STAFF REPORT
ACTION REQUIRED

Green Bus Technology Plan

Date:	November 13, 2017
To:	TTC Board
From:	Chief Executive Officer

Summary

The City of Toronto's TransformTO action plan sets a target to reduce greenhouse gas (GHG) emissions of 80% by 2050 (against 1990 levels). In order for the TTC to do its part, we join other leading transit organizations in the C40 Fossil-Fuel-Free Streets Declaration, by targeting procurement of only zero-emission buses starting in 2025, and we will target a zero-emissions fleet by 2040.

This report summarizes the current state of available bus propulsion technologies and provides recommended next steps for the immediate and long-term adoption of low and zero-emissions buses into TTC's fleet of approximately 2000 buses.

Over the past year, TTC has been working with the Canadian Urban Transit Research and Innovation Consortium (CUTRIC), the Zero Emissions Bus Resource Alliance (ZEBRA), as well as Toronto Hydro, Enbridge Gas, bus OEMs, peer transit agencies, and others to better understand the required infrastructure investment and constraints, expected reduction in GHG emissions and improvement in local air quality, vehicle performance, system reliability, and life cycle costs associated with each of the available green propulsion technologies.

Currently, there are five options for bus propulsion technologies on the market:

All-Electric Propulsion Technologies	Fossil Fuel Technologies
Battery Electric Bus (BEB)	2nd Generation Hybrid-Electric (HEV 2)
Hydrogen Fuel Cell Electric Bus (FCEB)	Compressed Natural Gas (CNG)
	Clean Diesel (CD)

Table 1 – All available bus propulsion technologies

All-Electric Buses

Electric buses are the only truly green technology with the potential for zero emissions from generation through to bus operations. Electric buses have no tailpipe emissions, and in Ontario, generation of electricity for overnight charging is 100% nuclear and completely free of GHG emissions.

This technology may eventually get us to our target, however, the electric bus industry is so new that there have been no large scale fleets in long-term operations anywhere in North America, and so vehicle reliability, battery longevity, operating costs and maintenance costs are not truly known or proven. Of the 63,000 buses in operation throughout North America, fewer than 220 are either Battery Electric or Hydrogen Fuel Cell Electric.

While it would be premature to purchase electric buses in large numbers for our state-of-good-repair (SOGR) bus replacement program, the experience of other transit authorities over the past few years with battery electric buses (BEBs) has been very positive. London, Paris, Los Angeles, and others are building on early success with one to five pilot buses and they are now in their second or third procurement.

The TTC issued a Request for Information (RFI) in early September 2017 to survey the industry on currently available BEBs. There are three manufactures of long-range BEBs and the TTC proposes to procure ten from each OEM for the industry's first long-term, head-to-head comparison. This procurement of 30 all-electric buses will be used to verify all aspects of bus performance, including metrics for: vehicle reliably and service availability, customer satisfaction, battery charging time and range, maintainability, and the total cost of ownership. The results will assist the TTC and industry at large with the development of bus specifications for future green bus procurements.

Note on FCEBs (Hydrogen Fuel Cell Electric Bus): With an operational range of 450km between refueling, Hydrogen Fuel Cell Electric buses have significantly higher range than the current Battery Electric Bus at 250km per charge. While FCEB technology is very promising, there are only 20 buses in service in North America. The lack of in-service experience has led TTC staff to eliminate the option for the time being.

Fossil Fuel Buses

At this moment in time, the only technology that is proven reliable are Fossil Fuel Buses (FFBs). From this perspective, any one of the current technologies would be a good candidate for our current SOGR bus replacement program. The challenge is to select a propulsion technology that is both low in GHG emissions and a fiscally responsible choice.

Of the three options available, hybrid-electric vehicles (HEV 2), CNG, and Clean Diesel (CD), HEV 2s has the lowest emissions producing 25% less GHGs than either of the other two technologies. If purchased under the Government of Canada's Public Transit

Infrastructure Fund (PTIF), HEV 2s would be tied (within the margin of error) with CNG for the lowest Life Cycle Cost (LCC), which includes the purchase, overhaul, maintenance, and fuel cost over the 13 year life of the vehicle. The proven reliability, low emissions and low LLC of hybrid-electric vehicles makes it the best candidate for SOGR bus replacement.

Recommendations

It is recommended that

1. The Board delegate authority to the TTC CEO to negotiate and enter into up to three contracts for the supply of a total of 30 long range battery electric buses not to exceed the total project cost of $50M based on the following:

   a) The award of contract(s) will be based on negotiating an acceptable agreement, satisfactory to the TTC General Council with the only three qualified long range battery electric bus suppliers, New Flyer, Proterra and BYD that are compliant with Transport Canada Motor Vehicle Safety Standards; and

   b) All 30 battery electric buses are to be delivered no later than March 31, 2019 in order to ensure that the buses are eligible for PTIF funding.

2. The Board delegate authority to the TTC CEO to enter into a contract(s) with up to two suppliers for the supply of 230 new generation hybrid electric buses not to exceed the total project cost of $230M based on the following:

   a) The award of the contract(s) will be based on negotiating an acceptable agreement, satisfactory to TTC General Council with the only two bus suppliers, Nova Bus and New Flyer, capable of manufacturing hybrid electric buses that are compliant with Transport Canada Motor Vehicle Safety Standards; and

   b) Hybrid electric buses are to be delivered no later than March 31, 2019 in order to ensure that the buses are eligible for PTIF funding

3. Staff return to the TTC Board in Q1 of 2018 with an information report providing award details with respect to recommendations 1 and 2.

Financial Impact

This report recommends Board authority to negotiate and enter into contracts for the supply of 230 new generation hybrid buses and 30 battery electric buses and associated infrastructure with an upset financial impact of $280 million as reflected in the below table:

Purchases of Buses ($Millions)	**Total Project Cost***
230 New Generation Hybrid Electric Buses	230.0
30 Long Range Battery Electric Buses	50.0
Total Project Cost	**280.0**

*Reflects an Upset Limit

Under the Public Transit Infrastructure Fund (PTIF), capital projects commenced after April 1, 2016 and completed by March 31, 2019 may receive up to 50% funding of eligible costs.

The purchase of these new buses meets the criteria for funding eligibility under the program and reflects the City's priority project for the use of $121.5 million in current at risk PTIF funding, as approved by the City's Executive Committee during their meeting of October 24, 2017 in consideration of report *EX28.3 Public Transit Infrastructure Fund Phase 1 Update.*

There may be an issue applying all eligible PTIF funding to these bus procurements based on current PTIF guidelines, which directs that no more than 40% of funding can be applied to the final year of the program (April 1, 2018 to March 31, 2019).

As reported by the City in *EX28.3 Public Transit Infrastructure Fund Phase 1 Update*, 37.1% of overall City-wide PTIF spending is currently anticipated to occur in the final year of the program. Without any other changes, the addition of this project to the PTIF program will result in gross spending exceeding the 40% threshold in the final year of the program.

The City's Executive Committee has recommended that City Council reiterate its request that the Federal and Provincial Governments enhance the flexibility of the PTIF program, extending the completion deadline from March 31, 2019 to March 31, 2020; and increase cash flow spending limitations in the final year from 40% to 70% post March 31, 2018.

In the event that additional PTIF funding flexibility is not provided, maximum PTIF funding will be applied to these bus procurements under current program guidelines and any additional funding requirements will be made available through the acceleration of $281.0 million in existing funding for bus purchases available in the 2018 – 2027 Capital Plan, which will be considered by the Board on November 28, 2017. Cash flow funding available in the recommended 2018 – 2027 Capital Plan is detailed in the below table.

$Millions	2018	2019	2020	2021	2022	2023	Total
Annual Cash Flow for Bus Purchases	32.3	81.0	108.8	38.0	11.6	9.3	**281.0**

Any cash flow acceleration in the TTC's Capital Plan will require an equal offsetting cash flow deferral to ensure no net annual impact to the Capital Program. Authority for any required cash flow acceleration/deferral will be sought during in-year capital reporting.

