Moving Forward with Transit Bus Electrification in Canada

A follow-up to the report "Will Canada Miss the Bus?" released by Clean Energy Canada in March 2019

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Summary

An important new report entitled “**Will Canada Miss the Bus?**” was released in March 2019 by Clean Energy Canada, a non-governmental think-tank based at Simon Fraser University in British Columbia, focused on accelerating Canada’s transition toward renewable energy sources, and clean technologies that can help reduce greenhouse gas (GHG) emissions. The report specifically discusses electrification of transit buses and emphasizes three key messages: (1) electrification of transit is a significant and ongoing trend worldwide; (2) Canada is already a technology manufacturing leader in this field; yet (3) there has been no groundswell of adoption of new electric technologies by Canadian transit authorities. Given these circumstances, the resulting question posed is, “why aren’t we on the electric bus?”

The answer is more nuanced, and requires a further understanding both of current barriers and constraints being faced in transit operations, as well as the major considerations that need to be looked at by transit authorities and policy makers alike in order to move forward in a positive manner. Hence, this report has been prepared to provide explanation, as well as proposing recommendations.

The key recommendation for the federal government, and indeed for all federal political parties given the upcoming election, relates to a need for funding. While such a request would initially seem pat, what is specifically recommended is targeted, but relatively modest funding for electrified transit vehicles, to be provided in an ongoing and consistent manner, so as to be predictable for planning by transit authorities, using a simple and straightforward program approach, in order to ease administrative requirements and ensure the burden for application processes is minimized. Key intended outcomes are moving the country as a whole forward toward achieving the first of three identified major implementation steps in transit electrification, i.e., approximately 3% or more of the overall fleet, and preventing Canadian transit agencies from lagging further behind U.S. counterparts.

It is firstly important to define what exactly are electric buses? There are four relatively distinct bus technologies that provide a range of possible alternative options, as summarized in the following table (with more description and references in the main body). It is further important to emphasize that no single technology option may be necessarily the best for a given site or situation, emphasizing the need for evaluation.

Summary of technology options associated with transit electrification	
Technology	**Description**
Rubber-Tire Electric Trolley Buses	Operate electrically, but with ongoing energy supply by connection to overhead wires via extended pole(s)
Fuel Cell Electric Buses (FCEB)	Employ hydrogen as an energy carrier supplying fuel cells, to produce electricity for operation without on-board emissions
Hybrid Electric Buses (HEB)	Incorporate electric drives with battery energy storage, but combined with more-conventional engine technologies and using liquid fuel as the primary energy source
Battery Electric Buses (BEB)	Incorporate electric drives, but only use on-board battery packs, typically some form of lithium-ion chemistry, as electrical energy storage units, and with electricity supplied from the grid

Of these options, BEB and FCEB are, obviously, the most prominent. HEB are less directly relevant to discussions on electrification, given they still rely on liquid fuel as the primary energy source. At the same time, they incorporate batteries, providing useful experience relating to maintenance and servicing. They are also more efficient than diesel, representing useful options for sites with high GHG-intensity grid mixes. Trolley buses, on the other hand, represent a relatively old technology that has seen applications diminish for good reasons.

In order to move forward positively on transit electrification in Canada, eight relevant considerations are identified, and briefly summarized as follows:

Lifecycle Economics: Electric buses, particularly BEB and including FCEB, are clearly the future for transit, but near-term reluctance to jump on-board is justified. A range of recent economic evaluations has confirmed that electric buses, especially BEB, are promising, but do not yet show compelling economic advantages. Lifecycle costs are still either higher than or similar to diesel counterparts. Further, improvements in economic viability over time continue to be gradual, with no dramatic disruptive change occurring. A simplified incentive program is recommended to help address this situation.

Integration: Integration is emerging as a critical issue facing transit operations into the future as they implement BEB and other advanced technologies, even though this issue is not yet well recognized in the media. Transit involves complex networks incorporating many buses, with the nature the systems, importantly, having built-up over time primarily around the characteristics of diesel buses. Introducing electric buses imposes changes, both obvious and subtle, that translate to increased costs, especially when combinations of diesel and electric buses are involved. More investigation of this issue is recommended.

Deployment Strategy: Recognizing the importance of integration, especially for large-scale implementation, a gradual transition to electric, i.e., a few buses at a time, is recognized as not being meaningful. Instead, three defined quantum changes in the numbers of electric buses at transit authorities have been already suggested, with at each major step, proof of operability and cost effectiveness needing to be confirmed.

Technical Uncertainties: Due to a lack of sufficient in-service experience with electric technologies, given newness, unresolved technical uncertainties remain, impacting both economic viability and emission reductions. Most important is the realistic life that can be expected for batteries. Second is the extent of travel, whether annual km or hours per day, practically achievable for individual buses in actual operating conditions. This relates directly to the extent to which a diesel bus can be fully replaced without additional backup. More testing and experience are obviously required.

Changing Ownership Structures: A useful observation is that across North America electric buses are still primarily being applied in many short-term tests of one or two units at a time at individual transit authorities, meaning the technology practically here is still mostly at a demonstration status. Moving toward implementation, especially at larger scale, transit authorities need to have greater control in terms of ownership structure and conventional purchasing procedures, even in circumstances involving some sort of leasing arrangement. This has implications, both in costs and extended timeframe that need to be recognized.

