Report

Battery Electric Bus Implementation Plan and Cost Report

Brantford Transit Electric Bus Needs Assessment and Feasibility Study

Prepared for The Corporation of the City of Brantford
by IBI Group
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Table of Contents

Table of Contents (continued)

Table of Contents (continued)

Table of Contents (continued)

Executive Summary

City of Brantford has declared a climate emergency, and the Federal government has set goal of achieving net carbon neutrality by 2050. Transportation is a key contributor to Brantford's emissions, and electrifying transit presents an opportunity for substantial emissions reduction. The City is investigating the feasibility and associated cost of transitioning the Brantford Transit bus fleet to battery electric buses (BEBs), including fixed route buses and specialized Brantford Lift vehicles. IBI Group is supporting the City by assessing and recommending an approach to a full fleet electrification transition.

Technology Alternatives

BEBs use electric energy for propulsion, converted from charge stored in onboard batteries. Conventional BEBs are available in standard sizes (35-foot, 40-foot, 60-foot) and specialized transit vans. Cutaway buses such as those used for Lift service are also starting to enter the North American market.

BEB range is determined by the size of the battery, the weight of the bus, the characteristics of the service it provides, and external operating conditions such as temperature. It is important to note that when discussing BEB charge levels, an *effective* charge of 100% typically refers to 80% to 85% of the nominal battery capacity; habitually charging or discharging the battery outside this threshold will impact the ultimate battery lifespan. Charger device requirements are different between the conventional and specialized fleets, necessitating different equipment.

Advantages of BEBs include:

- **No/Low Local Emissions** – BEBs produce no greenhouse gas (GHG) emissions from vehicle propulsion at the point of operation in mild weather (though upstream emissions depend on local electricity generation methods). In cold-winter climates some transit systems include a small auxiliary diesel-powered interior heater.
- **Lower Energy Costs** – BEBs can be charged using electricity from the grid, which in Ontario is significantly less expensive than diesel or gasoline. **Disadvantages of BEBs**

Disadvantages of BEBs include:

- **Long Charge Times** – Fully charging a BEB can take anywhere from 30 min to 4 h.
- **Depot Configuration and Equipment** – Long charging times for each bus mean that most agencies will have to charge many buses in parallel to meet service needs. This typically requires many spaces to be outfitted with dispensers.
- **Range Limits** – Current BEBs are unable to achieve the same range on a single charge as a traditional diesel bus, requiring operational adjustments and/or on-route charging.
- **Range Sensitivity to Weather Conditions** – BEB batteries are more sensitive to extreme weather (especially cold weather) than diesel buses, requiring insulation and heating. The range of BEBs is also impacted in extreme weather (cold or hot) more noticeably than diesel buses, since BEB range is more constrained in any weather.

Charging can be performed in a garage setting or on-route at strategic locations in the network, depending on what is cost-effective and operationally advantageous for a particular transit system. For charging and storage off-hours (e.g. overnight), indoor facilities are preferable to account for winter heating requirements. Space and structural constraints in the existing Brantford Transit Service Centre restrict options for charging equipment types and configurations. Ground-mounted plug-in units are the most feasible to install from a structural perspective, however this requires sacrificing some storage space to install indoors due to the design of the existing garage, and not all charging would be accommodated indoors.

Fleet Transition Scenarios

Four scenarios have been included in this assessment:

- **Business as Usual:** Do not pursue a BEB transition.
- **End-of-Life Replacement:** Pursue a BEB transition in step with the expected end-of-life of the existing fleet, targeting full conversion by 2030 for the Lift fleet and 2037 for the conventional fleet.
- **Accelerated Replacement:** Pursue a BEB transition at a pace faster than the expected end-of-life of the existing fleet, targeting full conversion for all fleets by 2030.
- **Flash Cut:** Convert the entire conventional and Lift fleets simultaneously in 2024, regardless of remaining useful life.

In all transition scenarios, the date to introduce the first BEBs is projected to be 2024, based on the expected retirement date for Brantford Transit's oldest existing fleet as well as lead times to:

- Approve the transition strategy and associated budget;
- Manufacture and deliver the first vehicles; and
- Manufacture and install the first charging infrastructure.

The Flash Cut scenario is not considered likely to be feasible for cost and change management reasons. This is included primarily to establish a baseline for the maximum theoretically achievable GHG emissions reduction.

Recommendations

IBI Group identified the following key recommendations through the study:

- That Brantford Transit pursue an end-of-life replacement timeline for the current fleet;
- That Brantford Transit purchase first-generation BEBs with auxiliary diesel heaters for resiliency purposes in extreme cold weather, while considering pursuing heat pump technology as the technology becomes available on the North American market;
- That in the near-term, Brantford Transit install initial charging equipment indoors, in a configuration that supports charging buses either stationary or as dedicated charging stalls for buses to rotate through, and that Brantford Transit decide which charging approach to implement based on observed performance of the initial order of BEBs.
- That in the medium-term, the City of Brantford investigate options for a new or relocated facility for transit operations, given the space constraints at the existing garage.

Analysis Methodology Overview

The technical analysis included the following major components:

- A review of the existing transit garage to understand the current context and constraints to account for when planning charging equipment implementation
- Energy consumption analyses for the conventional and Lift fleets, to determine what energy requirements and scheduling adjustments would be involved in delivering 2022 service levels using BEBs, including a comparison of extreme weather scenarios using diesel and electric heating

- Charging analyses for the conventional and Lift fleets, to identify alternative scheduling and equipment layout options that would allow Brantford Transit to reliably meet service
- An implementation planning step to consider the timing of fleet and equipment purchases to support a coordinated rollout, along with electrical service upgrades
- A GHG assessment projecting the emissions associated with each transition scenario
- A cost of ownership assessment projecting capital and operating cost impacts from each transition scenario.

The analysis was structured around the 3 fleet replacement scenarios defined at the beginning of the study. Further dimensions of analysis were identified during study development:

- Interior space heating (2 alternatives):
  - All-electric heating
  - Diesel space heating
- Charging equipment layout (3 alternatives developed based on facility constraints):
  - Stationary charging, where buses park in one location overnight to charge
  - Indoor rotating batch charging, where buses are cycled through an indoor area with dedicated charging stalls
  - Outdoor rotating charging, where buses are stored indoors and driven to outdoor charging stalls, to avoid removing storage space in the garage

Considering all permutations of these dimensions of analysis, a total of 18 scenarios were modelled.

