



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

**Date:** April 14, 2021  
**To:** TTC Board  
**From:** Chief Vehicles Officer

### Summary

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This report summarizes preliminary results of the TTC's head-to-head evaluation of long-range, battery-electric accessible buses (eBuses).

In November 2017, the TTC Board approved the TTC's Green Bus Technology Plan. At that time, eBus technology was, and still is, relatively new. The plan was to procure from the only three suppliers of long-range eBuses – BYD Canada (BYD), New Flyer Industries (NFI) and Proterra – and to closely monitor both vehicle and vendor performance.

In June 2019, the TTC's first of 60 eBuses entered service. The head-to-head evaluation formally commenced in October 2020. While it is expected that we will learn the most in the first two years of service, there are vehicle systems that will continue to be monitored over bus fleet's entire 13-year life cycle.

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 are being monitored, tracked and analyzed as part of the head-to-head evaluation. This report provides preliminary 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 Life Cycle Cost

While preliminary 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 dashboard below provides a snapshot of how each bus has performed in the four key domains.

	Battery-Electric Buses			Baseline
	BYD K9M	NFI XE40	Proterra E2	Nova HEV
<b>System Compatibility</b>				
<b>Accessibility</b>				
<b>Vehicle Performance</b>				
<b>Vendor Performance</b>				




Legend:  Very Good     Satisfactory     Needs Improvement

Figure 1 – Dashboard Preliminary Results for Primary Evaluation Domains

In summary, of the three eBus vendors, only NFI and its eBus has delivered at or above the performance required.

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. When the TTC procured its eBus fleet, Nova Bus did not offer a long-range battery electric bus. However, it is now building on its experience with HEVs and opportunity charged battery-electric buses to offer a long-range bus starting in 2022.

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. Further, as the results are preliminary, we expect that action plans across all vendors will result in improvements to vehicle and vendor performance that will be reflected in our next report on the eBus head-to-head evaluation in Q1 2022.

As well, new eBuses offered by BYD, NFI and Proterra are expected to address system compatibility issues, which for the TTC will be critical for the successful adoption of this technology.

In conclusion, while improvements are required to all eBus platforms, all manufacturers have demonstrated a commitment to making the required improvements to our existing fleet and to their next generation of long-range battery-electric buses. The lessons learned to date found no ‘show stoppers’ to the TTC’s progress toward full-fleet electrification. These lessons will be applied to the technical and commercial terms of the TTC’s next eBus procurement of 300 buses to be delivered starting in 2023.

## Recommendations

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It is 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 pre-qualify 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.

## Implementation Points

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The TTC's Green Bus Program identifies a procurement strategy to transition the fleet to become zero-emissions by the year 2040. This plan is in alignment with the City of Toronto's Transform TO Action Plan and the C40 Fossil-Fuel-Free Streets Declaration.

When the entire fleet is zero-emissions in 2040, benefits are expected as follows:

1. Greenhouse gas emissions will be reduced by approximately 250,000 tonnes of CO<sub>2</sub> annually;
2. Diesel emissions will be eliminated from bus operations thereby improving local air quality;
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 procurement;
2. HEV bus procurement;
3. eBus procurements;
4. Electrification infrastructure; and

## 5. Associated business transformation program.

### Next Procurement of HEVs and eBuses

The TTC has gained valuable experience from its last procurement of 255 HEVs and 60 eBuses. The TTC will be applying lessons learned to develop technical and commercial specifications for the next 600 new accessible buses, including 300 HEVs and 300 eBuses, to be delivered in 2022 through early 2025.

The TTC has also undertaken a thorough benchmarking of recent procurements by Brampton Transit, Chicago Transit, Los Angeles Transit, Massachusetts Bay Transportation Authority, Mississauga Transit, New York City Transit and York Region Transit. Through this exercise, we continue to learn best practices for application to both our technical requirements, commercial terms and tendering process.

Finally, staff engaged GEF Consulting, a procurement consultancy firm, to conduct a review of recent industry procurements and identify best practices, which improved management of technical and contractual risk while adding both flexibility and clarity to a greatly simplified tendering process.

The TTC is now 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, operations and maintenance throughout the GTHA and beyond.

### Electrification Infrastructure

Since 2017, the TTC has been working in partnership with Toronto Hydro-Electric System Ltd. (THESL) on the installation of required electrification infrastructure for the existing fleet of 60 eBuses.

As the TTC continues on its path to full electrification of the bus, Wheel-Trans and non-revenue vehicle fleets, this infrastructure must be expanded accordingly. The TTC is working with Ontario Power Generation (OPG) and THESL to ensure on-time upgrade of the local grid distribution system and implementation of required infrastructure at TTC sites.

At the April 2021 TTC Board meeting, staff will present a framework for agreement between TTC, OPG and THESL outlining the parties' mutual interest and commitment to collaboration; roles and responsibilities; and associated definitive agreements.

### 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 require a transition program to ensure that transit services are maintained.

### Ongoing Industry Engagement

The TTC is working 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 bi-monthly call to discuss technical and operational challenges, including lessons learned. The call originally started with four agencies, but has grown to include 24 agencies. Currently, the list of participants are as follows:

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

OPTA has recently established a Zero-Emissions Bus Committee through which the TTC will work with other transit leaders on joint procurement opportunities for zero-emissions buses. As mentioned, the aim of this collaboration is to develop a single bus procurement specification to reduce cost and standardize customer experience, operations and maintenance.

### **Financial Summary**

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The TTC’s Green Bus Program transitions the city bus fleet to zero emissions by using hybrid diesel-electric buses and new all-electric buses to phase out clean diesel buses. From April 2016 to March 2020, the TTC has used the Government of Canada’s Public Transit Infrastructure Fund (PTIF) program to refresh its fleet of city buses, and to start

the transition of this fleet from clean diesel to zero emissions buses. Through the PTIF program, the TTC purchased 1,043 new buses, which have all been delivered and are in service. These procurements included:

- 728 clean diesel buses;
- 255 hybrid diesel-electric buses; and
- 60 electric buses and related charging infrastructure

The City-approved funding for the above-noted procurements totalled \$827.6 million of which approximately \$797.7 million has been spent to the end of 2020.

At its February 18, 2021 meeting, City Council approved the TTC's 2021-2030 Capital Budget and Plan. A total of \$688 million is approved 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 600 of the 1,612 buses identified in its fleet plan to be procured during this 10-year capital planning timeframe.

This report is being provided as an update to the Board on the status of the Green Bus Program. The Interim Chief Financial Officer has reviewed this report and agrees with the financial impact information.

## **Equity/Accessibility Matters**

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This section outlines recent advancements in Procurement Equity, Accessibility and Green Procurement.

### **Procurement Equity**

Each proponent, as part of its proposal, shall include a plan outlining how the proponent will report on their annual progress with procurement equity. The successful proponent will be audited based on any claims made in its proposal with respect to areas in Social and Green Procurement.

Each proponent, as part of its proposal, shall include the following:

1. Its policy on no child labour and forced labour in the manufacture of any products, components, subcomponents, or any other materials incorporated into contract deliverables.
2. An outline of its experience in procurement equity (equitable procurement), including the use of small enterprises, businesses owned by equity-seeking groups, diverse suppliers and investments made in the community;
3. Its policy on procurement equity and/or procurement equity programs that have been implemented (proponent to provide examples of implementing such procurement and/or program(s));

4. Its workforce diversity and inclusion policy and plan to transition its workforce at all levels to better reflect the local community with respect to local equity-seeking groups;
5. Its policy on supply chain diversity and/or plans to transition to supply chain diversity. Emphasis should be made on the use or planned use of diverse suppliers certified by organizations such as, but not limited to, the following:
  - (a) Canadian Aboriginal and Minority Supplier Council (CAMSC).
  - (b) Inclusive Workplace and Supply Council of Canada (IWSCC).
  - (c) Minority Supplier Development in China (MSD China).
  - (d) Minority Supplier Development UK (MSDUK).
  - (e) Supply Nation (Australia).
  - (f) National Minority Supplier Development Council (NMSDC).
  - (g) South African Supplier Diversity Council (SASDC); and
  - (h) Demonstrate corporate leadership with examples of active memberships in equity causes, such as, but not limited to: the Conference of Minority Transportation Officials (COMTO), Women Business Enterprises Canada (WBE Canada) and Women in Transportation Seminar (WTS).
6. Proponents must declare and will be held to account for the percentage of contract value to be spent on Disadvantaged Business Enterprises (DBEs) or similar.
7. Proponents must declare the number of equity-seeking groups hired in apprentice programs from local colleges.
8. Project documentation should use gender neutral terms and phrasing and avoid references to a person's colour, ethnicity or racial background. Examples of such terms include, but are not limited to: Master / Slave, Mr. / Mrs., he / she, and Native / White.

### Accessibility

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

Studies have shown that people who have less access to 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 and 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

Each proponent shall 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**

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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, New Flyer 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://www.ttc.ca/About\\_the\\_TTC/Commission\\_reports\\_and\\_information/Commission\\_meetings/2017/November\\_13/Reports/4\\_Green\\_Bus\\_Technology\\_Plan.pdf](https://www.ttc.ca/About_the_TTC/Commission_reports_and_information/Commission_meetings/2017/November_13/Reports/4_Green_Bus_Technology_Plan.pdf)



June 12, 2018: 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, New Flyer 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://www.ttc.ca/About the TTC/Commission reports and information/Commission meetings/2018/June 12/Reports/27 Green Bus Technology Plan Update.pdf](https://www.ttc.ca/About%20the%20TTC/Commission%20reports%20and%20information/Commission%20meetings/2018/June%2012/Reports/27%20Green%20Bus%20Technology%20Plan%20Update.pdf)

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:

[http://www.ttc.ca/About the TTC/Commission reports and information/Commission meetings/2018/July 27/Minutes/Minutes.jsp](http://www.ttc.ca/About%20the%20TTC/Commission%20reports%20and%20information/Commission%20meetings/2018/July%2027/Minutes/Minutes.jsp)

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://www.ttc.ca/About the TTC/Commission reports and information/Commission meetings/2020/February 25/Reports/7 TTC Green Bus Program Update.pdf](https://www.ttc.ca/About%20the%20TTC/Commission%20reports%20and%20information/Commission%20meetings/2020/February%2025/Reports/7%20TTC%20Green%20Bus%20Program%20Update.pdf)

Decision:

[https://www.ttc.ca/About the TTC/Commission reports and information/Commission](https://www.ttc.ca/About%20the%20TTC/Commission%20reports%20and%20information/Commission)

[meetings/2020/February\\_25/Reports/Decisions/7\\_TTC\\_Green\\_Bus\\_Program\\_Update\\_Ddecision.pdf](#)

On October 22, 2020: Staff presented a report on the 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 the 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:

[http://www.ttc.ca/About the TTC/Commission reports and information/Commission meetings/2020/October 22/Reports/5 TTC Fleet Procurement Strategy and Plan.pdf](http://www.ttc.ca/About_the_TTC/Commission_reports_and_information/Commission_meetings/2020/October_22/Reports/5_TTC_Fleet_Procurement_Strategy_and_Plan.pdf)

Presentation:

[http://www.ttc.ca/About the TTC/Commission reports and information/Commission meetings/2020/October 22/Reports/5 Staff Presentation TTC Fleet Procurement Strategy and Plan.pdf](http://www.ttc.ca/About_the_TTC/Commission_reports_and_information/Commission_meetings/2020/October_22/Reports/5_Staff_Presentation_TTC_Fleet_Procurement_Strategy_and_Plan.pdf)

Decision:

[www.ttc.ca/About the TTC/Commission reports and information/Commission meetings/2020/October 22/Reports/Decisions/2047 5 TTC Fleet Procurement Strategy and Plan Decision.pdf](http://www.ttc.ca/About_the_TTC/Commission_reports_and_information/Commission_meetings/2020/October_22/Reports/Decisions/2047_5_TTC_Fleet_Procurement_Strategy_and_Plan_Ddecision.pdf)

## **Issue Background**

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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.

The preliminary results from the eBus head-to-head evaluation is the subject of this report.

## **Comments**

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This report is technical in nature, but 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. Further, as the results are preliminary, we expect that action plans across all vendors will result in improvements to vehicle and vendor performance that will be reflected in our next report on the eBus head-to-head evaluation in Q1 2022.

The TTC's first 60 eBuses were procured from BYD, NFI and Proterra. Prior to the delivery of these eBuses, three garages were retrofitted with depot charging systems to accommodate charging up to 25 eBuses per location. All 60 eBuses procured are now in service at the TTC. The first eBus entered service on June 3, 2019 and the 60th vehicle entered service on December 4, 2020.

The table below is a summary of the three eBus vendors, battery capacity, mileage accumulated and emissions reductions as of December 31, 2020:



Make	BYD	New Flyer	Proterra
Model	K9M	XE40	E2
Length	40'	40'	42'6"
Battery Capacity [kWh]	360	400	440
Quantity	10	25	25
1st Bus In-Service [mm/dd/yy]	9/8/2020	6/3/2019	10/26/2019
Mileage LTD [km]	94,433	713,950	365,591
GHG Reduction [Tonnes]	110.5	716.8	480.3

Table 1: TTC eBus Fleet Summary

The TTC has been tracking 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, which include the following:

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

Since vehicle and vendor performance issues are typical of new vehicle acquisitions over the first several months, or even years, the evaluation accounts for the amount of time each vendor has had to improve performance.