Electric Power Infrastructure: Electrification of transit, especially fleets at large-scale, will require large amounts of electrical energy. Electrical “demand” can be affected, but this is of less importance in terms of operating costs. Economic viability of electric vehicles, including heavy-duty buses, is not very sensitive to the price of electricity. Rather, concern is with the capital cost of infrastructure, ensuring adequate upgrades where required, but not overbuilding. An unrecognized impact is that constructing electrical supply systems for increasingly larger levels can trigger environmental assessment processes, and will need to be considered.

Externalities: Externalities involve costs associated with adverse environmental and social impacts. Transitioning from diesel to electric involves positive reductions overall, but not entirely. Three top benefits of going electric involve: reducing GHG emission costs caused by diesel; avoiding diesel fuel price volatility costs, frequently faced by transit authorities; and reducing noise-related costs. Perhaps surprising, reducing urban air pollutants does not save much, given improvements with conventional engines.

Three major adverse concerns, all still with lower costs today, are: battery rare-mineral scarcity and social impacts; weight-induced infrastructure damage; and end-of-life battery disposal. Opportunities for more cost-efficient technology selection are available, based on grid GHG-intensity of individual jurisdictions. Given improved bus efficiency, emission reductions can occur even if grid emissions are high, but grid GHG-intensity varies dramatically across Canada, impacting the extent of reductions achieved. A further point, with funding implications, is that two separate and complementary GHG reductions are involved. First is modal-shift, which is more conventional, i.e., getting consumers out of private vehicles, whereas, second is changing the motive energy of the bus itself. Funding programs need to reflect this distinction.

Federal Funding Support: A final major consideration is providing adequate funding, in particular from the federal government, in order to support electrification. One obvious single factor that helps to explain why urban areas in the U.S. have continued to move progressively ahead of counterparts in Canada is consistent and available funding from the U.S. Federal Transit Administration (FTA). There is nothing like this at all within Canada. Indeed, major Canadian new-technology transit projects for some time have involved one-off funding approaches, nothing ongoing or consistent.

The current federal government has expressed interest, especially regarding GHG reductions, which is positive. The realities of funding programs, however, are a different story, bluntly not very good, being onerous and convoluted. The major funding programs that exist are also largely oriented to modal-shift, not really considering changes of bus motive energy. In order for Canada to succeed, the funding situation needs to change. Integration is identified as a major consideration for the future, but costs are not fully understood yet. More investigation is warranted, but, at the very least, recognition needs to be provided that explicit integration costs should be included for eligibility within existing transit-related funding programs.

In the near-term, the higher purchase prices of electric buses, and lack of definitively positive business cases in terms of lifecycle costs need to be addressed. The adverse concern is that without action Canadian transit agencies likely will continue to fall further behind. Thus, on a more immediate basis, it is strongly recommended that a modest but targeted federal electric bus incentive payment of $250,000 per eligible zero-emission bus be implemented, with a simple and straightforward application process to reduce administrative burden on transit organizations. This program is proposed to last for six years overall, but with the incentive value tapering downward starting in the third year. The anticipated uptake in this case, based on rough total costs of $100 million, would represent somewhat over 3% of all buses within Canada, providing the opportunity for many transit authorities across Canada to reach the first step of large-scale deployment.

1. Review of “Will Canada Miss the Bus?”

Clean Energy Canada, in March 2019, released an important new report entitled, “**Will Canada Miss the Bus?**” The report discusses electrification of heavy-duty and other types of buses relevant for transit operations as an opportunity to improve service and to reduce greenhouse gas (GHG) emissions. It emphasizes three key messages (CEC 2019):

- Firstly, the progressive electrification of public transit is a significant and ongoing trend. Although most obvious in China, it is indeed evident all over the world. This point is already well recognized and acknowledged, although, as noted later, the precise timing for the economic tipping point in Canada is not quite clear.

- Secondly, Canada is already a technology-leader, often unsung, in the manufacturing of transit and other buses, including electric versions. Indeed, the top two current manufacturers of heavy-duty transit buses of all types in North America as a whole are both Canadian, i.e., NFI Group (formerly New Flyer) and Nova Bus. There are other emergent Canadian companies in this expanding vehicle area.

- Lastly, Canadian transit authorities have shown interest, but there has been no groundswell, as yet, of adoption of new electric technologies, especially at large-scale, which leads to the question, “Why aren’t we on the electric bus?”

The answer is more nuanced. Moving forward requires a slightly deeper understanding both of current barriers and constraints faced with the new technologies, hence this report. To assist, there are significant useful information sources already available in the public domain. These lead to a number of conclusions and recommendations, some obvious and some subtle. An important recent observation is that hesitancy by transit agencies to adopt electric bus technologies is not limited to Canada. As noted by Sclar et al. (2019), progress around the world on electric buses has been uneven, with various types of potential barriers identified by them.

Transit authorities across Canada, indeed around the world, certainly have been innovators, but have tended to be conservative when looking at operations and expenditures. This is natural. While they are funded in part by ridership, they rely significantly on public funding. They typically do not have access to deep pockets, instead being run as “tight-ships.” The primary focus also, overwhelmingly, is on moving passengers, especially in urban areas, which is a critical public service. Transit systems already involve complex network operations that, importantly, have developed largely around the characteristics of diesel buses. This latter observation has consequences for any transition to electric buses, as noted later.

There have been many calls by many individuals in many cities across Canada to immediately jump to electric buses. Electrification is a good idea, but the principle of sustainability actually does include being business-minded and economically realistic (Parsons 2018). We do not want to short-change the effort by making it appear too easy when it is not. It is important for our transit systems to be on the “leading edge,” but not end up on the “bleeding edge.”

