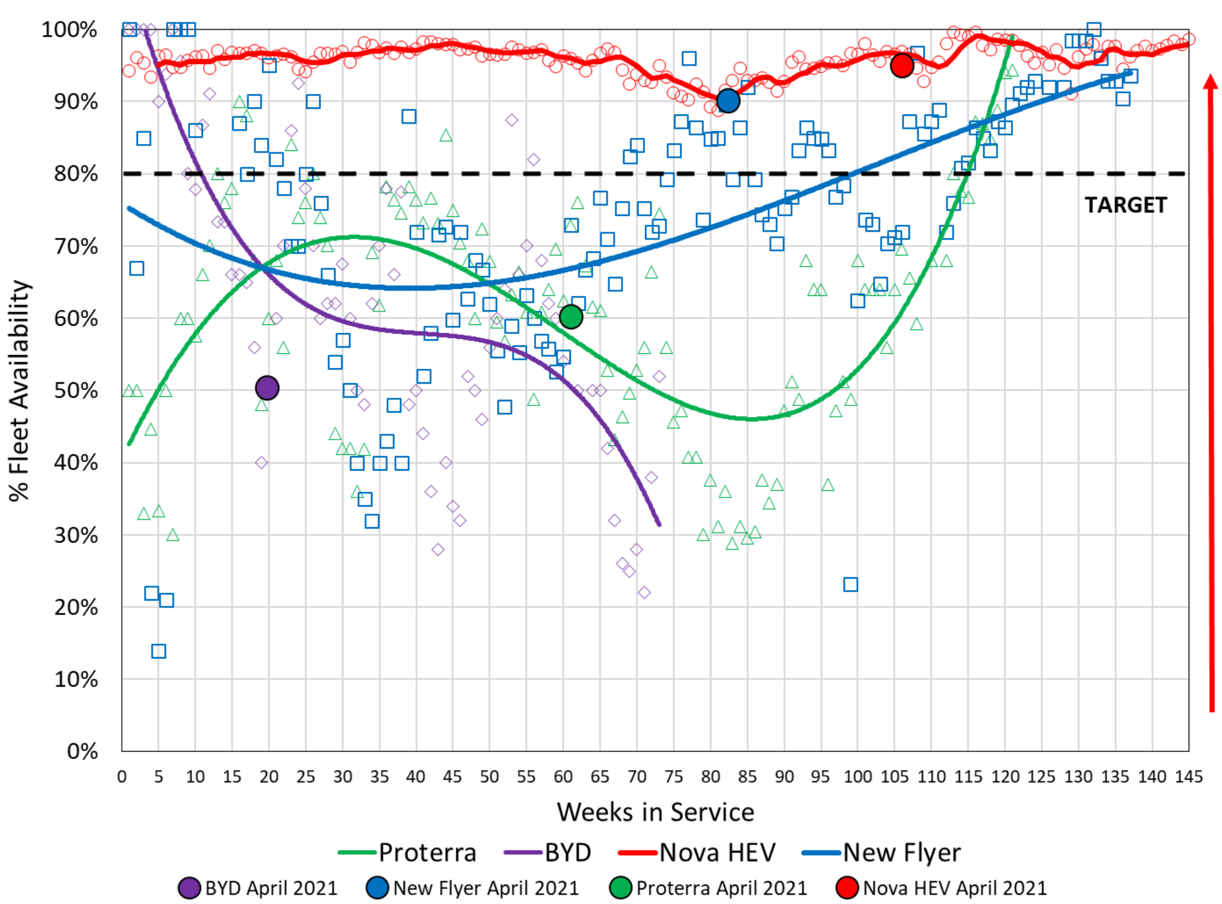

Chart 2: eBus vs. HEV Fleet Availability

NFI achieved 95% which is an increase of 6% since April 2021. BYD achieved 30% which is a reduction of 22% since April 2021 and is trending downward. Proterra achieved 95% which is an increase 33%. By comparison, the benchmark Nova HEVs continue to perform consistently at above 95% availability.

Challenges impacting vehicle availability with respect to BYD buses continue to be complex propulsion system faults with insufficient engineering support, parts unavailability and long lead-times and lengthy bus retrofit campaign work.

		BYD	New Flyer	Proterra	Nova HEV
Fleet Availability	April 2021	!	✔	!	✔
	April 2022	!	✔	✔	✔

Figure 7 – Dashboard Final Results for Fleet Availability

Lessons Learned and Next Steps:

1. Continue to monitor eBus availability performance, mature product with vendors and prioritize retrofit campaigns that will yield reliability and availability improvements.

2. BYD to hire a second field service technician in Q2 2021.

3. Include availability metrics to be achieved by the eBus OEM in future procurement contracts. Failure to meet the availability targets will result in liquidated damages.

Updates:

1. Second field service technician for BYD fleet support started working in Q3-2021.

2. A minimum availability target to be achieved by the eBus OEM coupled with liquidated damages has been incorporated into the next bus procurement contract.

<u>Work Order Defect Analysis</u>

The following section provides an updated analysis of faults experienced to date that influence both reliability and availability. A review of all repair work orders was performed and top problematic systems were identified and analyzed for each eBus.

Below is a chart summarizing top defects for each eBus by system.

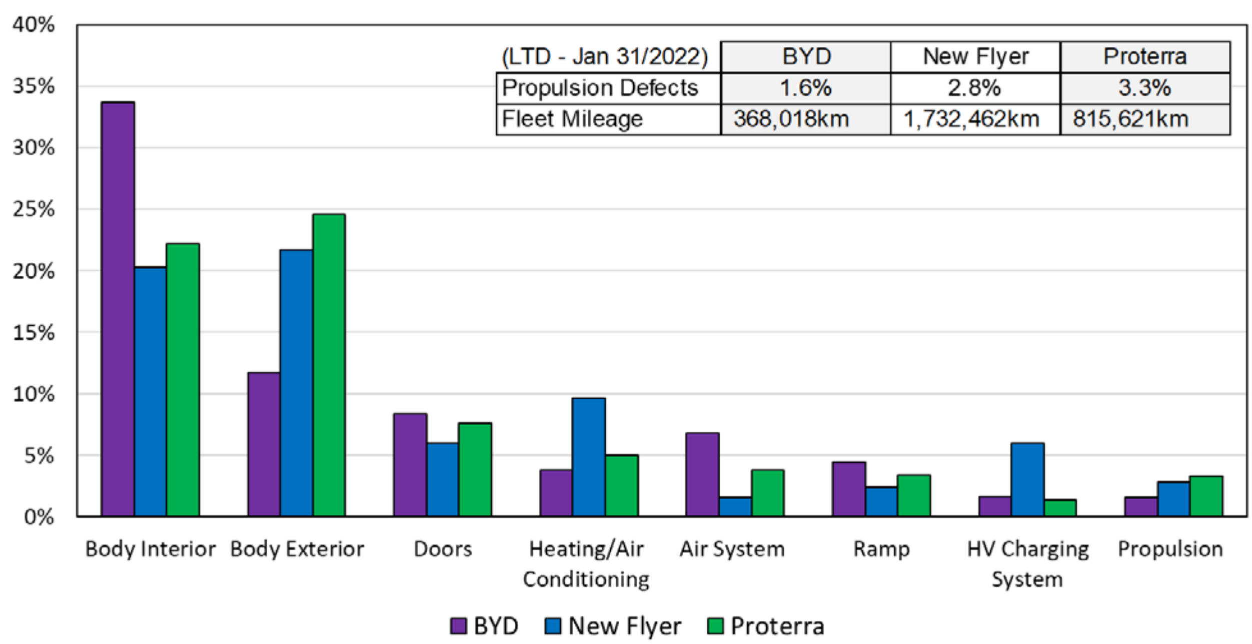

Chart 3: Top eBus Problem Systems

As depicted above, body interior and exterior account for 50% of faults, which are largely related to common bus systems (including diesel and hybrid electric fleets) and not defects specific to eBus propulsion technology. The propulsion system itself for all three eBuses have been reliable thus far and accounts for less than 4% of the defects experienced. Latent defects are cumulative failures of identical component exceed 15% of the bus fleet at any time prior to the expiration of the bus warranty period that require the vendor to make and implement design modifications, repairs, adjustments and replacements as required to correct or prevent the failure in all buses. Below is a summary of the propulsion and charging issues and latent defect count for each eBus.

<u>BYD Defects</u>

Reliability performance of the BYD eBus fleet is currently meeting the target of 30,000 km but trending downwards. The top five vehicle systems accounting for 65% of the defects experienced to date include: Body Interior (34%), Body Exterior (12%), Doors (8%), Driveline (7%) and Heating/Air Conditioning (4%). Driveline issues in particular are related to axle water contamination that will require a breather tube retrofit. To date, a total of 11 latent fleet defects have been identified by the TTC that will require BYD to make and implement design modifications, repairs, adjustments and replacements as required to correct or prevent these fleet defects. To date, there have been 34 product improvement campaigns of which 56% have been completed.

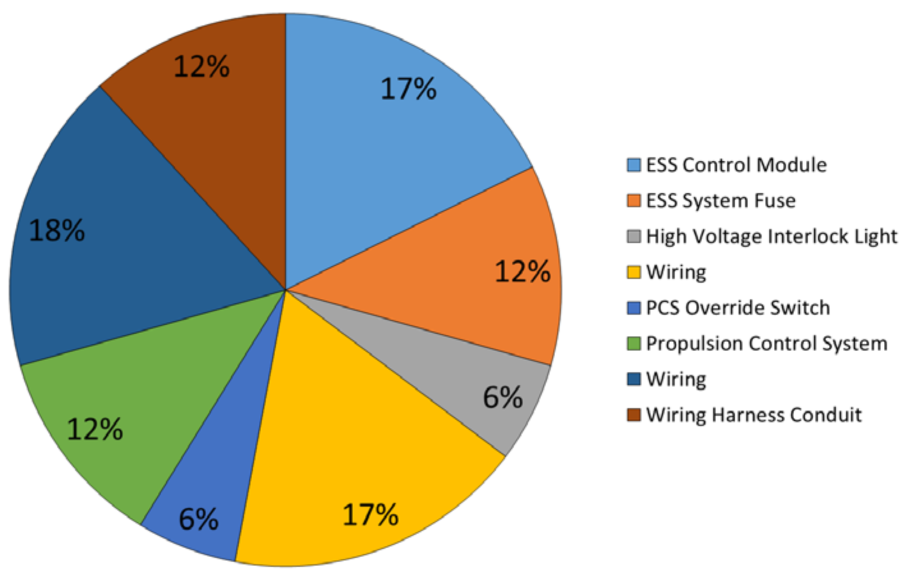

Chart 4: BYD Propulsion System Defects

Propulsion system defects account for 1.6% while bus charging related defects account for 2%. Looking deeper into the propulsion system defects, the energy storage system (ESS) control module, propulsion control system (PCS) switch and wiring account for 64% of the defects. The majority of these faults are harness/wiring related or water intrusion of components. These faults can be complex to resolve and in many instances, 250-plus days were required to troubleshoot and repair some of these issues. These long repair times negatively impact bus availability. An example of a complex issue is intermittent battery thermal management faults that have been an ongoing issue since summer 2021. Programming improvements were made to alleviate the issues but a countermeasure that is 100% effective has yet to be identified.

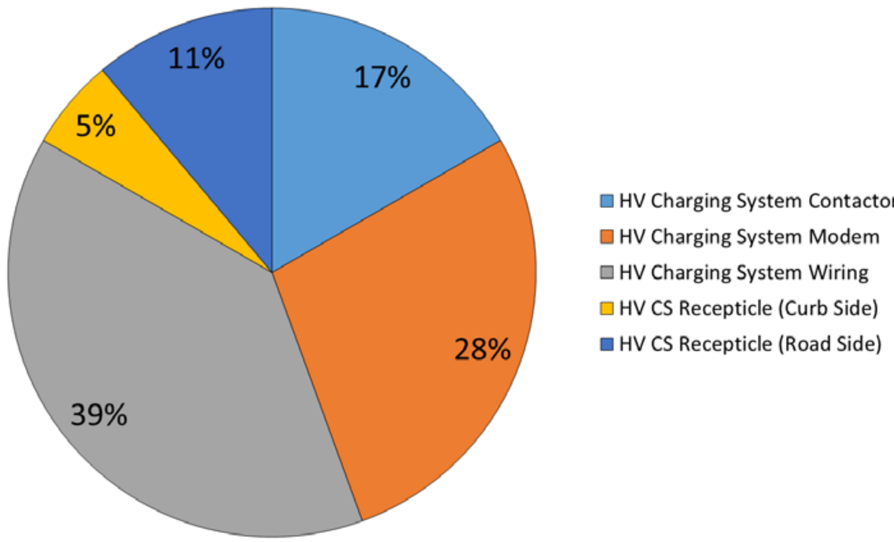

Chart 5: BYD Charging System Defects

The majority of bus-side charging system defects have been a result of a faulty resistor in the charge port circuit that was not weather proof and has since been campaigned with a sealed resistor. Remaining faults are a result of faulty wiring, defective V2G modules and a defective charge port receptacle box.

Repairing BYD buses has been challenging for both the OEM and the TTC. BYD has not provided sufficient engineering support on site and remotely. Repair manuals and procedures are of poor quality and BYD's diagnostic tool is currently not available in English. Moving forward, BYD has committed to sending an engineer from China that previously supported a large deployment of BYD buses in South America in Q2-2022 to help troubleshoot complex problems and train BYD field service technicians. The TTC will also be evaluating a new diagnostic tool in Q3-2022.

<u>New Flyer Reliability</u>

Reliability performance of the NFI eBus fleet is currently meeting the target of 30,000 km and trending in a positive direction. The top five vehicle systems accounting for 64% of the defects experienced to date include: Body Exterior (22%), Body Interior (20%), Heating/Air Conditioning (10%), Doors (6%), and Driveline (6%). Many of these deficiencies have been corrected through campaigns. To date, there have been a total of 97 product improvement campaigns of which 91% have been completed. A total of 10 latent fleet defects thus far have been identified by the TTC that will require NFI to make and implement design modifications, repairs, adjustments and replacements as required to correct or prevent these fleet defects.

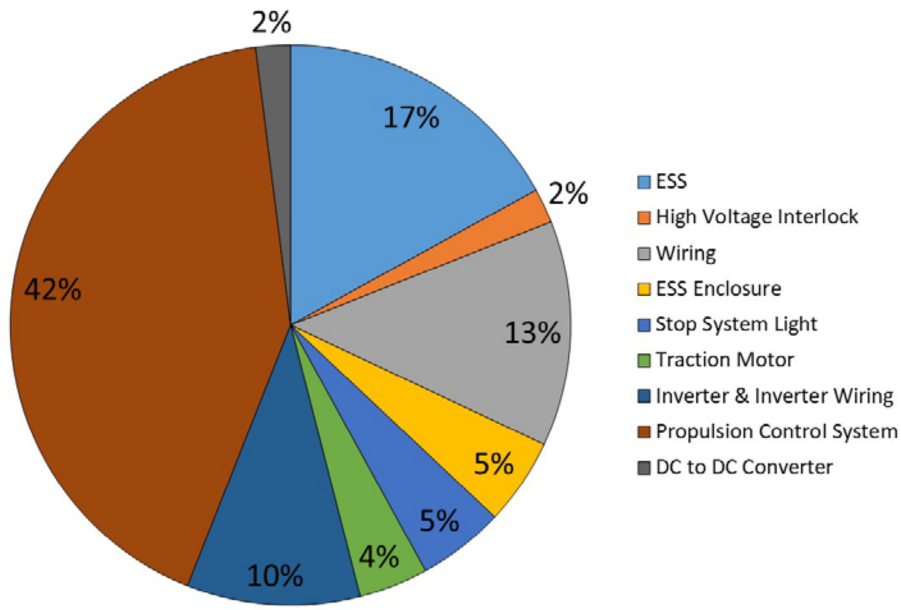

Chart 6: New Flyer Propulsion System Defects

Propulsion system defects account for 2.8% while bus charging-related defects account for 6%. The energy storage system and propulsion controls account for 61% of the propulsion defects. To date, 11 high voltage batteries have been replaced to address battery strings going off-line in service and unstable performance at lower state of charge (<15% SOC) due to an imbalance in voltage between cells within the battery pack.

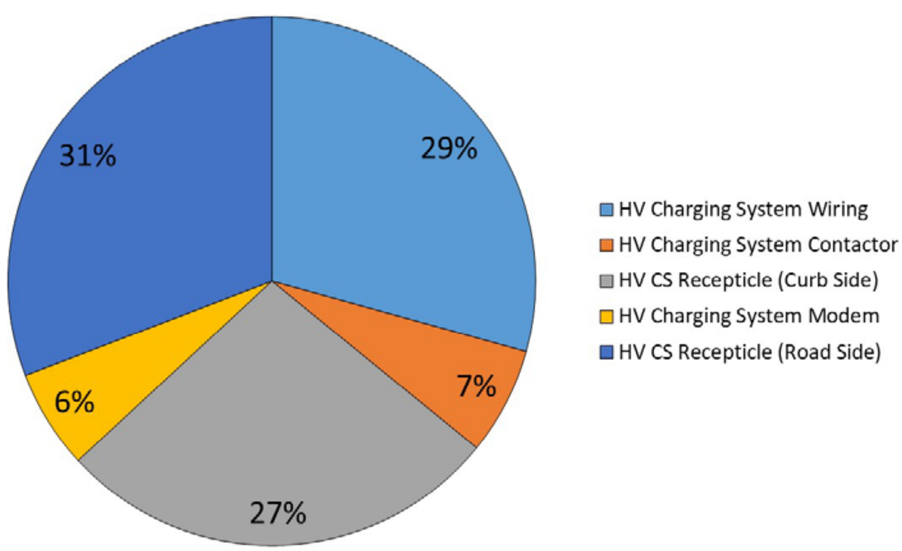

Chart 7: New Flyer Charging System Defects

The majority of bus-side charging system defects have been a result of either faulty charge receptacle lock motors or inadequate charge port high voltage cable end crimping. NFI has completed a campaign to re-crimp the high voltage cable ends. Overall, the service and technical support from NFI has been excellent.

Proterra Reliability

The Proterra eBus fleet is now meeting the MDBF performance target of 30,000 km. The top five vehicle systems accounting for 65% of the defects experienced to date include: Body Exterior (25%), Body Interior (22%), Doors (8%), Heating/Air Conditioning (5%), and Driveline (5%). As reported in April 2021, the Proterra body is constructed with lightweight impact-absorbing, carbon-fiber-reinforced composite materials and several exterior body cracks have been identified that required campaigns to repair. To date, there have been a total of 120 product improvement campaigns of which 61% have been completed. A total of eight latent fleet defects thus far have been identified by the TTC that will require Proterra to make and implement design modifications, repairs, adjustments and replacements as required to correct or prevent these fleet defects.

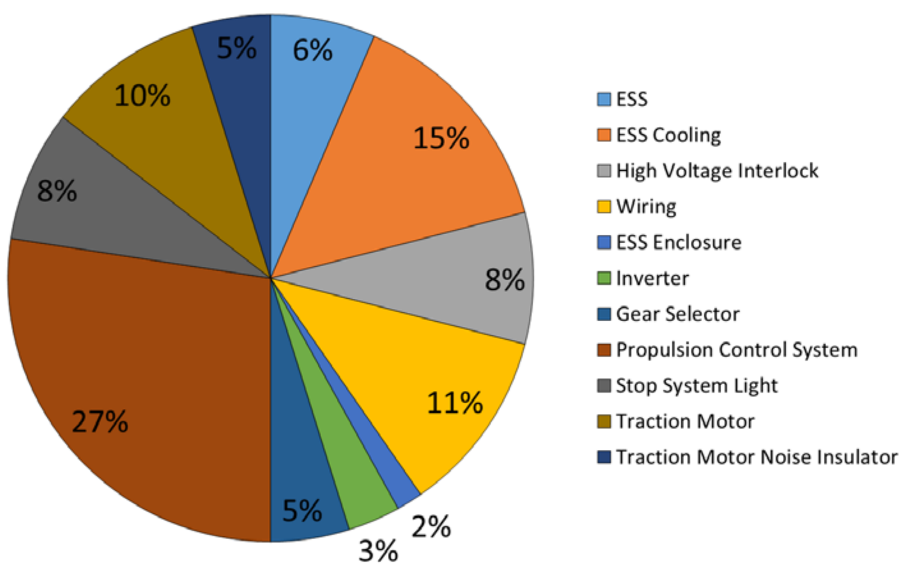

Chart 8: Proterra Propulsion System Defects

Propulsion system defects account for 3.3% while bus charging related defects account for 1.4%. The energy storage system and propulsion controls account for 42% of the propulsion defects. The majority of these issues are a result of poor harness pin connections and corrosion at terminals. Proterra is investigating solutions to protect electrical connections from environmental elements that will likely result in further product improvement campaigns.

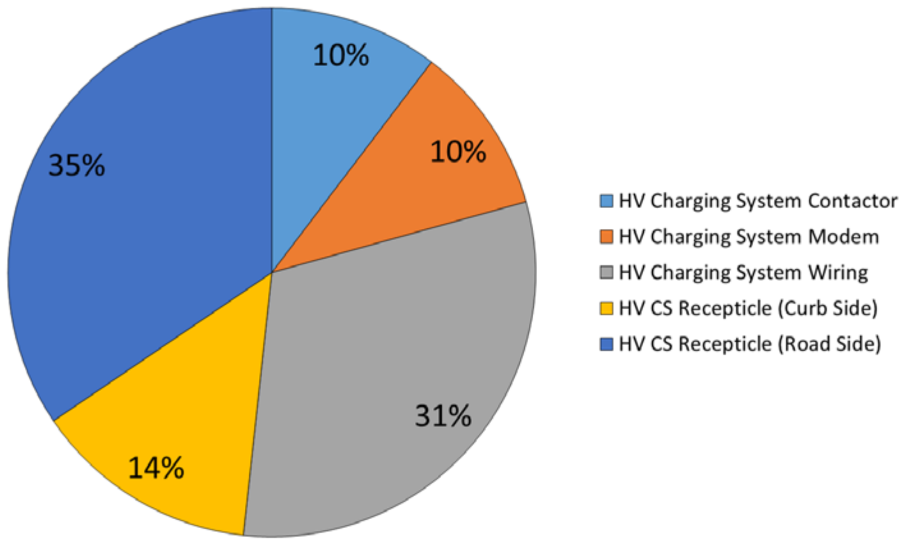

Chart 9: Proterra Charging System Defects

Charging system defects have been a result of either faulty charge receptacle lock motors defective charge port receptacles and charge controllers. To date, a total of five lock motors, three charge controllers and two charge port receptacles have been replaced. Overall, the service and technical support from Proterra has been excellent, but the ongoing challenges with body crack repairs have hurt the fleet's availability performance.

Engineering Tests

To assess the performance of the TTC's 60 eBuses, a variety of tests have been performed. Evaluation of eBuses in-service, and over a series of controlled engineering tests to compare their relative performance, has enabled the TTC to study this emerging technology with the goal to expand green technologies on a large scale in a robust and reliable method.

The fleet consists of 60 buses from three OEMs with five unique models in total. Each OEM is stationed at a different garage across the city. The table below summarizes the fleet.

Manufacturer	Garage	Bus Type	Qty	Bus#	Listed Battery Capacity (kWh)	Report abbreviation
New Flyer	Arrow Rd	SR2304	10	3700-3709	400	NF1
		SR2382	15	3710-3724	400	NF2
Proterra	Mount Dennis	Catalyst 40 E2 RR ProDrive	10	3725-3734	440	PT1
		Catalyst 40 E2 RR DuoPower	15	3735-3749	440	PT2
BYD	Eglinton	K9M	10	3750-3759	360	BYD

Table 1: TTC eBus Fleet Summary

General summary of each bus is provided below:

- New Flyer SR2304: 40-foot bus with single direct drive 160kW Siemens electric drive motor. Operates on a 600V system charged via J1772 DC fast charging ports

- New Flyer SR2382: 40-foot bus with single direct drive 160kW Siemens electric drive motor. Operates on a 600V system charged via J1772 DC fast charging ports with added J3105 overhead charge rails. Identical propulsion system to SR2304

- Proterra Catalyst 40 E2 RR ProDrive: 40-foot bus with a single PowerPhase 220kW traction motor with a 2-speed gearbox. Operates on an 800V HV system charged via J1772 DC fast charging ports

- Proterra Catalyst 40 E2 RR DuoPower: 40ft bus with dual Parker 2 x 205kW traction motor with a two-speed gearbox. Operates on an 800V HV system charged via J1772 DC fast charging ports with added J3105 overhead charge rails

- BYD K9M: 40-foot bus with dual direct drive 2x 150kW BYD electric drive motors. Operates on a 600V system charged via BYD proprietary AC charger

Vehicle energy consumption performance was performed by looking at three areas of evaluation:

- In-service (InS) energy consumption: Reviewing the energy consumption of each bus in service by recording the telematics data and calculating performance metrics to identify key energy consumption drivers as well as quantify the real-world driving range.

- Head to Head (H2H) Engineering Controlled Test: The first generation of each bus was ballasted to approximately 9,000 lbs and driven by experienced TTC instructors back to back on the same routes to get direct comparisons between each OEM.

- HVAC Stationary Test: One bus from each OEM, including a Nova Hybrid, instrumented with temperature sensors across the interior of the bus and measured for HVAC energy consumption.

In-service (InS) Energy Consumption

In-service energy consumption is a critical metric of eBus performance and is affected by several factors, as described in the April 2021 report. Over the course of this program, quantifying the overall energy consumption and specific areas of consumption is critical to understanding the true range of the eBuses as well as identify key areas with improvement opportunities to maximize the range available for service.

Historically, fuel economy has been measured primarily on a mileage basis (e.g. L/100km or kWh/km). However, over the course of this program it was noted that there are specific energy consumers that are less influenced by mileage and more by time (e.g. on an hourly basis). The analysis breaks down the consumers and identifies the relevant metrics to quantify the performance of each OEM relative to those consumers.

Primary energy consumers are described below:

- Overall/Net Energy Efficiency: Overall energy used from the High Voltage (HV) batteries to power all systems of the bus. Typically measured on a mileage basis (kWh/km) for most analysis.

- Low Voltage Accessories (LV Acc) Energy Efficiency: On board electronics and modules powered by the 12V/24V batteries. This is typically a very small fraction of overall consumption and is not evaluated in this report

- Powertrain Energy Efficiency: Power consumed from the propulsion system to move the bus. Measured on a mileage basis kWh/km. Driven mainly by vehicle speed, acceleration and traction which can be impacted by road grade, operator driving style, traffic conditions, and slippery road conditions

- Electric Heat and High Voltage Accessories (eHeat + HV Acc): A combination of electric heat and high voltage powered systems (e.g. air conditioning, air compressor, power steering, etc.). Measured on a time basis (kWh/h) as this is predominantly driven by maintaining HVAC conditions which is less influenced by mileage. This is driven mainly by the ambient temperature which dictates the HVAC requirements of the bus as well as the operator's need for heat and windshield defrosting.

Given each eBus OEM is at a different garage, there will not be any overlapping in-service routes that are run by different OEMs. As a result, it is important to distinguish the relevant metrics for each type of energy consumer. The chart below shows the average speed of each bus in service over the course of the year. It can be seen that Proterra, which is dispatched from Mount Dennis, has a slower vehicle speed in service on average as a result of servicing routes that are closer to the city centre. NFI and BYD, which cover service in more suburban areas, have a higher average speed and are more closely matched.