Key Findings

Energy & Charging Analysis

A total fleet size of 39 conventional BEBs and 14 specialized BEBs was identified as being necessary under the winter/summer energy consumption scenarios modelled. This is contrasted with the 2022 fleet size of 31 conventional diesel buses and 18 Lift vehicles.

The expansion in the size of the conventional fleet was identified through the energy modelling analysis, which indicated that in order to cover all scheduled passenger service, buses would need to rotate in and out of service for midday charging, and would therefore need to be relieved by recently recharged buses. Year-round fleet size requirements were not found to be improved by using diesel heaters, as peak summer air conditioning power demands still require buses to recharge midday.

The charging analysis validated the 3 workable alternative equipment layouts that would enable the full fleet to charge overnight, with varying equipment quantities and degrees of labour required. Electrical upgrades were identified that would enable charging at the existing garage, using a separate delivery point for charging needs to avoid altering the existing building infrastructure.

Implementation Planning

Through the implementation planning exercise, fleet replacement timelines were developed that would achieve the alternative target dates for full electrification. In limited cases early in the transition, delaying retirement of existing vehicles by one year was recommended to account for lead time in manufacturing the first order of BEBs.

An equipment rollout sequence was developed for indoor charging equipment, involving a common initial set of phases that could support either stationary or rotating charging. At Transition Year 6 (approximately 2029) the equipment installation sequence would diverge, requiring a decision from Brantford Transit on the path forward based on observed performance data from the first batch of BEBs, and whether a new facility could be planned. At full buildout in the existing garage, rotating charging would require 12 indoor dispensers for conventional BEBs, at the cost of one lane of parking being removed. For stationary charging, 24 dispensers for conventional BEBs could be outfitted indoors, with 2 lanes of parking removed, and an additional 8 required outdoors. In either scenario, Lift charging would need to take place outdoors.

GHG Assessment

The GHG analysis identified significant emissions reductions from the transition to BEB technology. Projected annual GHG emissions reductions are shown in **Exhibit E-1**.

Exhibit E-1: Projected GHG Emissions Reductions from BEB Transition

BEB Fleet	Projected Annual Total GHG Emissions Reduction from Diesel/Gasoline Vehicles	
	Operating Only	Total
39 Conventional BEBs, Electric Heaters	96%	78%
39 Conventional BEBs, Diesel Heaters	93%	75%
14 Specialized BEBs at Maximum Projected Energy Consumption	96%	65%

As could be expected, the pace of transition impacted total GHG emissions through to 2037, with a theoretical flash cut option representing the maximum emissions savings assuming Brantford could sell its existing fleet to other operators.

Cost of Ownership

Major cost elements considered in the cost of ownership projections included:

- Capital cost of vehicles and charging equipment;
- Operating costs including energy (fuel and electricity) and maintenance:
- Administrative costs of re-training staff.

A summary of the total cost of ownership from all transition options is presented in **Exhibit E-2**.

Exhibit E-2: Comparison Matrix of Total Cost of Ownership, 2024-2037
(Including First Generation Capital Purchases Only, 2023 Present Value, 000s)

		(1) Stationary Charging	(2) Rotating Indoor Batch Charging	(3) Rotating Outdoor Charging
(a) End-of-Life Replacement	Electric Heat	$ 178,811	$ 181,875	$ 182,372
	Diesel Heat	$ 180,118	$ 183,181	$ 183,685
(b) Accelerated Replacement	Electric Heat	$ 173,843	$ 178,949	$ 179,174
	Diesel Heat	$ 176,754	$ 181,859	$ 182,095
(c) Flash Cut Replacement	Electric Heat	$ 165,037	$ 172,186	$ 172,140
	Diesel Heat	$ 168,996	$ 176,143	$ 176,111
Business-as-Usual				$ 161,378

While a business-as-usual scenario incurs the lowest overall cost, it does not achieve the objectives of the City in addressing the climate emergency, or the Federal targets for net-zero emissions by 2050. Of the BEB transition options, when only first-generation capital costs are considered, a flash cut transition incurs the lowest overall transition cost by replacing fossil fuel with cheaper electricity. However, this option incurs the highest risk from not being able to observe BEB performance in local conditions, or to allow staff to progressively learn from these observations when planning future orders. An end-of-life transition was therefore recommended. Stationary charging is acknowledged as the preferable approach due to lower total costs, however the constraints in the existing facility would require a significant degree of charging to take place outdoors. For this reason, the recommendation of this study is to install initial charging equipment indoors in a configuration that would allow a future decision based on BEB performance and new facility opportunities. The cost of ownership and GHG emissions projections for the two final equipment layout options are presented in **Exhibit E-3**.

Exhibit E-3: Recommended Options Summary of Incremental Costs and GHG Savings Comparison
(Including Conventional BEBs with Electric Heaters; First- and Second-Generation Capital Purchases)

Year	Annual Costs (2023 Present Value, 000s)						Annual GHG Emissions (t CO2-eq)		GHG Emissions Savings ("Cars off the Road")
	Business as Usual		Alternative 1a (Stationary Charging, End-of-Life Replacement)		Alternative 2a (Indoor Batch, End-of-Life Replacement)		Business as Usual	BEB Transition (Either Equipment Layout)	
	Capital	Operating	Capital	Operating	Capital	Operating			
2024	$ 2,748	$ 9,026	$ 7,102	$ 9,206	$ 7,102	$ 9,206	3839	3491	106
2025	$ 758	$ 9,026	$ 6,583	$ 9,007	$ 6,583	$ 9,007	3839	3338	153
2026	$ 3,202	$ 9,026	$ 4,939	$ 8,633	$ 4,939	$ 8,633	3839	2973	265
2027	$ 1,298	$ 9,026	$ 3,567	$ 8,501	$ 9,965	$ 8,392	3839	2764	329
2028	$ -	$ 9,026	$ -	$ 8,513	$ 8,506	$ 8,339	3839	2764	329
2029	$ 1,947	$ 9,026	$ 5,209	$ 8,316	$ 7,317	$ 7,944	3839	2441	428
2030	$ 2,510	$ 9,026	$ 5,517	$ 8,159	$ 9,267	$ 7,237	3839	2342	458
2031	$ 152	$ 9,026	$ 1,950	$ 8,184	$ 1,950	$ 7,281	3839	2342	458
2032	$ 2,704	$ 9,026	$ 6,499	$ 8,014	$ 1,560	$ 7,330	3839	2020	557
2033	$ 606	$ 9,026	$ -	$ 8,048	$ -	$ 7,382	3839	2019	557
2034	$ -	$ 9,026	$ -	$ 8,087	$ -	$ 7,441	3839	2018	557
2035	$ 3,245	$ 9,026	$ 6,128	$ 7,821	$ -	$ 7,506	3839	1574	694
2036	$ 3,245	$ 9,026	$ 10,884	$ 7,756	$ 4,756	$ 7,578	3839	1129	830
2037	$ 3,159	$ 9,026	$ 10,273	$ 7,658	$ 6,706	$ 7,658	3839	913	896
Total	**$ 25,574**	**$ 126,364**	**$ 68,651**	**$ 115,903**	**$ 68,651**	**$ 110,934**	**53752**	**32127**	