Figure 1. Photograph of second-generation battery-electric bus on-route in operation with Winnipeg Transit on Graham Avenue, Winnipeg, Manitoba (February 2017 by R. Parsons)

2. Background on Electric Buses

It has been well identified that electrification of public transit is neither uncommon nor new. There have been a range of subway, light-rail, streetcar, tram trolley, and even bus systems implemented, but, so far, with a major common characteristic of tethering in some way to electricity supply. At the same time, new technologies having been introduced that are changing the dynamics of the situation.

Within the specific category of heavy-duty buses themselves, four main technology options are important to note, which reflect both technology progress, as well as the range of possible alternative directions available for different locations. Providing explicit descriptions also helps to clarify differences and avoid confusion. Further, no single technology option may be necessarily the best for a given situation, emphasizing the need for conscious evaluation of the circumstances at individual sites and urban centres. The four identified technology options are summarized as follows:

2.1 Rubber-Tire Electric Trolley Buses: These buses involve relatively old technology, whereby bus gliders are operated electrically, but with ongoing energy supply by connection to overhead wires via extended pole(s). These types of buses once operated extensively across Canada, however, over time their implementation dwindled, today used solely in the Vancouver area. There are three main problems inherent with their operation: (a) expensive purchase cost despite apparent simplicity, as well as requirement for expensive overhead wiring infrastructure;

(b) relative inflexibility in route applications; and (c) relative inefficiency, which is less obvious. The latter makes sense given the need to energize extensive overhead wiring networks, with associated losses, even before a single bus runs.

2.2 Fuel Cell Electric Buses (FCEB): These buses employ hydrogen as an energy carrier supplying fuel cells, typically proton exchange membrane (PEM) technology, to produce electricity for operation without on-board emissions, hence their inclusion as electric. Interest and activity with FCEB rose significantly during the decade of the 2000s, reaching an apex in Canada with the implementation of the 20-bus deployment by BC Transit over five years starting in 2009, this in conjunction with the 2010 Winter Olympic Games. This project remains one of the largest FCEB fleets implemented at a single location in the world, certainly the largest in North America. Performance was also well documented, in particular through the U.S. National Renewable Energy Laboratory (Eudy and Post 2014). From a technical perspective, these buses were highly successful, with some acknowledged technical hiccups that were addressed. Their key downside, however, was identified as high cost. This general concern continues to remain. An inherent issue relative to other technologies is the need for provision of hydrogen, either through a separate production step, or purification if adequate quantities of hydrogen are available, such as via by-product. This additional step can complicate economics, although FCEB represent a potentially viable option under certain conditions.

2.3 Hybrid Electric Buses (HEB): These buses incorporate electric motors with battery energy storage, but in combination with more-conventional engine technologies, also solely using liquid fuels as the primary energy source. During the late 1990s and early 2000s, HEB were a significant focus for advanced bus motive technology (Eudy and Gifford 2003). Their implementation also paralleled the state of battery development at the time, including movement toward nickel-metal hydride as a preferred battery. They continued to gain prominence as their use increased (Clark et al. 2009, Transport Canada 2009). Just as in the case of light duty passenger vehicles, significant numbers of HEB have been, and continue to be implemented in cities across Canada. HEB certainly provide enhanced efficiency compared to conventional diesel buses, reducing fuel consumption. They thus represent a valid approach for GHG reduction. That said, all energy for such buses comes ultimately from liquid fuels, including conventional fossil fuels, without capability to directly supply external, potentially clean, electricity to the batteries. Emission reductions are only incremental, and, thus, more limited.

2.4 Battery Electric Buses (BEB): These buses involve the newest technology, also being most prominent today in the media. BEB incorporate electric drives, but use on-board battery packs, typically some form of lithium-ion chemistry, as electrical energy storage units, with electricity supply from the grid. Their configurations are based either directly on existing diesel bus gliders or closely resemble them. They are in many ways more similar to diesel buses than earlier tethered vehicles. They also show higher efficiency, almost twice that of older trolley-based buses, this given they do not require extensive overhead wiring infrastructure. As with other bus options, development of BEB paralleled that of advanced battery technologies. An earlier report by the U.S. Transportation Research Board listed a total of only 133 such bus-type vehicles had been implemented in the entire U.S. (Arcadis, Geraghty & Miller 1998). BEB then were also generally much smaller, given dominance of lead-acid batteries, which limited operational capabilities. BEB continued to be less prominent through the early 2000s, but with ongoing development, based on newer lithium-ion battery technologies, in a number of locations around the world, notably Korea, Japan, U.S. and China (Li 2016). By the beginning of the decade of the 2010s, BEB began to move to the forefront, based on lithium-ion batteries, as their costs declined and performance improved. Indeed, batteries based on lithium-ion chemistries now dominate in both light-duty cars and heavy-duty electric buses. The obvious change in position relative to FCEB in the 2000s versus 2010s is useful to note. Costs and performance of FCEB certainly improved, but eclipsed by more rapid improvements with lithium-ion batteries. Two general approaches for BEB have also been well noted, which involve a trade-off in costs: large battery capacity buses oriented to slow depot charging; versus smaller battery capacity buses combined with on-route rapid-charging stations.