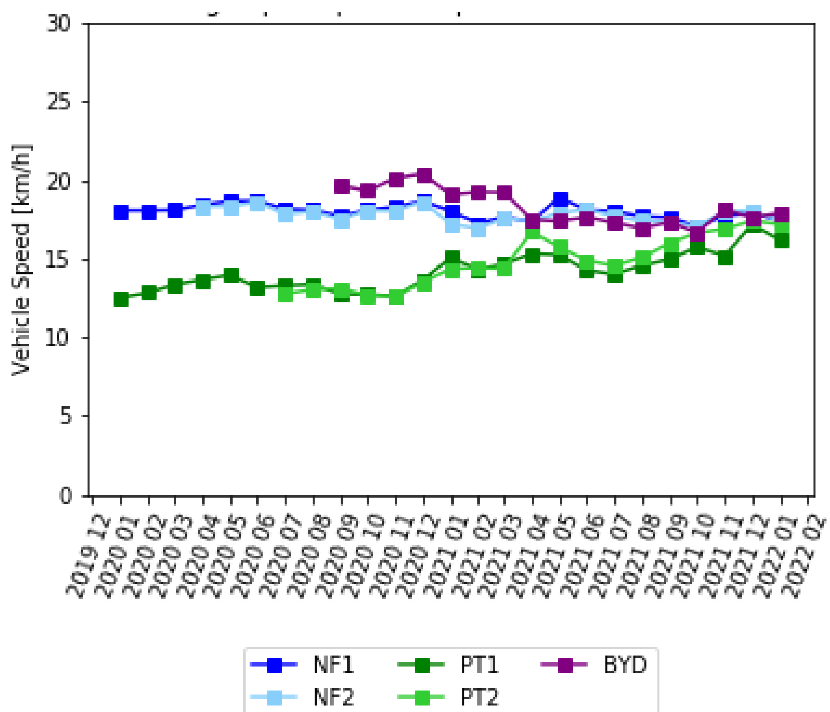

Chart 10: Average Speed per Shift per eBus In-Service

The chart below shows the daily average distance covered and the daily hours in-service when a bus is in service (excluding out-of-service buses) for each month.

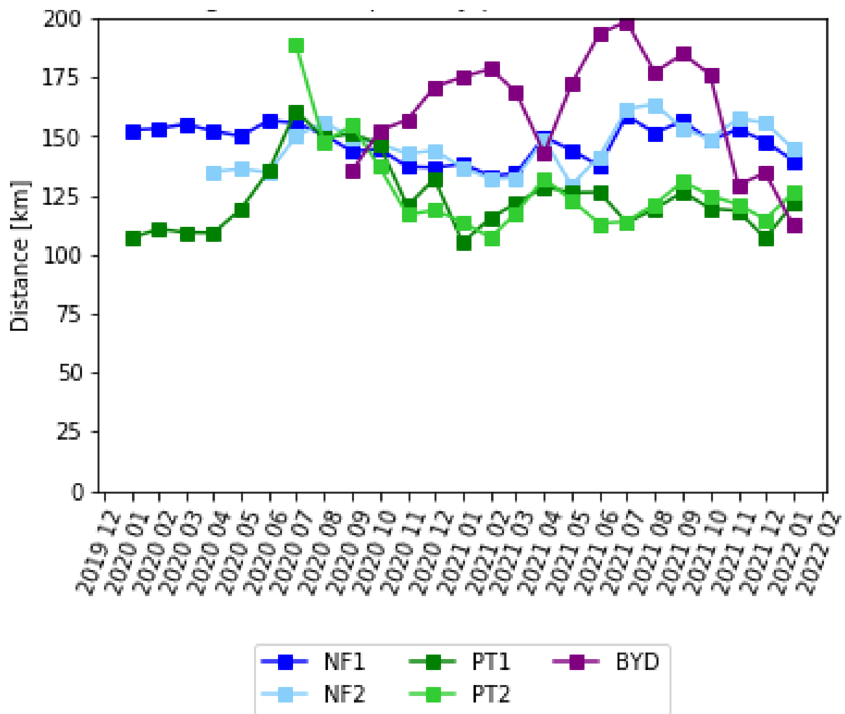

Chart 11: Average Distance per Day per Bus In-Service

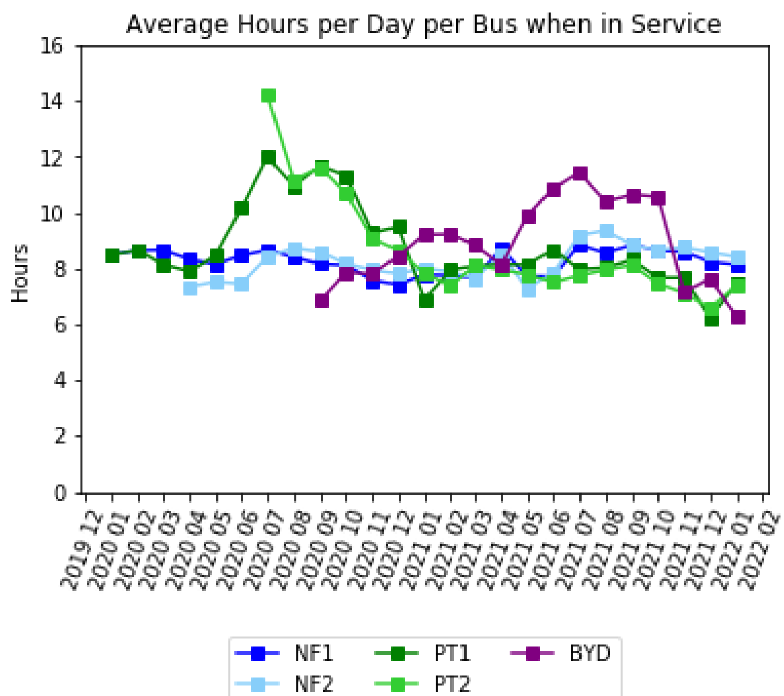

Chart 12: Average Hours per Day per Bus In-Service

It can be seen that the route speeds impact the distances covered for approximately equivalent hours in service. The dispatching strategy of the eBuses has been conservative to date to ensure that no negative impact to service (e.g. depleted battery). Several factors impact the maximum range of the bus, in particular, seasonal changes have been shown to have the largest impact on range, will be discussed further in this report.

To include the impact of bus availability, the total distance and total hours' in-service is plotted and normalized to the number of buses in each fleet in the figures below.

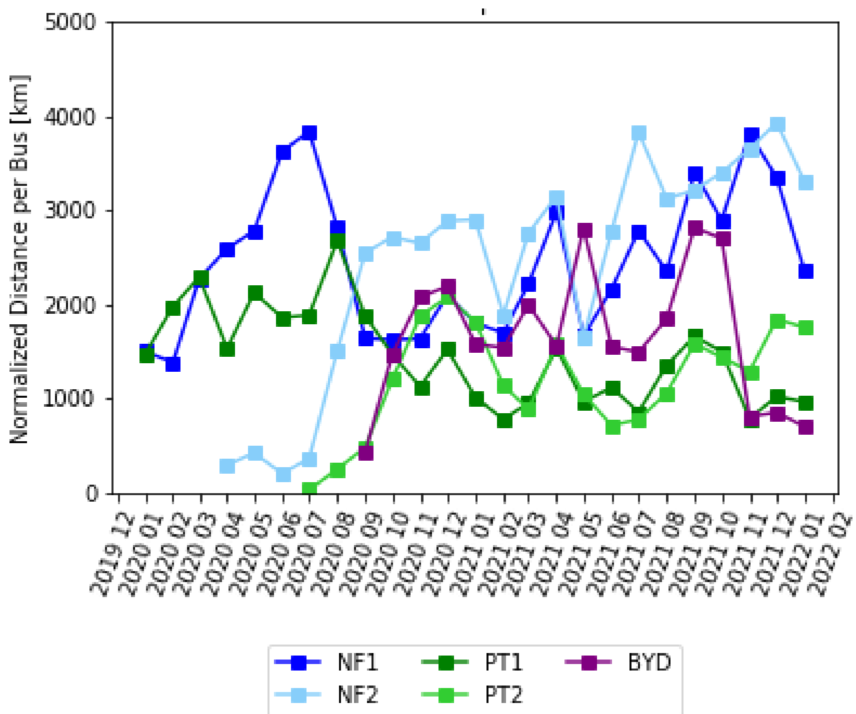

Chart 13: Normalized Distance per Month In-Service

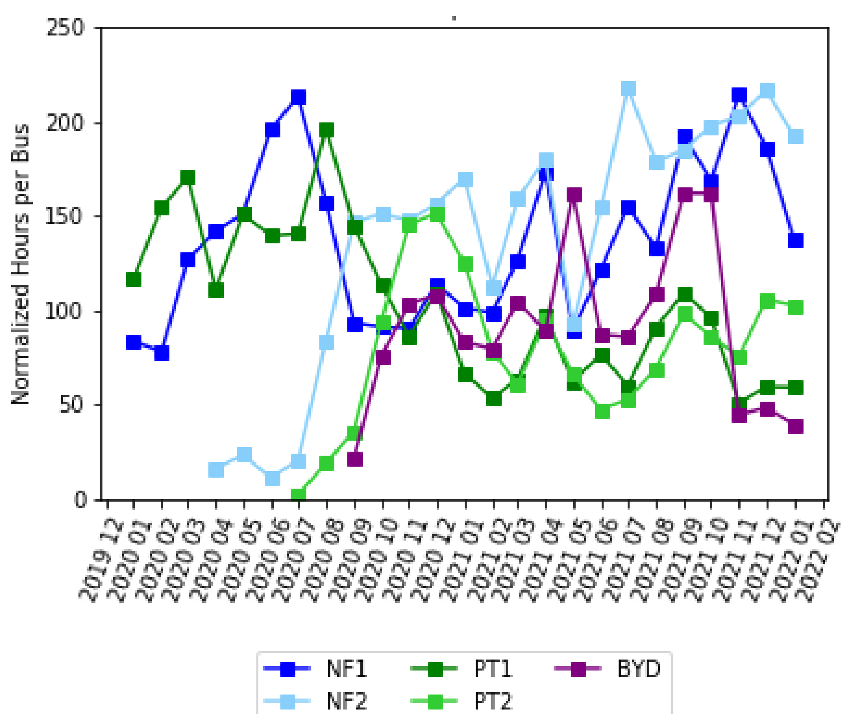

Chart 14: Normalized Hours per Month In-Service

NFI has the highest distance and hours in service per bus when accounting for fleet availability. Proterra and BYD showed initially higher time in-service, but have dropped as a result of bus maintenance and reliability.

The overall In-service energy consumption was averaged for each month and shown in the figure below on a mileage kWh/km basis.

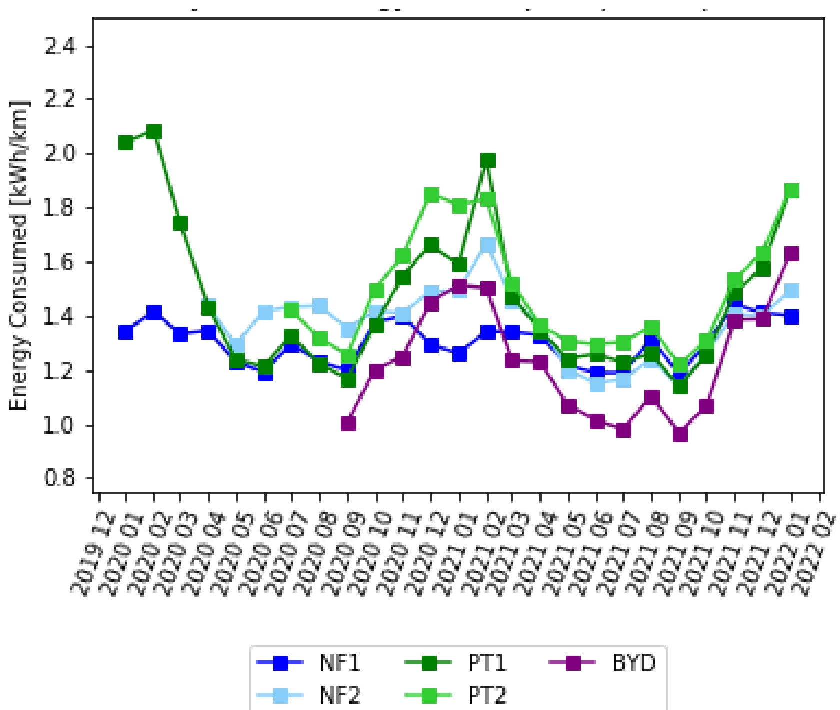

Chart 15: Monthly Overall Energy Consumption per km per Shift

2020	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Standard Deviation
BYD	-	-	-	-	-	-	-	-	1.00	1.20	1.25	1.45	1.23	0.182
New Flyer - 1	1.34	1.42	1.33	1.34	1.23	1.19	1.29	1.23	1.20	1.38	1.40	1.29	1.30	0.077
New Flyer - 2	-	-	-	1.44	1.29	1.42	1.43	1.44	1.35	1.42	1.41	1.49	1.41	0.056
Proterra - 1	2.04	2.09	1.74	1.43	1.24	1.21	1.33	1.22	1.17	1.36	1.55	1.66	1.50	0.318
Proterra - 2	-	-	-	-	-	-	1.42	1.32	1.25	1.50	1.62	1.85	1.49	0.218
2021	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Standard Deviation
BYD	1.51	1.50	1.23	1.23	1.07	1.01	0.98	1.10	0.97	1.07	1.38	1.39	1.20	0.200
New Flyer - 1	1.26	1.34	1.34	1.33	1.22	1.19	1.19	1.31	1.18	1.30	1.44	1.41	1.29	0.086
New Flyer - 2	1.49	1.67	1.46	1.37	1.20	1.15	1.16	1.24	1.14	1.26	1.41	1.40	1.33	0.164
Proterra - 1	1.59	1.98	1.47	1.35	1.24	1.26	1.23	1.26	1.14	1.26	1.48	1.58	1.40	0.233
Proterra - 2	1.81	1.83	1.52	1.36	1.31	1.29	1.30	1.36	1.22	1.31	1.53	1.63	1.46	0.208

Table 2: Monthly Overall Energy Consumption per km

The highest energy consumption correlates to colder seasons. Proterra and BYD are more significantly affected by the swings in seasonal changes while NFI is more stable throughout the year. This is a significant finding to be able to utilize a consistent dispatching strategy for the garages. Looking deeper at the individual consumers, the key contributors can be identified.

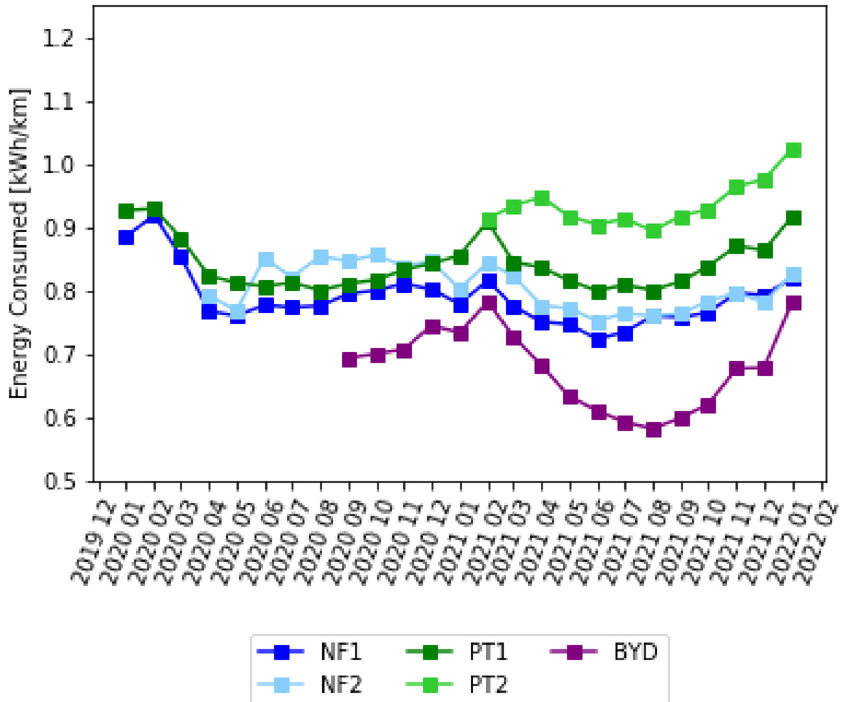

Chart 16: Monthly In-Service Powertrain Energy per km per Shift

The in-service powertrain consumption is shown for the same period as above. It can be seen that there is also a correlation with the seasonal changes. However, this is likely due to road conditions rather than temperature itself. All OEMs in general are more consistent in powertrain demand over the year.

It is worth noting that the Proterra DuoPower (PT2) which has dual traction motors is showing a higher powertrain consumption in general. In this case, there is an opportunity for improvement since the expectation is to have increased brake regeneration with the dual motors.

It is also worth noting that BYD is showing very low powertrain consumption. However, this is not realized in the overall efficiency. This may be due to other consumers that are accounted for in the HV Accessories that the TTC does not have visibility on due to the limitations of the telematics and signals available to the TTC from the OEM.

The eHeat + High Voltage Accessories are plotted on a time basis (kWh/h) in service for the same period as above in the chart below. Similar trends are observed to the overall energy consumption, where Proterra and BYD are more affected by the seasonal changes than NFI.

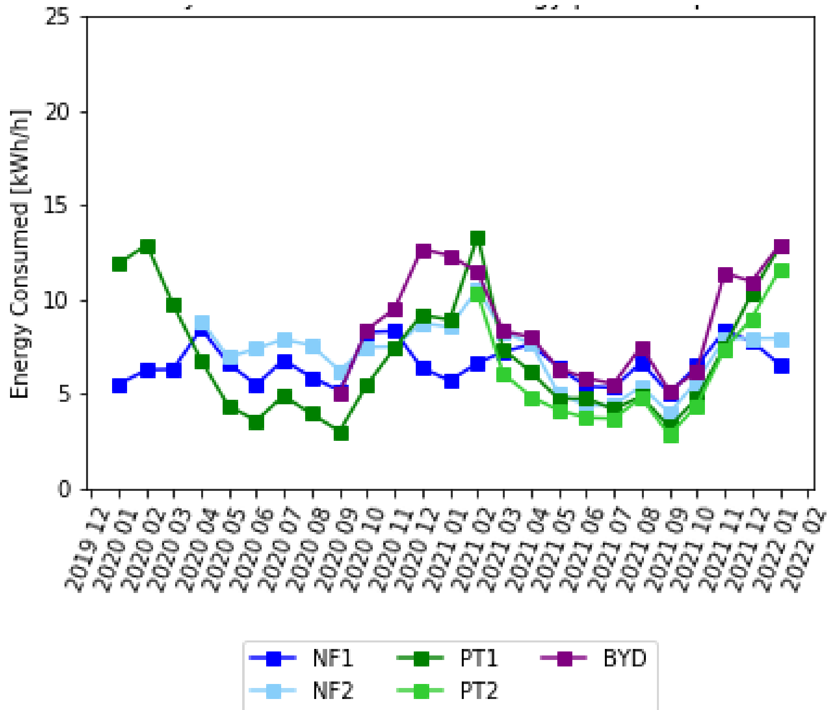

Chart 17: Monthly In-Service eHeat + HV Accessories Energy per km per Shift

To visualize the effect of energy efficiency on temperature, the in-service data was averaged on a weekly basis and plotted in the chart below. This shows the same trend of OEMs susceptibility to seasonal changes.

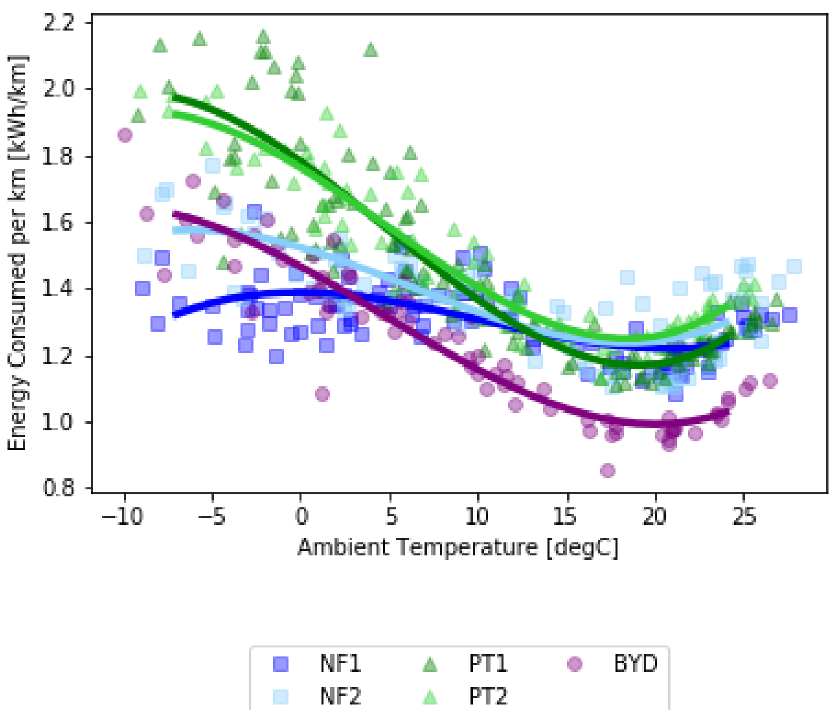

Chart 18: Weekly In-Service Overall Energy per km vs. Ambient Temperature

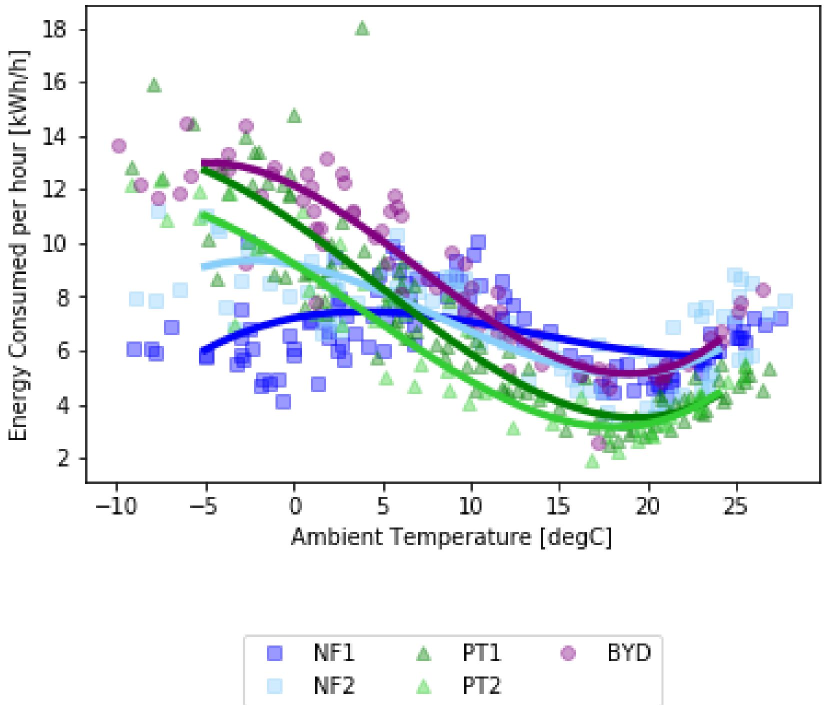

Chart 19: Weekly In-Service eHeat + HV Accessories Energy per hour vs. Ambient Temperature

When looking at the eHeat + HV Accessories consumption which is the main driver of the overall change versus temperature, the same trend is observed. This is largely attributed to the heating strategies of the OEMs. NFI has a central heating unit that uses both electric and diesel heating to manage the conditioning of the cabin, driver, and battery system. Proterra and BYD also have an auxiliary diesel heater but also have independent electric heating systems across the bus for various systems. As a result of the central heating system, NFI relies less on the electric heater and more on the diesel auxiliary heater. The chart below shows each OEM’s diesel use per hour in-service for Q1-2021, where it is expected to be at it’s highest. Electric heating is a very significant energy consumer and minimizing its use will have a large impact on overall efficiency.

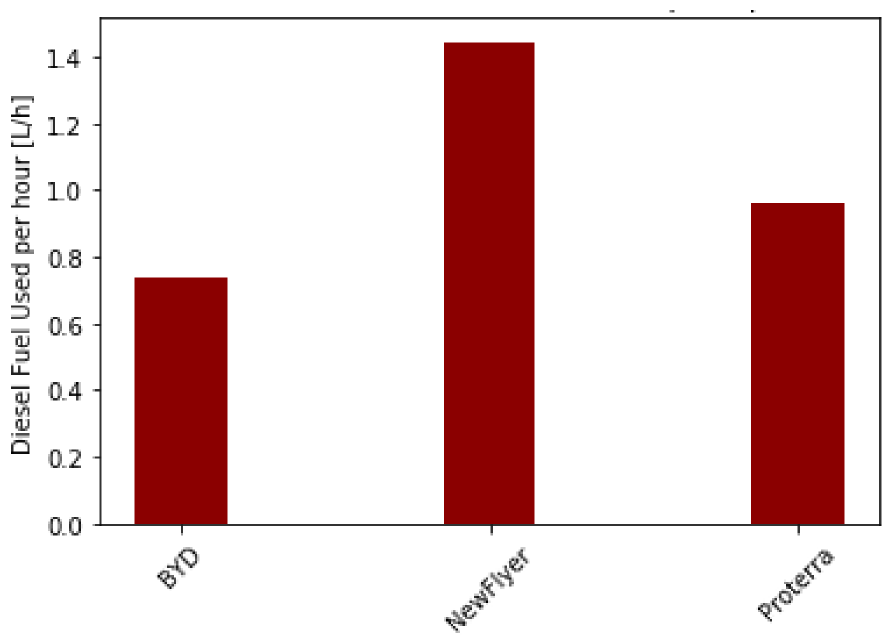

Chart 20: Q1-2021 In-Service Auxiliary Heater Diesel Consumption per Hour

The effects of precipitation can impact the energy efficiency through loss of traction and wheel slip which can lead to degradation in brake regeneration and increased powertrain consumption in slippery conditions. This is highly dependant on road conditions and operator driving behaviour since driving habits can directly impact traction on the road. Predicting performance is difficult since it does not affect every bus consistently on a given day if an operator adapts differently to the road conditions. For the sake of visualization, the average powertrain consumption for all e-buses in-service is plotted versus total precipitation. Precipitation data is taken from Environment Canada's historical weather data and aligned with the in-service data collected.