While preliminary 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.

- **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 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.

	BYD	New Flyer	Proterra	Nova HEV
<b>Physical Compatibility</b>				

Legend: Very Good    Satisfactory    Needs Improvement

Figure 2 – Dashboard Preliminary 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.

	BYD	New Flyer	Proterra	Nova HEV
<b>Charging Technology Interoperability</b>				N/A

Figure 3 – Dashboard Preliminary 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.

New Flyer and Proterra meet this requirement. New Flyer uses a stainless steel frame while 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
<b>Corrosion Resistant Frame Structure</b>				

Figure 4 – Dashboard Preliminary 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 interface and communication standards to allow for maximum charge rates, competitive procurement, and interoperability between buses and chargers across all maintenance facilities.

**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
<b>Accessibility</b>				

Figure 5 – Dashboard Preliminary Results for Accessibility

In April 2018, the TTC held an information session with ACAT. Each eBus manufacturer brought their demonstration vehicle to the TTC, which provided an opportunity for ACAT to review accessibility features offered by each bus.

Accessibility features adopted from this review included, but were not limited to:

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.

After all three eBus types entered revenue service, a follow-up meeting with ACAT was held on October 28, 2020. The TTC presented a summary of the accessibility features on each of the eBuses delivered and the latest Nova HEV.

Additional improvements were identified as follows:

1. Configuration of stop request button size;
2. Configuration of priority stop request button size and location; and
3. Minimize installation of securement equipment in PMD floor area.

These features will be incorporated into the technical specifications for all future procurements.

## **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: Reliability, Availability and Energy Consumption, all of which are detailed below. Appendix A includes results from additional vehicle performance metrics.

### Reliability

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

To date, NFI has achieved an MDBF of 40,000 km, BYD is currently performing at 25,000 km and Proterra is currently achieving 22,000 km. As shown in the chart below, NFI's and BYD's reliability is trending positively while Proterra's reliability appears to be plateauing.

By way of comparison, Nova HEV has achieved an MDBF of 75,000 km.

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

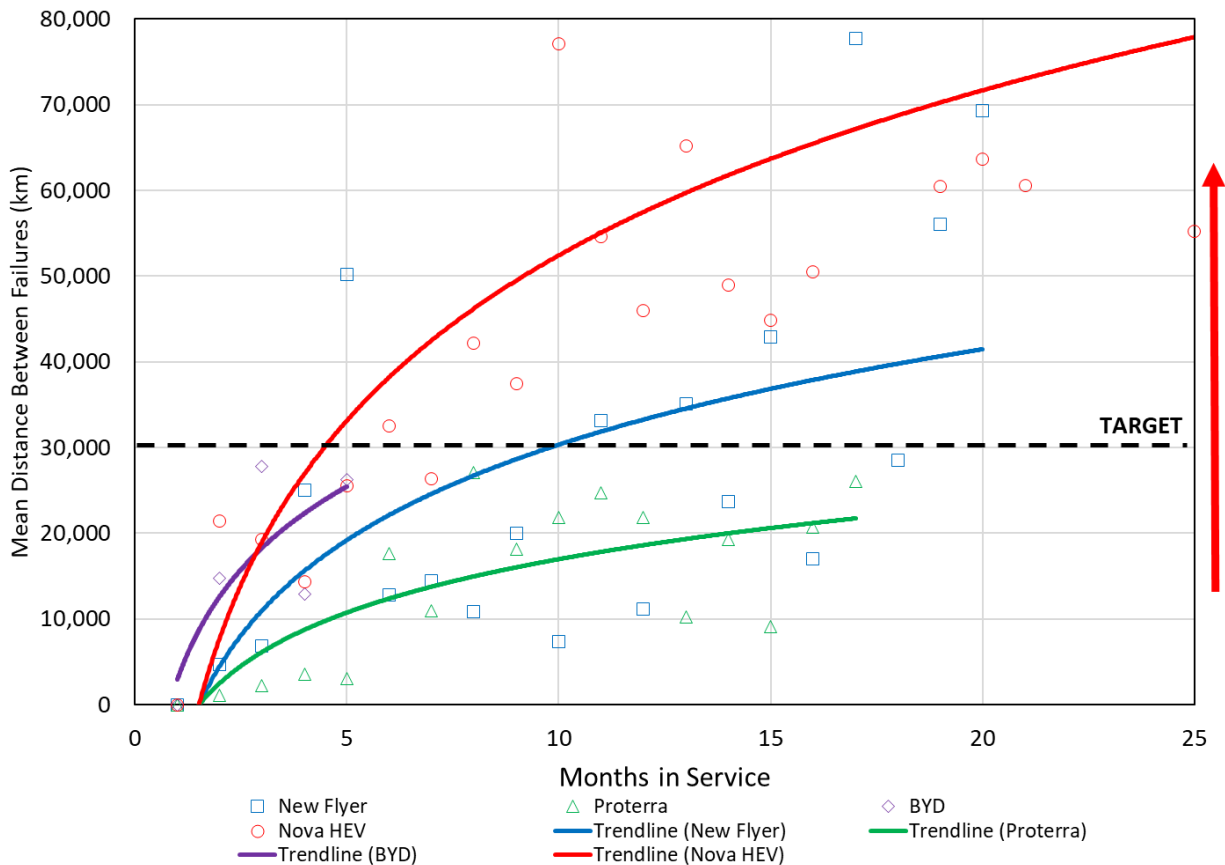


Chart 1: eBus vs. HEV Mean Distance Between Failures (MDBF)

	BYD	New Flyer	Protterra	Nova HEV
<b>Vehicle Reliability MDBF</b>	⚠️	✅	⚠️	✅

Figure 6 – Dashboard Preliminary Results for Reliability

Although MDBF is one of the key indicators to measure reliability, it does not account for minor faults identified during service or when buses are out of service. These faults may not require a bus to be removed from service, but can prevent a bus from being available to enter service the following day.

These minor faults add to maintenance backlog and have the potential to place significant burden on TTC forces. The Distance Between Repairs (DBR) is calculated by summing the distance travelled by a bus fleet and dividing it by the number of faults (major and minor) over a defined period of time.

As shown below, Nova HEV achieved the greatest distance between repairs at 948 km, while BYD achieved the least at 202 km. NFI achieved 482 km, while Protterra achieved 359 km.



Company	BYD	New Flyer	Proterra	Nova HEV
Distance Between Repairs	!	!	!	✓

Figure 7 – Dashboard Preliminary Results for Distance Between Repairs

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.

Fleet Availability

Bus fleet availability is the extent to which the vehicles are available for revenue service. 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 achieved by the eBus fleet in comparison to the Nova HEV fleet.

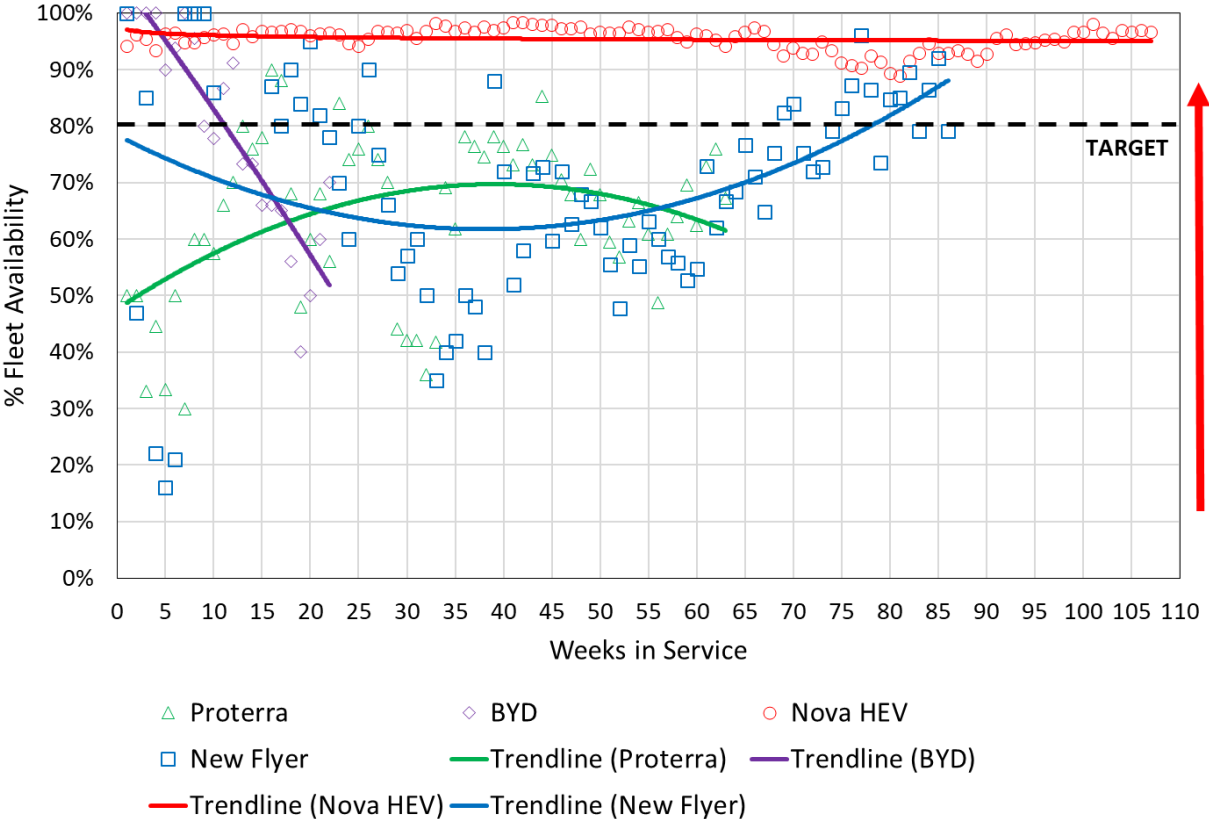


Chart 2: eBus vs. HEV Fleet Availability

NFI is currently achieving 89% availability with an upward trend. BYD and Proterra are performing at 52% and 62% respectively, and both are trending downward. By comparison, the benchmark Nova HEVs have been performing consistently at above 95% availability.

Challenges impacting vehicle availability with respect to buses from BYD and Proterra include parts unavailability and long lead-times, insufficient vendor resources on-site, lengthy bus retrofit campaign work and complex propulsion system faults.

	BYD	New Flyer	Proterra	Nova HEV
<b>Fleet Availability</b>				

Figure 8 – Dashboard Preliminary 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.

Energy Consumption

Energy consumption is another critical metric of vehicle performance. Consumption rate is measured in kWh/km and is impacted by variables, such as: passenger load, operating speed, driver behaviour, ambient temperature, inclement weather conditions and route topography. The rate of energy consumption ultimately translates to range and overall life-cycle cost. For example:

- Increased passenger loads will consume more propulsion energy;
- Higher speeds will consume more propulsion energy and reduce opportunities for regenerative braking;
- Aggressive operator behaviour or poor driving habits will reduce opportunities for regenerative braking;
- Ambient temperatures will increase loads on HVAC system and consume more on-board energy;
- Inclement weather conditions will reduce opportunities for regenerative braking; and
- Climbing grades consume more propulsion energy.

Since energy consumption directly correlates to range, large variations in energy consumption pose a significant challenge with respect to the planning of service and dispatching of buses.

The following table reports the 2020 monthly average energy consumption rate of the eBus fleet:

2020	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Standard Deviation
BYD	-	-	-	-	-	-	-	-	0.99	1.18	1.23	1.43	1.21	0.182
New Flyer	1.34	1.40	1.34	1.34	1.26	1.21	1.30	1.31	1.30	1.40	1.40	1.42	1.33	0.065
Proterra	2.03	2.09	1.72	1.42	1.24	1.20	1.30	1.21	1.16	1.36	1.54	1.65	1.49	0.319

Table 2: 2020 Daily Average Energy Consumption of eBus Fleet in kWh/km

Inclement weather conditions in the winter months significantly impacts vehicle performance. Cold temperatures, snow and ice conditions require the vehicles to expend more energy by way of heat and traction power. To mitigate this, the TTC's eBuses are equipped with auxiliary diesel heaters to minimize battery consumption. This will continue to be the TTC's requirement moving forward until heat pump technology develops into a viable alternative.