Figure 1. Photograph of prototype battery-electric bus during rapid charging event at Manitoba Hydro, Taylor Avenue temporary charging site, Winnipeg, Manitoba (July 2014 by R. Parsons)

Although not well acknowledged on a national basis, Winnipeg, Manitoba for some time has been the clear leader within Canada regarding BEB implementation and demonstration. Initial work toward BEB began in 2010, leading to the formation of an international consortium, with rollout of the initial prototype bus in 2012. This led directly to a larger in-service pilot with Winnipeg Transit involving four second-generation buses, beginning in 2014 and co-funded by Sustainable Development Technology Canada. In late 2015, a Joint Task Force on Transit Electrification was formed, primarily involving the Manitoba Government and the City of Winnipeg. There has also been significant documentation, with a variety of useful reports publicly available:

- Report of findings by the Joint Task Force on Transit Electrification, released later-on but involving economic analysis based in 2016 (JTF 2016);

- Prototype bus final report by Red River College (RRC 2017);

- Analysis of externality benefits and costs of moving from diesel to electric bus operation by MBA students at the I.H. Asper School of Business (Parsons et al. 2017), which was made public through the auspices of the Canadian Urban Transit Research and Innovation Consortium (CUTRIC); and

- Economic and environmental update for the Joint Task Force on Transit Electrification by Red River College (RRC 2018).

Information from these reports is noted extensively throughout this work.

3. Major Considerations for Transit Electrification

Transit electrification can involve a myriad of complex issues. Based on experience so far, eight major considerations are identified for transit authorities and policy makers alike to keep in mind in order to simplify the transition. These are each summarized as follows:

3.1 Lifecycle Economics: Electric buses, particularly BEB and including FCEB, are clearly understood to be the direction of the future for transit. There is little question on this. In the here-and-now world of transit operations across Canada, however, hesitancy is justified, especially when looking at lifecycle economics.

Three credible and publicly available economic analyses of BEB, all clustered around 2016 as evaluation year, show BEB likely to be somewhat more expensive than diesel counterparts in terms of lifecycle costs, noting all are on a stand-alone, discounted basis. These include Tong and colleagues from Carnegie-Melon University (Tong et al. 2017), the Manitoba-based Joint Task Force on Transit Electrification (JTF 2016), and the highly detailed feasibility study by knowledgeable, Montreal-based consultant Marcon for Edmonton Transit (Marcon 2016). Marcon did show at the time a depot-charging option was better, with costs closer to diesel, but with a rapid-charging option clearly more expensive.

The recent update on economics and environment for the Manitoba-based Joint Task Force on Transit Electrification (RRC 2018), shows over a two-year period, the economic situation for BEB has changed somewhat. Depending on assumed operational configuration and lifespan, it is suggested BEB have become roughly at par with diesel buses on a lifecycle cost basis, but still subject to important uncertainties. What this analysis shows is that the progression toward

BEB becoming dominant in terms of economics is incremental and slower-paced. A dramatic "disruption," as is popular to portray in the media, is not likely to occur.

It is very easy to urge movement toward BEB, but much harder to make it happen in reality. The new technologies need at least to show a prospect they can make economic sense in the relatively near term. Transit operations can and do respond to political directions, but fully understand that a steep price can be paid. In this regard, consistent and ongoing funding assistance for transit operations is absolutely required, as discussed later.

Winnipeg, which has involved five separate BEB so far, will still remain for at least a period of time as the site having the largest number of BEB within Canada. Various cities across the country have voiced longer-term plans to transition entirely to electric transit buses (CEC 2019). While essentially notional commitments, in some cases these are more substantially oriented, in particular within Quebec, where the provincial government already indicated that, starting around 2025, it will provide funding support only for purchases of electric buses (Government of Quebec 2018). More relevant are commitments to purchase significant numbers in the near-term. Transit agencies publicly noted to be proceeding with more than five electric buses include: Edmonton, Toronto, Brampton, York Region and Montreal. All, however, have done so with open eyes regarding the relatively high-costs involved.

Edmonton Transit committed to acquire two BEB initially, with potential for 23 more by 2020 (City of Edmonton 2018). Toronto Transit Commission committed to acquire ten BEB each from three manufacturers, with the option for 30 more depending on performance (TTC 2018). Deliveries began in April 2019, with an expected total number of 60 practically around 2020 to 2021. Brampton Transit and York Region Transit are part of the Pan-Canadian Electric Bus Demonstration, with delivery of eight and six BEB respectively anticipated in the near-term. Originally conceived as the Pan-Ontario Electric Bus Demonstration, this project is being undertaken in conjunction with CUTRIC (Petrunic 2018), involving two bus manufacturers, two rapid charging system manufacturers, and three sites. Societe de transport de Montreal (STM) already has three electric buses under testing, but committed to purchase 30 more units, with deliveries anticipated beginning by late 2019 (Bruemmer 2018). Several other transit agencies are also moving forward, but with smaller numbers (i.e., less than five). At the same time, there also has been notable cautiousness expressed about proceeding with electric buses, for example in Ottawa (Willing 2019) and Charlottetown (Davis 2019).

3.2 Integration: Integration is emerging as a critical issue facing transit operations into the future as they implement BEB and other advanced technologies, even though this is not yet broadly recognized in the media. The concern has come to light, primarily through the Manitoba-based Joint Task Force on Transit Electrification (JTF 2016), and reflects the important direct involvement of Winnipeg Transit. To date, Winnipeg Transit has had by far the most practical experience across Canada of any transit authority in working with the intricacies of BEB.

Electric technology can and does compare favourably one-on-one with diesel, but overall transit operations are more than just individual vehicles. They instead involve complex networks incorporating many buses to deliver a critical public service. The nature of the systems, importantly, has built-up over time primarily around characteristics of diesel buses.