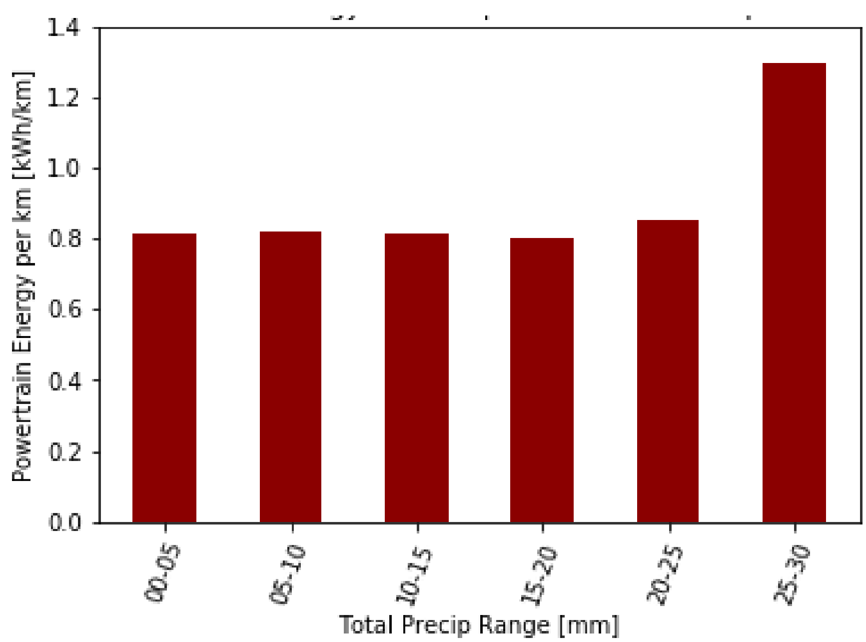

Chart 21: Fleet Average Powertrain Energy Consumption vs Total Precipitation

It is worth noting that this does not mean there is no impact at precipitation levels below 25 mm. There are likely impacts at the individual bus level on a given day where road conditions are slippery depending on the operator. However, this is very difficult to predict given the varying operator driving habits and localized road conditions of a given route.

<u>Regenerative Braking</u>

Regenerative braking is an energy recovery mechanism. When active, regenerative braking slows the bus down and converts kinetic energy into electrical energy that would otherwise be lost in the form of heat. This electrical energy is routed to recharge the onboard batteries and thereby extend the driving range. The more the regenerative braking, the longer the traditional friction brakes will last. All TTC eBuses use regenerative braking.

The regenerated energy is plotted below which is calculated from the power signals of the high voltage batteries using the bus telematics system. It is important to note that regenerated energy on an electric powertrain is a significant source of recovered energy. Proterra shows higher energy recovery rates but is also somewhat offset by the higher powertrain consumption rates. BYD also shows a high rate of recovery which is not necessarily realized in the overall efficiency as a result of HV Accessory consumption that is likely tied to powertrain but not visible to the telematics.

The regenerated energy rate does decrease with seasonal change. However, this is likely impacted to some degree by the energy demands of the heating system as the regenerated energy would feed both the battery and auxiliary systems simultaneously.

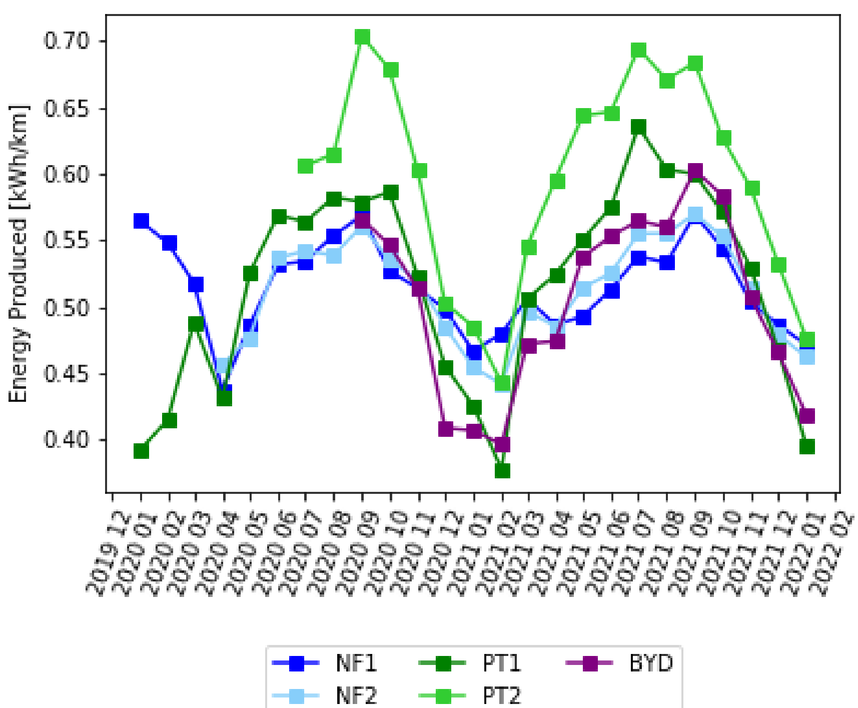

Chart 22: Monthly In-Service Regen

[kWh/km]	BYD	New Flyer	Proterra
Fall 2020	0.71	0.64	0.69
Winter 2020	0.56	0.54	0.61
Winter 2021	0.56	0.62	0.58
Summer 2021	0.63	0.60	0.63

Table 3: Brake Regeneration Energy by Season

		BYD	**New Flyer**	**Proterra**	**Nova HEV**
Fall Regen	April 2021	✓	⊖	⊖	N/A
	April 2022	N/A	N/A	N/A	N/A
Winter Regen	April 2021	⊖	⊖	⊖	N/A
	April 2022	✓	✓	✓	N/A
Summer Regen	April 2021	N/A	N/A	N/A	N/A
	April 2022	✓	✓	✓	N/A

Figure 8 – Dashboard Final Results for Brake Regeneration

<u>Energy Consumption Optimization</u>

Over the course of this program, Vehicle Engineering has been working with eBus OEMs to improve energy efficiency and maximize eBus range in service. Much effort has been made to optimize acceleration and braking regeneration of the eBuses. As an example, Vehicle Engineering worked with Proterra to improve efficiency on acceleration and increase the regeneration energy on decelerations. Although it is difficult to quantify the exact benefit of the changes, a comparison of the probability density before and after the change shows the shift in efficiency.

The chart below shows the density of the in-service data comparing Q3 2020 and Q3 2021, before and after the improvements, respectively. Q3 was selected to minimize the impact of seasonal factors to better highlight the improvements. The average over the quarter has shown a reduction in energy consumption to 1.25 kWh/km from 1.29 kWh/km, approximately a 3.1% reduction. Not only this but the frequency at which the buses are operating in lower energy range has shifted in the direction of lower consumption.

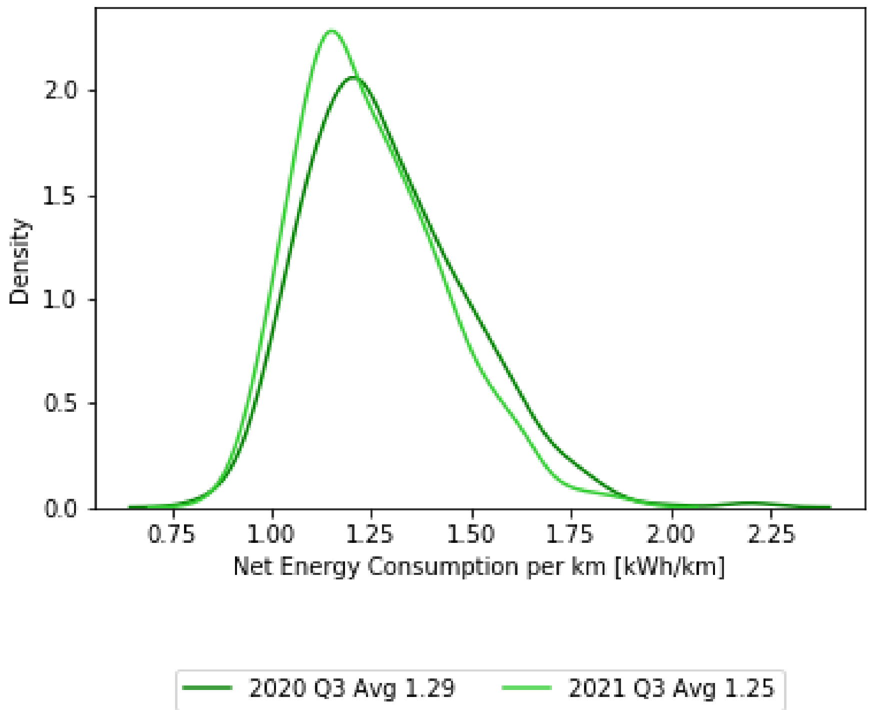

Chart 23: Proterra Energy Consumption Q3 2020 vs Q3 2021

An improvement in the regenerated energy to the batteries can also be noted to be shifted overall for the same period in time. The average over that period shows an increase of 10.1% of regenerated energy as a result of optimizing performance.

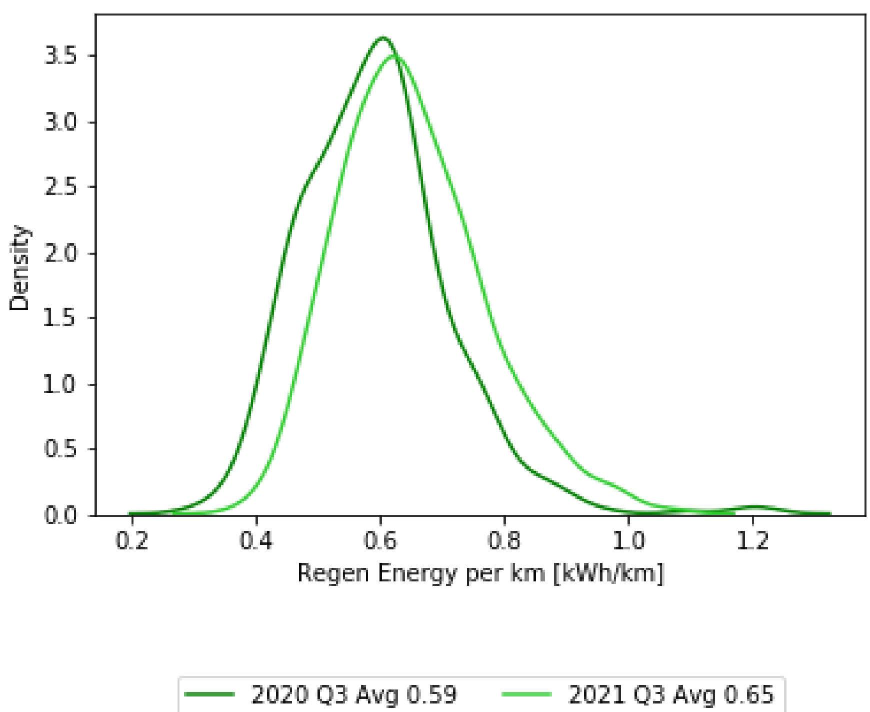

Chart 24: Proterra Brake Regeneration Energy Q3 2020 vs Q3 2021

A similar exercise was performed with BYD in the summer of 2021 and similar results were achieved. An Investigation into acceleration curves was performed over the entire TTC fleet, including the Nova Hybrid buses, and the work will be reflected in the upcoming bus procurement specifications to harmonize vehicle acceleration profiles and improve energy efficiency / fuel economy.

		BYD	New Flyer	Proterra	Nova HEV
Energy Consumption	April 2021	!	✓	!	N/A
	April 2022	!	✓	!	N/A

Figure 9 – Dashboard Final Results for Energy Consumption

Lessons Learned and Next Steps:

1. Predictable and reliable range is more important than achieving the lowest energy consumption.

2. Exploring defroster programming opportunities to further alleviate winter energy consumption concerns.

3. For future procurements, the TTC will avoid a pure-electric defroster unit without fully understanding the energy efficiency performance.

4. For future procurements, the TTC will continue to specify a diesel-fired heater requirement until heat pump technology is viable.

Updates:

1. Proterra has completed a campaign to retrofit a convector in the operator area to improve winter energy consumption.

2. A requirement for a non-electric defroster unit has been included in the next battery electric bus procurement specification.

3. A requirement for a diesel fired auxiliary heater unit has been included in the next battery electric bus procurement specification.

<u>Service Range</u>

There is a need for TTC operations to accurately determine the expected range of the buses. This is difficult given how many factors influence the efficiency and range of an eBus. The TTC attempted to estimate the range based on the in-service data through correlating the State of Charge (SoC) used per km and extrapolating to the full SoC range available. It must be noted that this is an oversimplification to estimate the range and SoC is a calculated value from the OEMs that we have found to not be entirely accurate. However, this simple calculation can be used to highlight the variation in range due to seasonal changes as well as to the large variation in efficiency as a result of the factors mentioned above.

The charts below represent a kernel density estimation of the Estimated Range by Quarter for the eBus fleet using the in-service data for 2021.

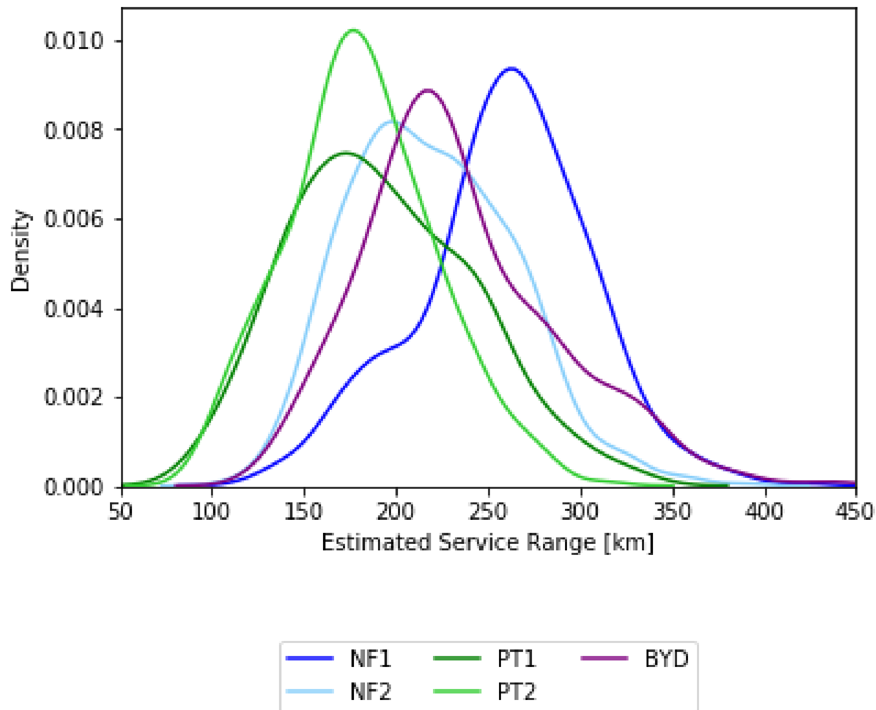

Chart 25: Q1-2021 Estimated Service Range

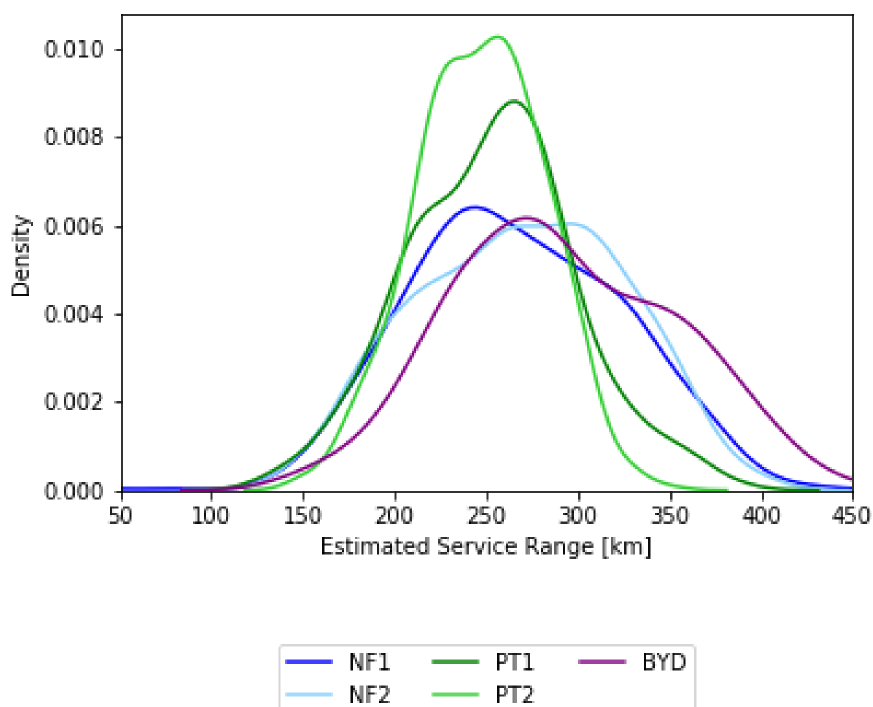

Chart 26: Q2-2021 Estimated Service Range

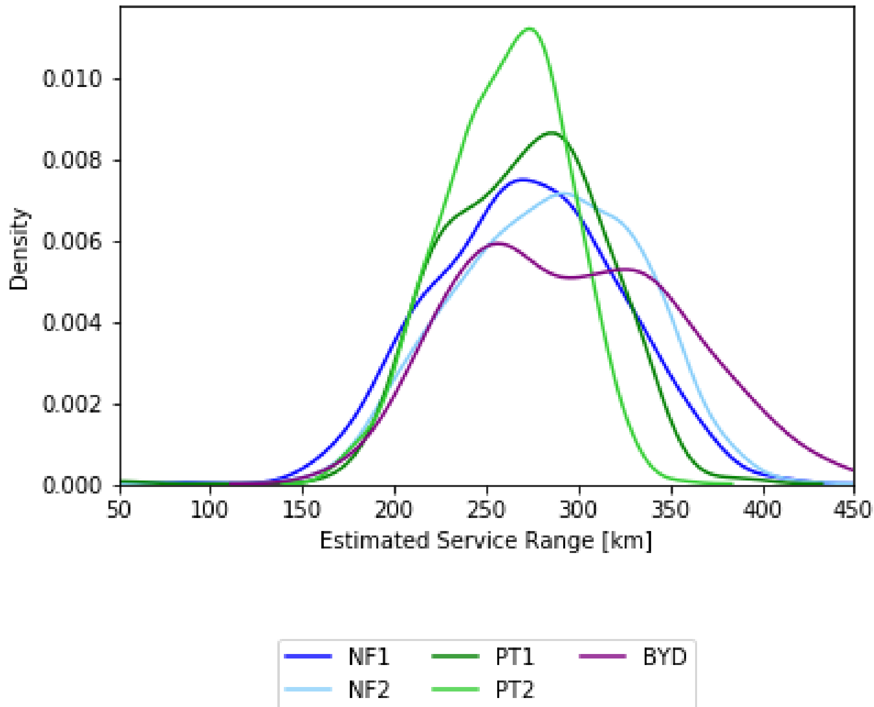

Chart 27: Q3-2021 Estimated Service Range

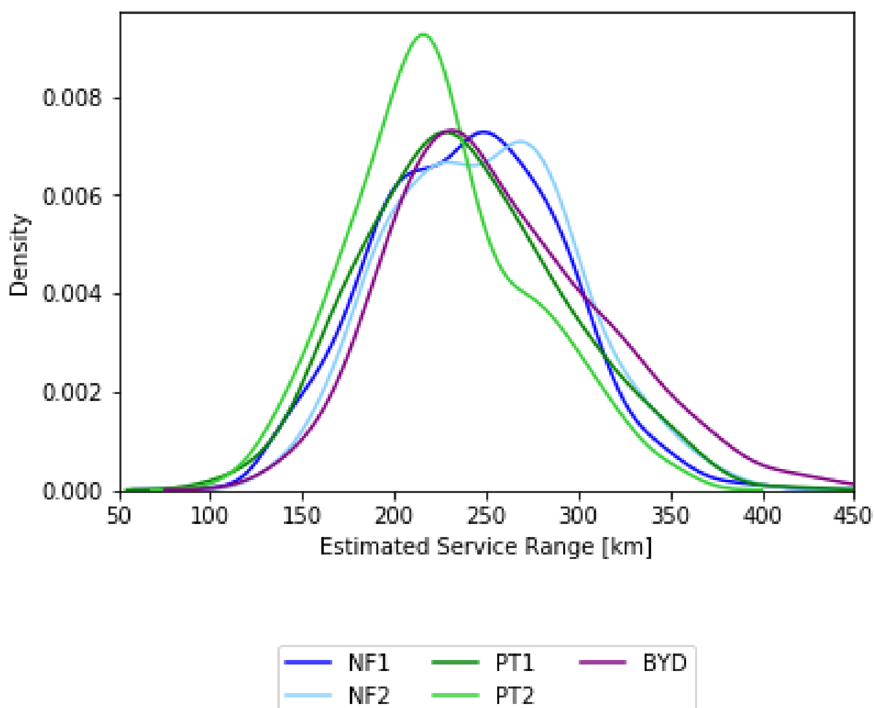

Chart 28: Q4-2021 Estimated Service Range

The variation in expected range is very large and the curves shift with seasonal impacts as expected. This highlights the need for a multi-dimensional model to account for all of the factors that may impact service.

Also note, that it is not advisable to dispatch to the upper limits of range due to the high variation in efficiency and risk of affecting service in real-world conditions. The upper range of values are likely a result of best-case efficiencies and not a practical dispatching strategy. The table below summarizes range estimates derived from in-service data:

Bus	Battery Capacity [kWh]	Useable Battery Capacity [kWh]	Year	Average Summer Energy Consumption [kWh/km]	Estimated Summer Range [km]	Average Winter Energy Consumption [kWh/km]	Estimated Winter Range [km]
BYD	360	291	2020	1.18	246	1.37	212
			2021	1.06	274	1.47	198
New Flyer	400	285	2020	1.30	219	1.39	205
			2021	1.22	234	1.40	203
Proterra	440	271	2020	1.27	213	1.76	153
			2021	1.28	212	1.68	161

Table 4 – Results for In-Service Range Estimates

The TTC is collaborating with Environment and Climate Change Canada's (ECCC's) Emission Research and Measurement Section (ERMS) and Transport Canada's ecoTechnology for Vehicles Program (TC-eTV) to evaluate the performance of fully-electric transit buses using chassis dynamometer testing. The eBuses will be tested by the ERMS using specialized equipment to measure its electrical energy consumption and expected driving range. Various heavy-duty vehicle drive cycles will be tested in-lab using a modified version of the SAE J1634 multi-cycle test method for battery-electric vehicles (BEVs). This testing will begin in Q2 2022 and the goal is to establish a standardized range measurement using a dynamometer that could be used in future bus procurement specifications.

		BYD		**New Flyer**		**Proterra**	
		Summer	Winter	Summer	Winter	Summer	Winter
Range	April 2021	✓	✓	✓	✓	✓	!
	April 2022	✓	✓	✓	✓	✓	!

Figure 10 – Dashboard Final Results for In-Service Range Estimates

Lessons Learned and Next Steps:

1. Optimizing acceleration characteristics of eBuses can further reduce energy consumption.

2. Develop a range estimating model that accounts for all factors that affect efficiency using real-time telematics and incorporates real-time notifications for operations.

3. Collaborate with Environment and Climate Change Canada's Emission Research and Measurement Section and Transport Canada's ecoTechnology for Vehicles Program to establish a standard test method to evaluate the range performance of fully-electric transit buses using a chassis dynamometer.

Update:

1. A harmonized vehicle acceleration profile has been established and adopted in the next eBus procurement specification to improve energy efficiency.

<u>Battery Capacity</u>

An estimation of the effective battery capacity was calculated by looking at the SoC Used (%) versus the Energy Used (kWh) as an attempt to determine the true useable capacity of each bus. The plots below show the distribution of the estimated effective battery capacity in kWh. This is highly susceptible to the accuracy of the SoC calculation of each OEM and is not to be considered an absolute value but rather identify trending behaviour.