The following chart reports average energy efficiency versus ambient temperature:

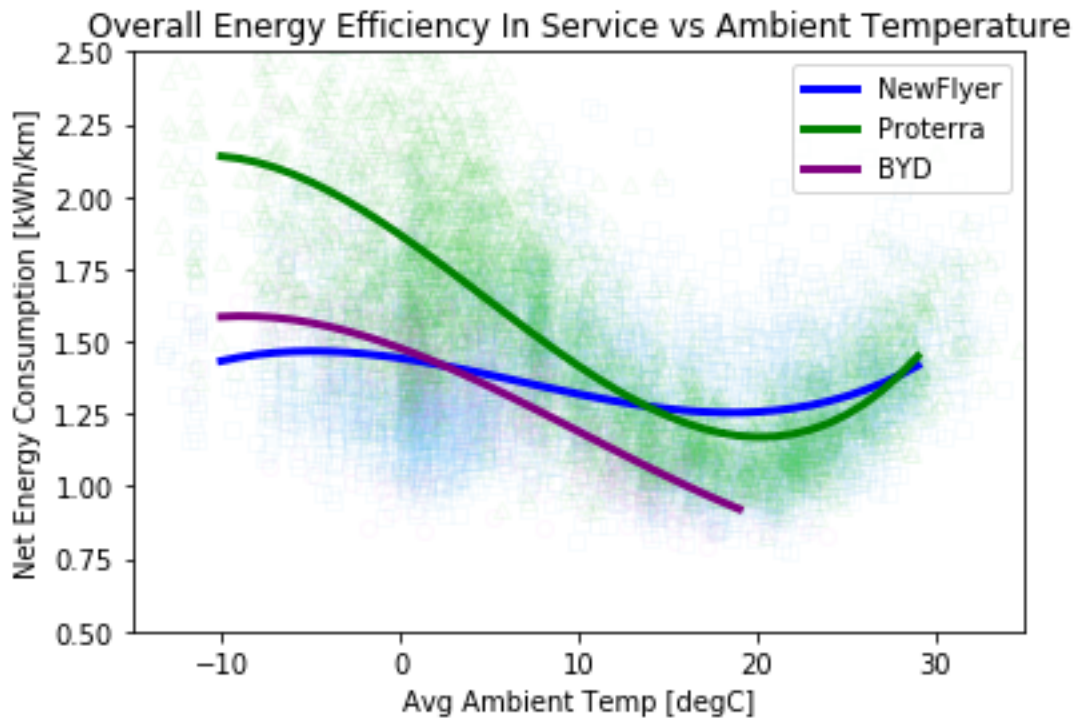


Chart 3: Energy Consumption vs. Ambient Temperature

Of the three vehicle models, Proterra has exhibited the most challenges in cold weather operations. Excessive battery consumption appears to be the result of several design-related features:

- Proterra uses an electric heater for the front windshield defroster, which is very inefficient while BYD and New Flyer use an air-over-water convector design similar to cabin heating.
- Proterra's first 10 buses did not offer heating in the operator area resulting in the front defroster being used as a source of heat. As a result, the defroster is consuming up to 10kWh/hour of energy throughout the day that could have otherwise been used to propel the bus.

### Controlled Engineering Test

Bus energy consumption performance is highly influenced by driving behaviour, passenger loading, operating speeds and route topography. To minimize the variables in energy consumption, TTC staff devised a controlled on-road engineering test that was performed on select routes to evaluate energy consumption, auxiliary systems and powertrain performance during fall and winter seasons.

Buses 3758 (BYD), 3700 (New Flyer) and 3729 (Proterra) were selected from the first batch of buses procured and test parameters included:

- Each bus loaded with 9,000 lbs of ballast to simulate seated and standee passenger loads (approximately 60 passengers);
- 48 routes (fall test) and 26 routes (winter test) were used as part of the controlled test (winter test still ongoing at time of writing this report);
- Each route was driven for three laps;
- Operating speeds were maintained on all routes in accordance to posted speed limits;
- Doors were cycled at each stop to simulate typical TTC in-service conditions;
- All three buses were operated back-to-back on the same routes at the same time;
- Performance data captured using an onboard telematics system; and
- Testing was performed in the fall of 2020 and repeated during the winter of 2020-2021.

Route selection was based on road topography that would subject the buses to Heavy Duty Cycles (HDC) and results of each bus are as follows:

- BYD buses consumed an average of 1.14kWh/km, achieving the lowest/best energy consumption rate during mild ambient temperatures in the fall season; however, with winter performance at 1.73kWh/km, BYD had both the highest consumption rate and the largest variation at 51%.
- NFI buses consumed an average of 1.35kWh/km, which was the highest/worst energy consumption rate during mild ambient temperatures in the fall season; however, with winter performance at 1.31 kWh/km, NFI had the lowest consumption rate and the smallest variation at 3%.

- Proterra buses consumed an average of 1.17kWh/km during mild ambient temperatures in the fall season. In the winter, Proterra buses achieved an average of 1.63kWh/km resulting in a variation of 40%.



Company	BYD	New Flyer	Proterra	Nova HEV
Energy Consumption				Not evaluated

Figure 9 – Dashboard Preliminary Results for Energy Consumption

Lessons Learned and Next Steps:

1. Predictable and reliable range is more important than achieving the lowest energy consumption.
2. Proterra has started a campaign to retrofit a convector in the operator area and is 30% complete.
3. Exploring defroster programming opportunities to further alleviate winter energy consumption concerns.
4. For future procurements, the TTC will avoid a pure-electric defroster unit without fully understanding the energy efficiency performance.
5. For future procurements, the TTC will continue to specify a diesel-fired heater requirement until heat pump technology is viable.

The vendor performance is summarized using all relevant metrics above and those in the Appendix A as follows:

Company	BYD	New Flyer	Proterra	Nova HEV
Vehicle Performance				

Figure 10 – Dashboard Preliminary Results for Overall Vehicle Performance

**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.

### Compliance to Vehicle Delivery Schedule

As part of the procurement contract, each vendor was required to submit a delivery schedule. The vehicle delivery schedule metric is calculated by comparing the contract versus the actual delivery schedule.





	BYD	New Flyer	Proterra	Nova HEV
<b>Compliance to Vehicle Delivery Schedule</b>				

Figure 11 – Dashboard Preliminary Results for Vehicle Delivery Schedule

- BYD buses were delivered on average of 186 days behind schedule.
- NFI buses were delivered on average of 43 days behind schedule.
- Proterra buses were delivered on average of 62 days behind schedule.

By comparison, the benchmark Nova HEVs were delivered on average three days ahead of schedule. Nova has been delivering buses to the TTC since 2014. As a result, they have a good understanding of the contractual obligations and provide realistic schedules. The other three manufacturers are new to the TTC and provided overly aggressive delivery schedules for a new product that they were ultimately not able to meet.

While adherence to delivery schedule is only one factor in assessing vendor performance, it is a key metric in assessing the overall vendor performance.

### Manufacturing Facility Quality Audit

The TTC retained a consultant to conduct a quality review of the eBus manufacturers, including: BYD, New Flyer, Nova Bus and Proterra. This review focused on the following key areas: production, safety and quality systems, materials management, staff training and vehicle quality.

The auditors visited two manufacturing plants for each manufacturer to conduct quality audits, including manufacturing plants across North America and China. An evaluation checklist containing the various evaluation criteria and their corresponding weight towards the final audit score was used to score the vendors. The evaluation checklist included a total of 68 evaluation criteria in the following six key areas:

1. General Facility and Operations;
2. Staff;

3. Manufacturing and Quality Assurance;
4. Production Line;
5. Health and Safety; and
6. Ethics and Fairness.

As shown below, the more mature facilities were deemed acceptable (Nova, New Flyer and the BYD plant in Hangzhou). Newer facilities, such as the BYD Newmarket, and Proterra facilities require improvement. Findings were discussed with and agreed to by eBus OEMs. However, details are not provided as access to the facilities to complete the audits was granted on the condition of confidentiality.

Company	BYD		New Flyer		Proterra		Nova	
	Hangzhou	Newmarket	Winnipeg	Crookston	LA	Greenville	St. Eustache	Plattsburgh
Quality Review								

Figure 12 – Dashboard Preliminary Results for Manufacturing Facility Quality Audits

It is important to understand the manufacturing facility and processes of each eBus OEM as it is directly related to quality defects found during bus commissioning and in-service performance. This audit was the first of its kind performed by the TTC for bus manufacturers and was found to be very beneficial.

Lessons Learned and Next Steps:

1. Facility audits to be performed during the pre-qualification process and major findings as they relate to safety and/or quality are to be addressed prior to start of production.

Quality Defects (Snags)

This metric measures the number of deficiencies identified by the TTC during the commissioning of the vehicle after delivery. Deficiencies are defects identified on the bus that do not meet the contract specifications. These deficiencies are then submitted to the vendor for repair.

All three eBus vendors had a high number of snags that required repair (BYD-44, NFI-34, Proterra-41). In comparison, Nova HEV buses had an average of 17 snags or 50% fewer snags when compared to the eBus vendors.

Similar to vehicle deliveries, Nova has been providing buses to the TTC since 2014. As a result, they have a good understanding of the TTC’s commissioning process and quality standards.

Company	BYD	New Flyer	Proterra	Nova HEV
Quality Defects				

Figure 13 – Dashboard Preliminary Results for Quality Defects

The number of quality defects identified during the bus commissioning process generally reflects the manufacturing quality of the bus vendor and increases effort and time required to prepare a bus to enter revenue service.

**Lessons Learned and Next Steps:**

1. While the TTC contracts full-time quality assurance inspectors at manufacturing and final assembly sites, additional process controls and resources will be considered to better control eBus manufacturing quality and minimize TTC cost and disruption upon vehicle delivery.

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.





Company	BYD	New Flyer	Proterra	Nova HEV
Duration to Final Acceptance				

Figure 14 – Dashboard Preliminary 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.

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 113 days (one bus remaining to achieve target); and
- BYD required 160 days (three buses remaining to achieve target).





Company	BYD	New Flyer	Proterra	Nova HEV
<b>30-Day Reliability</b>				

Figure 15 – Dashboard Preliminary 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 Reliability requirement.

### Contract Deliverables

This metric is the percentage completion of contract deliverables identified in the contract. Deliverables includes: 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 70% of these deliverables, NFI 90% and Proterra 95%.




Company	BYD	New Flyer	Proterra
<b>Contract Deliverables</b>			

Figure 16 – Dashboard Preliminary Results for Contract Deliverables

### Canadian Content Review

Each eBus vendor was required to provide their plan to achieve Canadian content requirements at the time of contract award. The minimum requirement for Canadian content is 25%.

The TTC retained a consultant to complete an audit of the eBus vendors Canadian content submission to verify compliance. This work was completed after the delivery of all vehicles and included a review of the invoices for the eligible claims (including component, subcomponent, test equipment, special tools, labour, project management, manuals, freight, warranty and engineering costs) and a comparison to the overall bus cost.

In summary, each eBus vendor met the minimum Canadian content requirement of 25%. Findings of this review were discussed with, and agreed to, by eBus OEMs. However, details are not provided due to confidentiality around proprietary technology and manufacturing processes.




	BYD	New Flyer	Proterra
<b>Canadian Content</b>			

Figure 17 – Dashboard Preliminary Results for Canadian Content Review

### Training

Although the TTC has experience with hybrid-electric buses that have a similar drivetrain to that of a battery-electric bus, additional training was required for the three models of eBuses. Typically, training is delivered by the OEM to the TTC’s Operations Training Centre who then prepare TTC-specific training course material and deliver to TTC employees. Below is a table summarizing the various training courses delivered to date by each eBus vendor:

Course	BYD	New Flyer	Proterra
Operation & Familiarization	✓	✓	✓
Technical Familiarization	✓	✓	✓
High Voltage Safety	✓	✓	✓
Multiplex & Schematics		✓	
Siemens Propulsion	N/A	✓	N/A
Maintenance 1			✓
Maintenance 2			✓
Doors	N/A	N/A	✓*
HVAC			✓*

\*Virtual Training

Table 3: eBus Vendor Training Received

COVID-19 has prevented some of the training from being conducted in person. As a result, some courses were delivered virtually by vendors to minimize risk. Training provided by all three vendors have met expectations with respect to training materials, course content and support for internal course development.

The TTC's Operations Training Centre has delivered operator training to more than 2,800 operators and 160 maintainers.




Company	BYD	New Flyer	Proterra
Training			

Figure 18 – Dashboard Preliminary Results for Training

In conclusion, while improvements are required to all eBus platforms, all manufacturers have demonstrated a commitment to making the required improvements to our existing fleet and to their next generation of long-range, battery-electric buses. The lessons learned to date found no 'show stoppers' to the TTC's progress toward full-fleet electrification. These lessons will be applied to the technical and commercial terms of the TTC's next eBus procurement of 300 buses to be delivered starting in 2023.

## Contact

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## Signature

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Richard Wong  
Chief Vehicles Officer

## Attachments

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Appendix A – Head-to-Head Evaluation Domain Results

## Appendix A

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This report is primarily technical in nature and the information presented here within is based on the TTC's experience in 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.

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

3. 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
4. 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 are being monitored, tracked and analyzed as part of the head-to-head evaluation. This report provides preliminary results in each of the evaluation domains including:

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

For completeness, this Appendix includes preliminary results of primary domains (i.e. System Compatibility, Accessibility, Vehicle Performance and Vendor Performance) already covered in the Summary and Comments sections of the report, in addition to the status/results of evaluation against all remaining domains.

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, would impose a

significant operational constraint that would prevent movement of buses between garages.

	BYD	New Flyer	Proterra	Nova HEV
<b>Physical Compatibility</b>				

Legend: Very Good    Satisfactory    Needs Improvement

Figure 1 – Dashboard Preliminary 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.

Company	BYD	New Flyer	Proterra	Nova HEV
<b>Charging Technology Interoperability</b>				N/A

Figure 2 – Dashboard Preliminary 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, TTC staff require more operational experience to evaluate the effectiveness of the solutions proposed by Proterra and BYD.

	BYD	New Flyer	Proterra	Nova HEV
<b>Corrosion Resistant Frame Structure</b>				

Figure 3 – Dashboard Preliminary 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.