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

Decision History

At its meeting on October 28, 2015, TTC Board was presented with the 2016-2015 Bus Fleet and Facility Plan:

https://www.ttc.ca/About_the_TTC/Commission_reports_and_information/Commission_meetings/2015/October_28/Reports/2016-2025_Bus_Fleet-Facility_Plan.pdf

Following this discussion, Commissioner De Baeremaeker moved the following motion

That staff report back on the City of Edmonton electric bus pilot project; the state of electric bus technology, CNG and other technologies; and how the TTC plans to meet the City of Toronto's energy efficiency and clean air targets

At its meeting on February 21, 2017, TTC Board discussed a new business item regarding a CUTA request for support in a national effort to establish electric bus charging stations:

https://www.ttc.ca/About_the_TTC/Commission_reports_and_information/Commission_meetings/2017/February_21/Reports/16_New_Business_TTC_Electric%20Bus%20Charging.pdf

Following this discussion, Commissioner Minnan-Wong moved the following motion

That the Chief Executive Officer be directed to evaluate before September 2017 the merits of electric buses and develop a strategy for the TTC, including consideration of a pilot project; and refer the CUTA motion for consideration in the development of this report

At its meeting on September 5th, 2017, TTC Board was presented with a request for a procurement authorization of 440 low floor clean diesel buses:

https://www.ttc.ca/About_the_TTC/Commission_reports_and_information/Commission_meetings/2017/September_5/Reports/9_PA_Purchase_440_Low_Floor_Clean_Diesel_Buses.pdf

Following this discussion, the TTC Board adopted the following member motions:

1. *The recommendations be amended to award 325 low floor clean diesel buses to Nova; and*
2. *The TTC issue an RFI for electric buses and report back on the results of the RFI in November and further bring forward the report on new technologies for buses at that time paying particular attention to the maturity of the battery power bus technology; and*
3. *That TTC staff report back on awarding Nova the additional 115 buses on the same terms if the TTC Board does not award a contract for 115 electric buses; and*
4. *That consideration be given to job creation opportunities in Toronto, Ontario and Canada in the RFI and bus technology report.*
5. *Staff report back by the December 11, 2017 meeting of the Board on any other bus fleet options that might be available to the TTC within the timelines set out in the PTIF program.*

Issue Background

By its nature, mass transit is green. Subways and streetcars are powered by electricity and even the diesel bus produces less than 1/10 the emissions per passenger than the personal automobile (Attachment 1, page 3).

With the evolution of diesel bus technology over the past 30 years, air quality standards have forced industry innovation and today's buses emit 99% fewer Oxides of Nitrogen (NOx) and 95% less particulate matter (Source: US Environmental Protection Agency).

The City of Toronto's TransformTO Climate Change and Clean Air Action Plan targets reducing 80% of the City's Greenhouse Gas emissions by 2050 (from 1990 levels). We need to begin adopting the technology now and work closely with industry to build on our mutual experience and to make improvements in zero emissions bus technology. The TTC's target for steady-state procurement of zero emissions buses is 2025, in line with the C40 Fossil Fuel Streets Declaration. C40 is a network of the world's megacities committed to addressing climate change. Signatories of the Declaration include Mayors of Paris, London, Los Angeles, Vancouver and others. With the TTC also targeting the procurement of only zero-emissions buses from 2025, we would have an all emissions free fleet by the end of 2040.

The TTC has been an early adopter of new technology in the past. It has had an early version of the trolley bus, articulated bus, low-floor bus, Compressed Natural Gas (CNG) bus, bio-diesel fuel bus, and more recently the beta version of the diesel hybrid-electric bus. Some technologies proved more reliable and more cost efficient than others. What is clear from this institutional experience is that when adopting new technology it is prudent to take measured steps to limit risk to the base fleet of vehicles – the SOGR bus replacement program. Adopting technology too fast can result in decades of poor system reliably, low customer and operator satisfaction, and/or a high cost of maintenance and operation. As the TTC operates the largest bus fleet in Canada and the third largest in North America, however, we also have a role to play in the advancement of technologies that promise to offer significant safety, environmental, vehicle reliability, customer focused improvements.

Accessibility/Equity Matters

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). TTC will strive to exceed minimum requirements and will include the Advisory Committee on Accessible Transit (ACAT) in design reviews and evaluations of pilot vehicles.

Comments

TTC Bus Fleet Overview

The internal combustion engine since it was first invented has been the prime engine type for the heavy trucking and bus industry. It is known for its superior energy density and its high reliability as a power plant. The downside is that internal combustion engines typically use fossil fuel such as gasoline, diesel, and natural gas that have high emissions of greenhouse gases (GHG), nitrogen oxides (NO_x), particulate matter (PM) and high noise levels.

North America has approximately 63,000 buses in operation, approximately 65% of which are diesel, 20% are CNG, 12% are hybrid electric, and less than 0.5% are zero emission battery electric or hydrogen fuel cell electric.

The TTC bus fleet consists of approximately 2,000 buses of 40-foot and 60-foot configurations. All TTC buses use diesel fuel as their primary source of energy. There is very little diversity in engine powertrain technology utilized as diesel engines power 63.5% of the fleet and diesel electric hybrids power the remaining 36.5%. An overview of the bus fleet is provided in Appendix A.

Over the past year, the TTC has been working with the Canadian Urban Transit Research and Innovation Consortium (CUTRIC), the Zero Emissions Bus Resource Alliance (ZEBRA), as well as Toronto Hydro, Enbridge Gas, bus OEMs, peer transit agencies, and others to better understand the required infrastructure investment and constraints, expected reduction in GHG emissions and improvement in local air quality, vehicle performance, system reliability, and life cycle costs associated with each of the available green propulsion technologies.

Currently, there are five options for bus propulsion technologies on the market:

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Table 1 – All available bus propulsion technologies

Our research into these technologies is summarised in the following sections.

Technology Overview

Based on the information available at the time this report was prepared, each bus technology offers distinctive GHG reductions along with unique technical challenges and in some cases significant capital investment. The challenge is determining which new green technology or technologies should be introduced to TTC's current fleet without compromising service reliability or introducing significant financial risk. Ultimate adoption of any green propulsion technology for buses would require thorough planning, training, and resources to ensure the TTC derives full benefits from their use. Side-by-side comparison of multiple technologies provide the optimal opportunity to capture actionable data on what works best in the TTC's specific operating environment.

Fossil Fuel Buses Overview

The chart below (Figure 1) plots carbon dioxide (CO2) GHG emissions for each of TTC's existing buses (i.e. conventional diesel, first generation hybrid electric vehicles (first GEN HEV), and clean diesel. Today's options for procurement of proven reliable technology include clean diesel, compressed natural gas (CNG/RNG), and second generation hybrids. As indicated, the technology that offers proven reliability and the lowest emissions is the latest hybrid-electric vehicle, which is 38% lower in emissions than our oldest buses and 25% lower than your newest clean diesel buses.