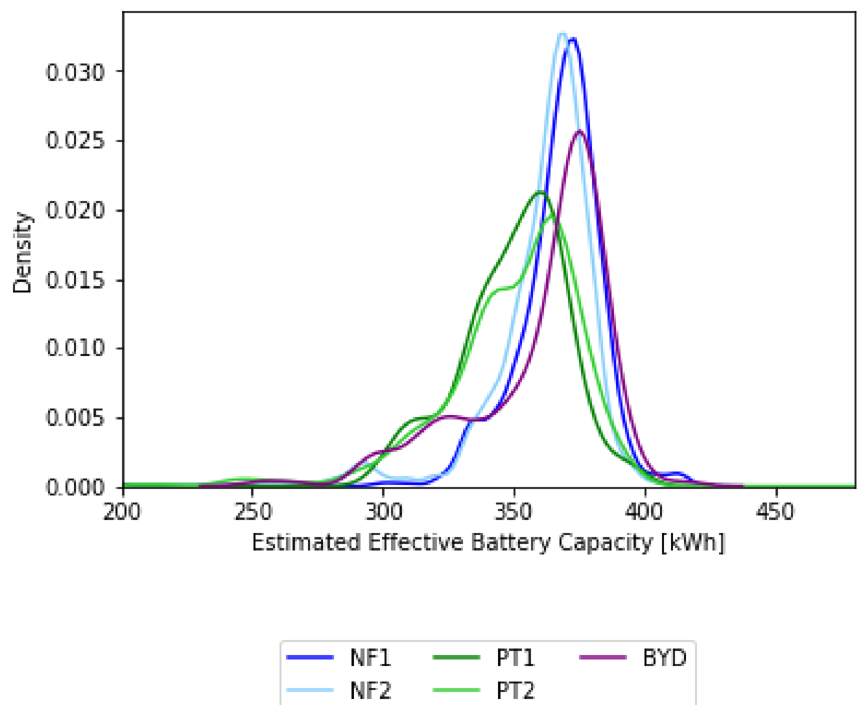

Chart 29: Q1-2021 Estimated Effective Battery Capacity

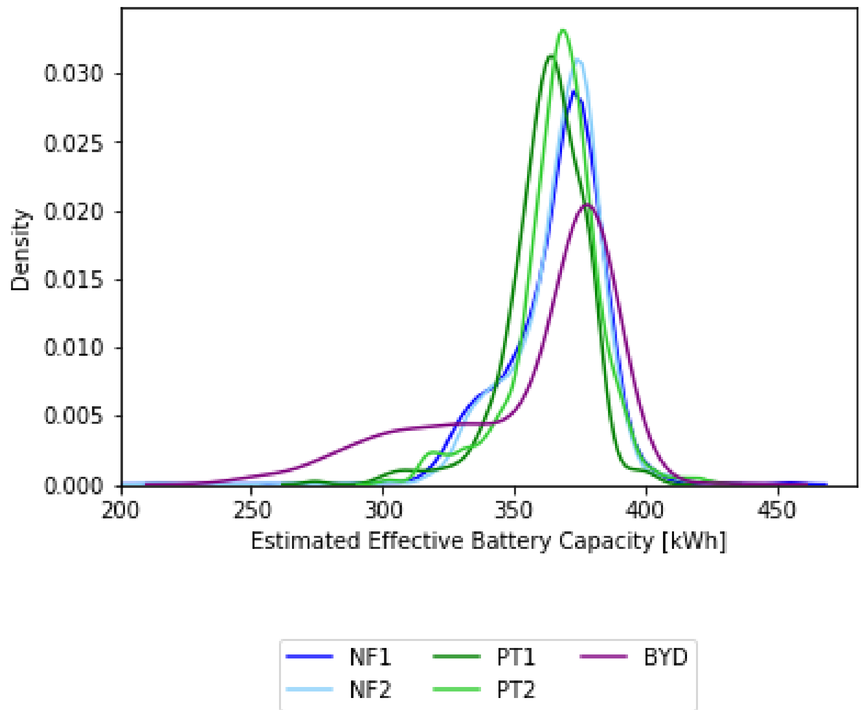

Chart 30: Q2-2021 Estimated Effective Battery Capacity

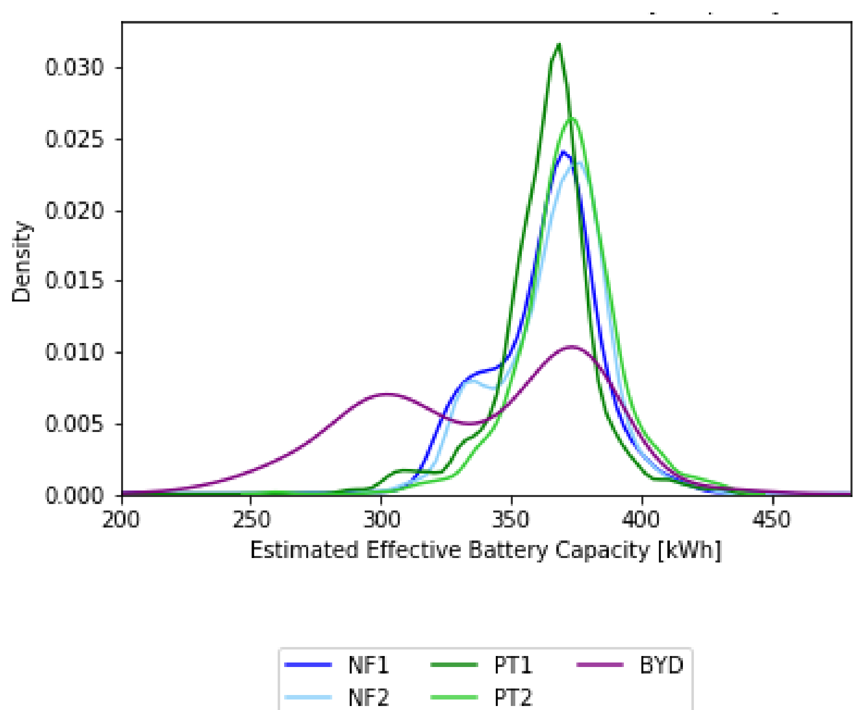

Chart 31: Q3-2021 Estimated Effective Battery Capacity

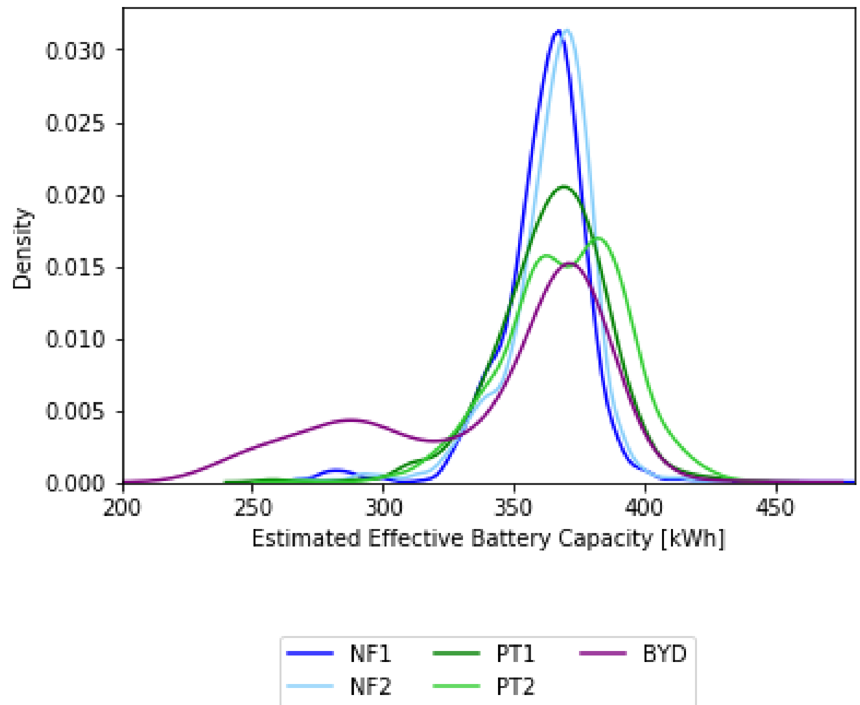

Chart 32: Q4-2021 Estimated Effective Battery Capacity

The plots above show that all OEMs, despite the difference in their posted battery capacity, seem to operate in approximately a similar range of available capacity. This is also dependent on each OEM's battery management strategy as it is common to protect the upper and lower ends of the battery range to protect battery health. This suggests that some OEMs are more conservative in their protection strategy than others. For example, Proterra has opened an additional 6% of useable battery capacity to the TTC as a result of in-service findings and updates to battery life calculations. The impacts to battery health will not be immediately noticeable and will be monitored by TTC Engineering over the course of the eBus life.

Lessons Learned and Next Steps:

1. Investigate lowering interior temperature set points without adversely affecting customer comfort;

2. Investigate early activation of diesel-fired heaters and disabling electric heat;

3. Future procurement specification to specify minimum useable battery capacity target and not advertised battery capacity; and

4. Future procurement specification to seek opportunities to improve efficiency, such as through the use of light-weight materials, heat pump, etc.

Updates:

1. Proterra useable battery capacity increased by 6%;

2. Minimal useable battery capacity specified for next battery electric bus procurement specification.

Head to Head (H2H) Engineering Controlled Test

A controlled test was performed with the first generation of eBus with each OEM to characterize their respective performance head-to-head. Each bus was ballasted to the same weight of approximately 9,000 lbs to simulate a full passenger load. The eBuses were then operated by experienced TTC Instructors to run simulated service on TTC routes from each eBus garage and a few additional runs from other garages. At the start of a route all three operators take the test bus to a common meeting point closest to the route of that day. Then they start the route and stop and cycle the doors at every second stop to simulate service. The route is run for a total of three laps in each direction to provide a larger sample size and ensure reliability. The same operators are used throughout the test and are rotated daily between each eBus so as not to bias the results to a specific operator's driving style.

This method yields the most direct comparison of the eBuses as they are running the same route, at the same time, under the same road conditions. A similar analysis of metrics is performed to the in-service data to compare the eBus performance.

This test was performed in the fall of 2020, in the winter of 2020 as reported in April 2021 and repeated for the winter of 2021 and the summer of 2021 to evaluate the differences in seasonal performance. In this case, because the buses were driven for the same duration each day on each route, we can look only to mileage-based metrics (kWh/km) since this will show the same trends as the time-based metrics (kWh/h). The complete breakdown of energy consumption by route by each consumer is presented in this section.

The overall energy consumption is shown below as a function of ambient temperature and as a kernel density estimation across all routes. It can be seen that not only is summer operation more consistent between eBuses, but the overall efficiency is significantly better than in winter operation. Winter operation shows a similar trend with NFI having less dependence on electric heating operation than the other two OEMs.

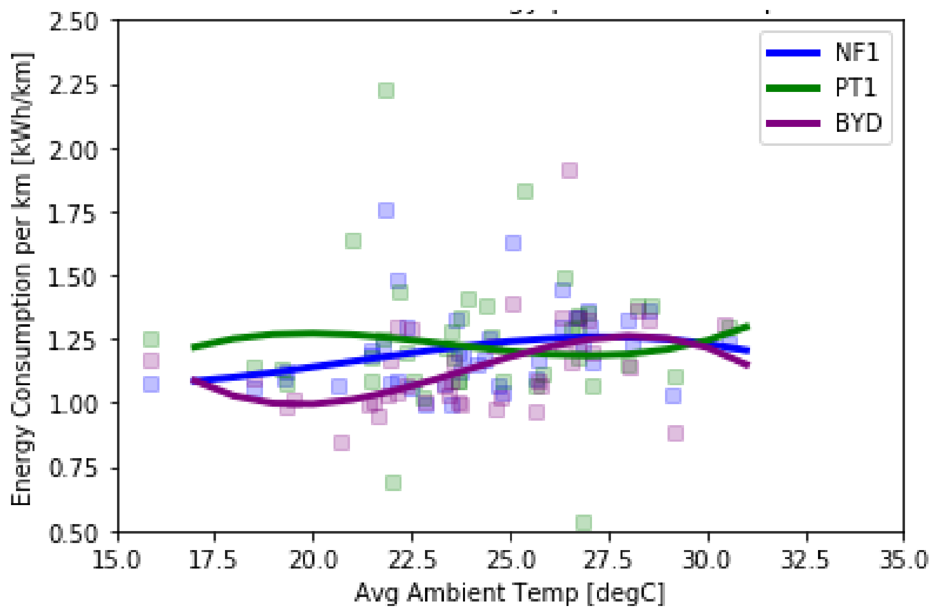

Chart 33: Head to Head Summer Overall Energy per km vs Temperature

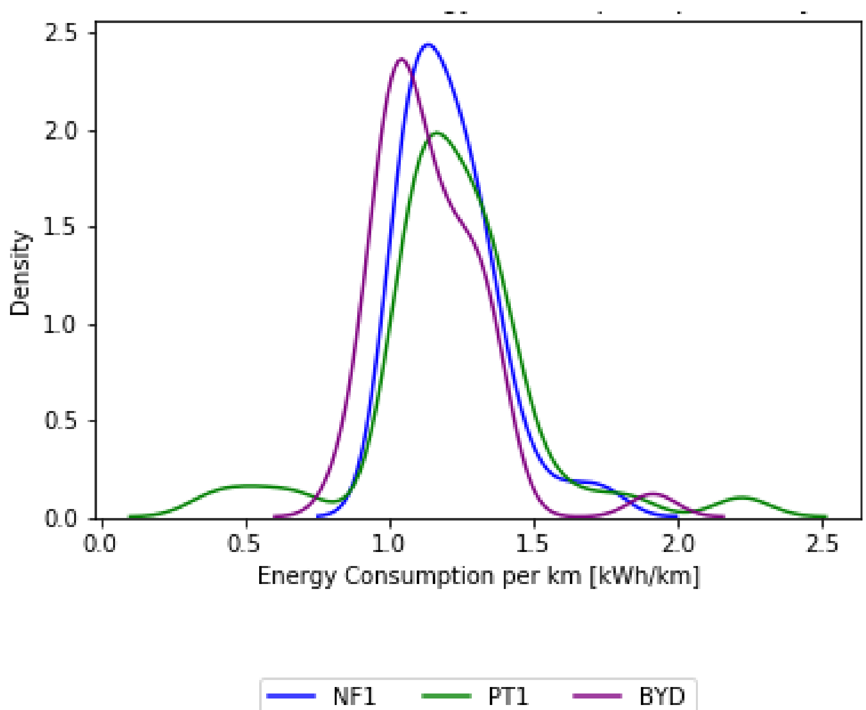

Chart 34: Head to Head Summer Overall Energy per km by eBus

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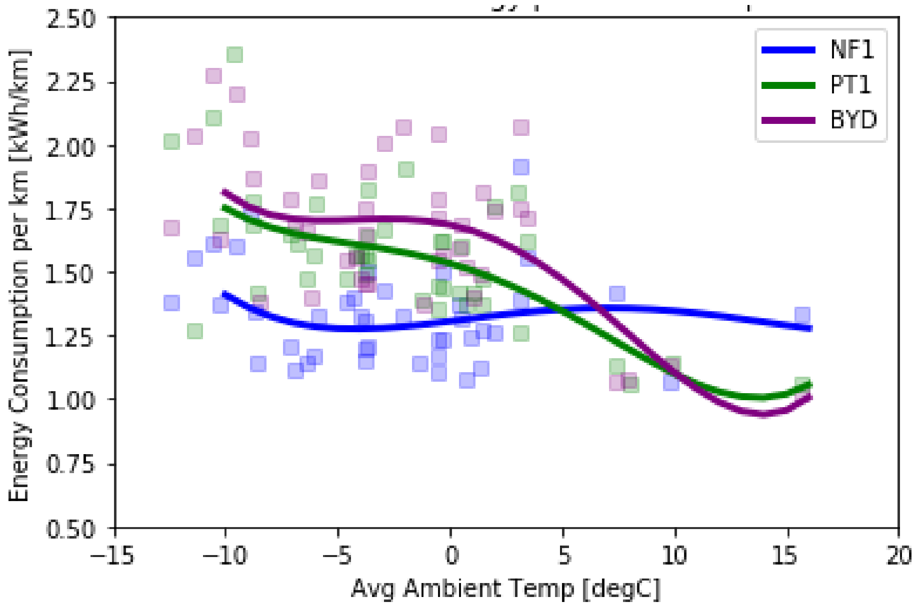

Chart 35: Head to Head Winter Overall Energy per km vs Temperature

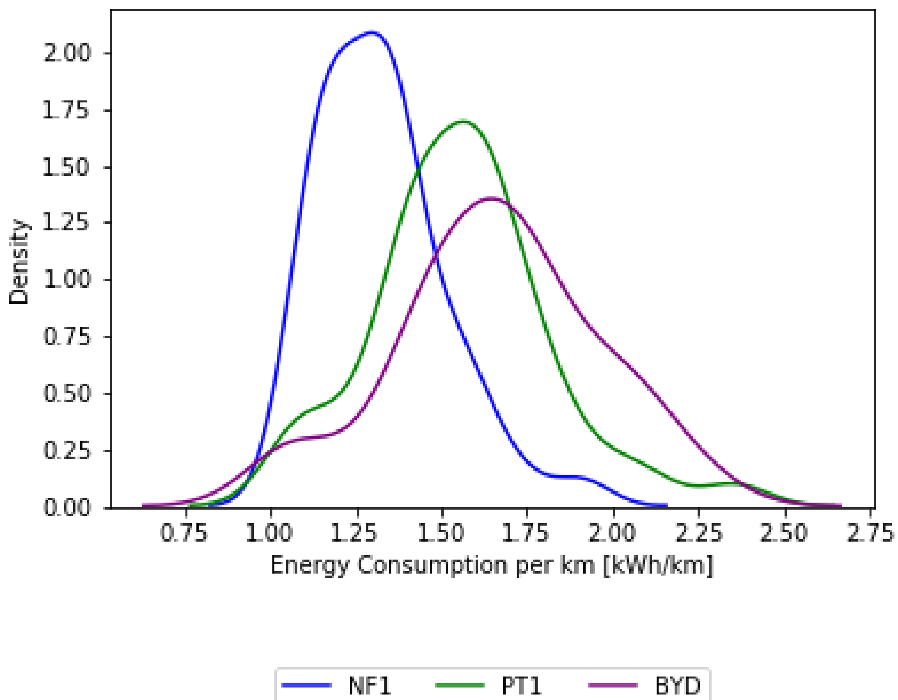

Chart 36: Head-to-Head Winter Overall Energy per km by eBus

Looking at the eHeat + HV Acc, a similar trend is reinforced. The summer performance shows much closer consumption between NFI and Proterra. BYD shows a larger variance, but as mentioned, there may be an additional high voltage consumer that is not accounted for in the powertrain that is shown in this calculation. This is a limitation of the telematics signals available with BYD.

Again, NFI is relying more on diesel heating at cold temperatures to manage temperatures in the cabin, driver area, and battery management systems, whereas Proterra and BYD are using a combination of electric heaters in parallel to the diesel heater. This is also reflected in the diesel fuel consumption over the course of the test, which shows almost double the fuel use for NFI.

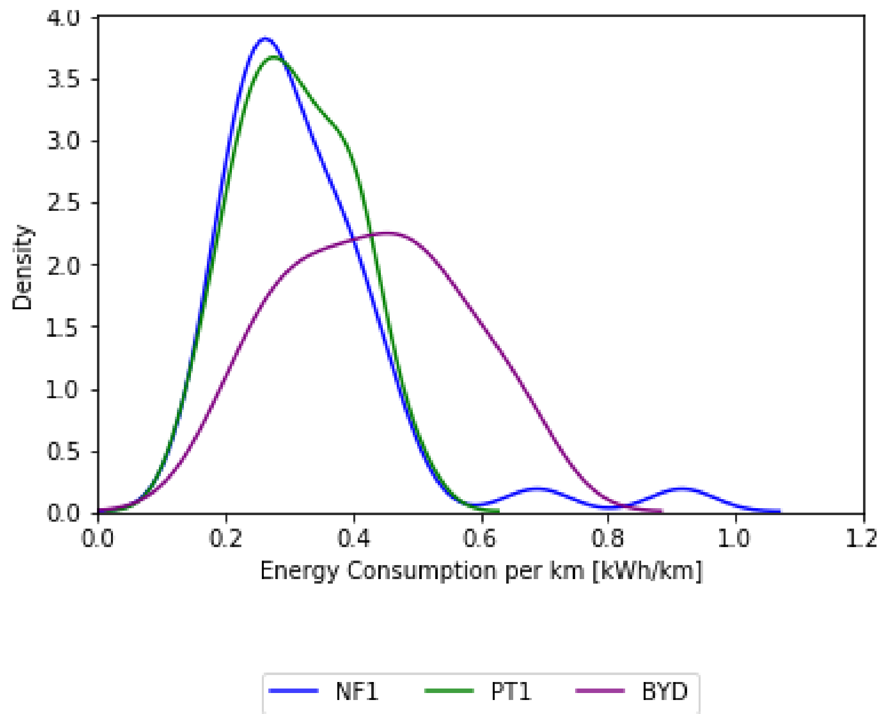

Chart 37: Head to Head Summer eHeat + HV Accessories Energy Consumption per km by eBus

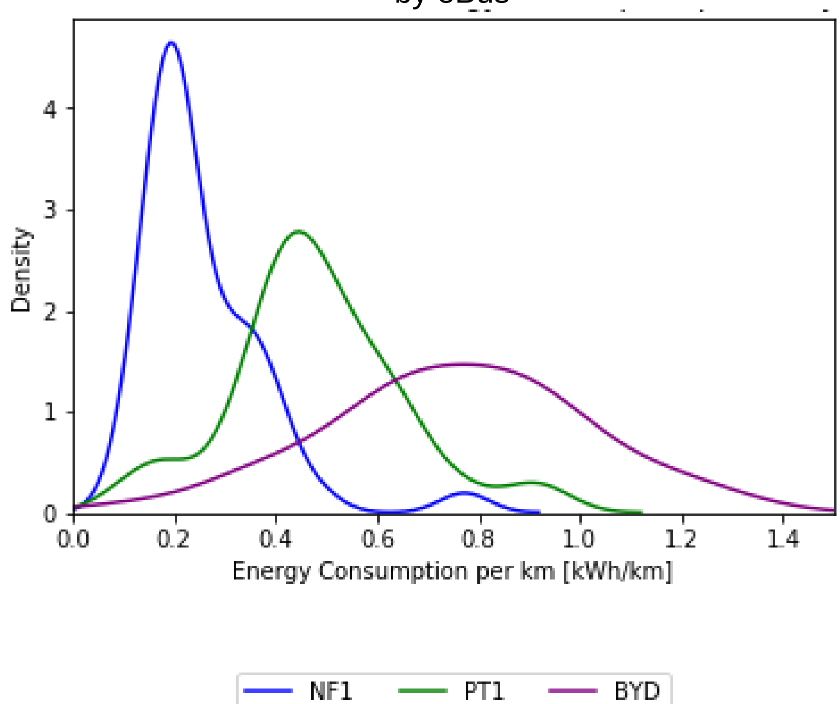

Chart 38: Head to Head Winter eHeat + HV Accessories Energy Consumption per km by eBus

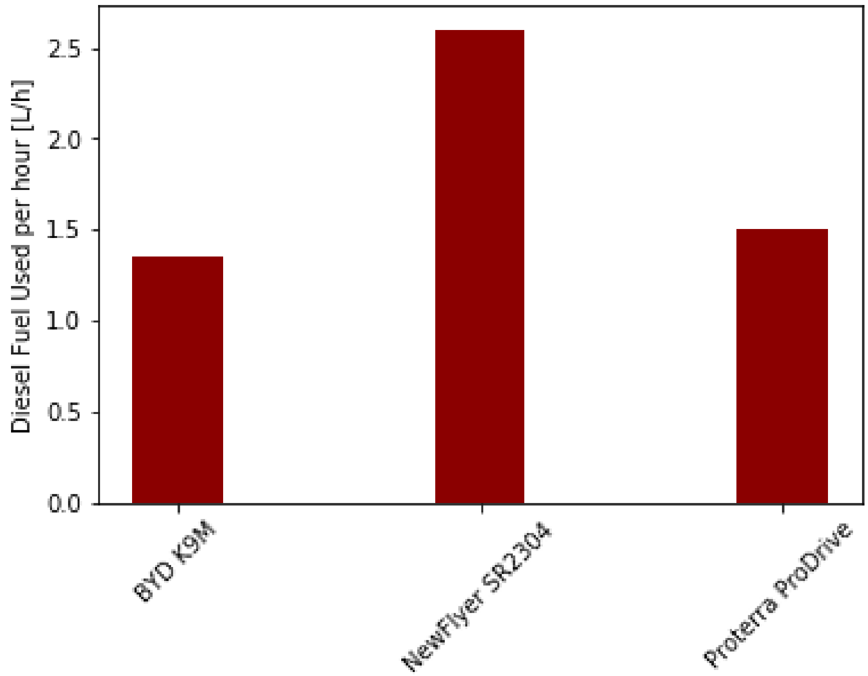

Chart 39: Head to Head Winter Auxiliary Heater Diesel Consumption per Hour

Powertrain consumption again is similar between NFI and Proterra, although NFI is showing lower consumption in general. BYD powertrain consumption is significantly lower, but this is offset by the HV Acc consumption for the reason described previously. In general, there is a higher consumption in the winter than summer and this a result of road conditions with snow and ice.

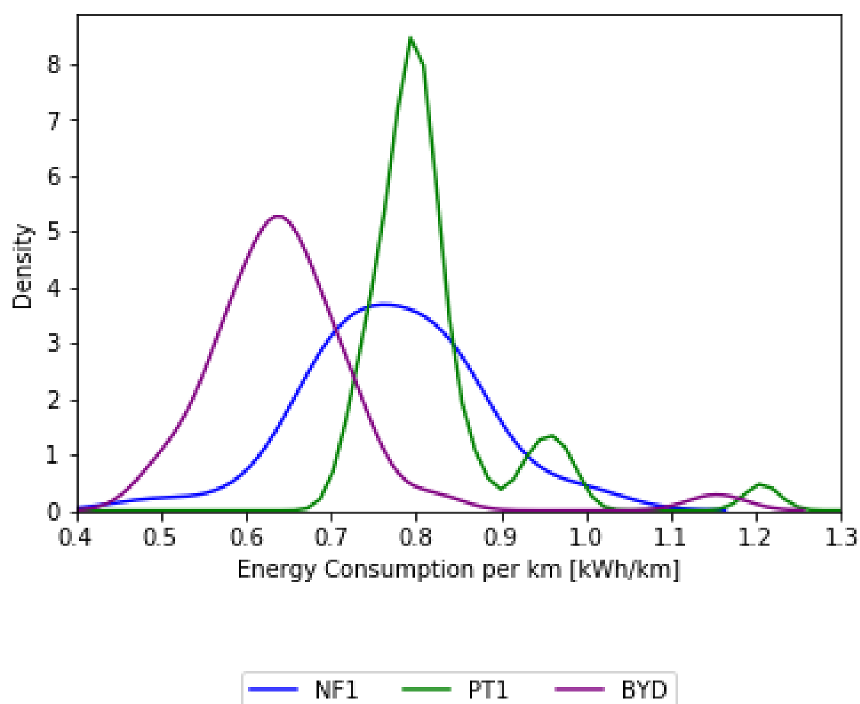

Chart 40: Head to Head Summer Powertrain Energy Consumption per km by eBus

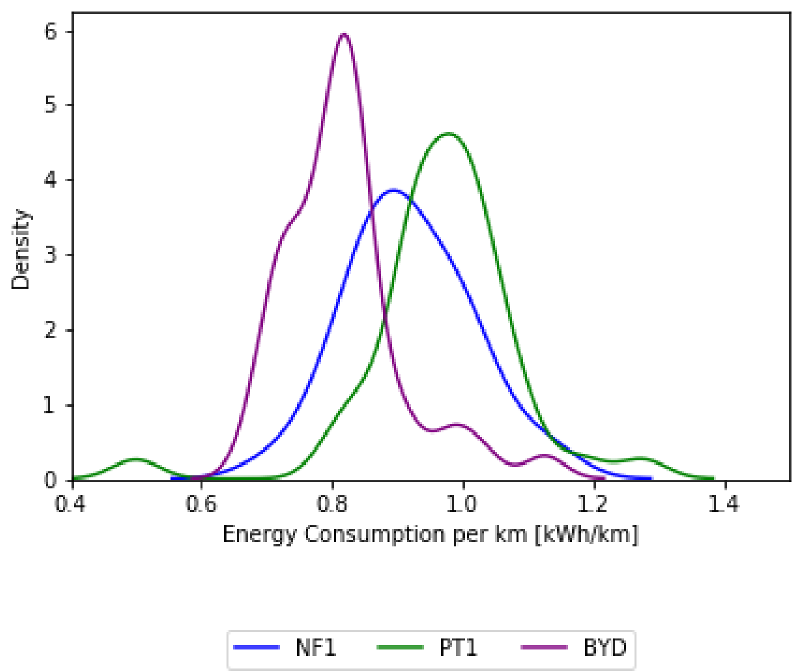

Chart 41: Head to Head Winter Powertrain Energy Consumption per km by eBus

Overall energy consumption was also assessed by grouping the routes by garage to see if there is a significant difference in consumption based on the routes that service different parts of the city. Additional routes were selected with other garages based on grades as High Duty Cycle (HDC) routes to add to the evaluation in comparison.

In general, Mount Dennis routes that service more frequently the core of the city do show higher consumption relative to the other garages. However, a deeper analysis is needed on a route by route basis to characterize the consumption of each route. This reinforces the need for a more accurate modelling tool to characterize consumption in more detail.