## Accessibility

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

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.

Company	BYD	New Flyer	Proterra	Nova HEV
Accessibility				

Figure 4 – Dashboard Preliminary Results for Accessibility

In April 2018, the TTC held an information session with the ACAT. Each eBus manufacturer brought their demonstration vehicle to the TTC, which provided an opportunity for ACAT to review accessibility features offered by each manufacturer.

Accessibility features adopted from this review included, but were not limited to:

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.

After all three eBus types entered revenue service, a follow-up meeting with ACAT was held on October 28, 2020. The TTC presented a summary of the accessibility features on each of the eBuses delivered and the latest Nova HEV.

Additional improvements were identified as follows:

1. Configuration of stop request button size;
2. Configuration of priority stop request button size and location; and
3. Minimize installation of securement equipment in PMD floor area.

These features will be incorporated into the technical specifications for all future procurements.

## Vehicle Performance

The vehicle performance domain measures the in-service performance from the time the vehicles have entered service.

### Reliability

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

To date, NFI has achieved an MDBF of 40,000 km, BYD is currently performing at 25,000 km and Proterra is currently achieving 22,000 km. As shown in the chart below, NFI's and BYD's reliability is trending positively while Proterra's reliability appears to be plateauing.

By way of comparison, Nova HEV has achieved an MDBF of 75,000 km.

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

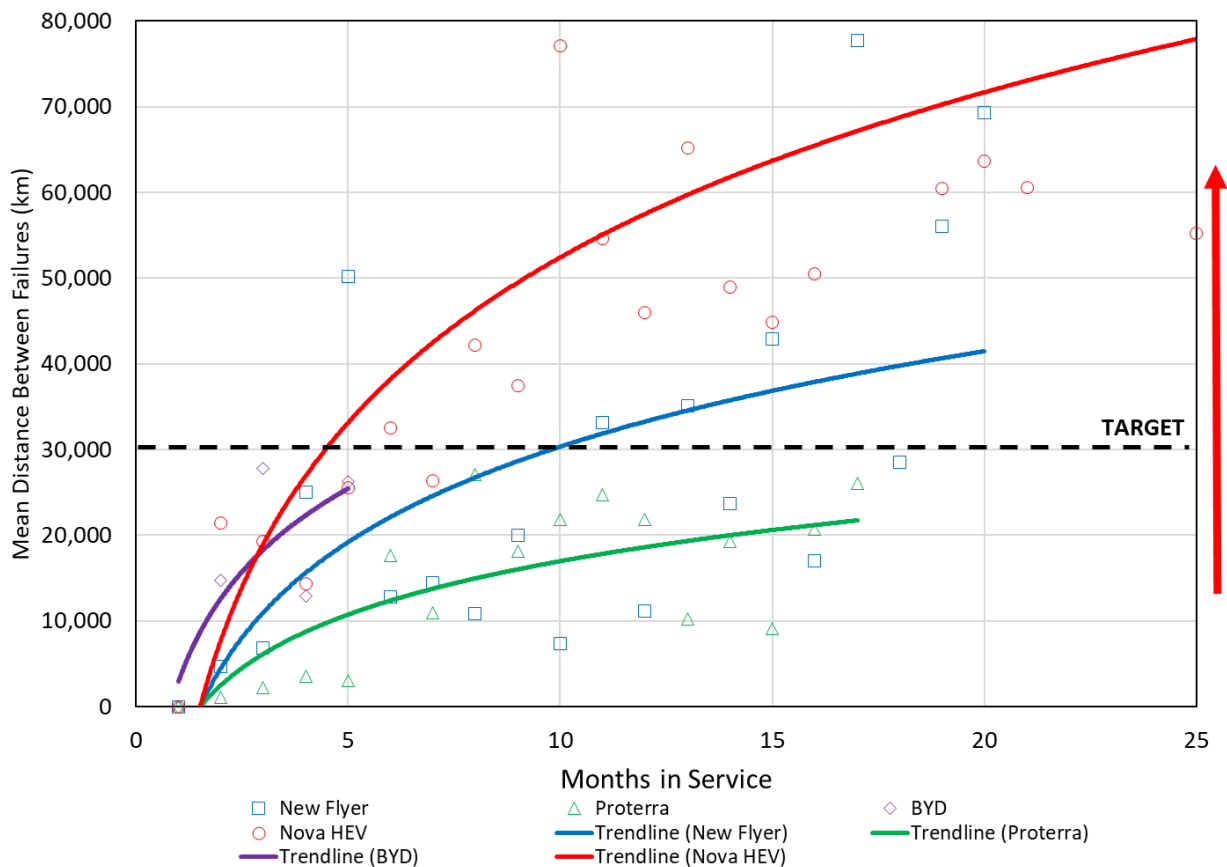


Chart 1: eBus vs. HEV Mean Distance Between Failures (MDBF)





Company	BYD	New Flyer	Proterra	Nova HEV
<b>Vehicle Reliability MDBF</b>				

Figure 5 – Dashboard Preliminary Results for Reliability

Although MDBF is one of the key indicators to measure reliability, it does not account for minor faults identified during service or end of service. These faults may not require a bus to be removed from service, but adds to maintenance backlog and increases down time of the asset. 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.

As shown below, Nova HEV achieved the greatest distance between repairs at 948 km while BYD achieved the least at 202 km. NFI achieved 482 km while Proterra achieved 359 km. Both BYD and Proterra have limited experience with the TTC’s operational duty cycle and environment. As a result, the achievement of BYD and Proterra is lower due to a higher volume of defect repairs on a per-kilometer basis.

Company	BYD	New Flyer	Proterra	Nova HEV
<b>Distance Between Repairs</b>				

Figure 6 – Dashboard Preliminary Results for Distance Between Repairs

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.

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.



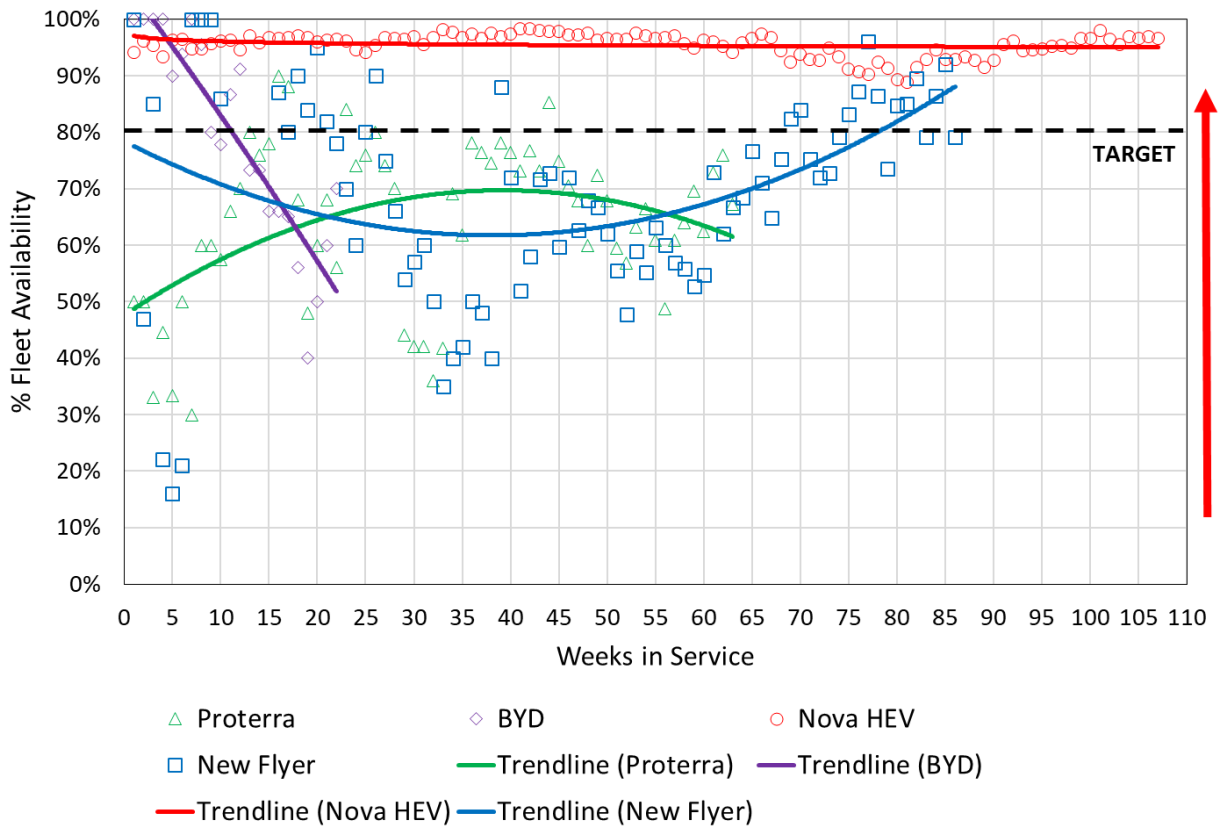


Chart 2: eBus vs. HEV Fleet Availability

NFI is currently achieving 89% availability, while BYD and Proterra are currently performing at 52% and 62% availability respectively, and are both trending downward. By comparison, the benchmark Nova HEVs have been performing consistently at above 95% availability.

Challenges impacting vehicle availability with respect to buses from BYD and Proterra include complex propulsion system faults, parts unavailability and long lead-times, insufficient vendor resources on location and lengthy bus retrofit campaign work.

Company	BYD	New Flyer	Proterra	Nova HEV
Fleet Availability	!	✓	!	✓

Figure 7 – Dashboard Preliminary 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.

### Work Order Defect Analysis

The following section provides an 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.

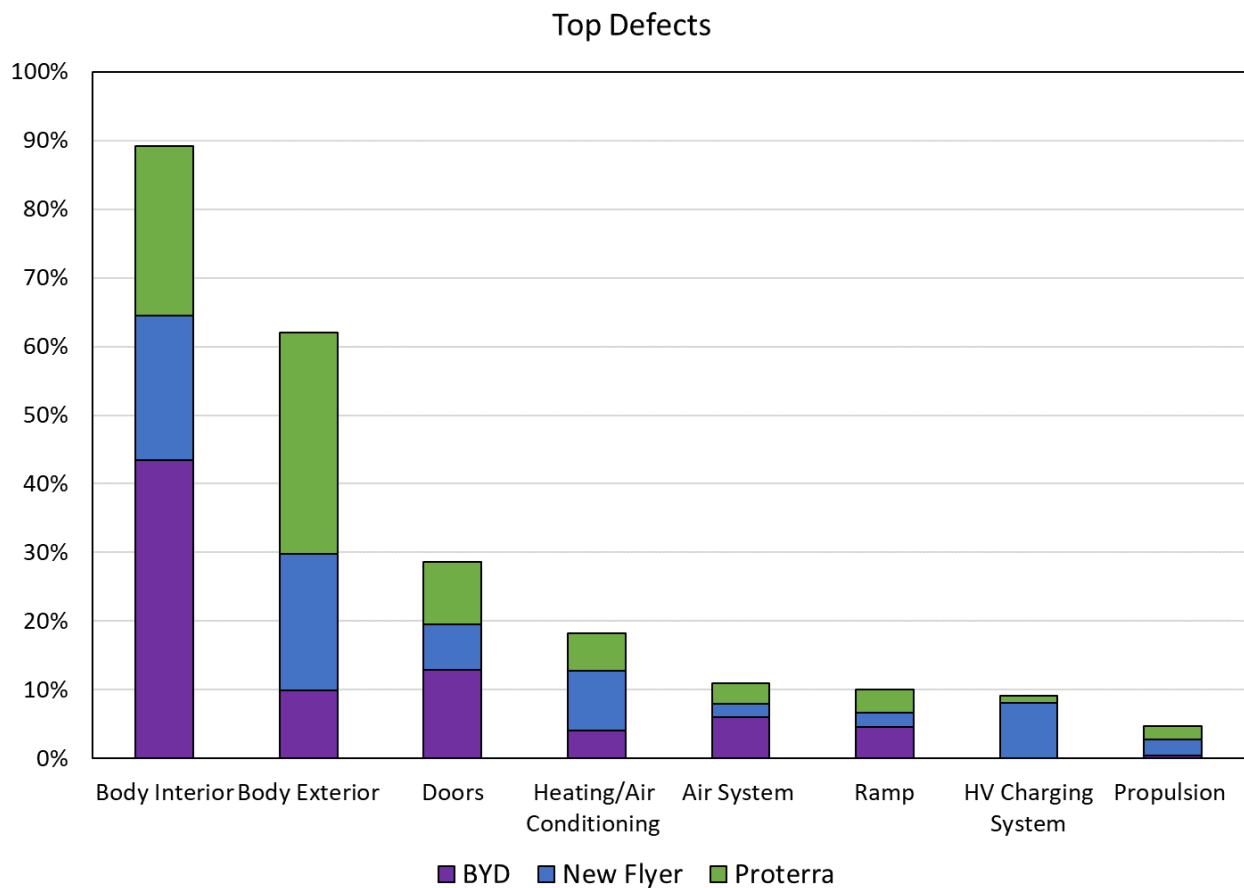


Chart 3: Top eBus Problem Systems

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 very reliable thus far and account for less than 2% of the defects experienced. Below is a summary of the top issues for each eBus.