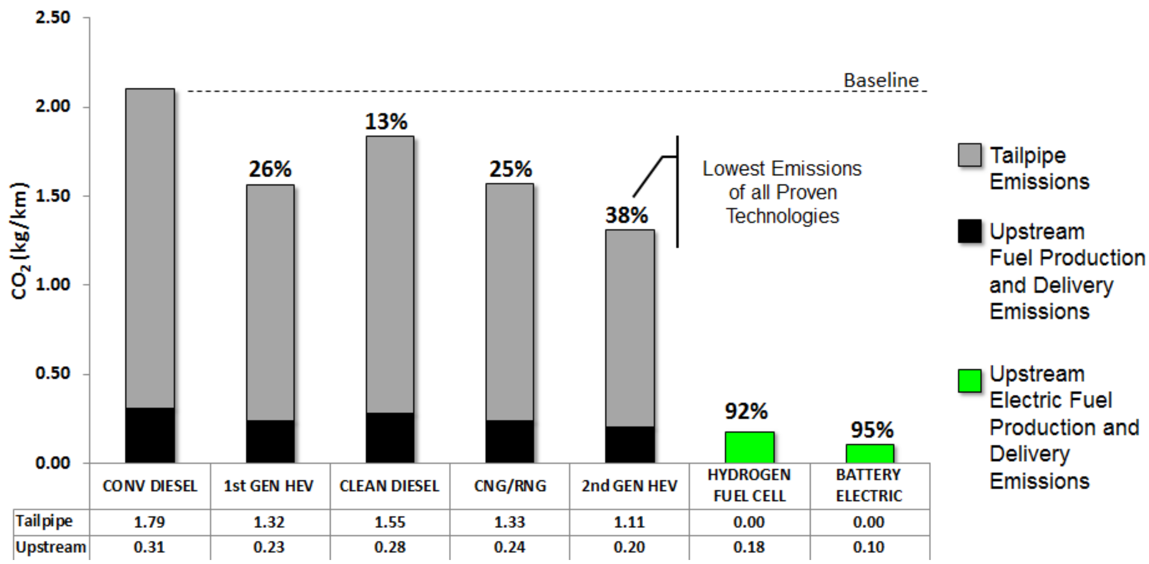
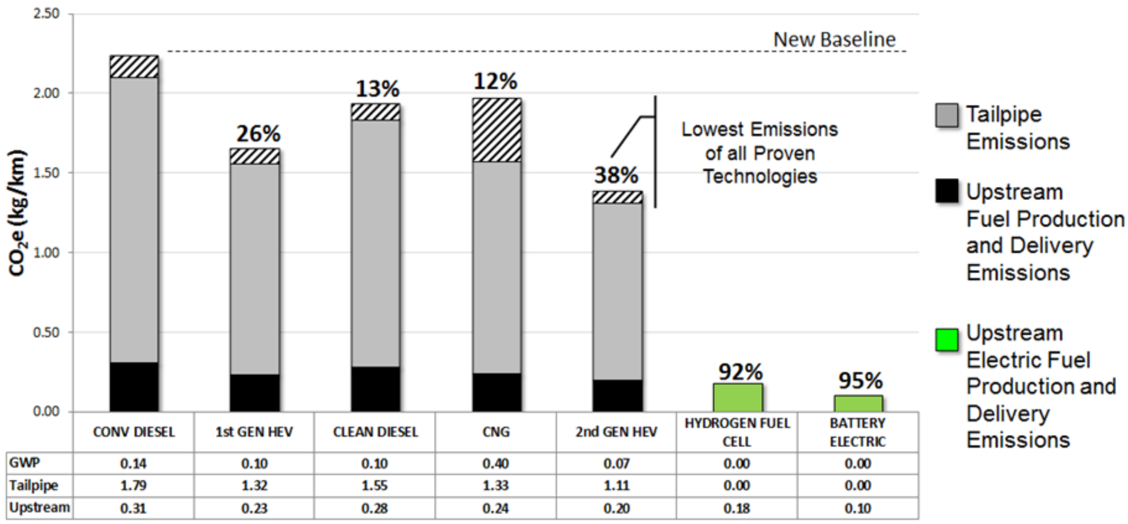


Figure 1: GHG Emissions by Bus Propulsion Technology (source: GREET 2017 GHG lifecycle analysis tool developed by the Argonne National Laboratory)

It is also clear from this chart that fuel cell electric buses (FCEB) and battery electric buses (BEBs) have no tailpipe emissions, which translates to zero local emissions. Additionally, the upstream emissions, which for fossil fuels are produced during extraction, refining and transportation, are also emissions free for electric buses. (This is due to the fact that in Ontario generation of electricity for overnight charging is 100% nuclear and therefore completely free of GHG emissions.)

Carbon dioxide is not the only GHG released during production, transportation, and combustion of fossil fuels – this perspective is often referred to as the well-to-wheel emissions. Under the Kyoto Protocol, Global Warming Potential (GWP) factors are to be used for calculating the total impact of all pollutants well-to-wheel. Methane, for example, has a GWP of 34, meaning that it is 34 times worse than CO2. Nitrous oxide, to use another example, has a GWP of 298.

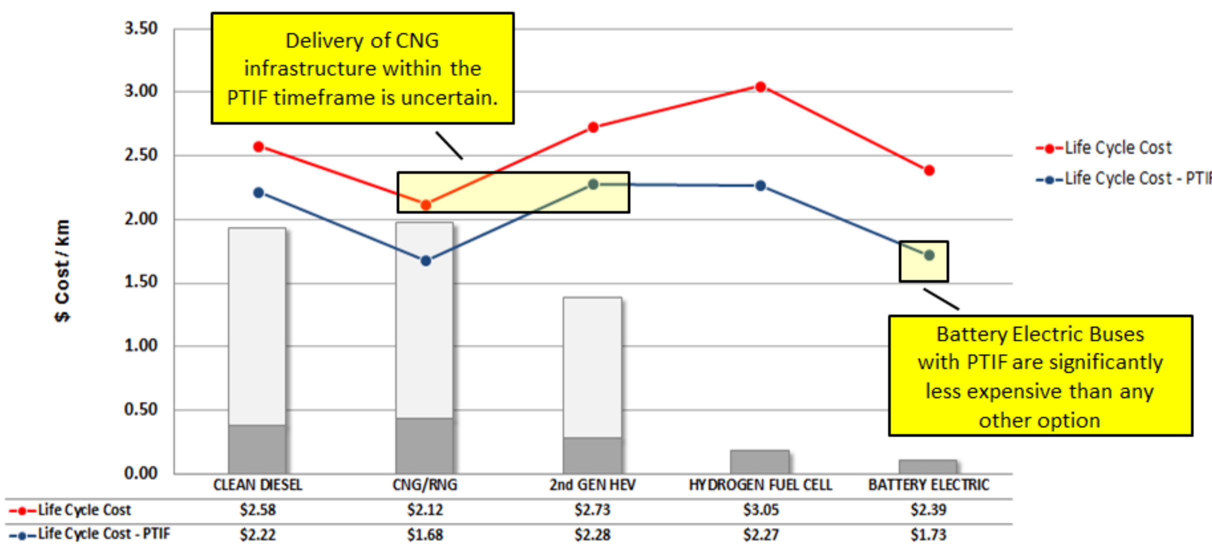
As seen in Figure 2, below, when you factor in all of the pollutants most fossil fuel buses actually emit the equivalent of 5% more CO2. A notable exception is with CNG buses, which run on methane, which emits an equivalent of 25 % more CO2.



	CONV DIESEL	1st GEN HEV	CLEAN DIESEL	CNG	2nd GEN HEV	HYDROGEN FUEL CELL	BATTERY ELECTRIC
GWP	0.14	0.10	0.10	0.40	0.07	0.00	0.00
Tailpipe	1.79	1.32	1.55	1.33	1.11	0.00	0.00
Upstream	0.31	0.23	0.28	0.24	0.20	0.18	0.10

Figure 2: CO2 Equivalent Emissions by Bus Propulsion Technology (source: GREET 2017 GHG lifecycle analysis tool developed by the Argonne National Laboratory)

Of the three options available, hybrid-electric vehicles, CNG, and Clean Diesel, it's the latest generation of hybrid-electric buses that have the lowest emissions, producing 25% less GHG than either of the other two technologies.



	CLEAN DIESEL	CNG/RNG	2nd GEN HEV	HYDROGEN FUEL CELL	BATTERY ELECTRIC
Life Cycle Cost	$2.58	$2.12	$2.73	$3.05	$2.39
Life Cycle Cost - PTIF	$2.22	$1.68	$2.28	$2.27	$1.73

Figure 3 – Life Cycle Cost Comparison

The columns in the figure above are same as shown on Figure 3, however, the only technologies included are those that can be purchased today. The emissions are included in the background of this life-cycle-cost (LCC) comparison for easy reference.

The top line is the life cycle cost, while the bottom line is the life cycle cost minus funding currently available through the Government of Canada's Public Transit Infrastructure Fund. Looking at life cycle cost, CNG is the lowest overall due to the low cost of methane gas, however, delivery of required infrastructure within the PTIF window is uncertain due to the need for extensive modifications to operating garages that do not have the space to accommodate large scale modifications.