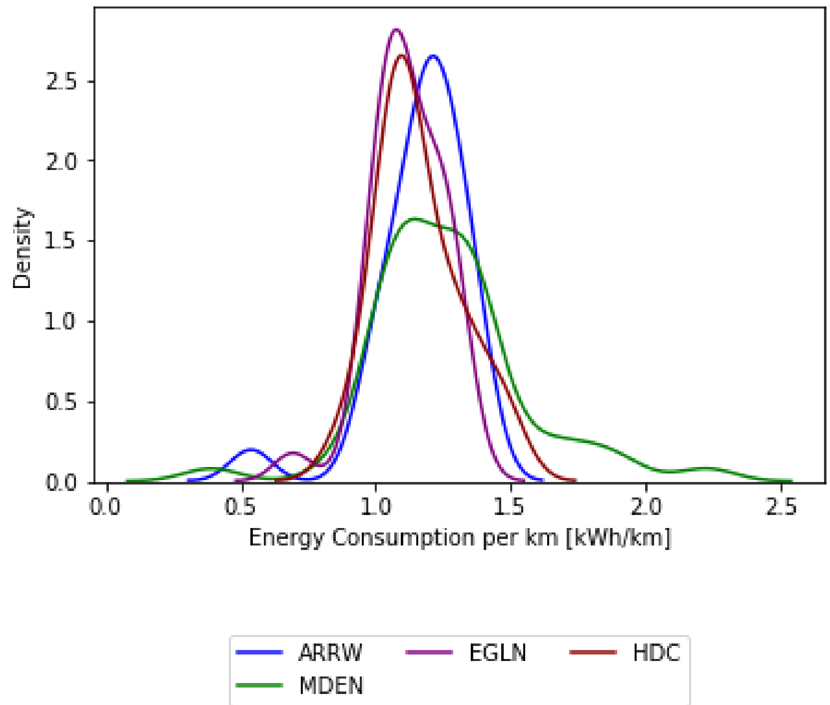

Chart 42: Head to Head Summer Overall Energy Consumption per km by Garage

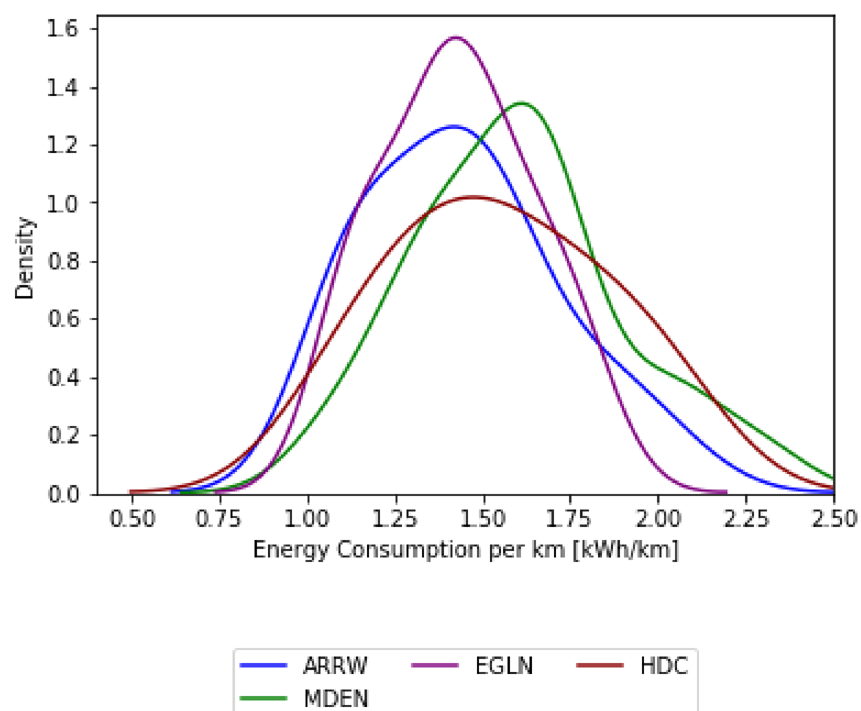

Chart 43: Head to Head Winter Overall Energy Consumption per km by Garage

A similar estimation on driving range was performed with the head-to-head test data and plotted by bus. As expected, in the summer the range between OEM is closer to one another and the variance is more significant in the winter test, which is more largely impacted by their respective heating strategies.

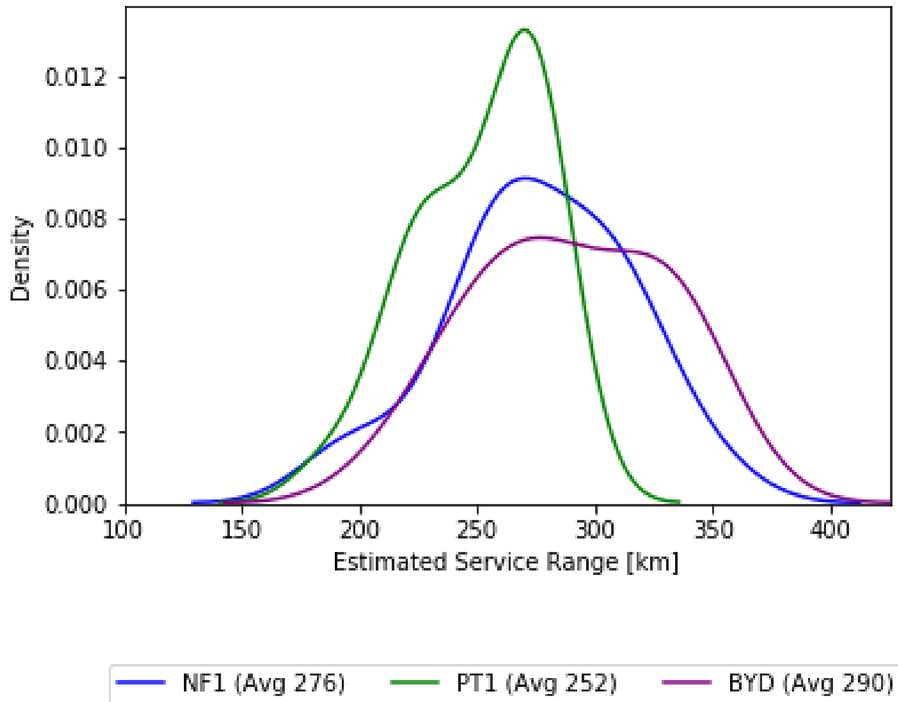

Chart 44: Head-to-Head Summer Estimated Range

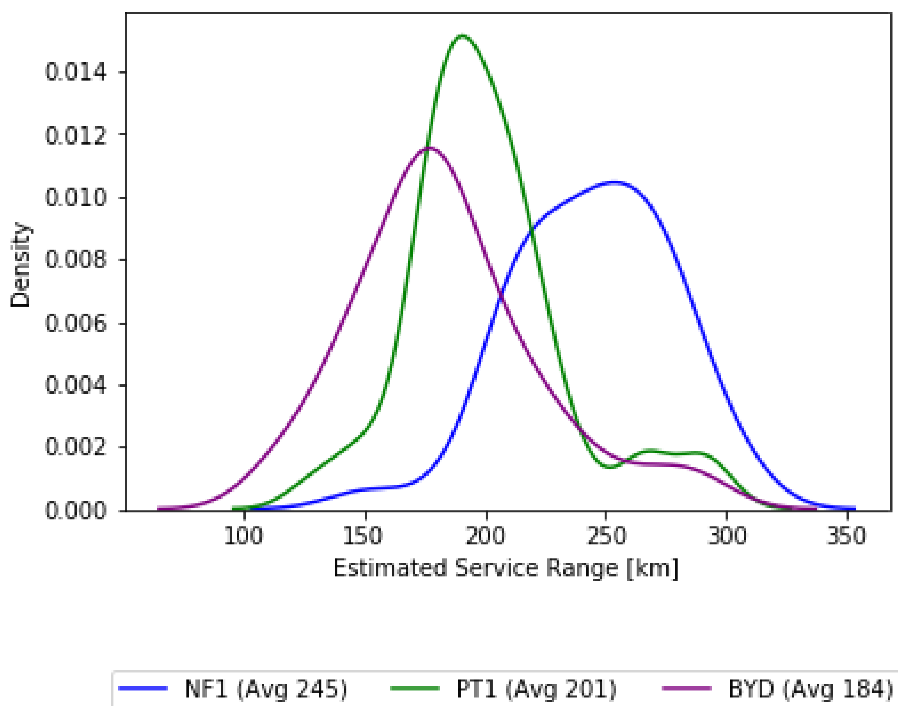

Chart 45: Head-to-Head Winter Estimated Range

		BYD	New Flyer	Proterra
Winter Range	April 2021	168 km	217 km	166 km
	April 2022	184 km	245 km	201 km

Table 5 – Summary of Results for Engineering Test Winter Range Estimates

		BYD	New Flyer	Proterra
Summer Range	April 2021	N/A	N/A	N/A
	April 2022	290 km	276 km	240 km

Table 6 – Summary of Results for Engineering Test Summer Range Estimates

The tables below summarize the results of the head-to-head engineering testing on a route-by-route basis:

			Net Energy Consumption [kWh/km]			Energy Regen per km [kWh/km]			DT Energy Consumption [kWh/km]			LV Acc Energy Consumption [kWh/km]			HV Acc + eHeat Consumption [kWh/km]		
Route Name	Route	Garage	NewFlyer	Proterra	BYD	NewFlyer	Proterra	BYD	NewFlyer	Proterra	BYD	NewFlyer	Proterra	BYD	NewFlyer	Proterra	BYD
BAY	6	MDEN	1.50	1.62	2.04	0.61	0.53	0.64	0.92	0.91	0.82	0.22	0.15	0.11	0.36	0.56	1.12
GLENCAIRN	14	MDEN	1.61	2.11	2.27	0.57	0.49	0.49	0.98	1.05	0.83	0.25	0.16	0.15	0.38	0.89	1.30
DON MILLS	25	EGLN	1.08	1.37	1.52	0.62	0.53	0.51	0.82	0.92	0.78	0.11	0.08	0.07	0.14	0.38	0.67
DUPONT	26	MDEN	1.39	1.26	1.75	0.55	0.60	0.66	0.78	0.85	0.80	0.14	0.09	0.08	0.48	0.32	0.86
DUFFERIN	29	MDEN	1.32	1.61	1.68	0.75	0.59	0.56	0.99	0.97	0.72	0.15	0.11	0.08	0.19	0.53	0.89
GREENWOOD	31	HDC	1.91	1.81	2.07	0.53	0.54	0.65	0.90	1.03	0.77	0.24	0.15	0.11	0.77	0.64	1.20
EGLINTON WEST	32	MDEN	1.33	1.06	1.02	0.57	0.62	0.75	0.90	0.82	0.84	0.12	0.08	0.07	0.31	0.16	0.11
JANE	35	ARRW	1.38	1.48	1.55	0.77	0.60	0.64	1.07	0.95	0.81	0.13	0.10	0.09	0.18	0.43	0.66
FINCH WEST	36	ARRW	1.07	1.14	1.14	0.59	0.69	0.61	0.76	0.84	0.71	0.11	0.09	0.07	0.20	0.21	0.36
ISLINGTON	37	MDEN	1.20	1.55	1.46	0.67	0.54	0.54	0.94	1.02	0.79	0.11	0.09	0.07	0.16	0.45	0.60
HIGHLAND CREEK	38	HDC	N/A	1.06	1.07	N/A	0.66	0.54	N/A	0.91	0.69	N/A	0.05	0.05	N/A	0.10	0.34
KEELE	41	MDEN	1.37	1.41	1.59	0.60	0.72	0.57	0.87	0.96	0.73	0.14	0.11	0.08	0.36	0.34	0.78
KENNEDY	43	EGLN	1.17	1.56	1.40	0.53	0.48	0.60	0.82	0.93	0.87	0.14	0.09	0.10	0.21	0.54	0.43
MARTINGROVE	46	ARRW	1.15	1.39	1.38	0.57	0.57	0.53	0.85	0.99	0.74	0.10	0.09	0.07	0.20	0.32	0.57
LANSDOWNE	47	MDEN	1.39	2.01	1.68	0.53	0.50	0.45	0.90	1.11	0.84	0.17	0.13	0.10	0.32	0.77	0.74
MIDLAND	57	EGLN	1.13	1.37	1.49	0.56	0.59	0.53	0.88	0.92	0.81	0.12	0.09	0.08	0.13	0.36	0.61
MAPLE LEAF	59	ARRW	1.50	1.82	1.89	0.77	0.52	0.52	1.12	1.07	0.87	0.16	0.12	0.10	0.22	0.63	0.92
STEELES WEST	60	ARRW	1.14	1.47	1.65	0.54	0.52	0.59	0.84	0.92	0.81	0.14	0.10	0.09	0.17	0.45	0.76
MAIN	64	HDC	1.56	1.27	2.03	0.72	1.14	0.74	0.99	0.50	0.91	0.24	0.12	0.13	0.32	0.65	0.99
PHARMACY	67	EGLN	1.10	1.35	1.71	0.60	0.50	0.51	0.79	0.80	0.73	0.13	0.09	0.09	0.18	0.46	0.89
WARDEN	68	EGLN	1.15	1.57	1.46	0.52	0.52	0.50	0.93	1.08	0.97	0.10	0.09	0.06	0.11	0.40	0.42
O'CONNOR	70	EGLN	1.17	1.44	1.55	0.63	0.65	0.55	0.88	0.93	0.75	0.13	0.10	0.08	0.16	0.41	0.72
RUNNYMEDE	71	MDEN	1.34	1.77	1.87	0.72	0.52	0.51	1.00	0.99	0.83	0.15	0.14	0.11	0.19	0.65	0.93
SWANSEA	77	MDEN	1.73	1.68	2.02	0.80	0.65	0.62	1.14	1.01	0.71	0.20	0.16	0.13	0.38	0.51	1.19
SCARLETT ROAD	79	MDEN	1.23	1.62	1.79	0.52	0.47	0.40	0.83	0.96	0.81	0.18	0.11	0.10	0.23	0.55	0.87
SHEPPARD WEST	84	ARRW	1.32	1.57	1.47	0.68	0.55	0.55	1.01	1.02	0.82	0.11	0.09	0.07	0.21	0.46	0.58
SCARBOROUGH	86	EGLN	1.14	1.42	1.38	0.52	0.51	0.44	0.86	0.91	0.79	0.11	0.07	0.07	0.17	0.43	0.52
WESTON ROAD	89	MDEN	1.40	1.57	1.56	0.65	0.78	0.71	1.03	1.01	0.73	0.15	0.11	0.09	0.22	0.44	0.74
WOODBINE	91	EGLN	1.26	1.75	1.74	0.50	0.51	0.43	0.98	1.18	0.99	0.14	0.11	0.07	0.15	0.46	0.67
WOODBINE SOUTH	92	HDC	1.28	1.47	1.82	0.60	0.56	0.64	0.89	0.94	0.83	0.17	0.11	0.08	0.21	0.42	0.91
WELLESLEY	94	MDEN	1.43	1.67	2.01	0.72	0.62	0.49	0.96	1.03	0.83	0.22	0.13	0.11	0.25	0.50	1.07
WILSON	96	ARRW	1.42	1.13	1.07	0.63	0.61	0.64	0.90	0.88	0.68	0.11	0.07	0.06	0.41	0.18	0.33
FLEMINGDON PARK	100	EGLN	1.32	1.76	1.85	0.58	0.51	0.65	1.00	1.02	0.85	0.14	0.11	0.11	0.18	0.63	0.90
MARKHAM ROAD	102	HDC	1.24	1.42	1.40	0.56	0.57	0.63	0.86	0.95	0.77	0.11	0.08	0.06	0.28	0.38	0.57
MORNINGSIDE	116	EGLN	1.23	1.44	1.57	0.66	0.53	0.58	0.91	0.93	0.84	0.12	0.08	0.07	0.20	0.43	0.66
CALVINGTON	120	ARRW	1.33	1.91	2.07	0.54	0.44	0.49	0.94	1.06	0.91	0.19	0.13	0.12	0.20	0.72	1.04
GRAYDON HALL	122	HDC	1.55	1.62	1.71	0.75	0.61	0.58	1.01	1.06	1.03	0.14	0.12	0.07	0.40	0.44	0.61
CHRISTIE	126	MDEN	1.31	1.49	1.75	0.75	0.69	0.59	0.95	0.99	0.73	0.17	0.13	0.10	0.20	0.37	0.92
DAVENPORT	127	MDEN	1.20	1.65	1.78	0.52	0.49	0.45	0.84	0.98	0.82	0.16	0.13	0.12	0.20	0.54	0.84
GERRARD	135	EGLN	1.37	1.69	1.63	0.60	0.54	0.57	0.91	0.99	0.85	0.16	0.09	0.09	0.30	0.60	0.69
ROGERS ROAD	161	MDEN	1.11	1.61	1.68	0.70	0.60	0.54	0.70	1.02	0.78	0.17	0.11	0.11	0.24	0.49	0.80
WESTON RD. NORTH	165	ARRW	1.20	1.64	1.65	0.56	0.54	0.61	0.85	0.99	0.82	0.15	0.11	0.09	0.20	0.55	0.75
SYMINGTON	168	MDEN	1.60	2.36	2.20	0.50	0.39	0.40	1.05	1.28	1.13	0.22	0.15	0.12	0.33	0.94	0.95
		Average	1.32	1.56	1.66	0.62	0.58	0.56	0.92	0.97	0.82	0.15	0.11	0.09	0.25	0.48	0.76
		Standard Deviation	0.18	0.26	0.30	0.09	0.12	0.08	0.10	0.12	0.09	0.04	0.03	0.02	0.12	0.17	0.25

Table 7: Winter 2021 Engineering Test Results

			Net Energy Consumption [kWh/km]			Energy Regen per km [kWh/km]			DT Energy Consumption [kWh/km]			LV Acc Energy Consumption [kWh/km]			HV Acc + eHeat Consumption [kWh/km]		
Route Name	Route	Garage	NewFlye	Proterra	BYD	NewFlye	Proterra	BYD	NewFlye	Proterra	BYD	NewFlye	Proterra	BYD	NewFlye	Proterra	BYD
GLENCAIRN	14	MDEN	1.63	1.83	1.39	0.65	0.58	0.72	0.98	1.21	0.67	0.18	0.14	0.09	0.47	0.48	0.63
BAY	19	MDEN	N/A	1.29	1.92	N/A	0.86	0.57	N/A	0.82	1.15	N/A	0.14	0.10	N/A	0.33	0.66
DON MILLS	25	EGLN	1.23	1.30	1.31	0.56	0.62	0.61	0.72	0.81	0.71	0.14	0.10	0.08	0.37	0.39	0.52
DUPONT	26	MDEN	1.16	1.07	1.20	0.57	0.53	0.58	0.65	0.72	0.56	0.14	0.09	0.08	0.37	0.25	0.56
DUFFERIN	29	MDEN	1.07	2.23	1.03	0.59	0.44	0.60	0.70	1.69	0.63	0.13	0.13	0.07	0.25	0.41	0.34
GREENWOOD	31	HDC	1.33	1.18	1.16	0.57	0.53	0.61	0.74	0.77	0.52	0.19	0.12	0.09	0.39	0.29	0.55
EGLINTON WEST	32	MDEN	1.33	1.15	1.14	0.64	0.64	0.60	0.84	0.80	0.57	0.14	0.10	0.07	0.35	0.24	0.51
JANE	35	ARRW	1.21	1.18	1.00	0.70	0.68	0.66	0.86	0.81	0.62	0.11	0.09	0.06	0.24	0.29	0.32
FINCH WEST	36	ARRW	1.23	1.38	1.36	0.49	0.54	0.59	0.67	0.77	0.63	0.16	0.12	0.09	0.40	0.49	0.65
ISLINGTON	37	MDEN	1.00	1.02	1.01	0.51	0.59	0.51	0.70	0.74	0.73	0.10	0.07	0.05	0.20	0.20	0.23
HIGHLAND CREEK	38	HDC	1.19	1.09	0.99	0.57	0.66	0.55	0.85	0.83	0.66	0.11	0.08	0.06	0.22	0.18	0.27
KEELE	41	MDEN	1.08	1.22	1.07	0.56	0.57	0.69	0.69	0.79	0.63	0.12	0.12	0.06	0.27	0.31	0.38
KENNEDY	43	EGLN	1.09	1.14	1.01	0.59	0.65	0.58	0.84	0.80	0.69	0.10	0.07	0.06	0.16	0.27	0.26
MARTINGROVE	46	ARRW	1.17	1.12	0.97	0.54	0.80	0.54	0.78	0.80	0.62	0.10	0.09	0.05	0.29	0.23	0.30
LANSDOWNE	47	MDEN	1.06	N/A	0.85	0.59	N/A	0.93	0.71	N/A	0.26	0.13	N/A	0.07	0.22	N/A	0.52
MIDLAND	57	EGLN	1.08	1.26	1.17	0.57	0.51	0.58	0.83	0.81	0.65	0.09	0.07	0.07	0.15	0.38	0.46
MAPLE LEAF	59	ARRW	1.26	1.26	1.23	0.60	0.58	0.75	0.81	0.80	0.64	0.13	0.12	0.08	0.31	0.34	0.50
STEELES WEST	60	ARRW	1.19	1.09	1.00	0.42	0.54	0.48	0.69	0.78	0.71	0.12	0.08	0.06	0.38	0.23	0.23
MAIN	64	HDC	1.48	1.44	1.30	0.75	0.84	0.83	1.01	0.97	0.69	0.17	0.12	0.09	0.30	0.35	0.52
PHARMACY	67	EGLN	1.22	1.25	0.95	0.61	0.61	0.59	0.92	0.93	0.68	0.10	0.09	0.06	0.20	0.23	0.21
WARDEN	68	EGLN	1.07	N/A	0.97	0.54	N/A	0.64	0.76	N/A	0.63	0.09	N/A	0.05	0.21	N/A	0.29
O'CONNOR	70	EGLN	1.00	1.28	1.04	0.66	0.67	0.62	0.49	0.80	0.50	0.12	0.09	0.07	0.39	0.39	0.47
RUNNYMEDE	71	MDEN	1.30	N/A	1.22	0.59	N/A	0.66	0.77	N/A	0.62	0.16	N/A	0.08	0.37	N/A	0.52
SWANSEA	77	MDEN	1.45	1.49	1.33	0.63	0.79	0.70	0.84	0.95	0.64	0.18	0.13	0.08	0.43	0.42	0.60
SCARLETT ROAD	79	MDEN	1.15	1.41	N/A	0.57	0.67	N/A	0.76	0.98	N/A	0.12	0.12	N/A	0.27	0.31	N/A
SHEPPARD WEST	84	ARRW	1.17	1.38	N/A	0.64	0.44	N/A	0.76	0.75	N/A	0.13	0.32	N/A	0.28	0.31	N/A
SCARBOROUGH	86	EGLN	1.04	1.09	1.03	0.54	0.57	0.62	0.74	0.85	0.72	0.10	0.08	0.05	0.21	0.16	0.25
WESTON ROAD	89	MDEN	1.20	1.09	1.00	0.69	0.67	0.66	0.82	0.78	0.58	0.13	0.09	0.06	0.25	0.22	0.36
WOODBINE	91	EGLN	1.24	1.18	1.22	0.53	0.56	0.65	0.82	0.78	0.67	0.12	0.10	0.07	0.29	0.29	0.48
WOODBINE SOUTH	92	HDC	1.06	1.08	1.29	0.79	0.69	0.59	0.59	0.76	0.82	0.15	0.09	0.07	0.31	0.23	0.40
WELLESLEY	94	MDEN	1.37	1.36	1.33	0.56	0.65	0.56	0.70	0.81	0.56	0.21	0.14	0.10	0.46	0.40	0.67
WILSON	96	ARRW	1.30	N/A	1.07	0.61	N/A	0.53	0.88	N/A	0.62	0.13	N/A	0.06	0.29	N/A	0.39
FLEMINGDON PARK	100	EGLN	1.13	1.34	1.09	0.59	0.71	0.71	0.75	0.80	0.60	0.13	0.21	0.07	0.25	0.33	0.43
MARKHAM ROAD	102	HDC	1.03	1.11	0.89	0.68	0.53	0.63	0.68	0.79	0.50	0.10	0.08	0.05	0.25	0.23	0.34
MORNINGSIDE	116	EGLN	1.13	1.08	0.98	0.57	0.58	0.60	0.80	0.82	0.74	0.11	0.09	0.06	0.22	0.17	0.17
CALVINGTON	120	ARRW	1.30	1.20	1.07	0.71	0.70	0.61	0.86	0.76	0.59	0.14	0.11	0.07	0.29	0.32	0.40
GRAYDON HALL	122	HDC	1.09	1.07	1.08	0.55	0.75	0.67	0.68	0.73	0.58	0.14	0.09	0.07	0.28	0.25	0.44
CHRISTIE	126	MDEN	1.37	1.38	1.33	0.64	0.67	0.61	0.73	0.84	0.57	0.19	0.13	0.09	0.44	0.41	0.67
DAVENPORT	127	MDEN	1.06	1.14	1.09	0.51	0.44	0.54	0.00	0.74	0.72	0.15	0.11	0.08	0.92	0.29	0.29
GERRARD	135	EGLN	1.09	N/A	1.04	0.57	N/A	0.58	0.75	N/A	0.65	0.11	N/A	0.06	0.22	N/A	0.33
ROGERS ROAD	161	MDEN	1.34	1.35	1.34	0.64	0.61	0.74	0.79	0.80	0.66	0.16	0.13	0.08	0.39	0.42	0.60
WESTON RD. NORTH	165	ARRW	1.34	1.29	1.16	0.65	0.61	0.60	0.88	0.80	0.66	0.13	0.11	0.07	0.33	0.38	0.43
SYMINGTON	168	MDEN	1.76	1.64	1.17	0.62	0.90	0.63	0.82	0.87	0.60	0.25	0.35	0.10	0.69	0.42	0.47
		Average	1.21	1.27	1.14	0.60	0.63	0.63	0.75	0.84	0.64	0.14	0.12	0.07	0.32	0.31	0.43
		Standard Deviation	0.16	0.23	0.19	0.07	0.11	0.08	0.15	0.17	0.12	0.03	0.06	0.01	0.14	0.09	0.14

Table 8: Summer 2021 Engineering Test Results

BYD buses consumed an average of 1.14 kWh/km, achieving the lowest/best energy consumption rate during mild ambient temperatures in the summer season on 30% of the routes; however, with winter performance at 1.66 kWh/km, BYD had the highest consumption rate on 67% of the routes.

NFI buses consumed an average of 1.21 kWh/km, and achieved the lowest/best energy consumption rate during mild ambient temperatures in the summer season on 23% of the routes; however, with winter performance at 1.32 kWh/km, NFI had the lowest consumption rate of all three buses on 84% of the routes.

Proterra buses consumed an average of 1.27 kWh/km, and achieved the lowest/best energy consumption rate during mild ambient temperatures in the summer season on 9% of the routes. In the winter, Proterra buses achieved an average of 1.56 kWh/km and the highest consumption rate on 28% of the routes.

Overall, these trends fall in-line with results reported in April 2021. From an operational standpoint, it is more important to have predictable and reliable range through all seasons that it is to achieve low energy cost. Proterra and BYD still achieve between 20% and 30% less range in the winter than they do in the summer but this difference has improved by 20% since the last head to head engineering tests performed in 2020.

		BYD	New Flyer	Proterra	Nova HEV
Energy Consumption (Winter)	April 2021	!	✓	!	N/A
	April 2022	!	✓	!	N/A

Figure 11 – Dashboard Final Results for Head-to-Head Winter Energy Consumption

		BYD	New Flyer	Proterra	Nova HEV
Energy Consumption (Summer)	April 2021	N/A	N/A	N/A	N/A
	April 2022	!	✓	!	N/A

Figure 12 – Dashboard Final Results for Head-to-Head Summer Energy Consumption

National Research Council Canada (NRC)

The TTC has partnered with NRC to study the performance of the TTC's eBus fleet. Since the start of the TTC's eBus evaluation, in-service data and head-to-head test results have been shared in order to assess the performance (i.e. energy consumption, electricity demands and emissions), maintenance requirements and operational requirements for the eBus fleet. The goal is to demonstrate how the buses are operating in the trial, and explore the reasons why. The full scope of the work consists of four quarterly status update reports, three status update reports on the head-to-head (H2H) controlled testing of the buses, and a cumulative final report evaluating the entire year of operation. To date, the findings of these reports have matched the TTC's own findings. The final reports will be shared with the broader transit community to help them understand all the various factors that drive energy consumption and inform their future procurement decisions.