1 Introduction

City of Brantford has declared a climate emergency, and the Federal government has set goal of achieving net carbon neutrality by 2050. Transportation is a key contributor to Brantford's emissions, and electrifying transit presents an opportunity for substantial emissions reduction. The City of Brantford is investigating the feasibility and associated cost of transitioning the Brantford Transit bus fleet to battery electric buses (BEBs), including fixed route buses and specialized Brantford Lift vehicles.

Full transition to a BEB fleet will be a multifaceted undertaking for Brantford Transit, as the capabilities of BEBs on the market and the infrastructure to support their operation differ from those of conventional fossil fuel powered vehicles. Existing transit operations and capital works were typically built for supporting fossil fuel propulsion technology at all levels, from day-to-day service planning to generational investments such as facility design.

IBI Group is supporting the City by assessing and recommending an approach to a full fleet electrification transition. This report is divided into sessions that articulate all study findings

Section 2: Current State Assessment describes the current state of Brantford Transit operations, the Transit Service Centre garage at 400 Grand River Avenue, and the state of the industry with respect to BEB capabilities and market offerings.

Section 3: Fleet Transition Scenarios sets up alternative procurement timelines for a new fleet, upon which the technical analyses in subsequent sections are structured.

Section 4: Conventional Transit Energy & Charging Analysis presents a modelling and simulation exercise undertaken to project the energy requirements to deliver conventional transit service, which informs charging infrastructure and fleet size requirements.

Section 5: Specialized Transit Energy & Charging Analysis presents a modelling and simulation exercise undertaken to project the energy requirements to deliver Brantford Lift service, which informs charging infrastructure and fleet size requirements.

Section 6: Implementation Planning responds to the findings from the energy and charging analyses to build timelines and quantities for fleet and equipment procurement, and equipment configurations to support charging operations.

Section 7: Greenhouse Gas Emissions Assessment projects the greenhouse gas (GHG) emissions produced under the various fleet procurement timelines proposed in **Section 6**.

Section 8: Cost of Ownership projects the capital and operating costs encountered under the various fleet procurement timelines proposed in **Section 6**.

Section 9: Evaluation and Recommendation evaluates the findings of the GHG emissions and cost of ownership assessments, and recommends a path forward for Brantford Transit.

2 Current State Assessment

2.1 Market Scan

2.1.1 Vehicles

BEBs use electric energy for propulsion, converted from charge stored in onboard batteries. These batteries can be charged by using the municipal power grid, sometimes supplemented by on-site power generation/storage (i.e. wind or solar) depending on local conditions.

BEB range is determined by the size of the battery, the weight of the bus, the characteristics of the service it provides, and external operating conditions such as temperature. BEBs are available in standard sizes (35-foot, 40-foot, 60-foot) and there are also companies that retrofit existing diesel buses to BEBs.

As of late 2021-early 2022, nominal charge storage capacities of BEB batteries typically range from 300kWh to 660kWh. It is important to note that when discussing BEB charge levels, an *effective* charge of 100% typically refers to 80% to 85% of the nominal battery capacity; habitually charging or discharging the battery outside this threshold will impact the ultimate battery lifespan. This results in 12 m (40') BEBs with a current high-end nominal battery capacity of about 660 kWh having an effective battery capacity of about 528 kWh to 560 kWh. This translates to a typical practical range of 360km to 530km depending on the operating conditions, and before accounting for other draws on the battery such as heating. Larger BEBs, such as articulated models, tend to be less efficient in terms of kilometres of range per kWh of charge storage capacity, as this tends not to scale evenly with the increased weight of the bus.

In practice, it can be challenging to support the necessary overnight depot charging for emerging higher battery capacity buses, since charging speed is constrained by the depot equipment and infrastructure, grid interface, and time available. Time constraints can be mitigated with faster depot chargers, however high-capacity batteries are limited in hourly charge rate to about one-third of the battery capacity. Using the same example, a 660-kWh battery can only accept charging at a maximum rate of about 220 kW.

The primary alternative approaches to high-capacity batteries are to increase the size of the fleet to facilitate swap-outs, and/or to deploy BEBs more suited to opportunity charging if that operation is appropriate in the local context. Opportunity charging provides high-power "top-ups" at major stops, long layovers or driver breaks at strategic network locations. In this context, high power refers to charging power greater than 150 kW, commonly 300 kW or 450 kW. Buses more capable of accepting rapid charging typically use a different type of battery that has lower maximum capacity but can accept charging at higher rates. These types of batteries have a shorter service life than the newer generation of higher capacity batteries suited to overnight depot charging, resulting from these high charging rates and the increased number of charge/discharge cycles involved.

Advantages of BEBs

Advantages of BEBs include:

- **No/Low Local Emissions** – BEBs produce no GHG emissions from vehicle propulsion at the point of operation, though upstream emissions depend on local electricity generation methods. In cold-winter climates where intense space heating would drastically shorten BEB operating range, some transit systems include a small auxiliary diesel-powered interior heater for resiliency. Bus OEMs in other global regions such as Europe are now adopting heat pump technology instead of resistance-based heating, which offers energy efficiency benefits.