When the PTIF funding is applied to the upfront capital investment, those technologies that require the larger upfront capital investment benefit the most from PTIF from a total lifecycle cost perspective. When comparing the cost of CNG without PTIF and second generation hybrids with PTIF, the cost is about on par (within the margin of error) but you get 30% lower emissions with hybrids.

Also worth of notice is that, BEBs – although not proven - are significantly lower in total life cycle cost than any other option – 18% lower than CNG. This target state is currently 33% lower in total life cycle cost than today's clean diesel.

In conclusion, the hybrid-electric bus offers the lowest GHG emissions of all proven technologies and under PTIF they have the lowest life cycle cost of all options that can be implemented within the PTIF window. As such, they are the recommended option for our current SOGR bus replacement program.

All-Electric Bus Overview

Electric buses are the only truly green technology with the potential for zero emissions from generation through to bus operations. (Electric buses have no tailpipe emissions, and in Ontario, generation of electricity for overnight charging is 100% nuclear and completely free of GHG emissions.)

This technology may eventually get the TTC to its target, however, the electric bus industry is so new that there have been no large scale fleets in long-term operations anywhere in the world, and so vehicle reliability, battery longevity, operating costs and maintenance costs are not truly known or proven. Of the 63,000 buses in operation throughout North America, fewer than 220 are either Battery Electric or Hydrogen Fuel Cell Electric.

While it would be premature to purchase electric buses in large numbers for our SOGR bus replacement program, the experience of other transit authorities over the past few years with BEBs has been very positive. London, Paris, Los Angeles, and others are building on early success with one to five pilot buses and are now in their second or third procurement.

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Note on FCEBs: With an operational range of 450km between refueling, Hydrogen Fuel Cell Electric buses have significantly higher range than the current Battery Electric Bus at 250km per charge. While FCEB technology is very promising, there are only 20 buses in service in North America. The lack of in-service experience has led TTC staff to eliminate the option for the time being.

Clean Diesel Bus Technology

The TTC has been purchasing clean diesels since 2010 with 629 clean diesels in service at the time of this report. Environmental Protection Agency (EPA) emissions standards have driven several technological changes in diesel transit buses. These include:

- Oxidizing Catalyst – Reduces unburned hydrocarbons and particulate matter
- Diesel Particulate Filters (DPF) – Physically filters engine exhaust of particulate matter (PM)
- Exhaust Gas Recirculation (EGR) – Recirculates engine exhaust gas into engine intake system reducing NO_x emissions
- Selective Catalyst Reduction (SCR) – Uses a mixture of urea and water also known as Diesel Exhaust Fluid (DEF) to remove NO_x from emissions

Although these systems have reduced NO_x by 99% and PM by 95%, and allowed the diesel engine to meet EPA emissions standards, they still release more particulate matter and nitrogen oxide pollutants than other green technologies. Early generation clean diesels were plagued with reliability issues associated with the new exhaust after-treatment systems. Problems included excessive DPF regeneration cycles and failures in the components handling diesel exhaust fluid (DEF). The higher operating fuel pressures of clean diesels, delicate fuel injectors and stringent fuel filtration requirements have given rise to a high rate of fuel injector failures, sometimes resulting in catastrophic engine failures. Most of these issues have since been addressed through product maturation.

Overall, maintenance costs have increased in comparison to older conventional diesel buses, and these experiences are shared amongst all North American transit properties. Fuel economy of clean diesels has been greatly improved over older conventional diesels and from TTC operating data are almost at par with the older diesel electric hybrids in the fleet. This is a good news story in the industry as it has helped offset the ever increasing cost of diesel fuel.

Summary:

- Used by majority of transit vehicles in North America
- Mature technology
- 13% GHG emissions reduction vs. conventional diesels; meets EPA standards
- Reliable
- Good range and fuel efficiency
- Increasing and unstable fuel costs
- Generally non-domestic fuel source
- Expensive exhaust after-treatment components and maintenance
- Louder than other propulsion systems.

Diesel Electric Hybrid Bus Technology

TTC was one of the early adopters of diesel electric hybrid technology. TTC purchased hybrid buses between 2006 and 2009 and currently operates a fleet of 691 Daimler Bus OrionVII 40-foot buses equipped with the first generation series hybrid system designed and manufactured by BAE Power Systems. These buses are essentially an electric bus with a generator driven by a diesel engine. Diesel electric hybrids allow for the recovery of braking energy (regenerative braking) meaning that energy produced when descending a hill or during braking is fed back to the energy storage system to reuse for propulsion, leading further to reduced fuel consumption and in turn, reduced tailpipe emissions.

In the early years, these buses presented many challenges related to the hybrid powertrain including frequent electrical failures during inclement weather, traction motor internal faults, high costs for replacement parts, and poor aftermarket supply chain support. As a result, the hybrid fleet underwent a multitude of design changes to improve key hybrid components. These changes included engineering improvements to the traction motor, traction generator, and energy storage system and control software optimization. To mitigate component costs and parts supply chain challenges, the TTC began in-house traction motor and generator overhaul programs to control quality and increase availability. More recently, a fault based hybrid technical training program was developed and delivered to technicians and staff. These efforts have improved the TTC's hybrid fleet reliability from 7,000 mean kilometers between defects (MKBD) in 2013 to over 15,000 MKBD in 2017.

Today's second generation of diesel electric hybrid buses have significantly improved. Key hybrid propulsion components are now expected to last a 12-year bus life. Traction motor durability has been improved through the use of ceramic bearings and the life of propulsion control components has been extended through the improvement of electronic switch cooling. The second generation hybrid integrates the traction motor and generator into a single unit mounted in a longitudinal configuration. This allows the new hybrids to have an engine start/stop feature that helps contribute to an overall 20% improvement in fuel consumption when compared to the older hybrids currently operated by the TTC. In addition, new hybrids can also operate for a limited driving range on only electric propulsion utilizing power stored on-board that can further improve overall fuel consumption. Transit agencies operating the new generation of hybrids have reported favorable results and view them as bridging technology to future fully electric buses.

Summary:

- Good driving range and fuel efficiency
- Lower GHG emissions vs. clean diesel and CNG
- Mature technology
- TTC has experience to support
- New generation systems offer limited range on electric only propulsion
- Higher initial vehicle purchase costs
- Higher maintenance & replacement component costs vs. diesel
- No infrastructure constraints.

Compressed Natural Gas (CNG) Bus Technology

Natural gas is a widely available fuel that comes primarily from domestic fossil fuel reserves. Approximately 20% of transit buses sold in North America use some form of natural gas whether it be compressed natural gas (CNG), liquefied natural gas (LNG) or renewable natural gas (RNG). The TTC owned and operated a fleet of 125 CNG buses purchased between 1991-1998 for 10 Million+ kilometers. The province aggressively promoted CNG technology at the time due to low exhaust emissions and fuel costs. The TTC benefited from provincial subsidies when these buses were purchased as the provincial government funded 75% of the capital purchase costs of 125 buses and 100% of the capital costs associated with the fueling station and necessary modifications to the bus garage.

The TTC experienced frequent ignition system failures, burnt engine valves, burnt cylinder head gaskets, fuel tank permeation, fuel solenoid control valve and pressure relief valve failures while operating CNG buses in the 1990s. The Majority of these issues have since been resolved, but agencies operating CNG buses today still report occasional piston failures that have not been 100% counter-measured.

As the transit industry has invested in CNG technology, advancements have resulted in much more reliable and clean burning engines. Today's CNG bus offers a 12% reduction in GHG emissions in comparison to a diesel with minimal particulate matter emitted from the tailpipe. Operators of this technology have reported a slight decrease in acceleration and power when driving uphill, which is the result of natural gas having a lower energy density than diesel fuel. Due to reduced combustion efficiency, approximately 10-20% more fuel must be stored on-board to achieve equivalent diesel bus driving range. But overall, the performance and operation of a CNG bus is very similar to that of a diesel.