### BYD Defects

Reliability performance of the BYD eBus is not currently meeting the target of 30,000 km. However, this fleet has limited time in service when compared to New Flyer and Proterra. As a result, mileage accumulation for the fleet is lower, but the reliability trend is positive.

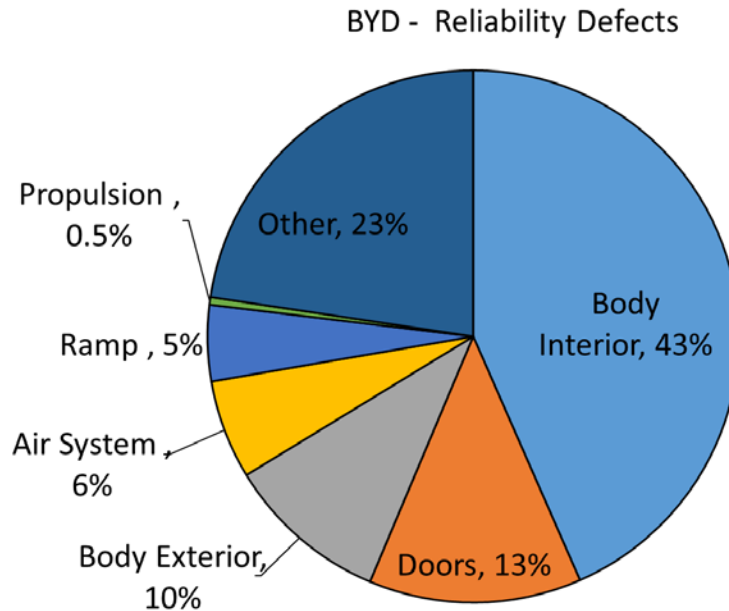


Chart 4: BYD Top Problem Systems

The top five vehicle systems accounting for 77% of the defects experienced to date include: Body Interior (43%), Doors (13%), Body Exterior (10%), Air System (6%) and Ramp (5%). The propulsion system only accounted for 0.5% of defects.

The majority of the Body Interior defects are seat and mirror defects. The TTC is finding loose seat inserts as a result of damaged retaining clips and loose hardware securing seat frames, wheelchair securements and interior mirrors. Door defects are primarily mechanical in nature resulting from loose hardware and incorrect door adjustments.

Body Exterior defects are primarily for loose splash panel and compartment door hardware. All these defects can be attributed to poor quality during final interior component assembly at BYD's Newmarket, Ontario facility.

Air leaks from quick connect fittings and leaking drain valves are driving all the Air System defects. A root-cause analysis (RCA) is ongoing for the leaking drain valves and a campaign to replace all drain valves is expected in Q2 2021.

The 0.5% Propulsion defect is from replacement of a rear axle unit due to drivetrain noise.

### New Flyer Reliability

Reliability performance of the New Flyer eBus Fleet is currently meeting the target of 30,000 km.

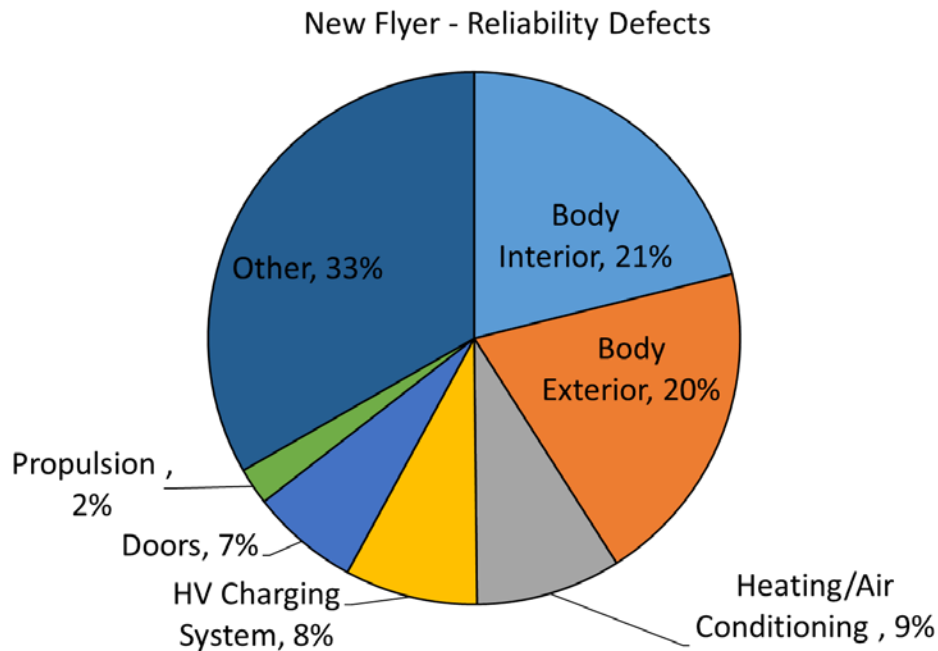


Chart 5: New Flyer Top Problem Systems

The top five vehicle systems accounting for 64% of the defects experienced to date include: Body Interior (21%), Body Exterior (20%), Heating/Air Conditioning (9%), HV Charging System (8%) and Doors (7%). The propulsion system only accounted for 2% of defects.

Body Interior defects are primarily for broken stop request buttons and a campaign is currently underway to replace buttons with an improved design.

Body Exterior issues were for mostly loose mirror arms and mirrors, which is a common problem for all buses regardless of propulsion.

Heating/Air Conditioning faults were the result of an electromagnetic interference (EMI) issue experienced during the summer of 2020 and recent auxiliary heater failures. The EMI issues have since been rectified through a communication harness replacement campaign. A root-cause analysis for the auxiliary heater failures is ongoing.

High Voltage (HV) Charging System faults were largely a result of early issues with repeatability of successful charging events and have since been addressed through bus charge controller software updates. The door issues experienced were mostly related to noise during operation and easily corrected with lubrication maintenance.

Propulsions issues were related to an imbalance in voltage between cells within the battery pack. This issue has since been corrected through improved battery management programming. It is also noted that to date one defective battery module and one traction motor have been replaced.

## Proterra Reliability

The Proterra eBus fleet has yet to meet the MDBF performance target of 30,000 km in its 16 months of service.

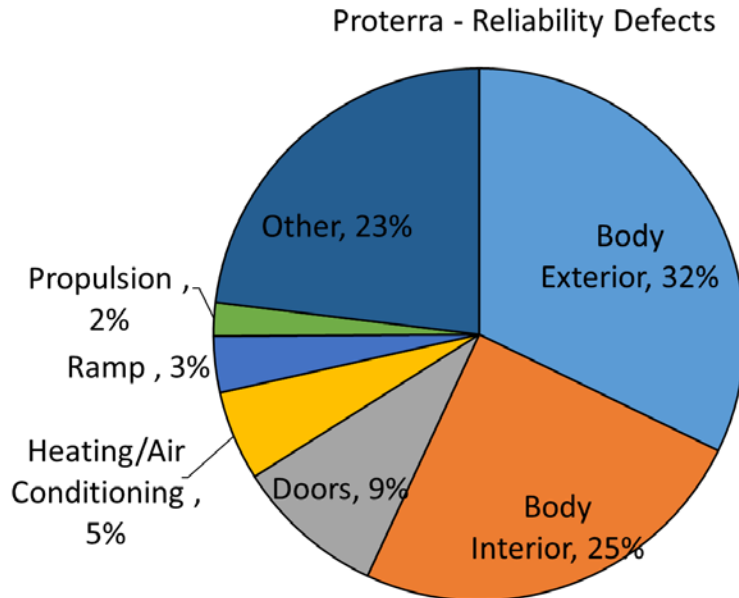


Chart 6: Proterra Top Problem Systems

The top five vehicle systems accounting for 75% of the defects experienced to date include: Body Exterior (32%), Body Interior (25%), Doors (9%), Heating/Air Conditioning (5%), and Ramp (3%). The propulsion system only accounted for 2% of defects.

The Proterra body is constructed with lightweight impact-absorbing, carbon-fiber-reinforced composite materials that eliminates concerns of long-term corrosion. However, the body structure itself has posed new challenges.

Although advertised as a 40-foot bus, the Proterra is actually 42 feet six inches long. This additional length has challenged operators driving in close quarters resulting in minor body and mirror collisions requiring a bus be removed from service for repairs.

Proterra has had success with this composite body in southern climates, but it has yet to be proven over the long-term in Toronto's environment with extreme seasonal temperatures.

To date, there have been superficial body gelcoat "spider" cracks at the corners of windows, and a significant crack at the rear exit doors in which a campaign is currently ongoing to repair. Coach technicians are unable to determine whether a crack is superficial (gelcoat) or structural. A non-destructive test does not exist today, but Proterra is actively investigating options.

A variety of common issues with seats, mirrors and compartment door deficiencies make up the bulk of Body Interior defects. However, the composite structure of the body requires components like compartment door hinges and stanchions to be bonded to the body with special adhesives. Defects experienced have been found to be a result of improper surface preparation prior to bonding at the factory.

Door system issues may account for 7% of defects, but they have been the number one reason why Proterra buses have been removed from service. The Proterra bus uses a new door vendor that the TTC has no past experience with, and a new “plug-slide” door configuration with passenger detecting light curtain. Early failures of the light curtain and five-position door controller switch resulted in two retrofit campaigns to improve reliability. A third campaign was recently completed to maintain door adjustments and several iterations of door control logic software were also necessary to ensure reliable operation.

Heating/Air Conditioning defects revolve around frequent breakdowns of the diesel-fired auxiliary heater during recent winter months. Absence of a functioning auxiliary heater has hurt Proterra’s winter range capability. Ramp defects are primarily a result of operators not fully understanding the control logic, and information campaigns have been launched by Bus Transportation Department to educate operators.

The propulsion system on Proterra has been reliable. To date, only one defective battery module with a temperature sensor defect and one noisy axle have been replaced.

### Energy Consumption

Energy consumption is another critical metric of vehicle performance. Consumption rate is measured in kWh/km and is impacted by variables, such as passenger load, operating speed, driver behaviour, ambient temperature, inclement weather conditions and route topography. The rate of energy consumption ultimately translates to range and overall life-cycle cost. For example:

- Increased passenger loads will consume more propulsion energy;
- Higher speeds will consume more propulsion energy and reduce opportunities for regenerative braking;
- Aggressive operator behaviour or poor driving habits will reduce opportunities for regenerative braking;
- Ambient temperatures will increase loads on HVAC system and consume more on-board energy;
- Inclement weather conditions will reduce opportunities for regenerative braking; and
- Climbing grades consume more propulsion energy.

Since energy consumption directly correlates to range, large variations in energy consumption pose a significant challenge with respect to the planning of service and dispatching of buses.

The following table reports the 2020 monthly average energy consumption rate of the eBus fleet:

2020	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Standard Deviation
BYD	-	-	-	-	-	-	-	-	0.99	1.18	1.23	1.43	1.21	0.182
New Flyer	1.34	1.40	1.34	1.34	1.26	1.21	1.30	1.31	1.30	1.40	1.40	1.42	1.33	0.065
Proterra	2.03	2.09	1.72	1.42	1.24	1.20	1.30	1.21	1.16	1.36	1.54	1.65	1.49	0.319

Table 1: 2020 Daily Average Energy Consumption of eBus Fleet in kWh/km

Inclement weather conditions in the winter months significantly impacts vehicle performance. Cold temperatures and snow and ice conditions require the vehicles to expend more energy by way of heat and traction power. To mitigate this, the TTC's eBuses are equipped with auxiliary diesel heaters to minimize battery consumption. This will continue to be the TTC's requirement moving forward until heat pump technology develops into a viable alternative.

The following chart reports average energy efficiency versus ambient temperature:

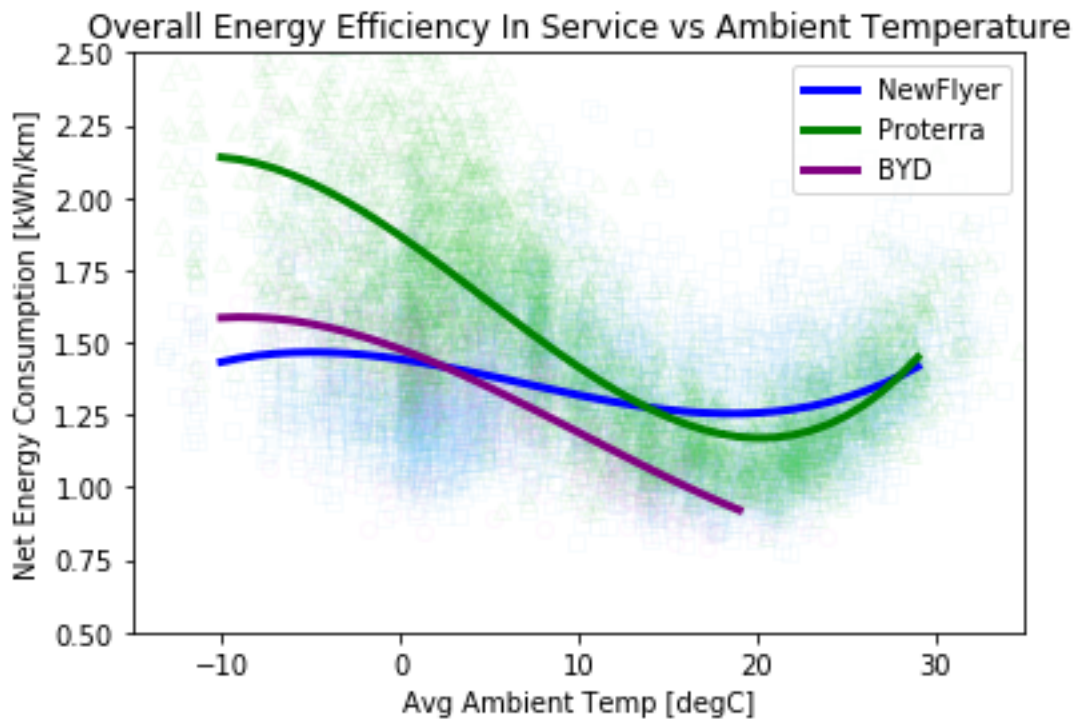


Chart 3: Energy Consumption vs. Ambient Temperature

Of the three vehicle models, Proterra has exhibited the most challenges in cold weather operations. Excessive battery consumption appears to be the result of several design related features:

- Proterra uses an electric heater for the front windshield defroster, which is very inefficient, while BYD and New Flyer use an air-over-water convector design similar to cabin heating.