- **Lower Energy Costs** – BEBs can be charged using electricity from the grid, which in Ontario is significantly less expensive than diesel or gasoline. Depending on the size of implementation, the local power supplier may need to upgrade the grid around bus charging sites and the facility interface to the grid. This is often the case for depots, which experience high demand for charging.

Disadvantages of BEBs

Disadvantages of BEBs compared with other propulsion types are largely centred on the charging process, which is significantly more time consuming than refuelling with diesel, hydrogen, or CNG/LNG. These time requirements introduce more complex logistics to coordinate charging for a full fleet. Specific disadvantages include:

- **Long Charge Times** – Fully charging a BEB can take anywhere from 30 min to 4 h. Multiple variables contribute to the charging time, including onboard battery storage capacity and power ratings of both the battery and charging infrastructure. For a fully electric fleet, the amount of time required for charging can lead to operational rigidity in service and at the depot, with less downtime to correct for disruptions to charging caused by unplanned events. At worst, this increases the potential for buses to not be sufficiently charged for the start of service. Strategies to mitigate this risk include:
  - Increasing the spare ratio of the fleet to provide more flexibility for dispatching and maintenance;
  - Implementing charging management software and system integrations to monitor power usage and dynamically adjust charging plans, and
  - Providing supplementary on route-charging at strategic network locations, accounting for the maximum constraint on charge rate imposed by the battery specification.
- **Depot Configuration and Equipment** – Long charging times for each bus mean that most agencies will have to charge many buses in parallel to meet service needs. This typically requires many spaces to be outfitted with dispensers. This comes with a significant capital investment cost, and space requirements when ground-mounted dispensers are required.
- **Range Limits** – Current BEBs are unable to achieve the same range on a single charge as a traditional diesel bus. Agencies using BEBs may require a larger fleet or a redesign of the service plan to break up challenging blocks (the pieces of work assigned to buses) or include mid-day charging intervals. The most affected blocks will be those that are longer, involve higher passenger loads, frequent stops, and/or more significant vertical grades.
- **Range Sensitivity to Weather Conditions** – BEB batteries are more sensitive to extreme weather (especially cold weather) than diesel buses due to the material properties of charge storage and ion transfer that power the bus. This requires insulation and heating to mitigate. The range of BEBs is also impacted in extreme weather (cold or hot) more noticeably than diesel buses, since BEB range is more constrained in any weather. These effects are related to interior heating, ventilation and air conditioning (HVAC; especially when battery electricity is used for interior heating) and reduced access to regenerative braking under slippery conditions.

2.1.2 Charging Equipment and Infrastructure

2.1.2.1 Conventional Fleet Chargers

For conventional BEBs, the two most common dispenser types in North America are ground-mounted plug-style connectors (**Exhibit 1**) and inverted pantographs (**Exhibit 2**). A third type – in-ground inductive pad dispensers – is also in use in some deployments in the United States, but was not considered for this analysis given that it would require demolition of the garage floor.

Exhibit 1: Example of Plug-In Cable Dispenser (GoRaleigh, Raleigh, North Carolina)

Exhibit 2: Example of Inverted Pantograph Dispenser (Spokane Transit, Spokane, Washington)

For slower charging up to 150 kW, both dispenser formats are typical. For fast charging above 150 kW, inverted pantographs are more common due to electrical resistance and cooling constraints with plug-style connectors, although this is subject to evolution of the technology. BEBs are typically manufactured to the customer's specification on which style of recharging connection to include, and options for where to position plug-style connectors relative to the BEBs parking locations (typically near one or more corners of the vehicle). It is also common for buses to support both dispenser types to allow for plug-style depot charging and overhead pantograph opportunity charging.

Typical charging equipment includes charger cabinets that convert AC grid power to DC and regulate the charge delivered to the dispenser. Cabinets be positioned separately from dispensers, however there is a maximum distance limit between the charger cabinets and the dispensers due to voltage drop and communications distance constraints. Exact distance limits vary by manufacturer but are generally 150m or less. Current state-of-industry charging configurations feature one power converter cabinet connected to multiple dispensers. The cabinet will direct electricity to each connected bus, either in parallel or in series. These buses can remain connected and stationary whether they are actively charging or not, to reduce labour and costs associated with repositioning buses.

2.1.2.2 Specialized Fleet Chargers

For specialized transit vehicles such as those used by Brantford Lift, charging is typically available at lower rates, up to approximately 50 kW. These vehicles use plug-style connectors and all-in-one chargers (i.e. with power conversion and dispensing functions in the same unit).

2.1.2.3 Data Communications

A common communication standard across charging equipment and vehicles is important for the charging ecosystem to function optimally when products from multiple vendors are operating in the same environment. Charger cabinets control the power levels being delivered via all connected dispensers, in response to automated communication from battery monitoring software onboard the connected buses.

2.1.2.4 Charge Management

At a facility level, a back-end Charge Management System (CMS) can optimize an overall charging plan across all facility equipment to ensure that buses receive the necessary amount of energy while staying within the applicable power consumption envelope.

The Open Charge Point Protocol (OCPP) is an open standard to ensure compatibility across suppliers in the mobility electrification space (including buses and lighter EVs), and it is the dominant industry standard for data exchange between charging equipment and charging management software in North America. IBI Group strongly recommends that any equipment procured by Brantford Transit be OCPP-compliant at version 1.6 or better to minimize cross-supplier compatibility challenges.

2.2 Peer Agency Scan

As of 2022, over 20 BEB implementations are underway at various agencies in Canada. Most of these implementations are either at the pilot phase, or in an early stage of rollout after gathering lessons learned from a pilot. Implementations underway or being planned at major agencies include the Toronto Transit Commission (TTC), Société de Transport de Montréal (STM), TransLink, Calgary Transit, Edmonton Transit System (ETS), and OC Transpo. Other agencies in southern Ontario planning or conducting BEB pilots include Grand River Transit, Oakville Transit, Brampton Transit, York Region Transit, Burlington Transit, Guelph Transit, and London Transit. The Canadian Infrastructure Bank has announced a $1.5 billion investment in Zero Emissions Bus Technology from 2021 – 2024, providing financing that may help progress innovation in this sector. A selection of Southern Ontario transit systems investigating or pursuing BEB transition in is provided below.

Brantford Comparator Municipalities

Guelph Transit – Guelph Transit is pursuing full fleet electrification, with the first 4 BEBs expected to be delivered in 2022. Guelph is also proceeding with development of a new garage to accommodate the BEB fleet.