While CNG engines may yield cost savings with the elimination of DPF maintenance on a diesel, they introduce new maintenance items including frequent spark plug (every

15,000km) and ignition system component replacement, more frequent oil changes and valve lash adjustments (every 30,000km). Strict adherences to these maintenance schedules are necessary to ensure optimal performance. In order to inspect and service natural gas vehicles, coach technicians require an Internal Combustion Alternative Fuel Technician certification (ICE-NG certificate) that entails the completion of a three-day course and writing a TSSA examination at a cost of $350 and requiring renewal on an annual basis at a cost of $130 per year. In addition, CNG storage tanks must be periodically inspected and hydrostatically tested in compliance with TSSA and Ministry of Labour standards.

Infrastructure Requirements

CNG buses require specialized fueling and defueling stations. Natural gas is delivered by the local gas companies via pipeline. It is then dried, compressed, stored at 4,500psi and dispensed to the bus at 3,600psi. Bus fill times can range anywhere between 5-12minutes depending on compression power. Methane leak detection systems, indirect-fired heaters, sealed lighting fixtures and upgraded ventilation systems are some modifications required at the bus maintenance and storage facilities to support CNG buses.

The TTC also anticipates a level of resistance from surrounding neighbourhoods and businesses regarding the perceived hazard/risks associated with natural gas fueling/defueling stations. As the TTC CNG fuel station from the 1990s has since been decommissioned, the cost of constructing a new station and upgrading maintenance facilities are estimated to be $33M per garage. Enbridge has proposed a turn-key solution for the necessary infrastructure that includes station installation and maintenance but implementing this solution within the PTIF deadline would be very challenging.

Renewable Natural Gas

Renewable Natural Gas (RNG) is methane produced from the decomposition of organic waste. This biogas can be harvested from landfills or from anaerobic digestion systems that are designed to process animal manure and other biomass. RNG provides the lowest carbon intensity of any heavy-duty transportation fuel available and GHG emission reductions are much greater than they are for fossil natural gas. However, RNG is extremely expensive at twice the cost of natural gas in Ontario and currently only available in limited supply or blends with fossil natural gas.

Many municipalities are harvesting RNG from landfills and selling this commodity to southern states like California for a profit. The City of Toronto will have two anaerobic digesters in-service by Q1 of 2019 producing a total of 5.3 million cubic meters of RNG annually, which would be sufficient to fuel 140 TTC buses. However, 90% of this RNG is already earmarked to supplement the City’s refuse truck fleet as part of a larger Solid Waste Management Department project. It is estimated that the City will generate 65 million cubic meters of RNG by 2035, which is viewed as a significant source of future revenues via carbon tax credit sales. The province of Ontario is anticipating 628 million cubic metres of RNG to come online by 2028. RNG can potentially reduce the TTC’s overall GHG footprint but, an RNG bus emits the same tailpipe pollutants as a CNG bus, which would still impact local air quality.

Cummins ISL-G Near Zero Engine

In mid-2016, Cummins started production of the new ISL-G Near Zero engine. This engine is touted to be the first mid-range engine in North America to receive emissions certifications from both the EPA and Air Resource Board (ARB) in California that meet the optional near zero emission standards. This new engine's exhaust NO_x emissions are claimed to be 90% lower than the current EPA NO_x limit of 0.2 g/bhp-hr and will yield methane emissions reductions that will result in an overall GHG reduction of 9% in comparison to the current Cummins ISL-G engine. Performance is achieved through the adoption of a new closed crankcase ventilation system and three-way exhaust catalyst. Los Angeles Metro is the first property in North America to purchase and operate these engines in 2017.

Summary:

- 20% of transit buses sold in North America are CNG
- Relatively low fuel cost
- Mature technology
- Low emissions and particulate matter
- Domestically produced fuel with potential for RNG
- Same driving range as a diesel
- Expensive fuelling & defueling infrastructure required
- Maintenance facility gas detection & ventilation upgrades required
- Lower energy density requires 10-20% more fuel to achieve diesel performance
- No recent experience with CNG at the TTC
- Coach technicians will require ICE-NG certification.

Battery Electric Bus (BEB) Technology

Battery electric propulsion is a relatively new technology in comparison to the previously discussed technologies that offers quiet operation and true zero tailpipe emissions. Although BEBs are more expensive than a diesel bus costing approximately $1M each versus $700,000 for a diesel, they use 30% fewer mechanical parts with the deletion of a diesel engine and exhaust, which the TTC expects will result in reduced maintenance costs.

Battery electric buses receive energy from an external power source that charges the on-board rechargeable batteries unlike a hybrid, which uses an internal combustion engine. The batteries then supply the electric bus traction motor with energy. As BEBs draw most of their power from the electrical grid, local electrical utility company's infrastructure can pose limitations on the ability to run large fleets of BEBs and the environmental impact of this technology is based upon the fuel the grid uses to generate its electricity. In

Ontario, the power generation is very green with generation split between nuclear and hydro, while natural gas supplements peak demands. In the scenario of an overnight charged BEB, the electricity would be 100% nuclear-generated.

There are a handful of transit bus OEMs offering commercially ready BEBs today, including BYD, New Flyer, Proterra and Nova Bus. Each company offers unique merits. BYD is the largest rechargeable battery manufacturer in the world and their bus is primarily an overnight charge, long range bus. New Flyer is one of the leading heavy duty bus manufacturers in North America and offers both long range and short range buses with both overnight and on-route charging strategies.

Proterra is a niche transit bus manufacturer that offers long range and short range buses, overnight or on-route charging and a composite bus body to reduce vehicle weight.

Nova Bus is the most recent OEM to offer a short range bus with on-route charging capability and are currently developing a long range bus. In North America, there are approximately 195 BEBs already operating in service today, 10 of which are in Canada. From surveying bus OEMs offering BEBs, approximately 318 BEBs are on order by various transit properties in North America. An overview of North American transit properties operating or waiting for delivery of BEBs is provided in Appendix B. Many of the BEBs in operation are part of demonstration programs in collaboration with industry partners to assess the status of the technology, performance in comparison to conventional baseline vehicles and feasibility of large scale fleet adoption.

Despite the ongoing demonstration programs, the maturity level and lack of long term operating experience results in several inherent risks with adopting this technology today including long term reliability, total cost of ownership, supply chain management and long term support of vehicles.

Battery Electric Bus (BEB) Range & Charging

Driving range is a key barrier that reduces the attractiveness of BEBs. The TTC operates a wide array of routes varying in distance and at the moment, only 50% of those routes could be fulfilled by BEBs as driving ranges of a BEB have yet to exceed 250km. As range is primarily associated with the amount of energy stored on-board, battery weight and performance is key. Battery technology has made significant strides over the past few years. Experimentation with various battery chemistries has resulted in energy output to weight improvements, increased cycle life and calendar life. These advancements are expected to continue for at least the next decade together with significant cost reductions.

While it may initially appear that a BEB bus strategy consisting of large onboard energy capacity with overnight plug-in charging is positive, it is important to consider the full ramifications of this approach. Charging a fleet of 300 BEBs at a rate of 100kW for five hours would produce an electrical load of 30megawatts, which is roughly equivalent to the load of approximately 8,000 residential homes for a span of 5-6 hours per day.

Opportunities, do however, exist through rapid on-route or opportunistic charging at stations and or stops during boarding or unloading of passengers. This would allow for range extension while distributing power over time. As the TTC does factor in scheduled recovery time at the end of bus trips to absorb any delays accrued, curb-side direct charge on-route rapid charging stations could be the long term solution for insufficient BEB range. On-route and overnight depot chargers can cost anywhere between $250,000-$500,000. TTC staff has visited and spoken to several transit agencies already operating BEBs. Operators that utilize an on-route charging strategy cited long construction time and many complications with securing land for chargers and electrical hardware, especially in urban environments. But the biggest drawback of on-route charging is the inability to operate BEBs elsewhere as they are tied to only routes with the charging infrastructure. Given the TTC's desire to procure BEBs while taking advantage of the Public Transit Infrastructure Fund with a deadline of March 31, 2019, short-range electric buses are not a viable option at this time.