HVAC Stationary Test

A stationary HVAC test was performed in the winter and summer seasons to evaluate the relative performance and energy efficiency between bus OEM. Each eBus and a Nova Hybrid bus was tested. The buses were instrumented with eight thermocouples along the interior described in the table below. The buses were left to soak overnight outside at a common garage and parked side by side to ensure they all return to ambient temperature. In the winter test, the measurements were take in the morning to achieve coldest temperatures in the day. In the summer, the measurements were taken in the afternoon to achieve the hottest temperatures in the day. On a given day, the buses were started at the same time at the maximum HVAC setting and the data was recorded simultaneously for approximately one hour. These tests were repeated three times.

The summarized data takes the average value of the thermocouples in the driver area and the cabin area to compare both values relative to each bus.

Thermocouple number	Location
1	Driver Area – Seat headrest
2	Driver Area – Steering wheel
3	Driver Area – foot area below dash
4	Cabin – Lower deck near front wheel
5	Cabin – Lower deck middle
6	Cabin – Lower deck near exit door
7	Cabin – Upper deck near front
8	Cabin – Upper deck near rear

Table 9 – Thermocouple Location Summary

HVAC Stationary Test – Winter Test Results

The results of the test are consistent with the In-Service and Head-to-Head results. Proterra is the largest consumer of the OEMs in terms of energy consumption followed by BYD, then NFI. In all instances the driver area is heated relatively quickly as this also needs to meet windshield defrosting requirements. The cabin heating is significantly slower and it is worth noting that of the eBuses, Proterra cabin heating rises the slowest. The Nova Hybrid heats up the slowest, but this due to the fact that it relies on engine heat, which was idling the entire time. This was run for reference only, but there are no issues to note of inadequate heat for Nova Hybrid buses in service.

It is also worth noting the significant difference in temperature ramp up times with different ambient temperatures. This would result in additional time to heat up a bus for service at the start of the day. TTC Engineering is working to develop a cabin pre-heating strategy with the OEMs as this was identified as an opportunity for further energy savings to improve in-service range.

The results are shown for each of the three runs conducted in the figures and table below.

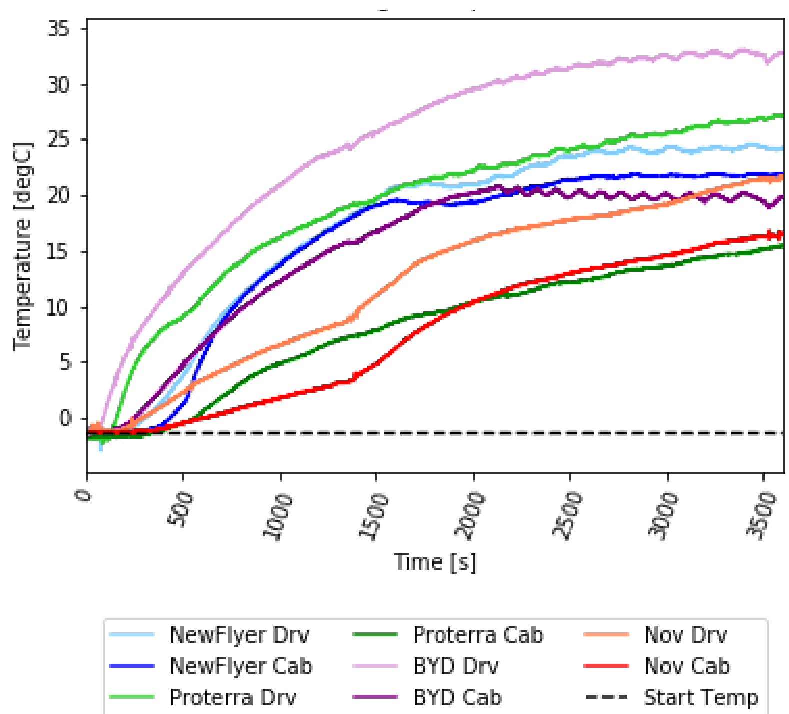

Chart 46 – HVAC Stationary Winter Test Results (Run1)

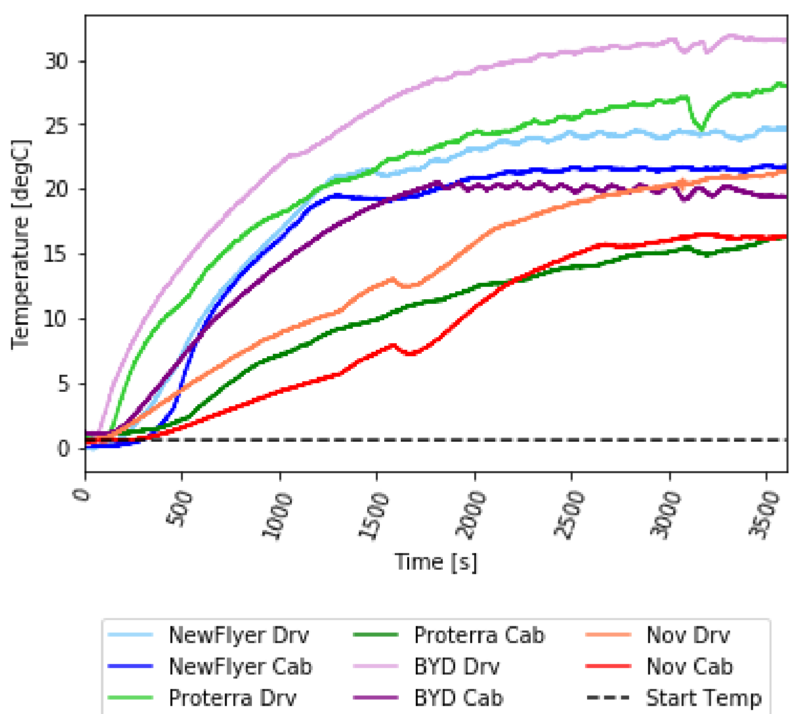

Chart 47 – HVAC Stationary Winter Test Results (Run2)

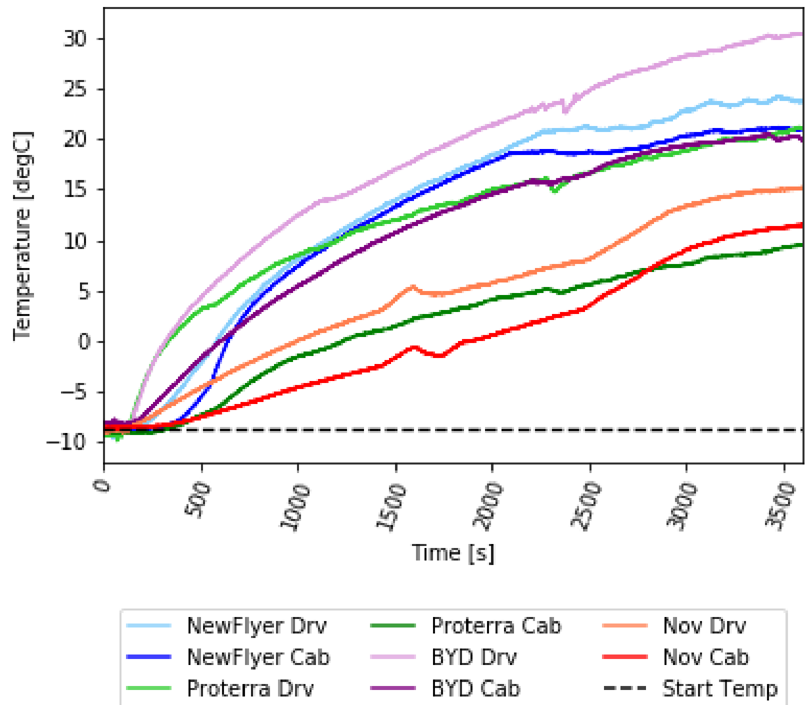

Chart 48 – HVAC Stationary Winter Test Results (Run3)

2021 Winter HVAC Stationary Test						
Run Number	Bus Type	Driver Area Avg Temp		Cabin Area Avg Temp		Energy Used
		Start [°C]	End [°C]	Start [°C]	End [°C]	[kWh/h]
1	New Flyer	-1.5	24.2	-1.4	21.9	16.53
	Proterra	-1.9	27.0	-1.7	15.4	30.22
	BYD	-1.3	32.8	-1.1	19.8	20.17
	Nova	-1.2	21.6	-1.3	16.5	N/A
2	New Flyer	0.0	24.7	0.2	21.7	15.48
	Proterra	0.8	28.0	1.1	16.4	28.79
	BYD	0.4	31.5	1.2	19.4	18.46
	Nova	0.6	21.4	0.6	16.4	N/A
3	New Flyer	-9.1	23.7	-8.8	20.9	16.32
	Proterra	-9.3	21.0	-9.1	9.5	32.21
	BYD	-8.5	30.4	-8.1	19.8	18.68
	Nova	-9.0	15.2	-8.6	11.5	N/A

Table 10 – HVAC Stationary Winter Test Results Summary

HVAC Stationary Test – Summer Test Results

The results of the test are again consistent with the In-Service and Head-to-Head observations. The energy consumption of each bus is more consistent with one another. BYD seems to have the strongest cooling capability as it cools both the driver and cabin area fastest. The other buses, including the Nova, cool the driver area slower. It is worth noting, there was a momentary issue in the data logger on Run 3 at the 1000s mark but this affected all logs equally and the data remains valid.

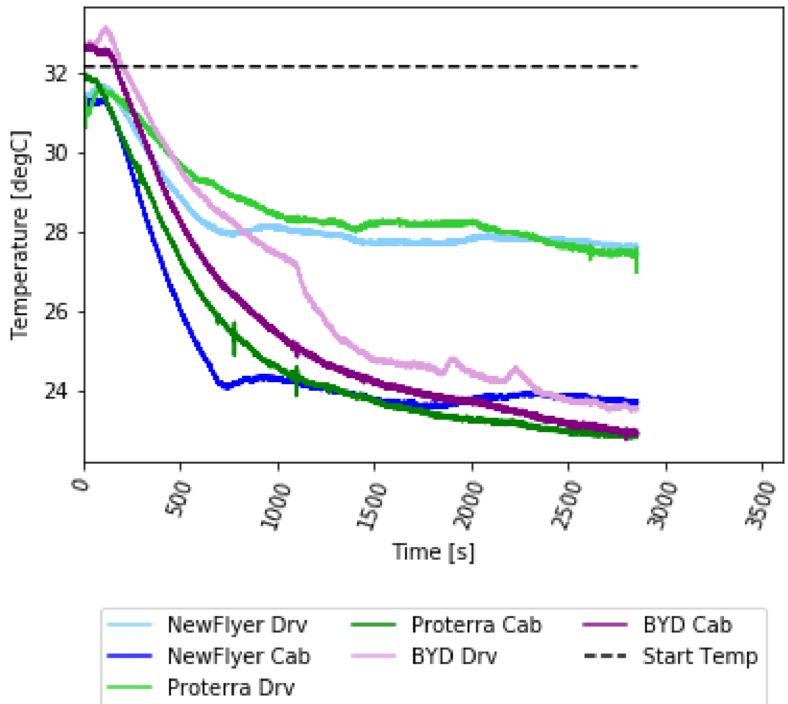

Chart 49 – HVAC Stationary Summer Test Results (Run1)

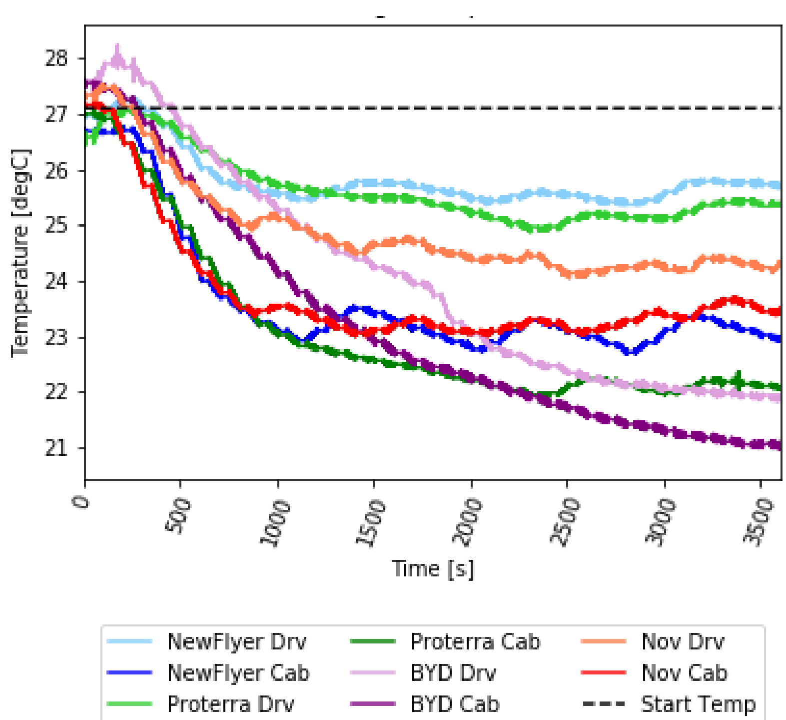

Chart 50 – HVAC Stationary Summer Test Results (Run2)

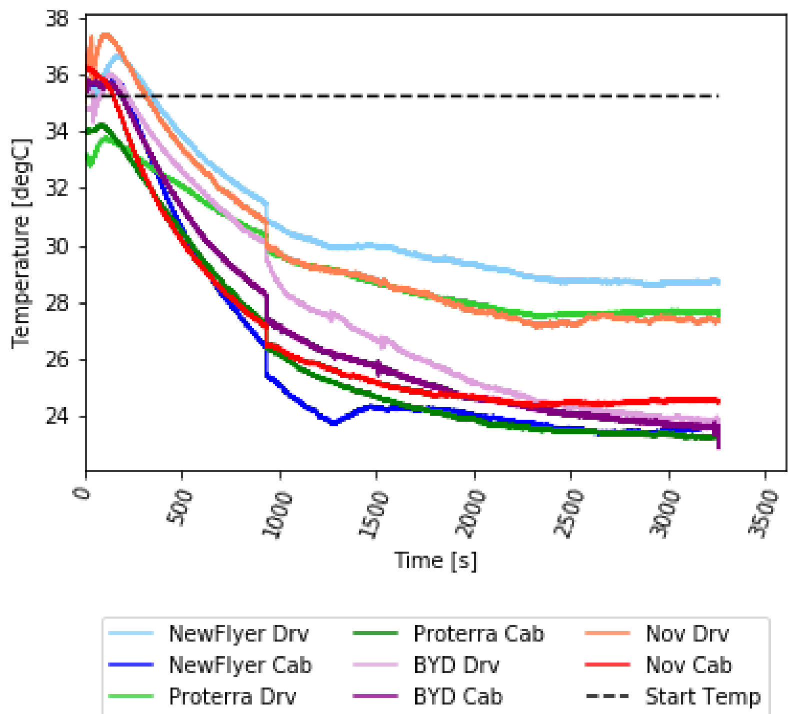

Chart 51 – HVAC Stationary Summer Test Results (Run3)

2021 Summer HVAC Stationary Test						
Run Number	Bus Type	Driver Area Avg Temp		Cabin Area Avg Temp		Energy Used
		Start [°C]	End [°C]	Start [°C]	End [°C]	[kWh/h]
1	NewFlyer	31.4	27.6	31.3	23.7	9.15
	Proterra	31.1	27.4	31.9	22.9	9.58
	BYD	32.7	23.5	32.6	22.9	10.79
	Nova	N/A	N/A	N/A	N/A	N/A
2	NewFlyer	26.9	25.7	26.7	22.9	7.36
	Proterra	26.6	25.4	27.0	22.0	6.46
	BYD	27.6	21.9	27.5	21.0	8.33
	Nova	27.3	24.3	27.1	23.4	N/A
3	NewFlyer	35.6	28.7	35.7	23.7	11.18
	Proterra	33.1	27.6	34.0	23.3	9.79
	BYD	34.8	23.9	35.7	23.6	10.08
	Nova	35.2	27.4	36.3	24.5	N/A

Table 11 – HVAC Stationary Summer Test Results Summary

Lessons Learned and Next Steps:

The data collected to date has provided insight to the challenges of electric bus technology and highlighted several opportunities for improvements to ensure the adoption of zero emissions technologies in future procurements.

1. Develop strategies for eHeat management to increase in-service range, including reducing electric heating use and cabin pre-heating strategies;

2. Develop a strategy to monitor and measure battery health and performance over the service life of eBus and electric vehicles;

3. Work with partners, such as NRC, to develop models to more accurately characterize bus range in service;

4. Work with OEMs to optimize acceleration and regeneration profiles to optimize energy efficiency in service; and

5. Develop strategies to optimize energy usage out of service to reduce overall site consumption.

Vendor Performance

The vendor performance domain is used to monitor the performance of vendor's quality and contractual requirements. Throughout the execution of the contracts with the three eBus vendors, the TTC has been monitoring the following metrics to track vendor performance, including:

- Compliance to the vehicle delivery schedule;
- Manufacturing facility quality audit;
- Quality defects (snags);
- Duration to final acceptance;
- 30-day reliability;
- Contract deliverables;
- Canadian content review; and
- Training

<u>Duration to Final Acceptance</u>

This measures the average time taken from delivery of the vehicle until the bus receives the final acceptance certificate (FAC) and is deemed ready for service. The FAC is issued to the vendor when all the quality defects identified during the commissioning of the bus are repaired to the satisfaction of the TTC.

Nova required on average of 50 days to achieve FAC. BYD took on average 242 days, with the delays largely attributed to excessive lead-time for parts and lack of local resources to repair buses. Proterra took on average 136 days, with the delays generally a result of insufficient resources on site due to COVID-19. NFI took on average 94 days, with the delays partially attributed to charging defects. These results have not changed since April 2021.

		BYD	New Flyer	Proterra	Nova HEV
Duration to Final Acceptance	April 2021	!	−	!	−
	April 2022	!	−	!	−

Figure 13 – Dashboard Final Results for Duration to Final Acceptance

Lessons Learned and Next Steps:

1. Through a comprehensive review of commercial terms against industry peers and across modes (i.e. bus, subway and streetcar), the TTC is restructuring its milestone payments. Included in this restructure is a higher milestone payment percentage due at FAC in order to motivate vendors to improve quality and responsiveness during the acceptance process.

Updates:

1. The TTC has restructured its milestone payments for the next bus procurements starting with hybrid-electric, to moving away from a high percentage due upon delivery (75%) to the following:
    - v. 20% upon Contract Award (notice to proceed)
    - vi. 10% upon Preliminary Acceptance Certificate (PAC)
    - vii. 50% at Final Acceptance Certificate (FAC)
    - viii. 20% upon achieving the 30-Day Reliability requirement

30-Day Reliability

As part of the contract requirements, the final milestone payment (5%) for each bus is contingent on the bus operating reliably for a period of 30 consecutive days from the time it first enters service. If the bus experiences an in-service failure as a result of a warrantable defect during these first 30 days, the clock resets until 30 consecutive days of no defects is achieved. Listed below is the average number of days taken for each bus vendor to achieve this 30-Day Reliability target.

- Nova required 38 days;
- NFI required 64 days;
- Proterra required 131 days (increase of 18 days from April 2021); and
- BYD required 244 days (increase of 84 days from April 2021).

		BYD	New Flyer	Proterra	Nova HEV
30-Day Reliability	April 2021	!	−	!	✓
	April 2022	!	−	!	✓

Figure 14 – Dashboard Updated Results for 30-Day Reliability

The length of time required to obtain the 30-Day Reliability metric generally reflects the manufacturing quality of the bus vendor and is an early indicator of bus reliability. As with the longer-term reliability measure of Mean Distance Between Failures, failures within this 30-day contractual period negatively impact customers.

Lessons Learned and Next Steps:

1. The TTC is restructuring its milestone payments. Included in this restructure is a larger percentage due upon achievement of the 30-Day Reliably requirement.

Updates:

1. The TTC has restructured its milestone payments for the next bus procurements. The percentage due upon achievement of the 30-Day Reliability requirement has been increased to 20% from 5%.

<u>Contract Deliverables</u>

This metric is the percentage completion of contract deliverables identified in the contract. Deliverables include: parts and maintenance manuals, test reports, part application approvals and drawings. The contract, which was the same for each vendor, required a total of 138 deliverables. BYD has satisfied 99% of these deliverables, NFI 100% and Proterra 100%. BYD has only one outstanding item but it is very significant. To date, BYD has yet to complete the four-post shaker testing of their frame structure

		BYD	**New Flyer**	**Proterra**	**Nova HEV**
Contract Deliverables	April 2021	⊖	✓	✓	N/A
	April 2022	⊖	✓	✓	N/A

Figure 15 – Dashboard Preliminary Results for Contract Deliverables

Lessons Learned and Next Steps:

1. BYD to complete four-post shaker testing of bus frame structure.

<u>Training</u>

The TTC has experience with hybrid-electric buses that have a similar drivetrain and propulsion controls to that of a battery-electric bus. However, additional training was required for the three new eBuses on some of the new systems found on this bus, such as plug-slide doors on the Proterra or ThermoKing HVAC on the NFI. To date, a total of 3,983 employees have been trained on eBus specific courses. Below is a table summarizing eBus training courses available and the number of employees trained thus far for each:

Course	BYD	New Flyer	Proterra
Operation & Familiarization - Operators	1096	1198	1089
Operation & Familiarization - Maintainers	93	56	47
Technical Familiarization	Pending	104	37
High Voltage Safety	Pending	41	52
Multiplex & Schematics	Pending	29	13
Maintenance 1	Pending	45	19
Maintenance 2	N/A	N/A	31
Doors	N/A	N/A	12
HVAC	Pending	18	3

Table 12: eBus Training Completion Status

In 2021, COVID-19 restrictions continued to impact training resulting in additional OEM train-the-trainer courses being conducted virtually. The TTC's Operations Training Centre has delivered operator training to more than 3,383 operators and 196 maintainers.

		BYD	New Flyer	Proterra	Nova HEV
Training	April 2021	✓	✓	✓	N/A
	April 2022	✓	✓	✓	N/A

Figure 16 – Dashboard Results for Training

Charging System Performance

<u>Description of Charge Systems</u>

The current charging infrastructure installed consists of two types, DC Fast Chargers and AC Fast Chargers. DC Fast Chargers are the predominant form of transit and heavy vehicle charging in North America. The AC Fast Charger while offering significant economy and space savings in the garage, is not offered in a standardized North American package suitable for transit buses at this time.

The DC Fast Charger performs the conversion from AC power to DC power tailored to the vehicles battery and state of charge. This conversion requires large and expensive power conversion equipment but allows for much higher charge rates and compatibility with a wide range of vehicles from cars to heavy trucks. The AC Fast Charger relies on power conversion equipment already present on the bus so limited infrastructure is required. While a standard exists for this type of charger, they are compatible with vehicles that are commercially available at this time.

The DC Fast Chargers are all ABB model HVC-150 and are used at Arrow Road Garage to charge our NFI fleet and at Mount Dennis Garage to charge our Proterra fleet. Each charger consists of one 150 kW charger connected to two eBuses via cable connections. As DC chargers can only charge a single vehicle at a time, the charger alternates between the two connected buses in what is called sequential charging. For reporting purposes, we are counting each charger unit as two charge points. The AC Fast Chargers at Eglinton, are a proprietary BYD system with a single charger connected to each bus via dual cables. Each unit with it's pair of cables is counted as a single charge point.

Site	Arrow Garage	Mount Dennis Garage	Eglinton Garage
Type of Chargers	DCFC	DCFC	AC Fast Charge
Maximum Power	150 kW	150 kW	80 kW
Quantity of Charge Points	25	25	10

Table 13: Summary of Installed Charge Systems

Charge Point Performance

Charger performance has been satisfactory in 2021. The warranty for the ABB DC Fast Chargers expired on July 31, 2021, and the TTC is now responsible for maintenance which is performed by the charger manufacturer until operating and maintenance of this equipment can be transferred to PowerON. BYD charger warranty expires September 9, 2022.

Site	Arrow Garage	Mount Dennis Garage	Eglinton Garage
Number of Charge Sessions	10,846	5,142	2,660
Number of charge point failures	15	11	1
Total charge point outage time (days)	51	115	41
Availability	99.4%	98.7%	98.9%
MTTR (days)	3.75	12.7	n/a

Table 14: Reliability Metrics Summary

Notes:

- The statistics for Eglinton do not include partial failures. There were eight defective cables that caused intermittent slow charging.

- Mean Time to Repair (MTTR) includes weekends, however, charger repairs are not currently performed on weekends to keep costs down for the availability required of the fleet.

- Failures do not include charger faults resolved through charger resets as these do not typically decrease eBus service availability.

The most common failure seen in both systems was cable and retaining clip damage. For the ABB chargers, this was generally due to cables run over by buses. For the BYD cables, the cables were defective, with the smaller control wires breaking likely due to the bending of the flexible charge cords. BYD has an improved design and cables are being replaced under warranty as the original cables fail. While cable management systems are in place, they are not always used and cables have been left on the ground and susceptible to being run over by the buses. To reduce the chances of an operator running over a cable, high-visibility banding has been added and improved cable management is being investigated.

The retaining clips on the ABB cables are a safety device that allows the vehicle to lock the connecter in the eBus charge port receptacle during charging. This prevents contact damage or possible injury should the cable be removed during a charge session. The cause of the retaining clip failure is believed to be misuse, as the clips are plastic and can be damaged by trying to remove a locked connector or by impact to the connector holster on the dispenser. The damage snaps the retaining clip off which prevents the bus from locking the connectors in place during the charging. Currently this is neither a user-serviceable nor ABB-repairable part and failure requires purchase of a new or remanufactured cable. The TTC is investigating methods to replace this part without replacing the entire cable and is pressing ABB for an improved design.

The remaining failures were generally communications modules or circuit boards. Only one failure of a significant component was reported and that was a power conversion module. Due to the design of the ABB chargers, this did not remove the unit from service but limited the maximum power output.

Other issues

All TTC chargers are currently using cellular communications for remote monitoring by the TTC, the charger vendor and control by the smart charge system. While the systems have sufficient reliability for remote monitoring, the chargers at Eglinton have suffered from multiple outage issues caused by the cellular carrier that suggest wired communication will be required for large scale charger control systems.

Smart Charge System

To manage the charging costs for eBuses, an energy management system is needed to ensure eBuses are fully charged for the route it will be dispatched on while minimizing infrastructure requirements and electricity cost. This ‘smart charge’ system was developed in 2021 by eBus telematics provider Viriciti and controls the ABB chargers using a common, open communications standard known as Open Charge Point Protocol (OCPP) which is widely supported by many charger vendors. During testing, problems were detected in the charger-side implementation of OCPP. ABB is aware of the issue and has been working on updates to the control software to resolve this issue.

		BYD	New Flyer	Proterra	Nova HEV
Charging System Performance	April 2021	✓	✓	✓	✓
	April 2022	✓	✓	✓	✓

Figure 17 – Dashboard Updated Results for Charging System Performance

Lessons Learned and Next Steps:

1. Charge systems have proven reliable and repairs are generally simple once parts are available. As the eBus fleet grows, it will be necessary to ensure that service providers have well-trained, local staff as well as common spare parts to minimize time to repair.

2. Cable management needs to be improved and included in future charging cables. The switch to pantograph charging will alleviate this issue for the eBus fleet.