Transit Windsor – Transit Windsor signed a letter of intent to purchase ten BYD electric buses in 2012. That agreement later fell through, after which Windsor initiated talks with Proterra to purchase ten electric buses in 2017. Ultimately, that plan did not come to fruition either due to regulatory challenges with the Proterra vehicles. Since that time, Canadian OEMs have launched product offerings and foreign OEMs (including Proterra and BYD) have entered the Canadian market through trials with other agencies. Transit Windsor is now undertaking an electrification feasibility study.

Kingston Transit – Kingston Transit launched a pilot of 2 BEBs in 2021 and is now proceeding with a transition feasibility study.

Peterborough Transit – Peterborough Transit is launching a transition feasibility study in 2022 examining BEB technology in comparison with a variety of other low-emissions alternatives such as hydrogen and natural gas.

Other Area Transit Systems

Sarnia Transit – Sarnia Transit pursued a transition feasibility study in 2021 and is currently redesigning its bus terminals with the capability to support BEB opportunity charging.

London Transit – Eight of London Transit's 218 buses are currently hybrid electric. The agency is considering transition to an all-electric fleet and approved a joint study with CUTRIC on the subject in April 2021. Following completion of the study, London Transit will engage in a one-year pilot to test the vehicles in real-world conditions.

GRT (Waterloo Region) – GRT first deployed diesel-electric hybrid buses in 2008 with a fleet of six vehicles, followed by a further six in 2011. In May 2020, Waterloo Regional Council adopted a motion to end purchases of conventional diesel buses. Ultimately, GRT intends to transition to a full BEB fleet. Due to the cost and range limitations of current BEBs, GRT has adopted an interim fleet procurement strategy consisting of a pilot of 11 BEBs in 2022-20223 to develop in-house expertise with the technology, supplemented by new diesel-electric hybrid buses to replace conventional diesel buses as these buses approach end-of-life.

HSR (Hamilton) – HSR began transitioning their bus fleet to CNG is 2013. More than half of their fleet now runs on natural gas. The agency is now considering BEB investment and has designed their future garage to accommodate 100 BEBs. The timeline for BEB procurement will depend on the development of this new facility.

2.3 Brantford Transit Service Centre

The Brantford Transit garage at 400 Grand River Avenue is the current base for operations and maintenance services. IBI Group visited the site on August 27, 2021. The Facility Field Review Report is included in Appendix A. This section summarizes the findings.

The garage contains 12 pull-through lanes of indoor vehicle storage. Historically, Brantford Transit has shared the facility with Brantford Power, with each organization having access to 6 lanes, separated by a central partition wall. A large outdoor backlot on the property has been used by Brantford Power to store equipment and materials. Brantford Power is planned to vacate the site, opening the rest of the indoor and outdoor space to Transit use. These areas are depicted in **Exhibit 3** below.

Each lane is 56.4 m (185 feet) long, enough to accommodate 4 conventional 12 m buses or 6 cutaway minibuses used by Brantford Lift, which vary between approx. 7.3 m and 8.3 m long. Pairs of lanes share garage doors, with structural supports between each door (**Exhibit 4**).

Exhibit 3: Facility Plan sketch superimposed on aerial image (for illustrative purposes only; source: Google Maps)

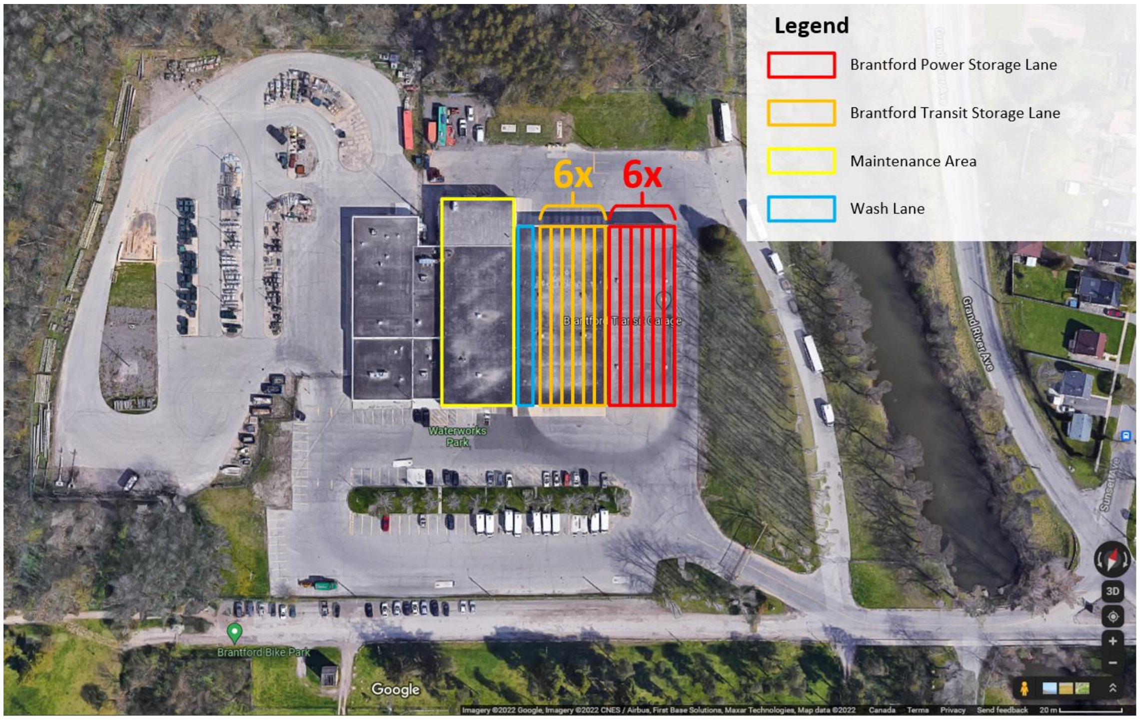


Exhibit 4: Exterior garage view showing double-width storage lane doorways and supporting columns

2.3.1 Layout and Space Programming

The site consists of a building with combined indoor storage, maintenance, and office functions. An outdoor storage lot is also on-site, at the west side of the property. The indoor storage barn includes two halves separated by a partition wall. Each half contains 6 storage lanes capable of storing 4 single bus equivalents (SBEs), for a total of 48 SBEs of storage space. As of August 2021, the garage was shared between Brantford Transit and Brantford Power, with each occupying one half of the storage barn. There is an expectation that Brantford Power will be vacating its portion of the property, doubling the indoor storage space available to Transit.