Early adopters of BEBs have also struggled with the impact of peak demand charges on electricity bills that affect the overall BEB business case. Peak demand charges are levied by electric utilities on their commercial and industrial partners to recover capital costs and are generally calculated based on the maximum amount of electrical power drawn from the grid during charging events. In some areas where demand charges are high, energy cost is more than double.

Without peak demand charges, BEBs show a clear advantage over diesel and CNG powered transit buses. There are potential options currently being explored that would mitigate the impact of peak demand charges for both on-route and overnight charged buses. Managing electric bus charging is one obvious option by increasing the number of charging stops or staggering night time charging. Another option being explored by the industry is the idea of utilizing energy storage systems to allow for low voltage charging in conjunction with super-capacitors capable of fast charging a bus when required.

Summary:

- Zero tailpipe emissions
- Quiet operation
- Relatively new technology
- Fuel (electricity) prices generally stable
- Potential for reduced maintenance costs
- TTC hybrid experience highly transferable
- Reduced driving range vs. diesel, hybrid & CNG
- Higher capital cost of buses
- Higher capital cost of charging infrastructure
- Durability and long-term performance is unknown
- Weight of battery packs decrease efficiency.

Battery Electric Bus (BEB) Request for Information (RFI)

The TTC released RFI# R32PH17912 on September 8, 2017 with a closing date of September 27, 2017. The purpose of the RFI was to identify BEB bus manufacturers who are registered and certified by Transport Canada that would be interested in participating in future testing and evaluation of BEBs in revenue service with the TTC. More specifically, the project would place a small fleet of BEBs into scheduled service within a sufficient timeframe to allow the TTC to begin developing technical and operating experience with this technology. This experience would then allow the TTC to better prepare for a wider deployment of this technology in future years. The TTC will be seeking input from bus manufacturers that build BEBs that are certified by Transport Canada to be registered and operated in Canada.

A total of four bus OEMs including BYD, New Flyer, Nova Bus and Proterra submitted proposals with information focusing on technology offerings, charging strategies, driving range, and local job creation opportunities. Respondents were invited during the week of October 2, 2017 to conduct a presentation of their RFI submission and to answer questions. An analysis of all RFI responses was performed and using a decision matrix, BYD, New Flyer and Proterra were identified as good candidates to collaborate further in the evaluation of BEBs in TTC service as they offered buses with long range, overnight charge capability that will feasibly allow the procurement and integration into TTC service within the PTIF window.

Fuel Cell Electric Bus (FCEB) Technology

FCEBs contain the same powertrain as a BEB but also feature a fuel cell system that continually produces electricity to charge the battery and power the electric motors. The fuel cell converts chemical energy of hydrogen into electrical energy through a chemical reaction. Canada is home to two manufacturers of Hydrogen Fuel Cells: Ballard Power Systems (in British Columbia) and Hydrogenics (in Ontario) and more than 2,000 organizations throughout the world are actively involved in fuel cell development. FCEBs have a range of approximately 450km that allows for 1:1 diesel bus replacement and meet driving range requirements without any roadside infrastructure requirements or route dependence. However, the complexity of handling these vehicles has kept most transit properties away from their adoption.

In 2006, the United States Federal Transit administration (FTA) started a multi-year cost shared research program called the National Fuel Cell Bus Program (NFCBP). The goal of the NFCBP was to develop and demonstrate commercially viable fuel cell technology for transit buses and twenty-one of those buses remain in service today. Many challenges were encountered during NFCP program. Participating transit properties experienced issues with the availability of components that have long lead times. This has since been improved as they learned what key components to keep on hand. Bus ranges were lower than originally anticipated but this was a result of hydrogen station fill rates. Finally, the cost of maintenance was high and labour intensive as a result of the steep learning curve associated with understanding how to fully maintain these buses. But the FCEBs themselves performed well and achieved reliability higher if not at par with diesel buses.

In 2010, Ballard System & New Flyer teamed up with BC Transit to deploy a fleet of 20 FCEBs for the 2010 Vancouver Olympics. The development of these FCEBs was rushed and resulted in performance complications. However, the biggest downfall of this program was the operating cost as hydrogen was trucked in rather than on-site generation resulting in operating costs exceeding that of a diesel. This fleet of FCEBs have since been removed from service and sold to Custom Coach Works in California.

In 2017 the FTA kicked-off another FCEB program called the Low-No Program. The primary purpose of this program is to deploy the cleanest U.S. made transit buses that have been proven in testing and demonstrations but not yet widely deployed in transit fleets. A total of 44 buses will be deployed under this program. An overview of North American transit properties operating or waiting for delivery of FCEBs is provided in Appendix C.

The TTC recently visited Sunline Transit in California, which is viewed in the industry as pioneers of FCEBs having successfully operated seven generations of them since 2000. Sunline currently operates four FCEBs and is expecting an additional 12 by the end of 2018. Sunline has an on-site hydrogen generating station and by the end of 2017 will start construction for a new electrolyzer to replace the older hydrogen generating station. It is clear that after 40+ years of development, today’s seventh generation fuel cells offer increased reliability and decreased cost over previous generations.

Hydrogen Generation & Refuelling

Hydrogen is the most abundant element in the world and could decrease North America’s dependency on oil as it can be produced from natural gas or renewable resources. Hydrogen can be delivered much like diesel or generated on-site and there are many factors to consider when selecting a strategy including capital costs, delivery costs, available space and permitting requirements. The TTC is fortunate to have the largest hydrogen plant in Canada in Sarnia, Ontario producing 80 million cubic feet of hydrogen per day that could keep delivery costs to a minimum. The plant in Sarnia, which is owned and operated by Air Products, uses natural gas for steam methane reforming.

Alternately, several companies now offer on-site, on-demand hydrogen generating and fuelling stations with a footprint equivalent to that of a diesel fueling station and bus fill times under 10 minutes. These stations can generate hydrogen through electrolysis using clean and or renewable energy from Ontario’s grid. The cost of a high output hydrogen generating fuel station to support a medium to large fleet of FCEBs is estimated to be more than $20M. In addition, bus maintenance facilities would require ventilation upgrades similar to CNG bus requirements to protect against gas leaks as well as very specialized fuel handling procedures for safety reasons.

Summary:

- Zero tailpipe emissions
- Quiet operation
- Hydrogen can be produced domestically or on-site using renewable resources
- New technology; still in demonstration phase
- Better driving range than BEB
- Would allow for 1:1 diesel bus replacement
- High capital costs of buses
- Expensive hydrogen generating infrastructure required
- Durability is unknown; not many long-term commercial FCEBs in operation.

Partnerships

CUTRIC

The Canadian Urban Transit Research & Innovation Consortium (CUTRIC) vision is to make Canada a global leader in zero and low emissions transportation technologies by supporting research, development, demonstration and integration through industry-academic project based collaborations. These advancements in turn will help drive forward innovation in transportation across Canada, leading to job growth, economic development and significant GHG reductions. CUTRIC membership is based on a "pay-to-play" fee structure for both private and public stakeholders to ensure that the bulk of government revenues are spent on innovation projects rather than operation costs.

CUTRIC is proposing a Low-Carbon Smart Mobility (LCSM) Innovation Supercluster Consortium that will look at obtaining transportation innovation funding from the Government of Canada. CUTRIC is currently conducting a modelling exercise of BEB buses on TTC routes. The results of these models will be available in Q4-2017 and will provide the TTC with a better understanding of the feasibility of BEB integration in TTC service. CUTRIC is also overseeing two technology demonstration programs that are of particular interest to the TTC.

Pan-Canadian Electric Bus Demonstration & Integration Trial

In collaboration with New Flyer, Nova Bus, ABB and Siemens in 2016, CUTRIC began Phase 1 planning of the Pan-Canadian Electric Bus Demonstration and Integration Trial. The demonstration that begins in late 2017 will see a total of 20 BEBs in revenue service at Brampton (10), York Region (6) and British Columbia's Translink (4). The demonstration will utilize standardized on route rapid overhead charging systems that will allow the BEBs to essentially stay in service indefinitely. In order to mitigate electricity demand charges incurred during charging events, Phase 2 of CUTRIC's BEB demonstration will introduce on route and end point energy storage with super-capacitor technology and increase test bus fleet size to 60. Phase 2 technical planning sessions will begin in September 2017.