3. Cellular communication is sufficiently reliable for small-scale charger deployments, but highly reliable wired communications systems will be required for critical charging infrastructure to prevent outages from affecting service.

4. Charger software needs to be evaluated for interoperability/compatibility with the smart charge systems ideally as a qualification prior to purchase.

<u>Charging Infrastructure Deployment Plan</u>

At the February 10, 2022 TTC Board Meeting, the Board approved proposed negotiated terms with PowerON Energy Solutions LP (PowerON) for the co-investment, ownership, design, build, operation, and maintenance of eBus charging systems electrification infrastructure. Through this innovative business delivery model, PowerON has been progressing the planning and engineering of works required to implement TTC's Green Bus Program. Below is a schedule of planned eBus procurements and how they align with the planned charging infrastructure implementation by bus garage.

	Year	2022	2022	2022	2022	2023	2023	2023	2023	2024	2024	2024	2024	2025	2025	2025	2025	2026	2026	2026	2026	2027	2027	2027	2027	2028	2028	2028	2028	2029	2029	2029	2029
	Quarter	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Arrow	eBus Procurement													42	42	21															26	41	42
	Chargepoints Available	25	25	25	25	25	25	25	25	25	25	25	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	260	260	260	260	260
Birchmount	eBus Procurement							26	18												20	43	16										
	Chargepoints Available						44	44	44	44	44	44	44	44	44	44	44	44	123	123	123	123	123	123	123	123	123	123	123	123	123	123	123
Eglinton	eBus Procurement							24								21	41	42	1														
	Chargepoints Available	10	10	10	10	10	34	34	34	34	34	34	34	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139	278	278
Malvern	eBus Procurement											16	28																				
	Chargepoints Available										44	44	44	44	44	44	44	44	44	44	44	44		131	131	131	131	131	131	131	131	131	131
McNicoll	eBus Procurement												45																36	41	15		
	Chargepoints Available											45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	137	137	137	137	137	137	137
Mt Dennis	eBus Procurement																		41	42	24												
	Chargepoints Available	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132
Queensway	eBus Procurement											40															25	43	10				
	Chargepoints Available										40	40	40	40	40	40	40	40	40	40	40	40	40	40	118	118	118	118	118	118	118	118	118
Wilson	eBus Procurement								32			4											27	43	20								
	Wilson - Chargepoints Available							36	36	36	36	36	36	36	36	36	36	36	36	36	126	126	126	126	126	126	126	126	126	126	126	126	126
eBus Procurement Totals by Year						100				133				167				170				175				175				165			

Figure 18 – eBus Procurement Schedule vs Charging Infrastructure Availability

As seen in Figure 18 (same as large version found in Appendix B), implementation of charging infrastructure at each garage is typically ahead by three to six months of eBus deliveries. This is intentionally planned this way to ensure new eBuse procurements deliveries arriving cancan be charged and dispatched into service without delay.

Customer Experience

The customer experience domain focuses on understanding the likes and dislikes of customers with respect to the various configurations and features found on the three eBus types, which will ultimately inform future procurement specifications.

The TTC aims to provide a best-in-class customer experience. A goal of the eBus program is to engage customers, understand what is important to them and collect feedback to inform future bus procurements. All three eBus types have different interior configurations and seating layouts that will allow for ACAT and customer focus groups to evaluate what works best and inform future bus procurements. Shown below are the interior configuration of all three eBuses and how they compare to the Nova bus.

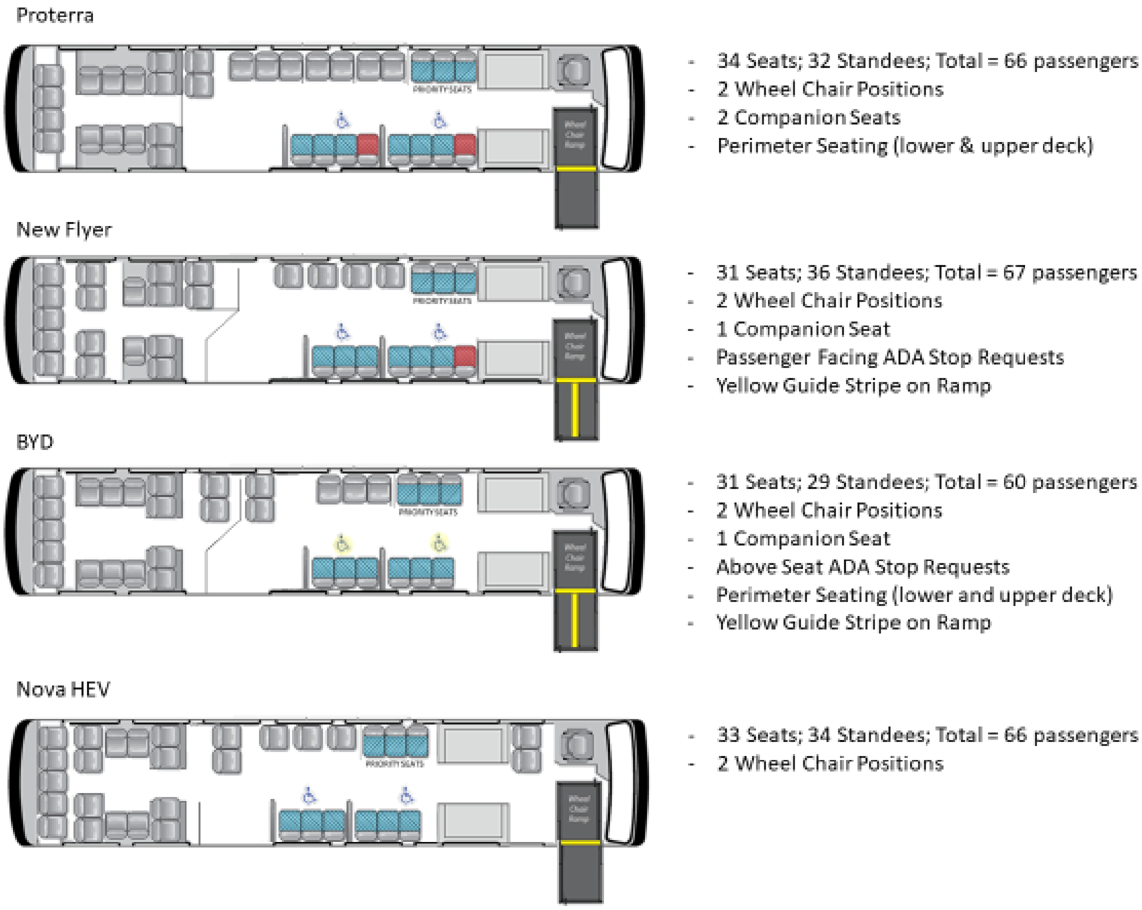

Figure 19 – Bus Interior and Seating Layout Comparison

The TTC completed two surveys to obtain customer feedback (Long-form customer survey and an online eBus survey).

<u>Bus Design Customer Survey</u>

The TTC, with support from Forum Research Inc. conducted a customer survey to help inform future bus procurements. The survey was conducted between February and March 2021 and took approximately 10 minutes for respondents to complete. A total of 1,002 TTC bus customers residing in Toronto and the GTA participated.

The survey was developed to better understand customer preferences on the following:

1. Standing capacity vs. seating capacity
2. Flip-up vs. fixed seating
3. Aisle vs. forward facing seating
4. Seat construction preferences
5. Personal device stowing
6. Stop request button vs. pull cord
7. Technology

A high level summary of the survey results is summarized below:

Results

- Overall, 70% of customers are satisfied with current TTC bus design.

- The majority of customers (60%) prefer more seating capacity over more standing capacity, with 90% saying seating capacity is important to their overall satisfaction.

- The majority of customers (64%) prefer flexible/flip-up seating over static/immovable seating, with 78% saying flexible seating is important to their overall satisfaction.

- The majority of customers (63%) prefer forward-facing seating over aisle-facing seating, with 77% saying forward-facing seating is important to their overall satisfaction.

- While customers reported no clear preference between padded fabric and plastic seats, hygiene and comfort were ranked as the most important seat attributes.

	Hygiene	**Comfort**	**Ease of Cleaning**	**Durability**	**Texture**
First rank	57%	35%	28%	11%	15%
Second rank	30%	31%	44%	28%	38%
Third rank	13%	34%	28%	61%	48%

- The majority of customers (63%) would prefer a dedicated area on a bus for customers travelling with strollers or other large items.
- The majority of customers (56%) prefer more vertical handles (poles) to overhead handle options.
- Almost half of customers (47%) ranked digital screens as the most important technology element to have on buses. Wi-Fi was ranked by 17% of customers as the most important technology element.

<u>Online eBus Survey</u>

The TTC conducted an online customer survey between February 2021 and January 2022. Survey links and QR codes were advertised on interior posters on the 60 eBuses in service. Each eBus model was given a unique link in order to compare results by vendor.

The survey was intended to provide a better understanding how the customer experience differs between eBus models and identify what works best for customers and what needs improvement. The survey requested feedback on the following:

1. Overall satisfaction with eBuse experience
2. Customer perceptions of different eBus attributes
    a. Noise level
    b. Seat comfort
    c. Smoothness of trip
    d. Seating layout (lower level and upper level)
    e. Rear exit door size
    f. Lighting
3. Comparison of eBus to conventional TTC buses
4. Comparison of eBus attributes to conventional TTC buses
5. Additional customer comments on TTC's eBus program

A total of 369 customers completed the survey, with the breakdown by bus manufacturer listed below:

- BYD: 166
- New Flyer: 87
- Proterra: 115

Results

1. Overall, how satisfied were you with your eBus experience?
    - 84% of customers were satisfied with their overall experience on an eBus
        - BYD: 83% of customers were satisfied
        - New Flyer: 91% of customers were satisfied
        - Proterra: 79% of customers were satisfied

2. eBus attributes by Bus Model - satisfaction levels with different vehicle elements (% very satisfied/satisfied):

Model	**Noise level**	**Seat comfort**	**Smoothness of trip**	**Seating layout (lower)**	**Seating layout (upper)**	**Size of rear door**	**Lighting**
BYD	83%	85%	76%	77%	77%	82%	85%
New Flyer	90%	88%	79%	75%	80%	95%	87%
Proterra	75%	82%	64%	69%	58%	86%	87%

Green – highest scores, Orange – lowest scores

Table 15 – Summary of eBus Satisfaction Levels

3. Overall, how does the eBus compare to other TTC buses you have been on?

- 79% of customers consider eBuses to be better than other TTC buses they have been on. 10% consider them to be about the same.
    - BYD: 83% of customers say it is better than other TTC buses. 9% think it is about the same
    - New Flyer: 85% of customers say it is better than other TTC buses. 12% think it is about the same.
    - Proterra: 69% of customers say it is better than other TTC buses. 11% think it is about the same.

4. eBus attributes by Bus Model - satisfaction levels compared to other TTC buses you have been on? (% much better/better)

Model	Noise level	Seat comfort	Smoothness of trip	Seating layout (lower)	Seating layout (upper)	Size of rear door	Lighting	Exterior style
BYD	85%	58%	70%	54%	61%	46%	55%	64%
New Flyer	86%	54%	73%	56%	71%	64%	68%	84%
Proterra	74%	64%	55%	59%	49%	69%	57%	71%

Green – highest scores, Orange – lowest scores

Table 16 – Summary of eBus Satisfaction Levels Compared to Other TTC Buses

Operator and Maintainer Experience

The operator and maintainer experience domain focuses on understanding the likes and dislikes of operators and maintainers with respect to the various configurations and features found on the three eBus models, which will ultimately inform future procurement specifications.

The operators and maintainers are integral to the successful deployment of eBuses. In April 2018, the TTC held information sessions with operators and maintainers at all bus garages/divisions. Each eBus manufacturer brought their demonstration vehicle to the TTC, which provided an opportunity for operators and maintainers to review the eBus and provide feedback.

The TTC has completed two rounds of surveys with both the operators and maintainers. The first survey was completed in March 2021 and a second survey was conducted in February 2022. The surveys were sent out to obtain feedback on the following items:

1. Noise levels
2. Ergonomics
3. Visibility/Sightlines
4. Ride Comfort
5. Acceleration

6. Steering and maneuverability
7. Braking
8. Night driving
9. Maintainability
10. Diagnostic Tools
11. Maintenance manual content and navigation
12. Parts manual content and navigation
13. Layout of maintenance components

Operator Experience

There were two bus operator surveys conducted; one in March 2021 and the other in February 2022. Arrow Road, Eglinton, and Mount Dennis Garages participated in these surveys. The surveys were voluntary. Between the two surveys, there were a total of 898 surveys completed, which represents approximately 23% of the operators at those three garages.

Respondents were given the following options to respond to the questions; very satisfied, satisfied, neither satisfied nor dissatisfied, dissatisfied and very dissatisfied. In addition, comments were also requested.

The specific questions that the operators were asked to reply to are listed below

1. Overall, how satisfied are you with the eBuses as compared to hybrid / diesel buses (garage dependant)?

2. How satisfied are you with the following aspects of the eBuses as compared to hybrid / diesel buses (garage dependant)?
    - Noise level
    - Ergonomics
    - Visibility/Sightlines
    - Ride Comfort
    - Acceleration
    - Steering/Manoeuverability
    - Braking
    - Night Driving

<u>BYD Summary</u>

Eglinton Garage operates the fleet of 10 BYD electric buses. The survey questionnaire asked the operators to compare the BYD electric buses against the diesel buses operating out of Eglinton Garage. A tabulated summary of the survey results for 2021 and 2022 is presented below.

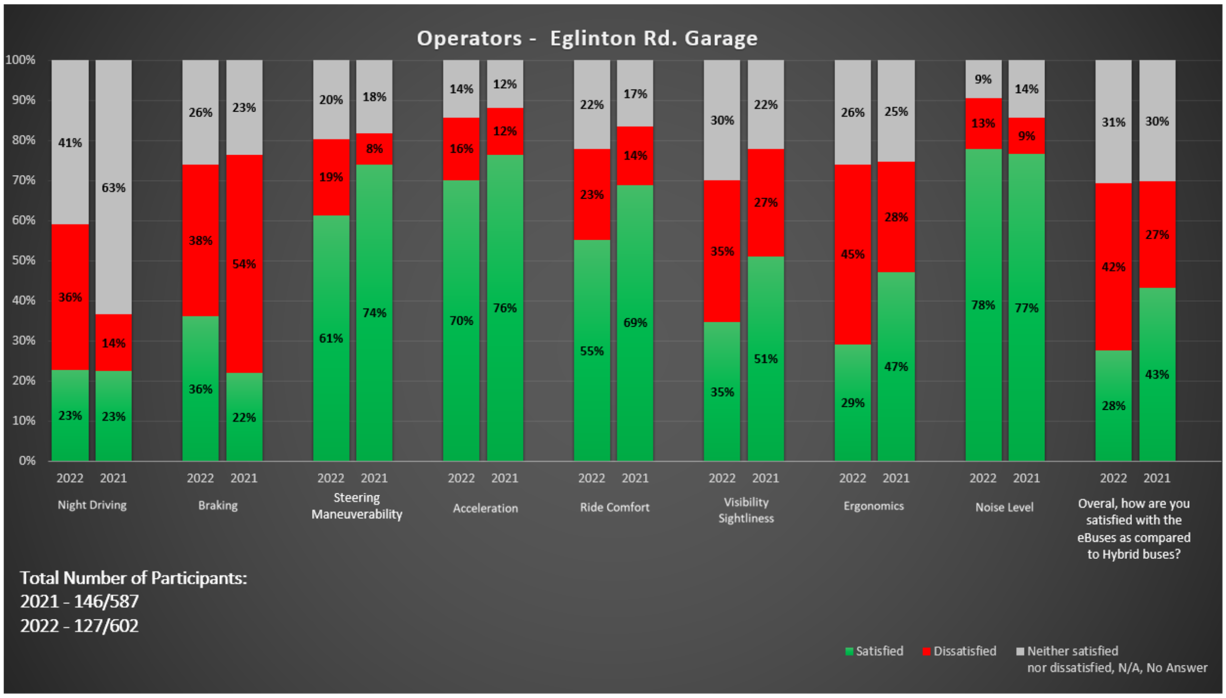

Chart 52 – Eglinton Garage Operator Survey Results

New Flyer Summary

Arrow Road Garage operates the fleet of 25 NFI electric buses. The survey questionnaire asked the operators to compare the NFI electric buses against the hybrid buses operating out of Arrow Road Garage. A tabulated summary of the survey results for 2021 and 2022 is presented below.

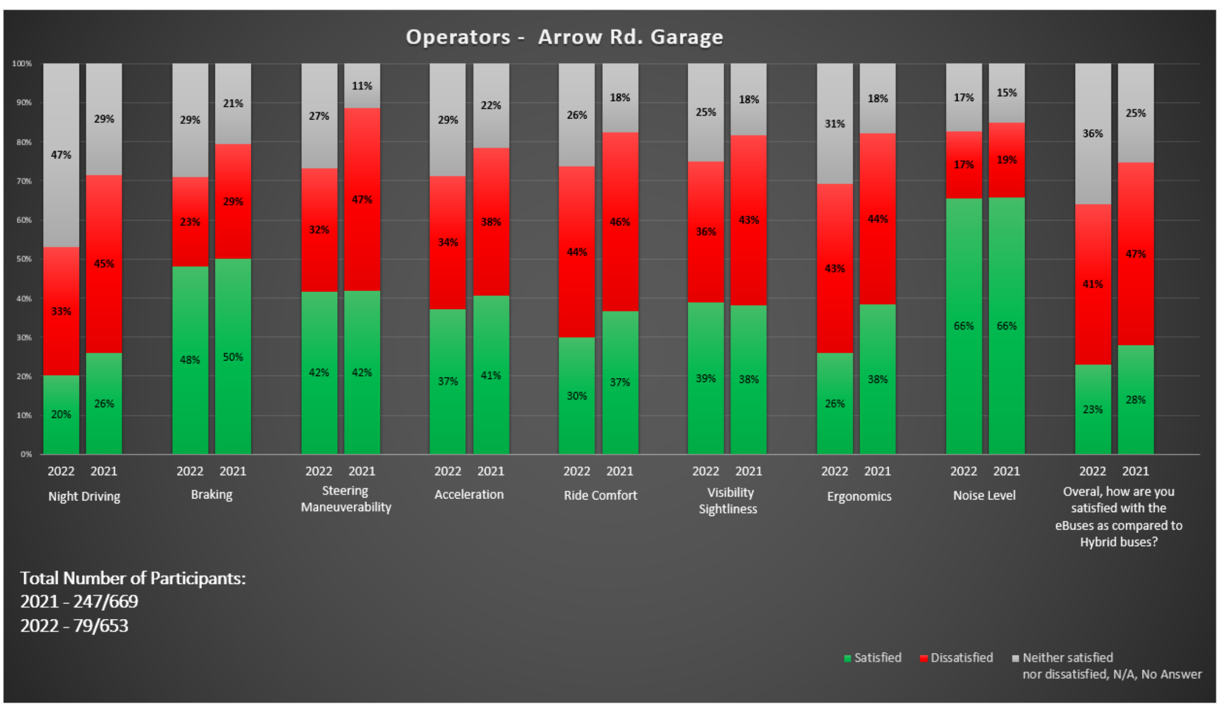

Chart 53 – Arrow Rd Garage Operator Survey Results

Proterra Summary

Mount Dennis Garage operates the fleet of 25 Proterra electric buses. The survey questionnaire asked the operators to compare the Proterra electric buses against the diesel buses operating out of Mount Dennis Garage. A tabulated summary of the survey results for 2021 and 2022 is presented below.

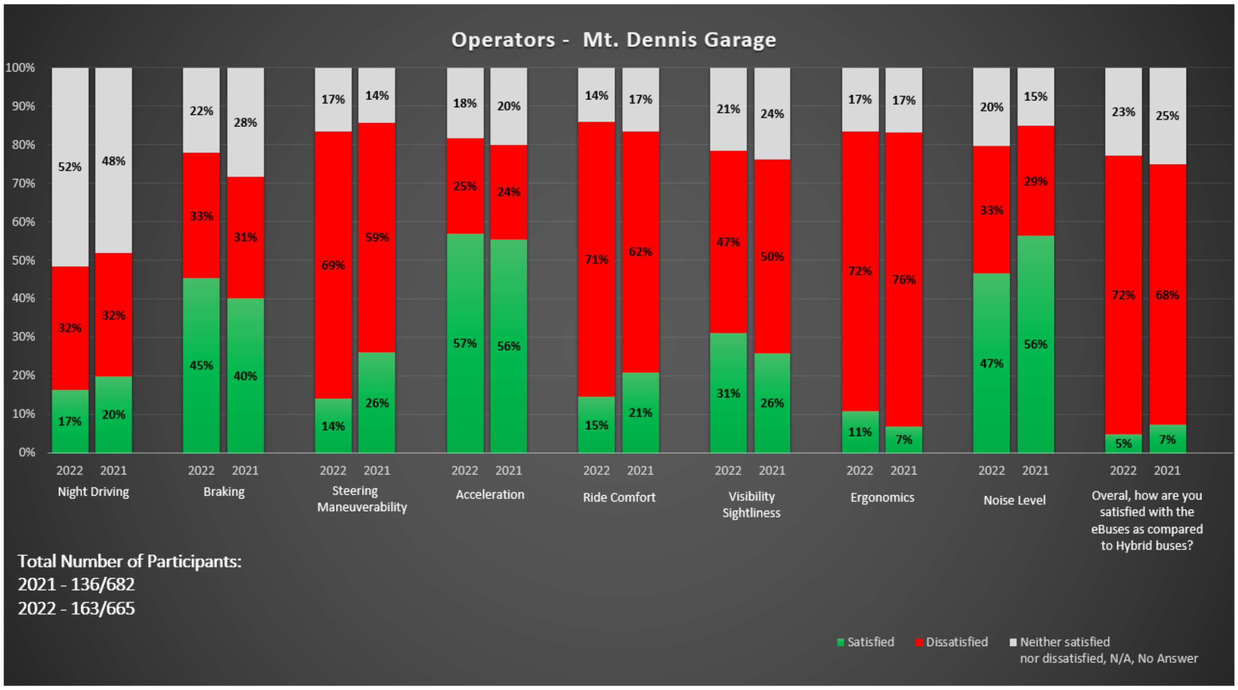

Chart 54 – Mt Dennis Garage Operator Survey Results

Operator Summary

The following is a summary of the operator survey results:

- Approximately 70% of the operators at Mount Dennis Garage were dissatisfied with the Proterra eBus when compared to a diesel bus. Operator respondents from Eglinton and Mount Dennis indicated that approximately 60% of them were satisfied or neither satisfied or dissatisfied when comparing the NFI and BYD electric buses to the other bus fleet at the respective garages.

- The BYD electric buses had the most favourable results from the surveys completed, scoring high in seven categories (> 70% satisfied or neither satisfied or dissatisfied); noise level, ergonomics, visibility/sightlines, ride comfort, acceleration, steering/manoeuverability and night driving. The only category that the BYD electric bus scored low (> 50% dissatisfied) was braking.

- The NFI electric bus scored high in two categories (> 70% satisfied or neither satisfied or dissatisfied); noise level and braking. However, approximately 40% of the respondents were dissatisfied with six categories: ergonomics, visibility/sightlines, ride comfort, acceleration, steering/manoeuverability and night driving.

- The Proterra electric buses scored poorly (>50% dissatisfied) in four categories; ergonomics, visibility/sightlines, ride comfort, steering/manoeuverability. However, they did score satisfactory (>50% satisfied) in two categories; noise level and acceleration.

- The most common write-in comments from the operators driving BYD buses were:
    - Dissatisfaction with the braking systems;
    - Glare/reflection on the front windshield during night driving; and
    - The location of the cup holder.

- The most common write in comments from the operators driving NFI buses were:
    - Braking and acceleration pedal locations, size and adjustment;
    - Small size of the driver’s compartment; and
    - Small size of the driver’ shield/barrier

- The most common write in comments from the operators driving the Proterra buses were:
    - Small size of the driver’s compartment;
    - The turning radius of the bus; and
    - The bus ramp kneeling issues.

Maintainer Experience

The were two bus maintainer surveys conducted, one in March 2021 and the other in February 2022. Arrow Road, Eglinton and Mount Dennis garages participated in these surveys. The surveys were voluntary. Between the two surveys, there were a total of 356 surveys completed, which represents approximately 78% of the maintainers at those three garages.

Respondents were given the following options to respond to the questions; very satisfied, satisfied, neither satisfied nor dissatisfied, dissatisfied and very dissatisfied. In addition, comments were also requested.

The specific questions that the maintainers were asked to reply to are listed below

1. Overall, how satisfied are you with the eBuses as compared to hybrid / diesel buses (garage dependant)?

2. How satisfied are you with the following aspects of the eBuses as compared to hybrid / diesel buses (garage dependant)?
    - Noise level
    - Visibility/Sightlines
    - Ride Comfort
    - Acceleration

- Steering/Manoeuverability
- Diagnostic Tools
- Maintenance manual content and navigation
- Parts manual content and navigation
- Layout of maintenance components

BYD Summary

Eglinton Garage maintains the fleet of 10 BYD electric buses. The survey questionnaire asked the maintainers to compare the BYD electric buses against the other fleet of buses operating out of Eglinton Garage. A tabulated summary of the survey results for 2021 and 2022 is presented below.

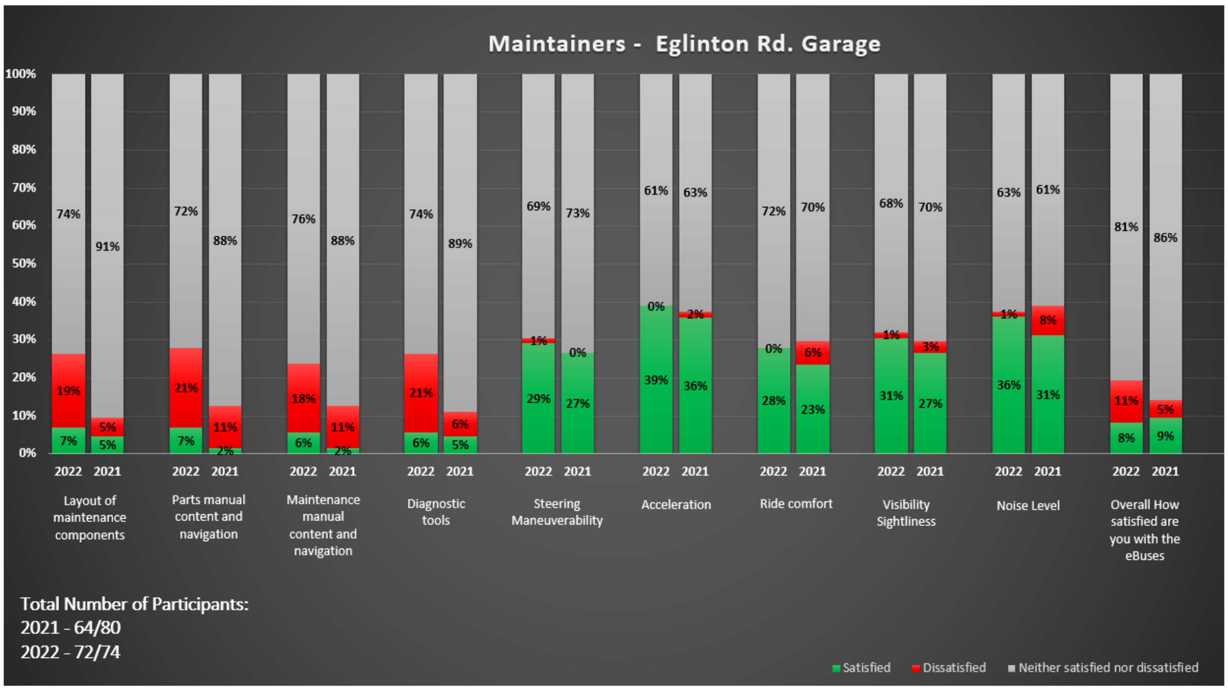

Chart 55 – Eglinton Garage Maintainer Survey Results

New Flyer Summary

Arrow Road Garage maintains the fleet of 25 NFI electric buses. The survey questionnaire asked the maintainers to compare the NFI electric buses against the other fleet of buses operating out of Arrow Road Garage. A tabulated summary of the survey results for 2021 and 2022 is presented below.