A first example is the use of so-called "interlining" whereby individual bus vehicles may transition across different routes during a day, sometimes quite frequently, in order for overall schedule requirements to be met. A second example is the pattern of how buses are employed as they progressively age in helping to meet transit demands. New vehicles typically are implemented in "high-use" applications. They operate constantly over daily periods of up to 18 to 22 hours, and accumulate high annual travel, around 70,000 km. But as they age, and maintenance requirements increase, bus vehicles are switched to "peak-use" applications, helping to address typical morning and late-afternoon commuter peaks. The latter can involve daily use around seven hours, and annual travel around 35,000 km. Over its lifespan, an individual transit bus can show average annual travel of about 50,000 km, but this does not reflect its use in two quite different applications. A change from diesel to BEB also requires a new set of skills for service technicians, necessitating significant retraining. Recharging of electric buses, especially with on-route rapid chargers, imposes additional requirements on operations and schedules. All these characteristics have implications for the use of BEB.

Costs associated with integration initially came to light via the need to provide redundancy, covering possible inability of BEB to fully meet schedule or route requirements. More recently it has become evident that a transition to BEB will require not just changes in technology, but a broad variety of changes in organization, planning, scheduling, training and other areas. Impacts due to the transition to BEB literally ripple throughout transit organizations and beyond, and can be more generally described in terms of "change management." These changes have cost implications too.

The impacts associated with integration can be significant. A recent Canadian example comes from Edmonton. After their significant commitment to proceed with BEB, it was discovered that the intended vehicle storage structure was not sufficient to handle the heavier weight, necessitating a $10.3 million upgrade (Fida 2018). Overall costs, thus, have been significantly increased. This point is not raised as a critique, given the problem was clearly identified and addressed, but, rather, serves to illustrate the many, often subtle, issues associated with BEB that may not be as well understood as for conventional diesel, and that can have profound consequences. Additional media stories from the U.S. noting performance and operational shortfalls for BEB have appeared, with the situation in Albuquerque, New Mexico being most dramatic (Knight 2018). Such situations, more than anything, reflect integration problems.

Adequately addressing integration requires robust and flexible implementation plans. It also necessitates sufficient resources be provided in order to ensure a successful transition, as also discussed later regarding funding.

3.3 Deployment Strategy: Given recognition of the importance of integration, especially for large-scale implementation, an important future direction was recommended by the Manitoba-based Joint Task Force on Transit Electrification for BEB deployment (JTF 2016). A gradual transition, involving just a few buses at a time was specifically identified as being not meaningful. Instead, a series of three quantum step changes were suggested, with, at each step, proof of operability and cost effectiveness needing to be confirmed:

- **First step**, involving deployment in the range of 12 to 20 buses, or **two to three percent** of fleet at minimum, permitting effective evaluation at a sufficient level to qualify as large-scale.

- **Second step**, involving deployment in the range of 120 to 200 buses, or **20 to 30 percent** of fleet, to truly represent a large-scale implementation.

- **Final step**, involving **fleet-wide or nearly fleet-wide** deployment.

Across North America, there have been many trials of one or two BEB at a time over relatively short periods, suggesting application of electric technology realistically still involves much "demonstration." Larger scale deployments are still relatively rare. In this regard making a commitment by some future year to transition to BEB does not yet represent implementation.

Only three transit agencies within Canada as noted earlier, Edmonton (i.e., 25 BEB, or 2-3%), Toronto (i.e., 60 BEB or 2-3%), or Montreal (i.e., 33 BEB or 2%), are likely to reach the first step level for large-scale deployment, described above, in the relatively near future. This is as long as implementations proceed as planned and depending on actual deliveries. Toronto anticipates the largest absolute number, but is also the largest system nationally.

3.4 Technical Uncertainties: Given a lack of sufficient in-service experience with BEB due to the newness of electric technologies, a number of technical uncertainties have not yet been fully resolved. These impact both prospective economic viability and emissions reduction (RRC 2018). The first and most important uncertainty is what realistic battery life can be anticipated, impacting both economics and the extent of maintenance savings. Significant general experience dealing with batteries has certainly been gained across Canada with HEB, but the specific characteristics of batteries in BEB can be somewhat different, with lithium-ion chemistries dominating, primarily lithium-nickel-manganese-cobalt (NMC) and lithium-iron-phosphate (LFP). Commercial warrantees are certainly applicable, but the process of identifying and addressing battery-related problems can be very time consuming.

Redundancy and orphaning of batteries is a significant near-term issue that has come to light in Winnipeg, given the extent and length of experience there. All the batteries employed so far in Winnipeg for prototype and second-generation operations have been early-commercial versions that helped to prove the validity of the technology, but are no longer commercially supported. This is likely to be less of an issue as implementations expand.

A second important uncertainty is the extent of travel that can be practically achieved under actual operating conditions, whether expressed as annual km or hours per day of operation. Economic viability and emissions reduction are enhanced as BEB are driven more, with increasing diesel consumption being offset. Given the noted practice of employing new buses for high-use applications, practical travel that can be achieved directly affects whether or to what extent BEB can fully replace diesel counterparts without additional backup. What sort of maximum travel can be maintained on a regular basis at individual site locations remains unconfirmed. More testing and experience are obviously required.

3.5 Changing Ownership Structures: In early BEB demonstration activities it has been typical for transit authorities to not actually own the vehicles being tested. As electrification moves toward implementation, especially at larger scale, transit authorities instead need to have much greater control in terms of ownership structure and conventional purchasing procedures, even in circumstances where BEB might be offered as part of some sort of leasing arrangement. A changing ownership structure has implications (RRC 2018). This leads directly to a need for electric bus specifications to be prepared, as well as quotation and ordering procedures, all of which take time and resources. Given that all transit buses tend to be custom-built to specifications, there is also a future delivery timeframe that needs to be considered.