- Proterra's first 10 buses did not offer heating in the operator area resulting in the front defroster being used as a source of heat. As a result, the defroster is consuming up to 10 kWh/hour of energy throughout the day that could have otherwise been used to propel the bus.

### Controlled Engineering Test

Bus energy consumption performance is highly influenced by driving behaviour, passenger loading, operating speeds and route topography. To minimize the variables in energy consumption, TTC staff devised a controlled on-road engineering test that was performed on select routes to evaluate energy consumption, auxiliary systems and powertrain performance during fall and winter seasons.

Buses 3758 (BYD), 3700 (New Flyer) and 3729 (Proterra) were selected from the first batch of buses procured and test parameters included:

- Each bus loaded with 9,000 lbs of ballast to simulate seated and standee passenger loads (approximately 60 passengers);
- 48 routes (fall test) and 26 routes (winter test) were used as part of the controlled test (winter test still ongoing at time of writing this report);
- Each route was driven for three laps;
- Operating speeds were maintained on all routes in accordance to posted speed limits;
- Doors were cycled at each stop to simulate typical TTC in-service conditions;
- All three buses were operated back-to-back on the same routes at the same time;
- Performance data captured using an onboard telematics system; and
- Testing was performed in the fall of 2020 and repeated during the winter of 2020-2021.

The tables below summarize the results of this testing on a route-by-route basis:



Route Name	Route #	Garage	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]		
			NewFlye	Proterra	BYD	NewFlye	Proterra	BYD	NewFlye	Proterra	BYD	NewFlye	Proterra	BYD	NewFlye	Proterra	BYD
Bay	6	MDEN	1.52	1.10	1.09	0.66	0.71	0.79	0.84	0.83	0.59	0.16	0.11	0.09	0.52	0.16	0.41
Glencairn	14	MDEN	1.91	1.32	1.39	0.58	0.71	0.74	0.98	0.94	0.66	0.19	0.11	0.09	0.74	0.27	0.64
Don Mills	25	EGLN	1.23	1.17	1.01	0.56	0.62	0.81	0.93	0.89	0.59	0.11	0.09	0.07	0.19	0.18	0.35
Dupont	26	MDEN	1.40	1.04	1.16	0.56	0.62	0.61	0.75	0.85	0.58	0.15	0.09	0.07	0.50	0.10	0.51
Dufferin	29	MDEN	1.44	1.11	1.06	0.67	0.78	0.76	0.83	0.88	0.61	0.14	0.11	0.07	0.47	0.12	0.38
Greenwood	31	HDC	1.26	1.19	1.12	0.68	0.74	0.58	0.85	0.88	0.59	0.15	0.11	0.09	0.25	0.20	0.44
Eglinton West	32	MDEN	1.34	1.14	1.04	0.71	0.62	0.74	0.88	0.86	0.67	0.12	0.09	0.07	0.34	0.19	0.30
Eglinton East	34	EGLN	1.22	1.15	1.13	0.69	0.60	0.63	0.81	0.80	0.64	0.12	0.10	0.08	0.29	0.25	0.41
Jane	35	ARRW	1.41	1.12	1.18	0.71	0.69	0.76	0.93	0.87	0.64	0.10	0.07	0.06	0.37	0.17	0.48
Finch West	36	ARRW	1.32	1.04	1.03	0.61	0.61	0.65	0.76	0.82	0.63	0.12	0.08	0.06	0.43	0.14	0.34
Islington	37	MDEN	1.51	1.24	1.06	0.62	0.56	0.70	1.01	0.86	0.64	0.09	0.09	0.05	0.41	0.29	0.37
Highland Creek	38	HDC	1.04	1.01	0.96	0.60	0.67	0.60	0.84	0.80	0.60	0.08	0.08	0.05	0.12	0.13	0.31
Keele	41	MDEN	1.51	1.19	1.14	0.60	0.70	0.76	0.89	0.87	0.70	0.14	0.09	0.07	0.48	0.24	0.37
Kennedy	43	EGLN	1.03	0.96	1.05	0.60	0.72	0.65	0.78	0.69	0.67	0.09	0.10	0.06	0.16	0.17	0.32
Martin Grove	46	ARRW	1.40	1.09	1.00	0.53	0.61	0.62	0.79	0.81	0.65	0.11	0.06	0.05	0.50	0.21	0.30
Lansdowne	47	MDEN	1.46	1.17	1.15	0.64	0.69	0.72	0.86	0.86	0.62	0.13	0.09	0.08	0.47	0.21	0.45
Lawrence East	54	EGLN	1.60	1.07	1.02	0.59	0.71	0.68	0.90	0.86	0.60	0.15	0.08	0.06	0.55	0.13	0.36
Midland	57	EGLN	1.07	1.07	1.14	0.58	0.64	0.74	0.73	0.78	0.72	0.09	0.10	0.06	0.21	0.18	0.37
Midland	57	EGLN	1.09	1.08	1.00	0.64	0.54	0.63	0.89	0.90	0.67	0.09	0.06	0.05	0.12	0.12	0.27
Maple Leaf	59	ARRW	1.44	1.33	1.24	0.64	0.85	0.74	0.92	1.01	0.66	0.13	0.12	0.07	0.39	0.21	0.51
Steeles West	60	ARRW	1.06	1.24	1.19	0.72	0.59	0.65	0.82	0.86	0.65	0.08	0.07	0.05	0.16	0.31	0.49
Steeles West	60	ARRW	1.31	1.14	1.22	0.52	0.59	0.63	0.81	0.92	0.66	0.10	0.07	0.06	0.40	0.15	0.50
Main	64	HDC	1.88	1.66	1.70	0.72	0.71	0.76	1.01	1.07	0.70	0.19	0.14	0.09	0.68	0.46	0.91
Pharmacy	67	EGLN	1.17	1.06	1.07	0.75	0.68	0.75	0.85	0.81	0.62	0.10	0.08	0.06	0.21	0.16	0.39
Warden	68	EGLN	1.16	0.84	1.07	0.75	0.82	0.79	0.72	0.63	0.78	0.10	0.08	0.06	0.33	0.13	0.24
O'Connor	70	EGLN	1.14	1.13	1.06	0.69	0.73	0.69	0.85	0.88	0.60	0.11	0.08	0.06	0.19	0.17	0.40
Runnymede	71	MDEN	1.53	1.17	1.11	0.62	0.70	0.86	0.92	0.88	0.65	0.14	0.10	0.07	0.48	0.19	0.38
Swansea	77	MDEN	1.74	1.29	1.19	0.67	0.75	0.94	0.89	0.92	0.63	0.18	0.13	0.09	0.67	0.24	0.46
Scarlett Rd	79	MDEN	1.21	1.26	1.19	0.75	0.65	0.64	0.95	0.94	0.72	0.10	0.08	0.07	0.16	0.24	0.41
Sheppard West	84	ARRW	1.25	1.10	1.06	0.58	0.70	0.69	0.81	0.93	0.57	0.10	0.07	0.05	0.34	0.10	0.44
Scarborough	86	EGLN	1.23	1.10	0.95	0.54	0.60	0.66	0.79	0.81	0.63	0.11	0.07	0.05	0.33	0.22	0.27
Weston	89	MDEN	1.27	1.03	0.98	0.75	0.63	0.64	0.84	0.77	0.54	0.13	0.10	0.07	0.29	0.17	0.37
Woodbine	91	EGLN	1.34	1.03	0.92	0.61	0.76	0.68	0.84	0.83	0.63	0.12	0.07	0.06	0.38	0.13	0.24
Woodbine South	92	HDC	1.71	1.37	1.00	0.58	0.64	0.66	0.78	0.84	0.67	0.19	0.10	0.08	0.74	0.43	0.25
Wellesley	94	MDEN	1.59	1.13	1.25	0.62	0.66	0.70	0.78	0.77	0.56	0.20	0.13	0.09	0.61	0.23	0.59
Wilson	96	ARRW	1.25	1.05	0.99	0.60	0.65	0.76	0.86	0.84	0.64	0.11	0.08	0.06	0.28	0.14	0.29
Flemingdon Park	100	EGLN	1.13	1.11	1.05	0.70	0.76	0.77	0.83	0.87	0.65	0.11	0.09	0.06	0.18	0.15	0.33
Markham Rd	102	HDC	1.27	1.56	1.20	0.71	0.70	0.72	0.95	1.20	0.69	0.10	0.12	0.05	0.21	0.24	0.46
Morningside	116	EGLN	1.13	1.15	1.08	0.63	0.73	0.68	0.86	0.91	0.64	0.09	0.08	0.05	0.18	0.16	0.39
Calvington	120	ARRW	1.32	1.12	1.01	0.60	0.73	0.72	0.84	0.88	0.62	0.13	0.09	0.07	0.36	0.16	0.32
Graydon Hall	122	HDC	1.71	1.43	1.44	0.64	0.63	0.76	0.96	0.98	0.74	0.14	0.10	0.08	0.61	0.35	0.62
Christie	126	MDEN	1.39	1.28	1.34	0.70	0.64	0.76	0.80	0.82	0.54	0.20	0.15	0.11	0.39	0.30	0.69
Davenport	127	MDEN	1.63	1.51	1.51	0.62	0.64	0.63	0.87	0.94	0.63	0.17	0.12	0.08	0.59	0.46	0.79
Gerrard	135	EGLN	1.57	1.29	1.43	0.55	0.67	0.59	0.91	0.93	0.70	0.14	0.09	0.07	0.52	0.28	0.66
Rogers Rd	161	MDEN	1.22	1.20	1.42	0.70	0.71	0.66	0.89	0.93	0.62	0.12	0.12	0.08	0.21	0.15	0.71
Weston Rd North	165	ARRW	1.37	1.12	1.14	0.62	0.78	0.72	0.87	0.94	0.68	0.11	0.08	0.06	0.39	0.10	0.39
Symington	168	MDEN	1.20	1.03	1.08	0.63	0.77	0.70	0.83	0.70	0.60	0.14	0.11	0.08	0.23	0.22	0.40
Bluffer's Park	175	HDC	1.00	1.18	0.93	0.77	0.95	0.87	0.72	0.93	0.51	0.12	0.10	0.07	0.16	0.15	0.35
Average			1.35	1.17	1.14	0.64	0.69	0.71	0.85	0.87	0.64	0.13	0.09	0.07	0.37	0.21	0.43
Standard Deviation			0.22	0.15	0.16	0.06	0.08	0.08	0.07	0.09	0.05	0.03	0.02	0.01	0.17	0.09	0.15