The current space between the storage lanes and side walls (approximately 800 mm) does not allow for the implementation of floor-mounted chargers and dispensers. However, the future availability of Brantford Power space will reduce this space constraint. Indoor overhead pantographs are not recommended for implementation due to the age of the facility and unknown status of structural trusses.

2.3.2 Electrical Service

The existing electrical delivery point to the site is a 750 kVA pad-mounted transformer. There is no outdoor emergency backup generator. The full capacity of the transformer will be available for Brantford Transit use once the Brantford Power Store moves out. The current garage power demand is 106 kVA, leaving approximately 644 kVA available for charging before an upgraded service would be needed. For higher power demand levels, an upgrade to the site power servicing would be required. The available tiers of site service offered by Brantford Power Inc. (BPI) are presented in **Exhibit 5**.

Exhibit 5: Transformer Capacity Tiers Offered by Brantford Power

Transformer Type	Max Capacity (kVA)
Existing BPI Pad-Mounted Transformer	750
General Service BPI Pad-Mounted Transformer	1500
Customer Owned Substation	>1500

Based on a 96% power factor (according to the most recent test at the site), the maximum power supply that can be expected for charging is presented in **Exhibit 6**.

Exhibit 6: Maximum power supply available for charging, by service type

Electrical Service	Maximum Available Power Supply for Charging (kW)
Current transformer on property	618
Replacement transformer serving all facility uses	1338
New, dedicated transformer for charging (additional delivery point from Brantford Power) [1]	1440

The site plan has potential space for expanding the electrical system required for full fleet electrification. In a scenario without an electrical service upgrade, the team observed two spare

[1] Brantford Power states in its Conditions of Service (**Section 3.1.7**) that additional delivery points to the same property are provided at their sole discretion: https://storage.googleapis.com/website-284719.appspot.com/1/2020/08/Conditions-of-Service_-Address-Updates-_August-4-2020.pdf

600 A breakers on the existing switchboard which could be utilized for new dedicated BEB power distribution panel feeders. In a scenario where an electrical service upgrade is required, the team identified two potential locations for a new main switchboard inside the current shop parts storage area by removing some storage racks to have space, or inside current power store area adjacent to where the existing panel is located. A new pad-mounted transformer could be installed in the yard close to the existing hydro transformer and hydro dip pole.

2.4 Charging Equipment Installation Feasibility

The current state facility review identified plug-in dispensers as the only feasible option for charging in the existing garage due to the scale of engineering and construction works required to implement other dispenser formats, which would not be cost-effective given the age and condition of the building. Plug-in dispensers can be retrofitted into the facility without cutting the floor slab by running overhead power conduits to cabinets located elsewhere in the facility. This approach has been implemented for other retrofitted BEB installations, including at the Toronto Transit Commission (**Exhibit 7, Exhibit 8**).

Unlike other dispenser types on the market, plug-in dispensers require dedicated floor space, including bollards for crash protection. At minimum, approximately 1 m of clearance between lanes is necessary to accommodate dispensers: 0.22 m for the dispenser unit (based on current models from a range of suppliers active in Canada), plus clearance to open the front panel and walk around the unit to (un)plug the connector. Supplier-agnostic dimensions used in this analysis for cabinets and dispensers are presented in **Exhibit 9** below.

Exhibit 7: Example of two plug-in dispensers mounted on pad with drop-down conduits and protective bollard, serving charging spaces on both sides of the traffic island (Toronto Transit Commission)

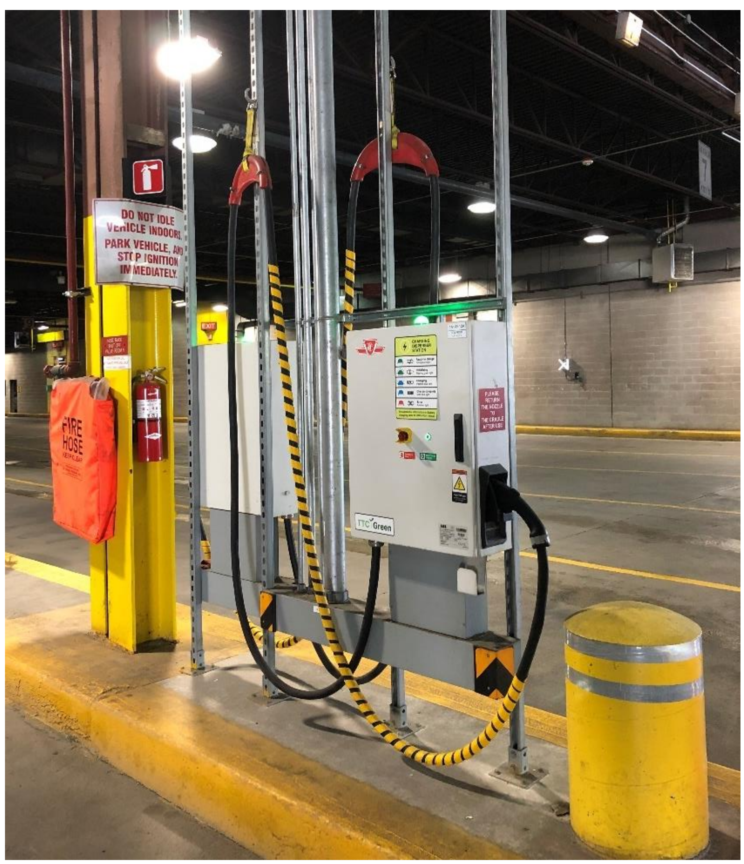
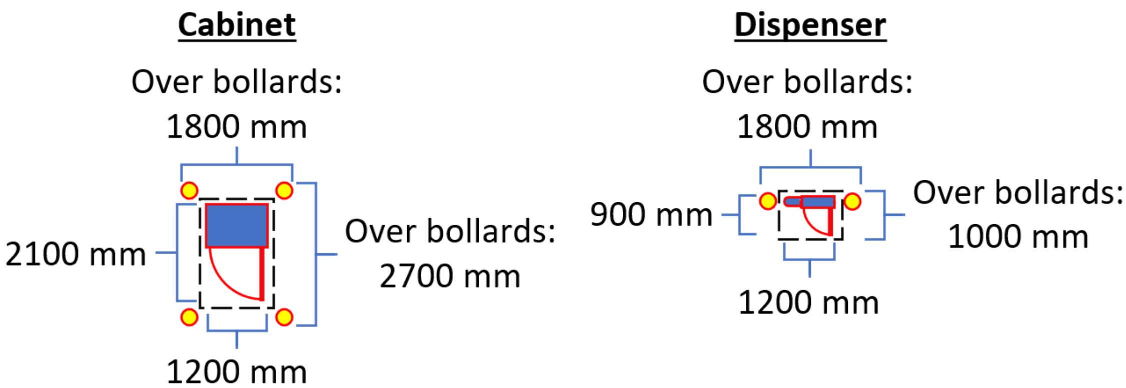