3.6 Electric Power Infrastructure: As heavy-duty electric vehicles, BEB consume a lot of electrical energy (i.e., kWh). When charging, by nature, they impose relatively significant electrical capacity requirements (i.e., kW) even when using slower, depot-based systems; much greater if on-route rapid-chargers are employed. The major resulting concern, however, is not quite so obvious.

Just as in the case of light-duty electric passenger vehicles, the economics of BEB are relatively insensitive to the price of electricity (JTF 2016). Rapid-chargers incurring high demand-fees end up being not really a significant concern. More important is controlling the level of capital costs of electrical infrastructure, i.e., being sufficient but not unnecessarily overbuilding. This situation is significantly magnified as the number of vehicles increases, necessitating review and possible upgrading of electricity supply systems for identified locations.

Ensuring adequate electrical supply infrastructure becomes increasingly critical for much larger deployments, and applies whether considering centralized or distributed charging options. Cost and implementation timing issues become more important. So too do possibilities that more-significant environmental assessment processes might be triggered, depending on line-size requirements, including environmental licensing and possible public-hearings (RRC 2018). Such situations are entirely logical, but not necessarily considered when looking at electrification of buses.

3.7 Externalities: Externalities are defined as effects from undertakings by an entity (typically a business) imposing costs or benefits on others, but not borne by the entity and thus not included in the cost or price of the good or service provided (Khemani and Shapiro 1993). Externalities arise significantly in terms of environmental and social impacts, but it is important to note that in some cases they can be internalized, such as through economic instruments, like emission fees or tradable permits in the case of pollution. The transition from diesel to electric buses involves primarily positive reductions of externality costs of diesel, but not entirely. Twelve externality factors regarding the transition from diesel to electric buses were systematically reviewed and monetized by Parsons et al. (2017), yielding important insights. The top three externality-factors, all being positive for BEB, are as follows, in order:

- Reduction of GHG emissions from fossil inputs, i.e., diesel fuel combustion and diesel exhaust fluid (DEF) use;

- Avoidance of diesel fuel price volatility (uncertainty), as now frequently faced by transit authorities; and

- Reduction of noise levels from diesel bus operations on streets.

Three negative externalities are identified, but with costs all lower at this time, as follows:

- Battery rare-mineral scarcity and social impacts, especially involving cobalt;

- Weight-induced infrastructure damage, due to higher mass of electric vehicles; and

- End-of-life battery disposal.

Additional findings relate to conventional air pollutants. These include nitrogen oxides, sulphur oxides, carbon monoxide, volatile organic compounds, and particulate matter. These are collectively reduced, leading to avoided costs, but not large, with present value of $3,000 to $6,000 for a single bus over lifespan depending on annual travel. The relatively low value reflects ongoing improvements in conventional engine systems, including for example Tier 4 requirements for diesel engines. In some literature, very large benefits have been claimed to result from reductions of such air pollutants, but appear over-stated. Parsons et al. (2017) based costing methods on recent authoritative work by Health Canada (2016) regarding the human health impacts of diesel exhaust in our country.

GHG reductions appear to be the most important benefit, but need to be carefully considered. It is thus important to clarify the emissions accounting used in Canada's National Inventory Report (NIR). While two common methods are considered for GHG evaluations, i.e., combustion only at vehicle, versus full-cycle or life-cycle basis, the NIR uses neither, instead counting emissions as they occur within the jurisdiction. Further, under transportation categories, only combustion emissions for fossil fuels are included. This results effectively in diesel only being considered on a combustion basis, but electricity counted on a full-cycle basis. This seems odd, but is still legitimate. This method reflects how Canadian jurisdictions are judged, and, further, how carbon pricing is applied.

Given the much greater overall efficiency of BEB compared to diesel, it is known that transitioning to BEB, even for a high GHG-intensity grid, will still result in some GHG reductions. At the same time, grid GHG-intensity varies dramatically across Canada, impacting to a degree the extent of reductions. Manitoba and Quebec have the lowest grid-emissions by far, not just in Canada but in North America as a whole, with the two not statistically different on a five-year average basis. It is known that emission reductions in Manitoba for BEB are more than 98%, this using NIR-based calculation. On the flipside, Alberta has literally the highest grid GHG-intensity in North America. Analysis by Marcon (2016) showed BEB in Edmonton could achieve upwards of 40% reductions, but this is on a full-cycle basis. Using NIR, the value can be quickly recalculated to represent a reduction of about 10%.[*] As such, there are indeed reductions, but they are more limited, because of the high GHG-intensity grid mix.

A similar situation applies for China, which has become by far the leading country in the world for BEB implementation. Yet, China's grid is still dominated by coal. Even if their 2020 grid target of 600 g per kWh can be achieved (Li et al. 2017), per-bus GHG reductions are only modest, i.e., reduced about one third compared to diesel. This emphasizes that China's efforts, while partially motivated by environmental improvements, are significantly oriented to securing international technology leadership on advanced batteries and electric vehicles, including buses, under their "Made in China 2025" plan (Barkenbus 2019).

Importantly, grid GHG-intensity continues to improve, both internationally and in Canada. A combination of provincial policies and federal regulations, i.e., recently updated Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations (Government of Canada 2018), means that high GHG-intensity grids across the country will continue to get cleaner. This will continue to improve emission reductions via BEB relative to diesel.