Table 2: Fall 2020 Engineering Test Results

Route Name	Route #	Garage	Net Energy Consumption			Energy Regen per km			DT Energy Consumption			LV Acc Energy Consumption			HV Acc + eHeat		
			NewFlyer	Proterra	BYD	NewFlyer	Proterra	BYD	NewFlyer	Proterra	BYD	NewFlyer	Proterra	BYD	NewFlyer	Proterra	BYD
Glencairn	14	MDEN	1.61	2.11	1.46	0.57	0.49	0.50	0.98	1.05	0.88	0.25	0.16	0.06	0.38	0.89	0.52
Don Mills	25	EGLN	1.08	1.37	2.27	0.62	0.53	0.49	0.82	0.92	0.75	0.11	0.08	0.15	0.14	0.38	1.38
Jane	35	ARRW	1.38	1.48	1.52	0.77	0.60	0.51	1.07	0.95	0.70	0.13	0.10	0.07	0.18	0.43	0.75
Keele	41	MDEN	1.20	1.55	1.55	0.67	0.54	0.64	0.94	1.02	0.73	0.11	0.09	0.09	0.16	0.45	0.74
Kennedy	43	EGLN	1.37	1.41	1.46	0.60	0.72	0.54	0.87	0.96	0.71	0.14	0.11	0.07	0.36	0.34	0.67
Lansdowne	47	MDEN	1.22	1.56	1.59	0.53	0.48	0.57	0.88	0.93	0.65	0.14	0.09	0.08	0.20	0.54	0.86
Midland	57	EGLN	1.39	2.01	1.40	0.53	0.50	0.60	0.90	1.11	0.78	0.17	0.13	0.10	0.32	0.77	0.52
Maple Leaf	59	ARRW	1.13	1.37	1.68	0.56	0.59	0.45	0.88	0.92	0.76	0.12	0.09	0.10	0.13	0.36	0.82
Steeles West	60	ARRW	1.50	1.88	1.49	0.77	0.52	0.53	1.12	1.12	0.73	0.16	0.12	0.08	0.22	0.64	0.69
Main	64	HDC	1.14	1.47	1.89	0.54	0.52	0.52	0.84	0.92	0.78	0.14	0.10	0.10	0.17	0.45	1.01
Pharmacy	67	EGLN	1.56	1.27	1.65	0.72	1.14	0.59	0.99	0.51	0.73	0.24	0.12	0.09	0.32	0.64	0.84
Warden	68	EGLN	1.10	1.35	2.03	0.60	0.50	0.74	0.79	0.80	0.82	0.13	0.09	0.13	0.18	0.46	1.09
O'Connor	70	EGLN	1.15	1.44	1.71	0.52	0.65	0.51	0.93	0.93	0.66	0.10	0.10	0.09	0.11	0.41	0.96
Runnymede	71	MDEN	1.16	1.76	1.55	0.62	0.52	0.55	0.87	0.99	0.68	0.13	0.14	0.08	0.16	0.64	0.79
Swansea	77	MDEN	1.34	1.68	1.88	0.72	0.65	0.51	1.00	1.01	0.75	0.15	0.16	0.11	0.19	0.52	1.02
Scarlett Rd	79	MDEN	1.73	1.62	2.02	0.80	0.47	0.62	1.14	0.96	0.64	0.20	0.11	0.13	0.38	0.55	1.26
Sheppard West	84	ARRW	1.23	1.44	1.79	0.52	0.53	0.40	0.83	0.93	0.73	0.18	0.08	0.10	0.23	0.43	0.95
Flemingdon Park	100	EGLN	1.32	1.91	1.57	0.68	0.44	0.58	1.01	1.06	0.75	0.11	0.13	0.07	0.21	0.72	0.75
Morningside	116	EGLN	1.33	1.65	2.07	0.58	0.49	0.49	1.01	0.98	0.82	0.14	0.13	0.12	0.18	0.54	1.13
Calvington	120	ARRW	1.23	1.69	1.78	0.66	0.54	0.45	0.91	0.99	0.74	0.12	0.09	0.12	0.20	0.60	0.92
Graydon Hall	122	HDC	1.33	1.61	1.63	0.54	0.60	0.57	0.94	1.02	0.76	0.19	0.11	0.09	0.20	0.49	0.78
Davenport	127	MDEN	1.20	1.64	1.68	0.52	0.54	0.54	0.84	0.99	0.70	0.16	0.11	0.11	0.20	0.55	0.88
Gerrard	135	EGLN	1.37	1.57	1.65	0.60	0.52	0.61	0.91	1.08	0.74	0.16	0.09	0.09	0.30	0.40	0.83
Rogers Rd	161	MDEN	1.16	1.57	1.47	0.66	0.55	0.55	0.75	1.02	0.74	0.17	0.09	0.07	0.23	0.46	0.66
Weston Rd North	165	ARRW	1.20	1.76	1.85	0.56	0.51	0.65	0.85	1.02	0.76	0.15	0.11	0.11	0.20	0.63	0.98
Symington	168	MDEN	1.60	2.28	2.20	0.50	0.36	0.40	1.05	1.21	1.01	0.22	0.15	0.12	0.33	0.92	1.07
Average			1.31	1.63	1.73	0.61	0.56	0.54	0.93	0.98	0.75	0.16	0.11	0.10	0.23	0.55	0.88
Standard Deviation			0.17	0.24	0.24	0.09	0.14	0.08	0.10	0.12	0.08	0.04	0.02	0.02	0.08	0.15	0.21

Table 3: Winter 2020-2021 Engineering Test Results

Route selection was based on road topography that would subject the buses to Heavy Duty Cycles (HDC) and results of each bus are as follows:

BYD buses consumed an average of 1.14 kWh/km, achieving the lowest/best energy consumption rate during mild ambient temperatures in the fall season; however, with winter performance at 1.73 kWh/km, BYD had both the highest consumption rate and the largest variation at 51%.

NFI buses consumed an average of 1.35 kWh/km, which was the highest/worst energy consumption rate during mild ambient temperatures in the fall season; however, with winter performance at 1.31 kWh/km, NFI had the lowest consumption rate and the smallest variation at 3%.

Proterra buses consumed an average of 1.17 kWh/km during mild ambient temperatures in the fall season. In the winter, Proterra buses achieved an average of 1.63 kWh/km resulting in a variation of 40%.

Given the TTC's specific route network, at this point it is more important to have predictable and reliable range through all seasons than it is to achieve low energy cost. While improvements are expected through planned retrofits, at this point in time BYD and Proterra buses achieve between 40% and 50% less range in the winter than they do in the summer. As such, while NFI buses have a relatively high overall average consumption rate, they performed best overall.

Company	BYD	New Flyer	Proterra	Nova HEV
Energy Consumption				Not evaluated

Figure 8 – Dashboard Preliminary Results for Energy Consumption

Lessons Learned and Next Steps:

1. Predictable and reliable range is more important than achieving the lowest energy consumption.
2. Proterra has started a campaign to retrofit a convector in the operator area and is 30% complete.
3. Exploring defroster programming opportunities to further alleviate winter energy consumption concerns.
4. For future procurements, the TTC will avoid a pure-electric defroster unit without fully understanding the energy efficiency performance.
5. For future procurements, the TTC will continue to specify a diesel-fired heater requirement until heat pump technology is viable.





Company	BYD	New Flyer	Proterra	Nova HEV
Vehicle Performance				

Figure 9 – Dashboard Preliminary Results for Vehicle Performance

Regenerative Braking

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 BYD bus achieved the highest fall test energy recovery rate of 0.71 kWh/km, while the New Flyer bus achieved the highest winter test energy recovery rate of 0.61 kWh/km. However, all three buses are within 10%.

Under slippery winter road conditions, regenerative braking is automatically disabled whenever wheel slip is detected. As a result, there is a significant reduction in regenerative braking experienced. The Proterra and BYD fleets experienced the largest reduction at 32% and 27% respectively.

This phenomenon is deemed to be a safety risk and needs to be considered when training operators, charging buses, planning for service and dispatching.

To mitigate this risk, Proterra released an updated braking and traction control system software calibration in February 2021 that is currently under evaluation. The TTC is also evaluating the benefits of using winter tires. Results of both evaluations will be shared in future program updates.










Company	BYD		New Flyer		Proterra	
	Average	Slip Condition	Average	Slip Condition	Average	Slip Condition
Fall Regen Rate (kWh/km)	0.71 		0.64 		0.69 	
Winter Regen Rate (kWh/km)	0.56 	0.36 	0.54 	0.41 	0.61 	0.37 

Figure 10 – Dashboard Preliminary Results for Regenerative Braking

Next Steps:

1. Evaluate Proterra braking and traction control software calibration update and if successful pursue a similar mitigation with BYD.
2. Evaluate benefits of winter tires with respect to winter regenerative braking rates.

### Battery Capacity and Range

It is often presumed that the bus with the largest battery capacity will have the longest range. However, this is not necessarily the case. The advertised battery capacity of each of the three buses types are different. With over a million kilometres of in-service data accumulated to date, it is clear that the useable battery capacity differs significantly from the advertised values. To optimize battery health and vehicle performance over the lifetime of the bus, the accessible energy in a battery pack is limited to provide a more consistent and predictable energy draw over its lifetime.

If a battery is regularly discharged and charged to 100% of its total capacity, it will degrade faster over time, resulting in a faster-than-expected decline in range over the vehicle’s lifetime. While each OEM may limit the usable capacity differently, this principle nevertheless applies across all battery-electric vehicle manufacturers. Useable battery capacity should therefore be used to estimate range for planning purposes.

The following tables estimate both useable battery capacity and corresponding range for summer and winter seasons based on 2020 in-service performance data and fall and winter engineering tests. Reduced ridership in 2020 due to COVID-19 resulted in lower energy consumption and is artificially increasing theoretical range estimates by approximately 10%.

Bus	Battery Capacity [kWh]	Useable Battery Capacity [kWh]	Average Summer Energy Consumption [kWh/km]	Estimated Summer Range [km]	Average Winter Energy Consumption [kWh/km]	Estimated Winter Range [km]
BYD*	360	291	1.18	246	1.37	212
New Flyer	400	285	1.30	219	1.39	205
Proterra	440	271	1.27	213	1.76	153

\*Limited in-service data available

Table 2: eBus Fleet Battery Capacity vs. Range for In-Service Data

Company	BYD		New Flyer		Proterra	
	Summer	Winter	Summer	Winter	Summer	Winter
Range (km)	246	212	219	205	213	153

Figure 11 – Dashboard Preliminary Results for In-Service Range Estimates

Bus	Battery Capacity [kWh]	Useable Battery Capacity [kWh]	Average Fall Test Energy Consumption [kWh/km]	Estimated Fall Range [km]	Average Winter Test Energy Consumption [kWh/km]	Estimated Winter Range [km]
BYD	360	291	1.14	255	1.73	168
New Flyer	400	285	1.35	211	1.31	217
Proterra	440	271	1.17	231	1.63	166

Table 3: eBus Fleet Battery Capacity vs. Range for Engineering Test Data

Proterra has the largest battery, but is conservative in their approach to protecting the battery resulting in 30% less useable capacity. In contrast, BYD has the smallest battery and protects the least, which results in a useable battery capacity larger than Proterra. Based on recent testing, Proterra is preparing to increase useable battery capacity by 6% that will result in increased range.

Company	BYD		New Flyer		Proterra	
	Fall	Winter	Fall	Winter	Fall	Winter
Range (km)	255	168	211	217	231	166

Figure 12 – Dashboard Preliminary Results for Engineering Test Range Estimates

## Lessons Learned and Next Steps:

1. Evaluate Proterra battery capacity increase benefits;
2. Investigate lowering interior temperature set points without adversely affecting customer comfort;
3. Investigate early activation of diesel-fired heaters and disabling electric heat;
4. Future procurement specification to specify minimum useable battery capacity target and not advertised battery capacity; and
5. Future procurement specification to seek opportunities to improve efficiency, such as through the use of light-weight materials, heat pump, etc.

## 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

### Compliance to Vehicle Delivery Schedule

As part of the procurement contract, each vendor was required to submit a delivery schedule. The vehicle delivery schedule metric is calculated by comparing the contract versus the actual delivery schedule.





Company	BYD	New Flyer	Proterra	Nova HEV
<b>Compliance to Vehicle Delivery Schedule</b>				

Figure 13 – Dashboard Preliminary Results for Vehicle Delivery Schedule

- BYD buses were delivered on average of 186 days behind schedule.
- NFI buses were delivered on average of 43 days behind schedule.
- Proterra buses were delivered on average of 62 days behind schedule.

By comparison, the benchmark Nova HEVs were delivered on average three days ahead of schedule. Nova has been delivering buses to the TTC since 2014. As a result, they have a good understanding of the contractual obligations and provide realistic schedules. The other three manufacturers are new to the TTC and provided overly aggressive delivery schedules for a new product that they were ultimately not able to meet.

While adherence to delivery schedule is only one factor in assessing vendor performance, it is a key metric in assessing the overall vendor performance.

### Manufacturing Facility Quality Audit

The TTC retained a consultant to conduct a quality review of the eBus manufacturers including: BYD, New Flyer, Nova Bus and Proterra. This review focused on the following key areas: production, safety and quality systems, materials management, staff training and vehicle quality.

The auditors visited two manufacturing plants for each manufacturer to conduct quality audits, including manufacturing plants across North America and China. An evaluation checklist containing the various evaluation criteria and their corresponding weight towards the final audit score was used to score the vendors. The evaluation checklist included a total of 68 evaluation criteria in the following six key areas:

1. General Facility and Operations;
2. Staff;
3. Manufacturing and Quality Assurance;
4. Production Line;
5. Health and Safety; and
6. Ethics and Fairness.

As shown below, the more mature facilities were deemed acceptable (Nova, New Flyer and the BYD plant in Hangzhou). Newer facilities, such as the BYD Newmarket, and Proterra facilities require improvement. Findings were discussed with and agreed to by eBus OEMs. However, details are not provided as access to the facilities to complete the audits was granted on the condition of confidentiality.









Company	BYD		New Flyer		Proterra		Nova	
	Hangzhou	Newmarket	Winnipeg	Crookston	LA	Greenville	St. Eustache	Plattsburgh
Quality Review								

Figure 14 – Dashboard Preliminary Results for Manufacturing Facility Quality Audits

It is important to understand the manufacturing facility and processes of each eBus OEM as it is directly related to quality defects found during bus commissioning and in-service performance. This audit was the first of its kind performed by the TTC for bus manufacturers and was found to be very beneficial.