Pan-Canadian Hydrogen Fuel Cell Vehicle Demonstration & Integration Trial

In collaboration with New Flyer, Ballard Power Systems, Hydrogenics, Air Products and BAE Systems in July 2017, CUTRIC began Phase 1 planning of the Pan-Canadian Hydrogen Fuel Cell Vehicle Demonstration and Integration Trial. This project proposes the deployment of 30 FCEBs at two transit agencies for a period of five years. However, the buses and fueling infrastructure are designed for 15+ years of operations, and it is envisioned that these buses would continue service following the defined demonstration period. This project would feature on-site hydrogen production, and fueling infrastructure including compression, storage and dispensing. This project offers the opportunity to showcase world class Canadian technology for both the buses and the low-carbon fueling infrastructure. The second technical planning session is tentatively planned for September 2017.

ZEBRA

The Zero Emission Bus Resource Alliance Group (ZEBRA) is organized by transit agencies for transit agencies, where transit management and staff can collaborate meaningfully to support the deployment of zero emission buses (ZEBs). ZEBRA's mission is to create a forum that allows transit agencies to inform, educate, and discuss regulatory, funding, and performance topics connected to ZEB deployments. Ultimately, participants will be sharing best practices to ensure more successful deployments, leverage resources for common use, develop materials that can assist in planning and deploying ZEB fleets, develop and join in workforce development programs and prescribe ZEB performance characteristics to ZEB OEMs. The TTC has committed to becoming a member moving forward.

Toronto Hydro

Toronto Hydro is the largest municipal electricity distribution company in Canada and is the current electricity provider to the TTC. Toronto Hydro operates in an environmentally responsible manner consistent with the City's Climate Change, Clean Air and Sustainable Energy Action Plan and support utilization of emerging green technologies. Toronto Hydro's view is that a unified and well planned approach to electrification of transportation across Ontario, and Canada, will yield maximum benefits, effectively utilize existing infrastructure, and minimize impact to rate payers.

As the pathway to reducing carbon emissions will rely heavily on electrical energy, Toronto Hydro has offered support to the TTC for any future green technology trials planned. Toronto Hydro's goal is to use knowledge obtained from green technology trials to potentially leverage intelligent time of day charging, explore vehicle-to-grid technology and learn about battery depletion to explore secondary battery use in grid attached storage. Toronto Hydro is also a member of CUTRIC and has made a commitment to the proposed Low-Carbon Smart Mobility (LCSM) Innovation

Supercluster Consortium and anticipates investments between $5M - $22M during the period from 2017-2022 to support collaborative projects. The TTC is in discussions with Toronto Hydro staff regarding modelling the charging of a large fleet of BEBs, impacts it would have to local grid infrastructure and how both organizations can better collaborate on future green technology trials.

Enbridge Gas

The TTC and Enbridge Gas Distribution Inc. (EGD) have discussed the latest trends in transit clean fuel technologies and the potential role that natural gas could play in helping the City of Toronto reduce GHG emissions. A joint TTC and Enbridge team was tasked with crafting a concept evaluation of CNG fuel and a preliminary assessment of the potential for integration of CNG buses into TTC operations. The assessment included fuel costs, expected GHG reduction, building modifications and site suitability. A total of four sites were evaluated in person including Arrow Rd, Eglinton, Malvern and Wilson garages. Key findings were consistent with other adopters of CNG buses. The Enbridge team has been in regular communication, most recently to discuss opportunities created by the emerging circular economy focused on converting bio mass to renewable natural gas (RNG) which will deliver net neutral emissions. Enbridge is an active member of CUTRIC and is committed to collaborating with the TTC on any future projects involving CNG technology.

Toronto Public Health

At the request of the TTC, Toronto Public Health performed a rapid analysis of tailpipe emissions from four different propulsion technologies including clean diesel, second generation diesel electric hybrid, CNG and BEB. The analysis was based on a preliminary review of emissions data obtained from the GREET 2017 emissions life cycle calculator and was limited to consideration of localized air quality impacts. They concluded that based on the emissions data provided, that the battery electric technology had the lowest emissions for all compounds reviewed and this zero emissions option would be ideal from the perspective of improving public health by reducing GHGs and improving air quality in Toronto, especially near busy roadways where traffic-related air pollution is highest.

Next, second generation diesel electric hybrid was ranked slightly higher than CNG although it was noted that relative differences between hybrid and CNG were too small to distinguish in a rapid analysis with each technology having trade-offs in terms of emissions of specific compounds. From a public health perspective, clean diesel was the least favourable option.

Experiences of Other Transit Fleets & Agencies

In General

All transit agencies in North America continually looking at ways to make their bus fleets more compatible with the environment. In the United States, federally funded programs designed to promote the testing and adoption of BEBs and or FCEBs has resulted in an increasing number of these buses in service. Performance and reliability of these buses has been very good to date. Besides federal, provincial and municipal environmental targets, agencies in both Canada and US are setting long term goals for zero tail pipe emissions bus fleets.

Where CNG infrastructure already exists, agencies are continuing to procure and operate this technology utilizing RNG when available to reduce their overall net carbon footprint while slowly introducing BEBs and FCEBs.

Most agencies in California, including Sunline Transit and Foothill Transit, fall into this category. Meanwhile many properties without existing CNG fuelling infrastructure are looking to diesel electric hybrid buses as a bridge technology while slowly integrating BEBs and FCEBs. Both Société de Transport de Montreal and York Region Transit have taken this approach.

Hamilton Street Rail

Hamilton Street Rail began operating CNG buses in 1985, but by late 2004 began to transition back to diesel buses due to the poor reliability and high maintenance costs of the first generation CNG buses. Today, as a result of the projected price gap in diesel and CNG, combined with the thought that the new generation CNG buses are much more reliable, they are considering once again CNG for future bus procurements. Hamilton has found that operating CNG is more affordable than a clean diesel as reliability problems and costs associated with diesel exhaust after-treatment system are eliminated. Hamilton has installed a new CNG fuelling facility in partnership with Union Gas and bus procurements in 2017 and beyond will be for CNG buses equipped with the new Cummins ISL-G Near Zero Engine.

Edmonton Transit Service

Edmonton Transit Service conducted an electric bus pilot that lasted four months from June to October 2014 using a BYD battery electric bus. Plans to conduct a winter test in 2014-2015 were put on hold as the heating system in the current electric buses did not meet the City of Edmonton’s zero emissions goal. However, a trial during the winter of 2015-2016 was completed and a final report submitted in September 2016. Edmonton’s trial concluded that a battery electric bus can perform as reliably as the rest of the fleet of diesel buses but would require thorough planning, training and resources to ensure they derive the full benefits of their use. The trial also concluded that propulsion energy use and battery performance was unaffected by colder ambient temperatures. Interior bus heat was acceptable but an auxiliary diesel fired heater was recommended. The City of Edmonton has released an RFP for the supply of five BEBs with an optimal operating range of 440km on a single charge and seven charging stations to be delivered in 2018 to trial bus performance and city infrastructure requirements.

St. Albert Transit

St. Albert tested battery electric buses from both BYD and New Flyer in 2014. The BEBs were tested on the same diesel bus routes for a total of 2,935kms over a 128 hour period. Their limited test pilot that included cold testing did not uncover any mechanical or electrical issues. St. Albert recently announced the order of three 35-foot electric buses from BYD that will have a range of 250kms. The BYD bus was chosen based on the commitment of providing a 12-year battery warranty. It is noted that 54% ($533,325/bus) of the capital bus purchase cost was subsidized by utilizing GreenTRIP – Green Transit Initiatives Program in Alberta. The new 35-foot BEBs began revenue service in July 2017.