Exhibit 8: Example of cabinets located separately from dispensing stations in the vehicle storage area (Toronto Transit Commission)

Exhibit 9: Supplier-agnostic cabinet and dispenser dimensions used in this analysis



The existing conditions at the Brantford Transit garage do not accommodate the dispensers clearance requirement in most lanes (**Exhibit 10**) – lane widths are approx. 3.2 m, which cannot be narrowed further due to driving tolerances, and there is no buffer between lanes. Lanes next to walls tend to have approx. 800 mm of available space, which is below the required dimensions to accommodate both the equipment and walkways. (**Exhibit 11**). Lane 1 (the westernmost lane in the facility) has more substantial clearance, however it is located next to the wash bay and associated equipment, access to which must be maintained (**Exhibit 12**).

Exhibit 10: Typical indoor storage lane condition at Brantford Transit, showing no buffer space between lanes

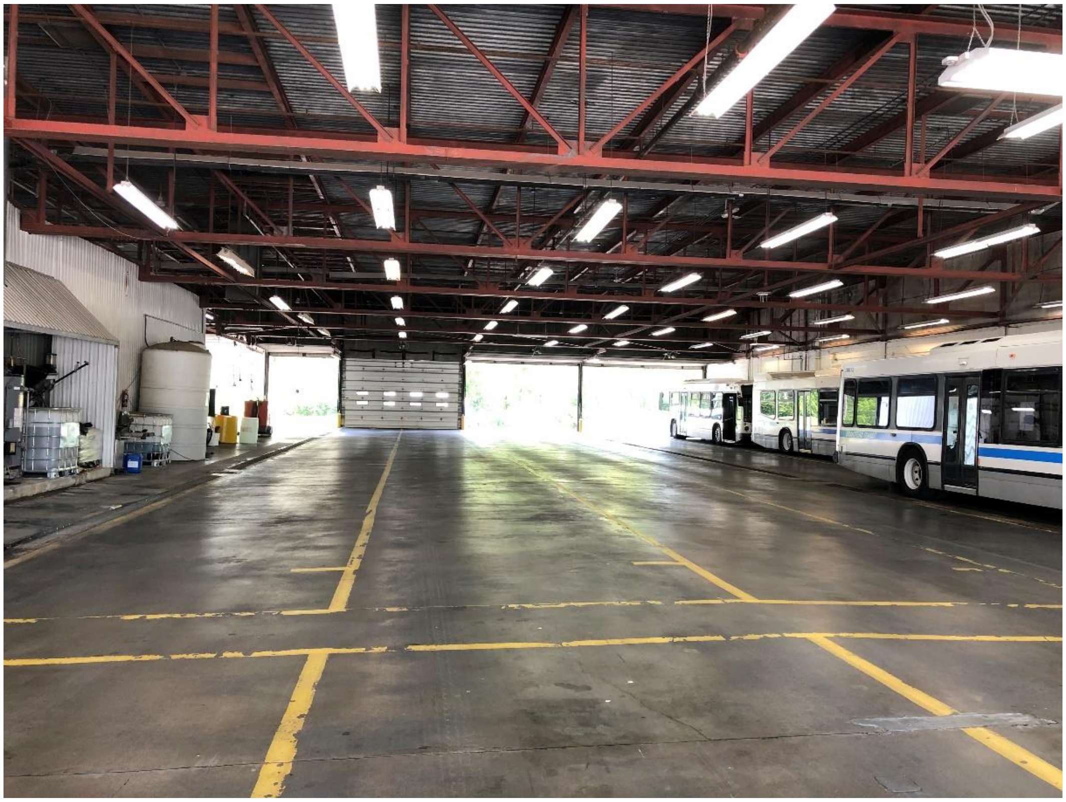


Exhibit 11: Lane 6 at Brantford Transit, showing walkway with minimal clearance

Exhibit 12: Lane 1 at Brantford Transit, showing adjacent wash bay and mounted equipment

Based on these observations of the current facility, there are two primary options available for installing charging equipment:

- Remove an amount of parking (to be determined) to accommodate indoor charging, or
- Install charging equipment outdoors and rotate buses out of indoor storage to use it.

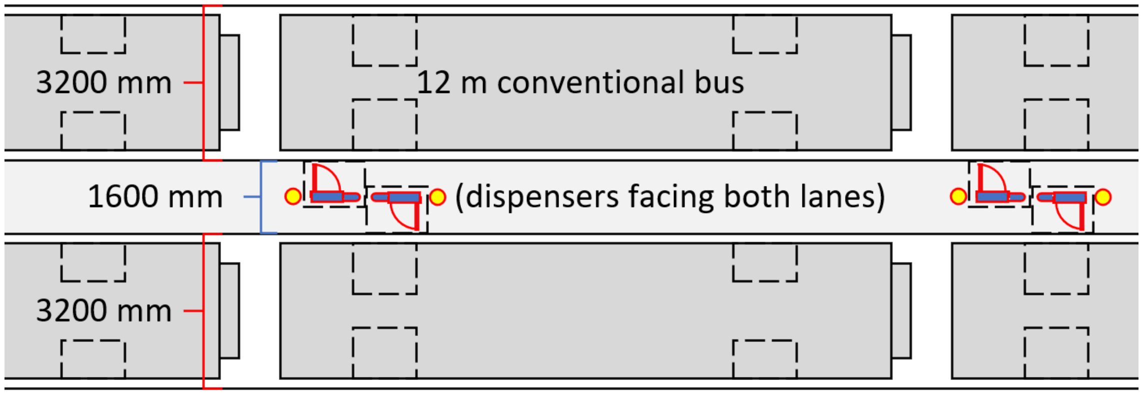
The City of Brantford indicated a preference for indoor charging if feasible, considering winter conditions. If the resulting parking layout could not accommodate both conventional and Lift fleets indoors, prioritizing conventional buses for indoor storage and charging was the approach confirmed by the City, due to the higher energy required to heat a full-sized bus after being parked outdoors overnight.