Lessons Learned and Next Steps:

1. Facility audits of selected vendors for future bus procurements will be completed in advance of bus production start.

Quality Defects (Snags)

This metric measures the number of deficiencies identified by the TTC during the commissioning of the vehicle after delivery. Deficiencies are defects identified on the bus that do not meet the contract specifications. These deficiencies are then submitted to the vendor for repair.

All three eBus vendors had a high number of snags that required repair (BYD-44, NFI-34, Proterra-41). In comparison, Nova HEV buses had an average of 17 snags or 50% fewer snags when compared to the eBus vendors.

Similar to vehicle deliveries, Nova has been providing buses to the TTC since 2014. As a result, they have a good understanding of TTC’s commissioning process and quality standards.





Company	BYD	New Flyer	Proterra	Nova HEV
Quality Defects				

Figure 15 – Dashboard Preliminary Results for Quality Defects

The number of quality defects identified during the bus commissioning process generally reflects the manufacturing quality of the bus vendor and increases effort and time required to prepare a bus to enter revenue service.

Lessons Learned and Next Steps:

1. While the TTC contracts full-time quality assurance inspectors at manufacturing and final assembly sites, additional process controls and resources will be considered to better control eBus manufacturing quality and minimize TTC cost and disruption upon vehicle delivery.

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.

Company	BYD	New Flyer	Proterra	Nova HEV
Duration to Final Acceptance				

Figure 16 – Dashboard Preliminary 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.

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 113 days (one bus remaining to achieve target); and
- BYD required 160 days (three buses remaining to achieve target).

Company	BYD	New Flyer	Proterra	Nova HEV
30-Day Reliability				

Figure 17 – Dashboard Preliminary 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.

Contract Deliverables

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 70% of these deliverables, NFI 90% and Proterra 95%.




Company	BYD	New Flyer	Proterra
Contract Deliverables			

Figure 18 – Dashboard Preliminary Results for Contract Deliverables

Canadian Content Review

Each eBus vendor was required to provide their plan to achieve Canadian content requirements at the time of contract award. The minimum requirement for Canadian content is 25%.

The TTC retained a consultant to complete an audit of the eBus vendors Canadian content submission to verify compliance. This work was completed after the delivery of all vehicles and included a review of the invoices for the eligible claims (including component, subcomponent, test equipment, special tools, labour, project management, manuals, freight, warranty and engineering costs) and a comparison to the overall bus cost.

In summary, each eBus vendor met the minimum Canadian content requirement of 25%. Findings of this review were discussed with, and agreed to, by eBus OEMs. However, details are not provided due to confidentiality around proprietary technology and manufacturing processes.




Company	BYD	New Flyer	Proterra
Canadian Content			

Figure 19 – Dashboard Preliminary Results for Canadian Content Review

## Training

Although the TTC has experience with hybrid-electric buses that have a similar drivetrain to that of a battery-electric bus, additional training was required for the three eBuses. Typically, training is delivered by the OEM to the TTC's Operations Training Centre, who then prepare TTC-specific training course material and deliver to TTC employees. Below is a table summarizing the various training courses delivered to date by each eBus vendor:

Course	BYD	New Flyer	Proterra
Operation & Familiarization	✓	✓	✓
Technical Familiarization	✓	✓	✓
High Voltage Safety	✓	✓	✓
Multiplex & Schematics		✓	
Siemens Propulsion	N/A	✓	N/A
Maintenance 1			✓
Maintenance 2			✓
Doors	N/A	N/A	✓*
HVAC			✓*

\*Virtual Training

Table 4: eBus Vendor Training Received

COVID-19 has prevented some of the training from being conducted in person. As a result, some courses were delivered virtually by vendors to minimize risk. Training provided by all three vendors have met expectations with respect to training materials, course content and support for internal course development.

The TTC Training Department has delivered operator training to more than 2,800 operators and 160 maintainers.




Company	BYD	New Flyer	Proterra
Training			

Figure 20 – Dashboard Preliminary Results for Training

## **Charging System Performance**

This domain focuses on the reliability and availability of the eBus charging systems, which is important to ensure buses receive the necessary charge prior to being dispatched to service.

Currently, there are two unique charging systems being used to charge the TTC eBus fleet. The New Flyer and Proterra fleets at Arrow Road and Mount Dennis garages use

a Direct Current (DC) charging system supplied by ABB. The BYD fleet uses an Alternating Current (AC) charging system supplied by BYD.

The ABB DC charging system uses SAE J1771 plug-in charger connectivity and communication protocols with a two bus to one charger sequential charging strategy. The ABB charger model used is an HVC-150 that consists of one charger and two remote dispensers and is capable of charging at a rate of up to 150 kW depending on bus battery system voltage. The ABB DC charging system currently has a 99% availability rate and majority of defects have been easily resolved with a remote reset of the charger. Minor hardware failures of various converters and power modules have been quickly repaired by the charger manufacturer under warranty.

The following table summarizes the charger defects experienced to date for the ABB DC chargers:

ABB Chargers HVC-150 January 1, 2020 - January 28, 2021			
Defect	Mount Dennis	Arrow Road	%
Remote Software Programing	3	2	23%
'CAN' Converter	2	0	9%
Fiber / Ethernet Converter	1	1	9%
Power Module 24 volts dc Dispenser	1	1	9%
Charging Cable (bus ran over)	1	1	9%
Clip on Charger Nozzle	2	0	9%
E-Stop Push Button	0	2	9%
480v AC K20 charger contactor	0	2	9%
Negative-Contactor in Dispenser	1	0	5%
50 KVA Power Module	1	0	5%
CPI board	0	1	5%
Total	12	10	100%

Table 5: ABB Charger Defects

The BYD AC charging system uses proprietary dual plug-in charger connectivity and communication protocols with a one to one bus to charger ratio. This system is capable of charging at a rate of up to 80 kW. In addition, this system uses two plugs per bus that charge at 40 kW each. In the event of a plug failure, the bus can still be charged at 40 kW using the second plug. The BYD charge system currently has a 99% availability rate and the only defect experienced to date has been with the communication failure of four plugs.

The following table summarizes the charger defects experienced to date for the BYD AC chargers:

BYD Chargers September 8, 2020 - January 28, 2021		
Defect	Eglinton	%
Charger Guns Intermittent Failure	4	100%

Table 6: BYD Charger Defects

Although both charging systems have achieved a high degree of availability, the majority of eBus fleets and bus manufacturers are using DC chargers. Although AC chargers may be slightly easier to install from an infrastructure standpoint, DC chargers are capable of charging at rates up to 300 kW in a depot and 450 kW on the road. In addition, interoperability between buses and chargers is possible since SAE standards are used for connectivity and communication.




Company	BYD	New Flyer	Proterra
Charging System Performance			

Figure 21 – Dashboard Preliminary Results for Charging System Performance

### 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 eBuses, which will ultimately inform future procurement specifications.

The TTC aims to provide the best possible ridership experience to customers. A goal of the eBus program was to engage customers, understand what is important to them and collect feedback to inform future bus procurements of both hybrid and battery-electric buses.

The TTC has initiated an online survey for customers that is advertised on eBuses, and asks questions that can help identify what works best for riders and what needs improvement. The survey seeks to obtain feedback on the following:

1. Ride comfort/quality of the bus
2. Seat comfort
3. Seating layout of lower area
4. Seating layout of upper area (beyond the rear door)
5. Rear exit door size
6. Interior noise levels
7. Lighting levels of the bus
8. Exterior styling of the bus

As the survey was initiated in February 2021, insufficient data has been obtained to draw any conclusions. However, preliminary results will be available in advance of finalizing the design of the next procurement.

In addition to the eBus specific survey, the TTC is working with Forum Research Inc. to conduct a quantitative long-form customer survey to help inform all future bus procurements. The TTC will be surveying a representative sample of TTC customers 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

The long-form survey is currently underway. Preliminary results will be available in advance of finalizing the design of the next procurement.

Lastly, prior to finalizing the design configuration of the next procurement, the TTC will co-ordinate a customer focus group to ride all three buses on the same routes in order to compare various parameters, including: ride quality, interior layouts, interior/exterior noise, communications and lighting. While the surveys will likely capture a larger population, this in-person focus group will allow staff to explore the results more deeply and to confirm our understanding of how to maximize the customer experience.

### **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 initiated surveys for operators and maintainers. The survey seeks to obtain feedback on the following:

1. Ride quality
2. Visibility
3. Ergonomics,
4. Acceleration
5. Steering and maneuverability
6. Braking
7. Night driving
8. Maintainability

Results will be available in advance of finalizing the design of the next procurement.

### **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 have provided maintenance support on the advanced propulsion systems and charging infrastructure. There is a learning curve that comes along with this new technology and challenges in the areas of technical troubleshooting and parts availability.

The following is a summary of the average time required to repair a defect on the eBus fleet:




Company	BYD	New Flyer	Proterra	Nova HEV
Average Days to Repair (days)	8.4 	4.1 	6.2 	1.3 

Figure 22 – Dashboard Preliminary Results for Average Days to Repair

The average defect repair time for eBus is four–to-eight times higher than the Nova hybrid-electric (HEV) fleet of similar age. This can be attributed to several factors, including:

1. Complex propulsion system faults that require vehicle communication network signal tracing using data loggers, engineering analysis of fault signals, software fix development, software implementation and validation. This is not the typical troubleshooting process for mature propulsion technology like clean-diesel or hybrid-electric.
2. Parts unavailability and long lead-times have significantly impacted fleet availability.
3. Insufficient vendor resources on location to troubleshoot and repair buses under warranty. COVID-19 has prevented BYD and Proterra technical staff from travelling to Canada to investigate issues in person.
4. Lengthy bus retrofit campaign work resulting in buses out of service for several days.

The maintenance challenges encountered point to the need for a mature supply chain and learning curve associated with new technology.

BYD bus frame structure uses carbon steel, which the TTC historically has avoided due to concerns with corrosion. In the spirit of evaluating BYD’s electric propulsion offerings and to evaluate carbon steel frame structure with modern corrosion prevention treatments, a deviation was accepted. However, it will take a minimum of six years and as long as 12 years of experience to validate the new treatment’s effectiveness.

The corrosion prevention system used by BYD does not dry completely and requires several days before the inhibitor stops dripping. As a result, buses must be kept out of service for three-to-five days. Further, while the rust inhibitor is environmentally friendly, it drips onto the garage floor presenting a slip hazard 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.

## Total Life-Cycle 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.

### Operating Costs

Operating costs are comprised of running and maintenance costs. A key benefit with the adoption of electric bus technology is the expectation of lower operating costs.

Since the start of the eBus program, energy cost per kilometre have been tracked on a monthly basis. TTC maintenance costs 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.

The table below compares the annual average running costs 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

\* 2020 Low Diesel costs due to Covid-19

\*\* Limited in-service time

Table 7: Average Annual Running Energy Costs

As shown in the table above, the 2019 eBus fleet cost approximately \$0.31 per kilometre less to operate than the diesel bus fleet. In 2020, the eBus fleet cost only \$0.10 per kilometre less than the diesel bus fleet due to abnormally low diesel costs, a result of COVID-19. Comparing the more typical diesel costs in 2019 with the most recent and complete electricity costs, the actual cost per kilometre for eBuses is approximately \$0.26 per kilometre less than diesel buses.



Based on the average 75,000 km distance travelled by a bus each year, this equates to a projected net fuel savings of approximately \$19,240 per year per bus. Extrapolating this out to a fully electric fleet in 2040 when the fleet size is estimated to include 2,600-plus buses, the total fuel savings would be \$50 million per year.

Opportunities are currently being explored to further reduce energy costs by leveraging the onsite energy storage systems (ESS). This strategy is estimated to save an additional \$0.015/km (approx.). Energy costs can be reduced still through energy arbitrage where energy is stored during periods when the cost is low and sold back to the grid during periods when the cost is high.





Company	BYD	New Flyer	Proterra	Diesel
Energy Costs (\$/km)	\$0.24 	\$0.31 	\$0.32 	\$0.56 

Figure 23 – Dashboard Preliminary Results for Cost

Energy cost is a direct function of energy consumption rate. As mentioned previously, BYD has the lowest energy consumption rate, which is positive with regards to cost. However, based on our experience to date their consumption rate varies as much as 50%. This results in a significant change range and reduces the number of runs that the BYD bus can be deployed on.

### Capital Costs

While eBus technology is new and immature, capital costs to date have been high in comparison to other propulsion technology, such as diesel and hybrid-electric.

Through a 2020 market engagement via a Request for Information (RFI), the capital cost difference between hybrid-electric and eBuses is approximately \$200,000. This is \$50,000 less than the November 2017 Board Report estimate, and it is expected that this gap will continue to close as the adoption of this technology becomes more widespread.

### Total Life-Cycle Cost

The costs mentioned in this report cannot be used to calculate total life-cycle cost. A comprehensive comparative analysis is to be undertaken as part of the upcoming fleet electrification study planned for Q4 2021.

## Overall Program Performance Summary

The following figure allows for an ‘at a glance’ summary of the findings of each evaluation domain that is described in the report.

Evaluation Domain	BYD	New Flyer	Proterra	Nova HEV
System Compatibility	!	✓	!	✓
Accessibility	✓	✓	✓	✓
Reliability - MDBF	!	✓	!	✓
Distance Between Repairs - DPR	!	!	!	✓
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	✓	⊖	⊖	!

Figure 23: Evaluation Domain Summary