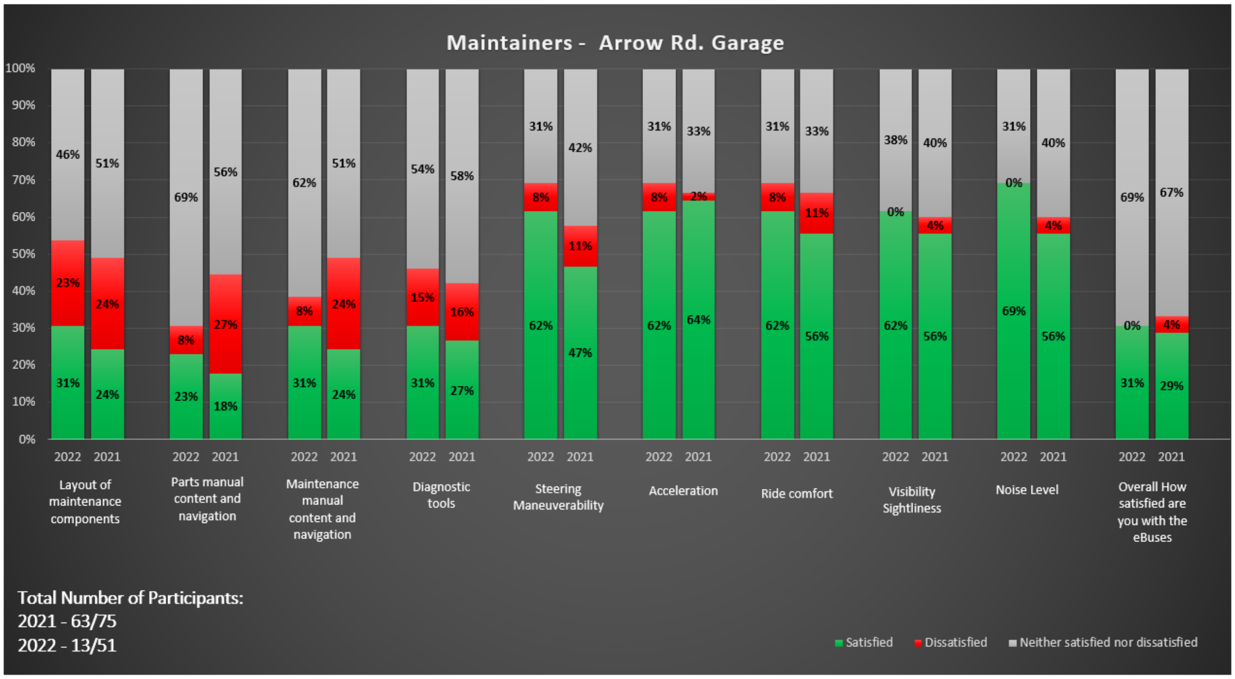

Chart 56 – Arrow Road Garage Maintainer Survey Results

<u>Proterra Summary</u>

Mount Dennis Garage maintains the fleet of 25 Proterra electric buses. The survey questionnaire asked the maintainers to compare the Proterra electric buses against the other fleet of buses operating out of Mount Dennis Garage. A tabulated summary of the survey results for 2021 and 2022 is presented below.

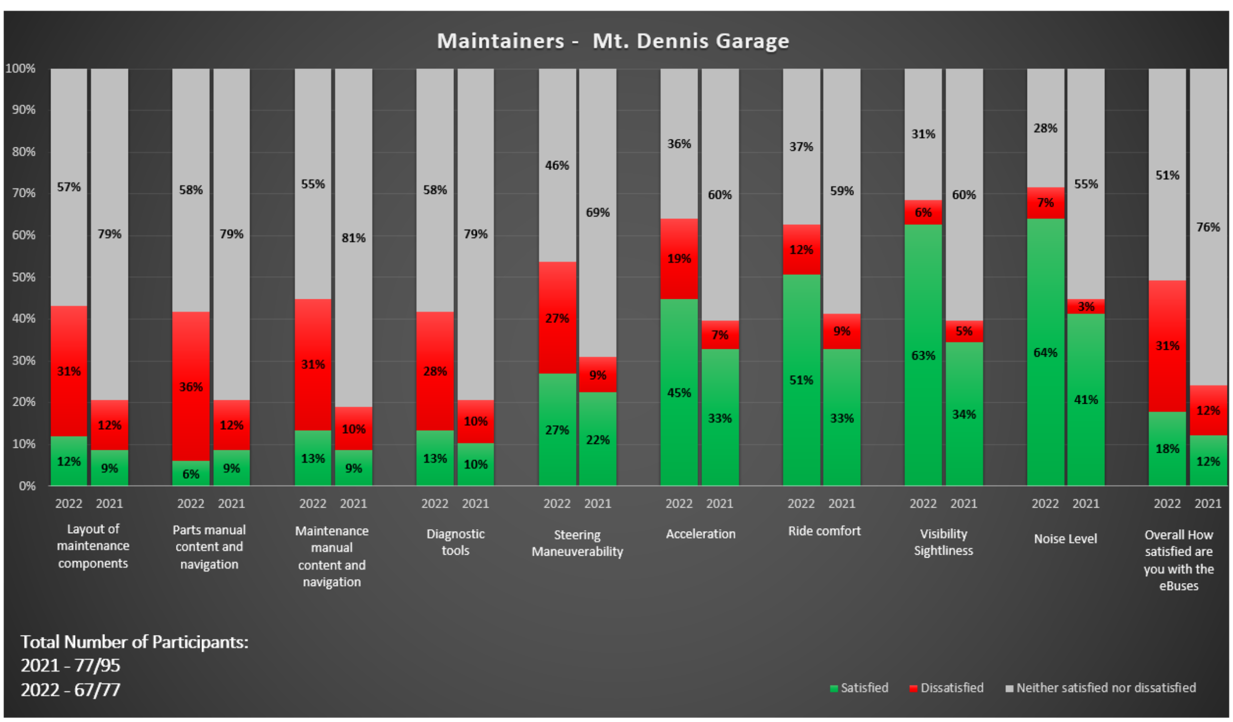

Chart 57 – Mount Dennis Garage Maintainer Survey Results

Summary

The following is a summary of the maintainer survey results:

- Overall 95% of the respondents from Arrow Road Garage (maintaining the NFI electric buses) and approximately 90% of the respondents from Eglinton Garage (maintaining the BYD buses) were either satisfied or neither satisfied or dissatisfied with these electric buses as compared to the remaining fleet of buses at those garages. However, the respondents from Mount Dennis Garage (maintaining the Proterra electric buses) indicated that approximately 15% were dissatisfied as compared to the other fleet of buses at this garage.

- Approximately 20% of the respondents at Eglinton Garage (maintaining the BYD buses) indicated they were dissatisfied with the following: diagnostic tools, maintenance manual content and navigation, parts manual content and navigation and layout of maintenance components. Approximately 30% indicated that they were satisfied in the following: noise level, visibility/sightlines, ride comfort, acceleration and steering/manoeuverability.

- The maintainers at Arrow Road Garage (maintaining the NFI electric buses) had the most favourable responses scoring high in all the categories (mostly over 85%).

- The maintainers at Mount Dennis Garage (maintaining the Proterra electric buses) scored high (>80% satisfied or neither satisfied or dissatisfied) in four categories: noise levels, visibility/sightlines, ride comfort and acceleration, and for the remaining categories; steering/manoeuverability, diagnostic tools, maintenance manual content and navigation, parts manual content and navigation and layout of maintenance components they scored well (>70% satisfied or neither satisfied or dissatisfied).

Maintainability

The maintainability domain evaluates the average time required to repair a bus defect. This domain is primarily affected by the difficulty of repair and parts availability and is significant as it affects bus availability.

All new buses procured include a two-year bumper-to-bumper warranty. As a result, the bus vendors continue to provided maintenance support on the advanced propulsion systems and charging infrastructure. However, Bus Maintenance is starting to perform some repairs internally.

The following chart provides an update on the average time required to repair a defect on the eBus fleet:

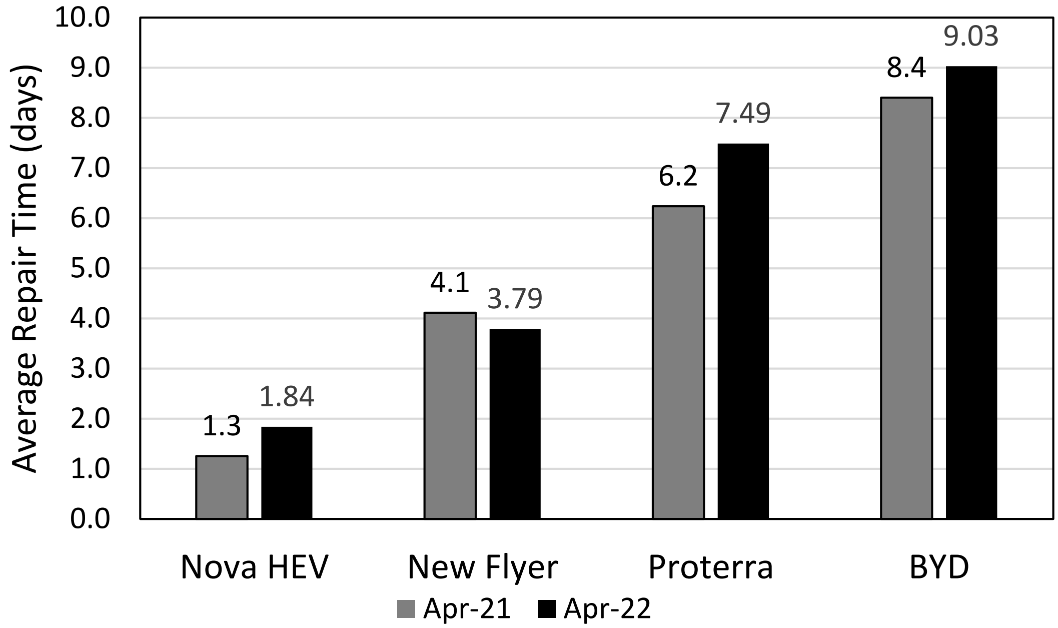

Chart 58 – Average Days to Repair

		BYD	New Flyer	Proterra	Nova HEV
Average Days to Repair	April 2021				
	April 2022				

Figure 20 – Dashboard Final Results for Average Days to Repair

The average defect repair time for eBus continues to be four–to-eight times higher than the Nova hybrid-electric (HEV) fleet of similar age. In fact, average repair times have increased in most cases except for NFI where a reduction of 8% was achieved. As reported in April 2021, there are a variety of reasons for this including complexity of propulsion faults, parts unavailability, vendor support and retrofit campaigns. Lengthy retrofit campaigns are the biggest driver of these results as repairs are often performed off-site and result in buses out of service for several days.

As reported in April 2021, BYD bus frame structure uses carbon steel that requires annual rust proofing treatment that keeps buses out of service for three-to-five days and introduces slip hazards in the storage areas.

Lessons Learned and Next Steps:

1. Time studies to be performed on all planned maintenance work to identify time savings when compared to a diesel and hybrid-electric buses.
2. For future procurements, a carbon steel frame coupled with an annual rust proofing program is not recommended.

Update:

1. A stainless steel frame structure coupled with six years of in-service experience has been specified for the next battery-electric bus procurement.

Total Lifecycle Cost

This domain measures both capital and operating costs of an eBus relative to a diesel bus. Total life-cycle cost is a combination of total operating and capital costs over the 13-year life of a bus. Complete maintenance costs are unavailable at this time as eBuses are still under warranty and the manufacturer is responsible for warranty repairs.

<u>Operating and Electricity Costs</u>

Electricity costs consist of three major components: the cost of electricity purchased at the market price, delivery fees that recoup the costs of operating the distribution and transmission systems, and the global adjustment, which is the cost of non-market electricity generation. To facilitate comparison between facilities, a simple $/MWh metric is reported. In 2021, the electricity cost to operate eBuses at Arrow Road was $140/MWh, $168/MWh at Eglinton and $141/MWh at Mount Dennis. Differences in monthly consumption patterns mean that average cost per kilometre of electricity varies both monthly and by garage.

The table below compares the annual average running costs for energy presented in $ per kilometre between eBuses and diesel fleets:

	Diesel Fleet [$/km]	BYD** [$/km]	New Flyer [$/km]	Proterra [$/km]	eBus Fleet [$/km]	Savings [$/km]
2018	$ 0.60	$ -	$ -	$ -	$ -	$ -
2019	$ 0.56	$ -	$ 0.25	$ 0.60	$ 0.25	$ 0.31
*2020	$ 0.41	$ 0.24	$ 0.31	$ 0.32	$ 0.30	$ 0.10
2021	$ 0.52	$ 0.27	$ 0.28	$ 0.41	$ 0.32	$ 0.20

* 2020 Low Diesel costs due to COVID-19

Table 17: Average Annual Running Energy Costs

A major change to the eBus electricity costs occurred in July when Arrow Road and Mount Dennis garages became Class ‘A’ customers under the IESO Industrial Conservation Initiative. This means that these garages pay global adjustment based on the amount of energy consumed during the five highest system peak hours over a year rather than based on typical consumer patterns. System peak hours have been between 11 am and 8 pm, with most occurring between 2 pm and 7 pm. As both the garage base load and the eBus charging load tend to peak outside these hours, our quantity of energy withdrawn is fairly low compared to the amount of energy drawn at facility peak hour. Eglinton Garage did not move to a Class ‘A’ customer due to the smaller BYD eBus fleet at Eglinton Garage not resulting in a monthly demand exceeding 1MW.

	Weighted Average Cost of Electricity ($/MWh)
Class A	115
Class B	168

Table 18: Class A versus B Annual Energy Cost Comparison

Energy consumption for the eBus program includes the energy used by the eBuses in operation as well as non-operating consumption. These non-operating uses include:

Loss Category	Examples
Conversion loss in the chargers	Energy lost as heat by the power converters during charging, losses in wires/transformers, etc.
Parasitic draw by chargers	Anti-condensation heaters in the chargers, controllers, etc.
Bus charging losses	Running the battery coolers, coulombic losses in the battery during the charge process
Bus standby losses	Maintaining cabin heat, auxiliary loads

Table 19: Non-Operating Energy Consumption Sources

Due to charger Open Charge Point Protocol (OCPP) issues, the chargers are not currently reporting all energy output. As a result, the losses between charger and bus cannot be quantified at this time. However, the total non-operating energy costs are 20% of the total energy costs for the eBus program.

The eBus transition is expected to have significant reductions in the diesel fuel budget and a reduction in bus maintenance costs. This will be partially offset by increases in electricity purchases and new costs for maintaining the charging infrastructure. As the fleet transitions from diesel, there will be further savings in ancillary costs such as:

- Reduced exhaust emissions in garages which will lead to reduced ventilation requirements and savings in natural gas and electricity costs.
- Reduced costs for fuel system maintenance including insurance costs associated with environmental liability

Accurate TTC maintenance costs for the eBus fleet are not yet available as the majority of repairs are still being performed by the bus OEM under the two-year, bumper-to-bumper warranty period. Below is a table of eBus repair and maintenance costs to-date compared to Nova hybrid bus which is similar in age to the eBus fleet.

	BYD [$/km]	New Flyer [$/km]	Proterra [$/km]	Nova HEV [$/km]
2018	$ -	$ -	$ -	$ -
2019	$ -	$ -	$ -	$ 0.011
2020	$ 0.006	$ 0.047	$ 0.027	$ 0.015
2021	$ 0.046	$ 0.053	$ 0.054	$ 0.133

Table 20: eBus Repair and Maintenance Costs

GHG Reduction

The greenhouse gases (GHG) reduction is primarily due to the avoidance of diesel fuel consumption. At an average fuel economy of 0.53 l/km, the TTC's Nova clean diesel buses release 1.4 kg of CO_2 per kilometre[1] driven. The generation of electricity also creates emissions through many factors including direct emissions from fuel-fired power plants. For Ontario, the average CO_2 emission for base load power is 32 g/kWh. The eBus fleet in 2021 averaged 1.62 kW/km (including all non-operating energy consumption sources), which equates to emissions of 0.05 kg CO_2/km. Based on the fleet mileage of 1,555,174 km in 2021, emissions associated with the electricity supply are 80.8 Tons CO_2. An equivalent clean diesel bus fleet would have emitted 2,177 Tons of CO_2.

Capital Budget

There is a capital cost premium associated with the purchase of eBuses over conventional buses. Although this is expected to be offset by the reduced running costs due to the distance a bus is driven over its life. The electrification infrastructure expenditure will be significant. However, the most expensive to install component, such as cables, switchgear and transformers all have life expectancies of 25 years or more. The biggest risk to this capital equipment is obsolescence of the chargers.

In addition, savings are expected in the following cost streams:

- Garage and station ventilation state-of-good-repair costs as existing systems can be replaced with smaller systems following the phase out of diesel buses.
- Reduction in tank replacement costs, in particular diesel, DEF, transmission and engine oil tanks.

Lifecycle Costs

Using the following assumption listed in Table 21, an estimate of eBus program life cycle costs have been estimated in Table 22.

[1] combustion of a litre of diesel releases 2.7 kg of CO2 per NRCAN/IPCC 2016 figures

Key Model Assumptions		
Parameter	**Value**	**Unit**
Diesel cost	1.03 to 1.90	$/l
Electricity cost	0.14	$/kWh
Electricity CO2 emissions	32	g/kWh
Bus Maintenance Cost	0.52	$/km
eBus Maintenance Savings	25%	
Escalation Factor	2.04%	
Baseline year	2022	

Table 21 – Lifecycle Cost Assumptions

A sensitivity analysis confirms that the largest, and most uncertain, variable among key model assumptions is the future cost of diesel. A range in diesel cost, of between $1.03 to $1.90, was based on the City of Toronto's current fuel contract price and the current cost of diesel at the pump, respectively. The range in escalation factor, of between 2.04% and 4%, was based on current the City of Toronto budget guidelines and the current Bank of Canada report, respectively.

		Total (to 2040)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Diesel Savings, Green Fleet to Baseline	million $	(2,275.09)	(10.91)	(18.69)	(27.09)	(40.36)	(55.72)	(68.07)	(80.90)	(93.56)	(108.41)	(123.82)	(137.74)	(148.58)	(163.23)	(178.18)	(184.81)	(198.09)	(205.01)	(212.21)	(219.71)
Bus Mtce Savings, Green Fleet to Baseline	million $	(331.06)	(0.52)	(1.55)	(2.89)	(4.63)	(6.47)	(8.44)	(10.48)	(12.49)	(14.86)	(17.32)	(19.88)	(21.88)	(24.68)	(27.55)	(28.60)	(30.52)	(31.61)	(32.75)	(33.94)
Net Operating Savings		(2,607.18)	(11.43)	(20.24)	(29.98)	(44.99)	(62.19)	(76.51)	(91.38)	(106.05)	(123.27)	(141.14)	(157.62)	(170.46)	(187.92)	(205.73)	(213.42)	(228.61)	(236.62)	(244.97)	(253.65)
Electrical Cost - est	million $	549.43	0.81	2.41	4.51	7.85	11.72	14.83	18.05	21.23	24.97	28.85	32.87	36.04	40.45	44.97	46.65	50.58	52.35	54.19	56.10
Mtce Cost - Electrical Infrastructure	million $	379.89	-	-	3.35	6.30	8.48	12.10	13.39	17.05	17.99	23.09	25.72	27.52	29.33	31.17	35.17	34.01	32.89	31.75	30.58
Net New Operating Expenses		929.32	0.81	2.41	7.86	14.16	20.21	26.92	31.44	38.28	42.96	51.94	58.59	63.56	69.77	76.14	81.81	84.59	85.24	85.94	86.68
Net Operating Budget Inpact	million $	(1,677.86)	(10.62)	(17.82)	(22.12)	(30.84)	(41.98)	(49.58)	(59.94)	(67.78)	(80.31)	(89.21)	(99.03)	(106.91)	(118.14)	(129.59)	(131.60)	(144.02)	(151.38)	(159.03)	(166.97)

Table 22 – eBus Life Cycle Cost Estimates (Operating)

Referring to Table 22 (see Appendix C for a larger view), the total operating budget savings estimated between 2022 and 2040 is approximately $2,606 million. The associated reduction in greenhouse gas emissions is 2,329 kilotons.

In 2040, when the capital costs and operating savings have normalized, the annual savings is projected to be $253.6 million.

Deployment Strategy

The operation of an electric bus is very different from that of a conventional diesel bus, and the deployment of eBuses across the TTC requires consideration of many factors for successful roll out in order to meet our commitment to be 50% zero emissions by 2028-2032 and 100% zero emissions by 2040.

The primary objective for the next five-to-six years is to mature operational readiness. The TTC is focused on evaluating the vehicle performance in the TTC's operating environment. The TTC operates buses on a variety of roads and in various urban conditions. It is critical to understand how these vehicles perform under all conditions and landscapes (topography, load, road configuration, weather). Therefore, the initial framework for deployment focuses on deploying eBuses on all routes operating from each garage to characterize performance while taking into consideration the current limitations in battery life and charging infrastructure.

During this phase and with the current vehicle limitations, eBuses are deployed using the following criteria:

- Summer months: A block of time in a schedule where the bus is dispatched from the garage and returns within approximately 200 kms of operation.
- Winter months: A block of time in a schedule where the bus is dispatched from the garage and returns within approximately 180 kms of operation.

It is anticipated that the next order of eBuses will have a longer range and therefore the target for a block of time can increase to approximately 275-300 kms.

In the medium term (by 2027-2028), as TTC procures more eBuses and each bus garage has a sufficient amount of eBuses to test from an operational perspective, eBuses will then be prioritized for deployment on routes that service Neighbourhood Improvement Areas (NIA) and overnight service.

An environmental noise study[2] for the City of Toronto, completed in 2017, found that a large proportion of residents in Toronto are exposed to residential sound pressure levels that exceed commonly applied guidelines. Residents living near major roads, in commercial residential land uses, and within lower income dissemination areas are particularly vulnerable to high noise exposures. The levels of noise observed in these areas are concerning as they exceed thresholds for negative effects on health observed in population-based studies. The study found that over 60% of residents in Toronto are exposed to traffic noise levels above 55 dBA during the day, and more than 90% of residents are exposed to nighttime total noise levels exceeding 45 dBA. Prioritizing the deployment of eBuses that travel through NIAs and on overnight routes, will help reduce the noise and emission levels in these areas.

In the long term, by 2037, it is expected that 100% of the bus fleet will be electric and prioritization will no longer be relevant as all routes will be deployed with electric vehicles.

Overall Program Performance Summary

The following figure provides a final summary of the findings of each evaluation domain for the eBus program.

Evaluation Domain	BYD	New Flyer	Proterra	Nova HEV
System Compatibility	!	✓	!	✓
Accessibility	✓	✓	✓	✓
Reliability - MDBF	!	✓	!	✓

[2] https://www.toronto.ca/wp-content/uploads/2017/11/8f4d-tph-Environmental-Noise-Study-2017.pdf

Distance Between Repairs - DBR	!	!	!	✓
Fleet Availability	!	✓	!	✓
Energy Consumption	!	✓	!	Not Evaluated
Fall Regen Rate	✓	−	−	Not Evaluated
Winter Regen Rate	−	−	✓	Not Evaluated
Winter Regen Rate - Wheel Slip Condition	!	−	!	Not Evaluated
Range - Summer	✓	✓	✓	Not Evaluated
Range - Winter	✓	✓	!	Not Evaluated
Vehicle Delivery Schedule	!	−	−	✓
Quality Review - Site 1	✓	✓	−	✓
Quality Review - Site 2	!	✓	−	✓
Quality Defects	−	−	−	✓
Duration to FAC	!	−	!	✓
30-Day Reliability	!	−	!	✓
Contract Deliverables	−	✓	✓	Not Evaluated
Canadian Content	✓	✓	✓	Not Evaluated
Training	✓	✓	✓	Not Evaluated
Average Days to Repair	!	−	!	✓
Customer Experience	✓	✓	✓	Not Evaluated
Operator Experience	✓	✓	✓	Not Evaluated
Energy Costs	✓	−	−	!
2 Year Performance	!	✓	!	✓

Figure 21: Final Evaluation Domain Summary

Appendix B

	Year	2022	2022	2022	2022	2023	2023	2023	2023	2024	2024	2024	2024	2025	2025	2025	2025	2026	2026	2026	2026	2027	2027	2027	2027	2028	2028	2028	2028	2029	2029	2029	2029
	Quarter	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Arrow	eBus Procurement													42	42	21															26	41	42
	Chargepoints Available	25	25	25	25	25	25	25	25	25	25	25	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	260	260	260	260	260
Birchmount	eBus Procurement							26	18												20	43	16										
	Chargepoints Available						44	44	44	44	44	44	44	44	44	44	44	44	123	123	123	123	123	123	123	123	123	123	123	123	123	123	123
Eglinton	eBus Procurement							24								21	41	42	1														
	Chargepoints Available	10	10	10	10	10	34	34	34	34	34	34	34	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139	278	278
Malvern	eBus Procurement											16	28																				
	Chargepoints Available										44	44	44	44	44	44	44	44	44	44	44	44		131	131	131	131	131	131	131	131	131	131
McNicoll	eBus Procurement												45																36	41	15		
	Chargepoints Available											45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	137	137	137	137	137	137	137
Mt Dennis	eBus Procurement																		41	42	24												
	Chargepoints Available	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132
Queensway	eBus Procurement											40															25	43	10				
	Chargepoints Available										40	40	40	40	40	40	40	40	40	40	40	40	40	40	118	118	118	118	118	118	118	118	118
Wilson	eBus Procurement								32			4											27	43	20								
	Wilson - Chargepoints Available							36	36	36	36	36	36	36	36	36	36	36	36	36	126	126	126	126	126	126	126	126	126	126	126	126	126
eBus Procurement Totals by Year						100				133				167				170				175				175				165			

Figure 1 - eBus Procurement Schedule vs Charging Infrastructure Availability

Appendix C

		Total (to 2040)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Diesel Savings, Green Fleet to Baseline	million $	(2,275.09)	(10.91)	(18.69)	(27.09)	(40.36)	(55.72)	(68.07)	(80.90)	(93.56)	(108.41)	(123.82)	(137.74)	(148.58)	(163.23)	(178.18)	(184.81)	(198.09)	(205.01)	(212.21)	(219.71)
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Figure 1 - eBus Lifecycle Cost Estimates (Operating)