An interesting note is that CUTRIC, which has a major role in promoting alternative bus technologies, both BEB and FCEB, has voiced deliberate neutrality on technology selection by partner organizations. Nevertheless, variations of grid mix across Canada suggest differential selection could be prudent. BEB are most usefully applied where the grid is cleanest, obviously Quebec, Manitoba, British Columbia, and Newfoundland and Labrador. On the other hand, where the grid still has higher emissions, such as Alberta, Saskatchewan or Nova Scotia, HEB could represent a better interim solution. HEB technology was noted earlier and can show GHG reductions around 25% compared to basic diesel buses (RRC 2018). FCEB technology can be more broadly applicable, but depends on circumstances. Nevertheless, where the grid has high emissions, applying FCEB with hydrogen reformed from natural gas, could still achieve GHG reductions upwards of 45% compared to diesel, representing a useful opportunity.

This latter point raises consideration of compressed natural gas (CNG) buses, which have not been included in this document. CNG buses have been popular in the U.S. with some implementations in Canada as well. Emission reductions in this case are modest at best (RRC 2018), in particular given the lingering question of fugitive methane emissions, which remains uncertain. The primary benefit of CNG buses compared to diesel is really fuel cost reduction. The cost of natural gas on an energy basis is dramatically lower, so gains are made even if CNG operation typically reduces engine efficiency.

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[*] Quick approximation: reduction of 40% means rough BEB emissions = 60% x 4.0 kg per Litre, which is rough diesel full cycle emissions = 2.4 kg per Litre equivalent. Then 2.4 kg per Litre equivalent ÷ 2.7 kg per Litre diesel combustion = 90% of diesel emissions based on NIR, hence reduction of about 10%.

3.8 Federal Funding Support: A final major consideration is the provision of adequate funding, in particular from the federal government, to support the transition to low-emission bus technologies, like BEB and FCEB. The need for funding is well illustrated by an interesting reference in Clean Energy Canada's new report, specifically relating to the work by Tong et al. (2017). It is noted using extensive graphics that, as per their published findings at the time, BEB are more expensive than diesel on a lifecycle cost basis, but if 80% of the purchase costs for BEB can be covered by external funding, the technology instantly becomes the most viable choice. This sounds almost overly simplistic without knowing the rationale for mentioning the 80% funding level or the associated source. The answer turns out to be funding programs to support advanced transit vehicles made available across the U.S. by the Federal Transit Administration (FTA).

Through programs such as "Transit Investments for Greenhouse Gas and Energy Reduction" (or TIGGER), or the "Low or No Emission Vehicle Deployment Program" (or Low-No Program), the FTA has helped to accelerate the implementation of advanced low-emissions bus technologies across the U.S., including BEB, FCEB and others. FTA funding, albeit operated competitively, has provided ongoing and consistent availability of funds to support transit operations that has also turned out to be relatively fair in terms of distribution. Nothing like this exists at all in Canada. Dramatically higher proportions of costs are covered as well, more than anything available here. Indeed, the presence of FTA funding can be identified as a major reason why Canadian urban centres have lagged increasingly behind their U.S. counterparts.

Canada's current federal government has certainly shown interest in transit, especially with regard to GHG emission reductions. This is acknowledged and appreciated, however, the detailed rules associated with federal funding programs have turned out to be highly restrictive and convoluted, with significant effort required just to navigate application details. A perfect example of inherent problems is the Low Carbon Economy Leadership Fund (LCELF). When first introduced, this appeared to involve funds intended for priority projects within individual provinces and territories that had signed onto the Pan-Canadian Framework, however, when detailed rules were released, it would only permit three narrowly defined types of projects, not including transit electrification, even if it is a provincial priority.

Beyond the general problem of program-complexity, there is also a subtle mismatch between the need for support of advanced low-emission bus technologies versus the orientation of major current transit-infrastructure programs of the Government of Canada. This involves the Public Transit Infrastructure Fund (PTIF), which was recently renamed as the Public Transit Infrastructure Stream (PTIS). Concern arises from the need to recognize that public transit involves two distinct and complementary mechanisms by which GHG emission reductions can be achieved, namely: **modal-shift**; versus changing **bus motive energy**.

Modal-shift refers to moving consumers away from private vehicles, particularly single occupancy vehicles (SOV), toward buses and other public conveyance methods. This concept is more traditionally embedded in discussions of public transit, and indeed is inherently reflected in the structure of conventional transit funding programs, like PTIF/PTIS. Although funding from

PTIF/PTIS certainly has been used in some selected cases to in part support advanced low-emission bus technologies, transit agencies face an awkward quandary given program limits. They can proceed with a small number of advanced zero-emission buses, or implement a much larger number of conventional diesel buses, thereby enhancing modal-shift reduction opportunities. One example of where this can have a critical impact is when a transit agency is facing excessive "pass-ups," i.e., buses being too full to allow additional boarding, requiring customers to wait for the next scheduled bus. This problem inherently reflects having too few buses on routes, and rationally can be addressed within available resources simply by having a larger number of diesel buses.