Winnipeg Transit

Winnipeg in a collaborative effort with New Flyer, Manitoba Hydro, Mitsubishi Heavy Industries and Red River College has operated two electric buses in regular service since the fall of 2014. The project is intended to be a four year demonstration on the technology utilizing four electric buses with the goal to compare operation and maintenance to that of a diesel bus. The project includes the installation of four AC charging stations at a bus garage and one DC rapid charger at the terminal point of the test route which is at the Winnipeg Airport. Winnipeg is only responsible for the operation of the bus in regular service and performing basic maintenance. Repairs related to the electric drive including battery storage, has been performed by the bus OEM New Flyer. The cost of the rapid charger was covered by New Flyer and Manitoba Hydro. Winnipeg struggled early on with establishing a connection between the bus and on-route charger but has not experienced any other significant problems to date. A final report on the Winnipeg electric bus pilot is expected in 2 years.

Société de Transport de Montreal

Société de Transport de Montreal has partnered with Nova Bus and the province of Quebec to test three battery electric buses in conjunction with two charging stations over a period of four years. The electric bus is based on the proven 40ft Nova LFS platform and the program is focused on continuous bus operation through on-route rapid charging where six minutes of charge will yield one hour of service. The STM BEBs started service on the 36 Monk line in June 2017.

Sunline Transit

TTC staff visited Sunline Transit in California on October 12, 2017. Sunline operates a fleet of 77 buses of which four are FCEBs and three are BEBs. Remaining buses in the fleet are powered by RNG. The BEBs operated by Sunline are of the long range, overnight charged type manufactured by BYD and are dedicated to their shorter routes. Sunline has however been a pioneer in the areas of FCEB maturation having operated seven generations of FCEBs in the early 2000s. Admittedly, FCEBs did have teething pains early on but today's FCEBs are running reliably. Sunline has plans to grow their FCEB fleet with 24 additional New Flyer buses by the end of 2018 and their ultimate goal is to operate a 100% zero emissions fleet utilizing a mixture of FCEBs and BEBs while phasing out CNG buses.

Foothill Transit

TTC staff visited Foothill Transit in California on October 11, 2017. Foothill operates a fleet of 350 buses powered by RNG and 17 BEBs of the short range on-route charging type manufactured by Proterra. Foothill was one of the early adopters of BEBs in North America when short range buses were the only option. Today, Foothill recognizes the short-comings of on-route charging strategies. Foothill had great difficulty in procuring land for the roadside charging infrastructure, especially in transit hubs were multiple counties meet. Besides difficulties with infrastructure, Foothill is frustrated with the fact that buses are constrained to only routes in which the charging infrastructure exists, leaving very little flexibility on bus deployment and route management. From this experience, Foothill has 14 additional long range Proterra BEBs on order and advised that future BEB procurements will all likely be for long range BEBs. Reliability of the BEBs they operate was reported to be very good.

Chicago Transit Authority

Chicago has two New Flyer electric buses relying exclusively on overnight plug-in charging with no on-route charging. These buses have been operating on a variety of different routes between 8-10 hours per day. They average about 500kms per week and have accumulated over 5,000kms. Chicago now regrets that they did not look into on-route charging more seriously and are in talks with New Flyer on the feasibility of converting buses to on-route charging.

New York City Transit

New York City Transit operates approximately 750 CNG buses and has experience with CNG's dating back to the mid-1980s. While NYCT admits that the new generation CNG buses are much more reliable than previous version, they did also claim that the maintenance required is substantially higher than a diesel as the engine's ignition system requires frequent maintenance. In December 2017, NYCT will be starting a battery electric bus demonstration program. This program will consist of leasing five Proterra long range, overnight charged buses and three New Flyer short range buses utilizing on route fast charging technology for a period of three years. The demonstration program is intended to provide the MTA and manufacturers of BEBs with actionable data on what works best in New York's metropolitan environment. The MTA will use the results from the pilot to refine and develop bus specifications for future electric bus procurements to ensure buses are fully able to meet the rigors of operating in New York City.

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Appendix A – TTC Bus Fleet Overview

Manufacturer/Model	Length	Quantity	Year Purchased	Propulsion	%
Orion VII LF	40'	389	2003-2005	Conventional Diesel - Detroit	20.6%
Orion VII LF	40'	80	2006	Conventional Diesel - Cummins	4.2%
Orion VII LF	40'	100	2007	Conventional Diesel + DPF - Cummins	5.3%
Orion VII LF Hybrid	40'	150	2006	Diesel Electric-Hybrid - Cummins/BAE	8.0%
Orion VII NG LF Hybrid	40'	538	2007-2009	Diesel Electric-Hybrid - Cummins/BAE	28.5%
Orion VII NG LF	40'	217	2010-2012	Clean Diesel - Cummins	11.5%
Nova LFS	40'	259	2015-2017	Clean Diesel - Cummins	13.7%
Nova LFS Articulated	60'	153	203-2014	Clean Diesel - Cummins	8.1%
		1886			

As of July 10, 2017

Appendix B – Overview of BEBs Operating in North America

Transit Property	State/Province	Manufacturer	Delivered	Total Ordered
Denver Regional Transport	CO	BYD	36	
Foothill Transit	CA	Proterra	17	14
TARC	KY	Proterra	16	
San Joaquin RTD	CA	Proterra	12	
Long Beach Transit	CA	BYD	10	
JLL	IL	Proterra	10	
COMO Connect Colombia	MO	BYD	9	
Nashville MTA	TN	Proterra	9	
WRTA	MA	Proterra	7	
CatBus	SC	Proterra	7	
Park City Transit	UT	Proterra	6	
SarMetro	FL	Proterra	5	
LEXTRAN	KY	Proterra	5	1
Anaheim Transportation Network	CA	BYD	4	
Link Transit	WA	BYD	4	
RTC	NV	Proterra	4	5
Winnipeg Transit	Manitoba	New Flyer	4	
St Albert	Alberta	BYD	3	
Sunline Transit	CA	BYD	3	
Antelope Valley Transit	CA	BYD	3	
Howard County Transit	MD	BYD	3	
VIA	TX	Proterra	3	
KCM Seattle	WA	Proterra	3	73
PVTA	MA	Proterra	3	
STM - Montreal	Quebec	Nova	3	
SolTrans	CA	BYD	2	
Chicago Transit Authority	IL	New Flyer	2	
Gtrans	CA	BYD	1	
WMATA	WA	New Flyer	1	
DTA	MN	Proterra		7
DART	TX	Proterra		7
SEPTA	PA	Proterra		25
Delaware Transit Corp	DE	Proterra		6
Everett Transit	WA	Proterra		4
Pierce Transit	WA	Proterra		2
Port Arthur Transit	TX	Proterra		6
LA SporTran	LA	Proterra		5
VTA	CA	Proterra		5
Quad Cities Metrolink	IL	Proterra		2
Kitsap Transit	WA	Proterra		1
Visalia Transit Division	CA	Proterra		2
Fresno County Rural Transit Agency	CA	Proterra		4
City of Modesto Transit Services	CA	Proterra		4
New York City MTA 5	NY	Proterra		5
Additional Unannounced Orders 115	TBD	Proterra		115
LA Metro	CA	New Flyer		5
MBTA Boston	MA	New Flyer		5
TriMet	OR	New Flyer		4
UTA	UT	New Flyer		5
CDTA Albany	NY	New Flyer		1
AC Transit	CA	New Flyer		5
			195	**318**

Appendix C – Overview of FCEBs Operating in North America

Transit Property	State/Province	Manufacturer	Delivered	Total Ordered
AC Transit	CA	Van Hool	13	
SunLine	CA	El Dorado	4	
OCTA	CA	El Dorado	1	
MBTA	MA	El Dorado	1	
Flint MTA	MI	El Dorado	1	
SARTA	OH	El Dorado		10
OCTA	CA	New Flyer		10
AC Transit	CA	New Flyer		10
SunLine	CA	El Dorado		6
Sunline	CA	New Flyer		6
Flint MTA	MI	Proterra		1
AC Transit	CA	New Flyer		1
		Total	**20**	**44**