As part of the work by Parsons et al. (2017), a specific request had been made by CUTRIC to include in the report a brief comparison of emission reductions that are possible by (a) **modal-shift**, versus (b) changing **bus motive energy**, specifically considering BEB versus diesel. As outlined (see second text box on page 7), it was found that modal-shift and bus electrification involve separate and distinct reductions, and, further, that the magnitude of reduction from electrification is comparable to the estimated reduction achievable via modal-shift, although the context in this case specifically involves the situation for Winnipeg. It is further identified that changing bus motive energy is a more definitive task that is more easily quantified, being not dependent on market response. It is also possible that interactive effects may come into play. The higher quality of transit service provided by BEB or FCEB, i.e., with reduced noise, and no exhaust or associated odours, means that modal-shift could be accelerated.

As a more general comment, there continues to be a lack of suitable ongoing, consistent and accessible funding to support advanced low-emission bus technologies within Canada. Major projects involving BEB and FCEB technologies for a long time have all tended to involve one-off funding arrangements and combinations of funds, nothing ongoing or consistent. Electric Mobility Canada, a non-profit group promoting electric transport, specifically recommended to the current federal government in 2016 to increase funding levels for transit projects that incorporate electrification (EMC 2016), but with this never acted upon. The Canadian Urban Transit Association (CUTA) as part of this effort at the time noted that, "the high incremental cost of purchasing alternative propulsion buses, instead of standard diesel buses, creates a procurement barrier for transit systems."

The situation within Canada has been further exacerbated by a less recognized concern, the softening of the Canadian dollar. Transit buses are obviously manufactured within Canada, but given continent-wide manufacturing arrangements, and typical sourcing of major electrical components, especially batteries, from outside the country, purchase prices are set in U.S. dollars, with affordability here depending significantly on the value of the U.S. dollar. Costs for electric buses thus have not declined here as quickly in absolute terms as in the U.S. The same concern applies to light duty electric cars within Canada.

In order for Canada to succeed, the funding situation certainly needs to change. More than anything, suitable ongoing, consistent and accessible funding support is needed, with programs that are simple to access and manage. The high levels of effort currently required in Canada represent an obvious concern. On a long-term basis, the FTA in the U.S. may not be perfect, with obvious politically-related concerns precipitating a need to justify continued funding (Kline 2018), however, this agency is a useful model of what can be possible to support advanced low-emissions bus technologies, and transit in general. It is further recognized that such a change would likely require significant time and effort, while the funding needs for transit on BEB and FCEB implementation are more in the here and now. Issues associated with integration costs warrant further investigation to consider, but at the very least, integration costs need to be explicitly included for eligibility with transit-related funding programs.

On a more immediate basis, a simplified six-year federal funding program is proposed, specifically targeted to support implementation of "zero-emission" transit bus vehicles. This involves a transit-vehicle rebate program, similar to rebate programs that have already been employed for light-duty low-emission vehicles across Canada, although with larger per-vehicle incentives. Payments would be provided from the federal level irrespective of any other funding sources involved. Payments would be triggered by valid registration of eligible new transit bus vehicles, with rebate payments directly back to the implementing municipal transit agency. The eligible "zero-emission" vehicles in this case would be new BEB or FCEB. The incentive level proposed is $250,000 per vehicle for the first two years, followed by four years where the incentive level tapers by $50,000 per vehicle per year. The funding level obviously would not make BEB or FCEB instantly the most viable choice, as in the situation described by Tong et al. (2017), but would significantly address the purchase price gap with diesel, and ensure on a lifecycle basis that electrified vehicles clearly hold the economic advantage. Transit authorities would be provided with a dependable and predictable funding level that could be readily incorporated in planning. Such an approach would also minimize administrative burden for the federal government, and greatly simplify the application process for transit authorities.

Based on an assumed uptake of 100 eligible buses per year, program costs over six years would total only $100 million, which is modest, resulting in implementation of about 600 such new buses if fully-subscribed. Such a vehicle penetration level is important, representing more than **three percent** of all transit buses within Canada, ensuring that across the country a broad number of transit authorities would be able to move at least to the major first step of larger-scale implementation, as described earlier (see Section 3.3). On a simple basis, the cost to government for such a program translates to just over $200 per tonne of GHG reduction. In its final report, the Specific Mitigation Measures Working Group (2016) estimated costs for policies to address emissions from heavy-duty vehicles, finding a range upwards of $350 per tonne, such that the estimated cost is reasonably in line. Analysis in this case assumes typical transit bus travel of 50,000 km per year, average diesel consumption of around 60 Litre per 100 km including increased biofuels content of 5%, and comparable electricity consumption of 165 kWh per 100 km with average Canadian electricity grid GHG-intensity of about 150 g per kWh.

It is, lastly, easy to begin to build a business case for such a program, given a host of broad-based benefits: economic; social; and environmental. Relevant major benefits are summarized in the following table.

Preliminary summary of benefit for a modest federal BEB and FCEB incentive program	
Aspect	**Benefit Description**
Economic	Supports manufacturing sector for which Canada has a demonstrable lead, enhancing sales and associated economic activity
Economic	Reduces ongoing operating costs for transit authorities, providing better financial stability to municipalities, linking back to reduced requirements for tax or fare increases, and in particular addresses vulnerability of transit authorities and customers to diesel price escalations
Economic	Enhances innovation and innovation capacity at companies, research organizations, and post-secondary colleges and universities
Social	Enhances quality of transit service for passengers given both reduced exhaust and noise levels
Environmental	Enhances general city environments given reductions of both noise and conventional air pollutants, especially in core urban areas
Environmental	Reduces greenhouse gas emissions in a cost effective manner
Environmental	Creates critical mass of new technology vehicles in the transit market to help accelerate transformation, specifically moving transit agencies more toward large-scale implementation, but also assists to accelerate adoption of cleaner options in transportation markets in general

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