In the case of indoor charging, the constrained lateral space precludes spreading dispensers across many/all lanes, as this would result in significant parking losses. Instead, dispensers would need to be concentrated in a limited number of lanes, at multiple/all spaces in the lane. This makes managing charging workflows an operational imperative, as the middle spaces in lanes are not always freely accessible. Alternative operational workflows in the garage are evaluated as part of the Energy & Charging Analysis (see **Sections 4 and 5**).

2.4.1 Proposed Approach to Indoor Parking Removal and Dispenser Layout

Each lane of parking removed to facilitate indoor charging results in an 8% reduction in storage capacity for the full 12-lane building. This is a substantial impact, so opportunities to maximize the recovered value of this parking space must be pursued. One row of dispensers does not require the full 3.2 m width of a removed lane, even to charge vehicles in lanes on both sides (**Exhibit 13**; see also photo example from Toronto Transit Commission – **Exhibit 7**).

Exhibit 13: Staggered dispenser configuration serving two adjacent lanes
(supplier-agnostic dispenser dimensions – illustrative purposes only, not to scale)



There is an opportunity to maximize the reuse of parking spaces removed from the Brantford Transit garage by laterally shifting one of the lanes in a pair, without interfering with the structural supports for the building, to enable a third storage lane to be reached by dispensers. An illustrative mock-up of this approach is presented in **Exhibit 14** (overhead view) and **Exhibit 15** (photo edited with visualization).

For simulating charging scenarios to their maximum feasible extent, our team assumed that a lane shift could be employed.

Further discussion of charging equipment placement options is found in **Section 6.2**, informed by findings from the Energy & Charging Analysis.

Exhibit 14: Potential no-construction lane shift to enable additional dispenser installation – Existing condition above, potential future condition below (supplier-agnostic dispenser dimensions – illustrative purposes only, not to scale)

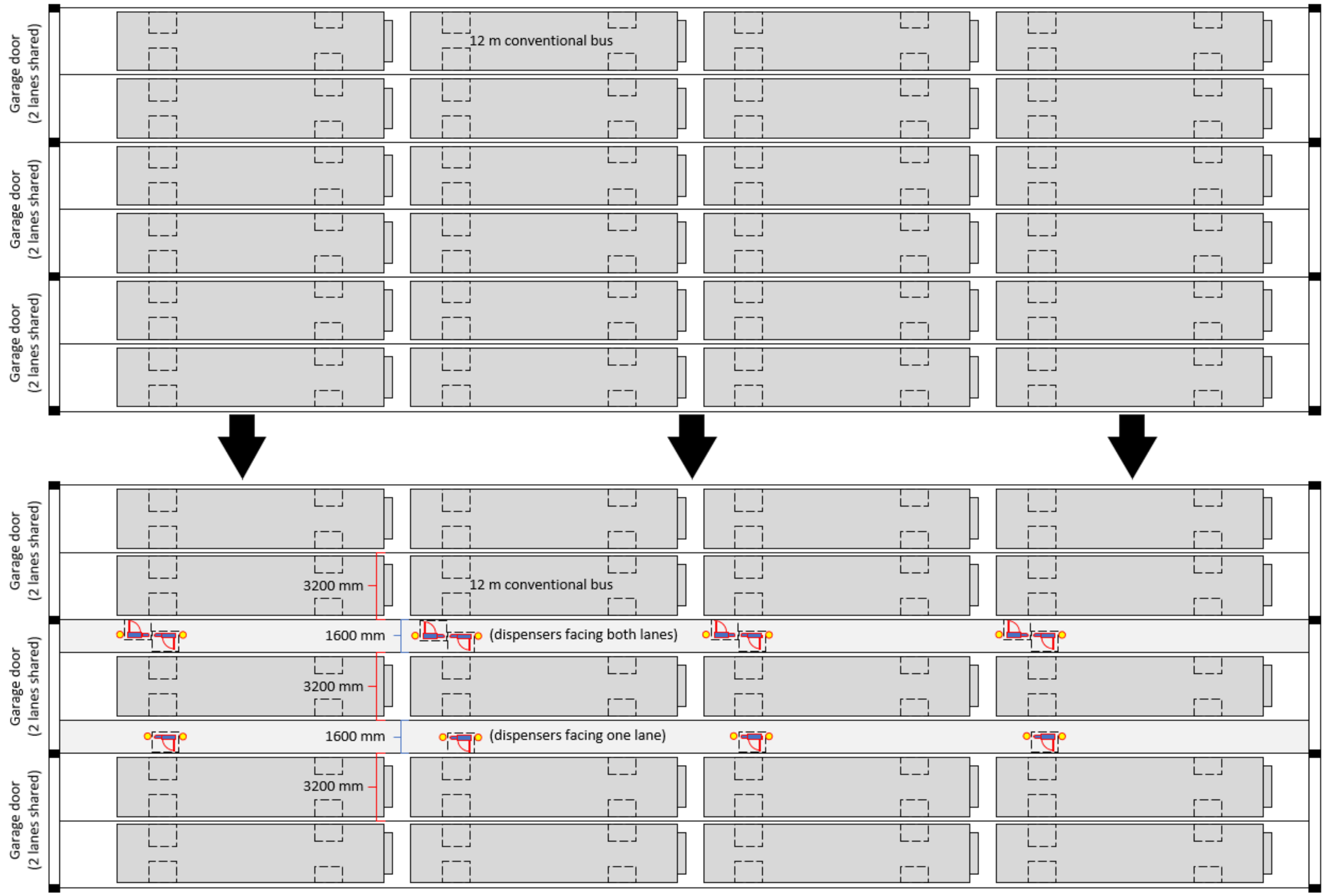
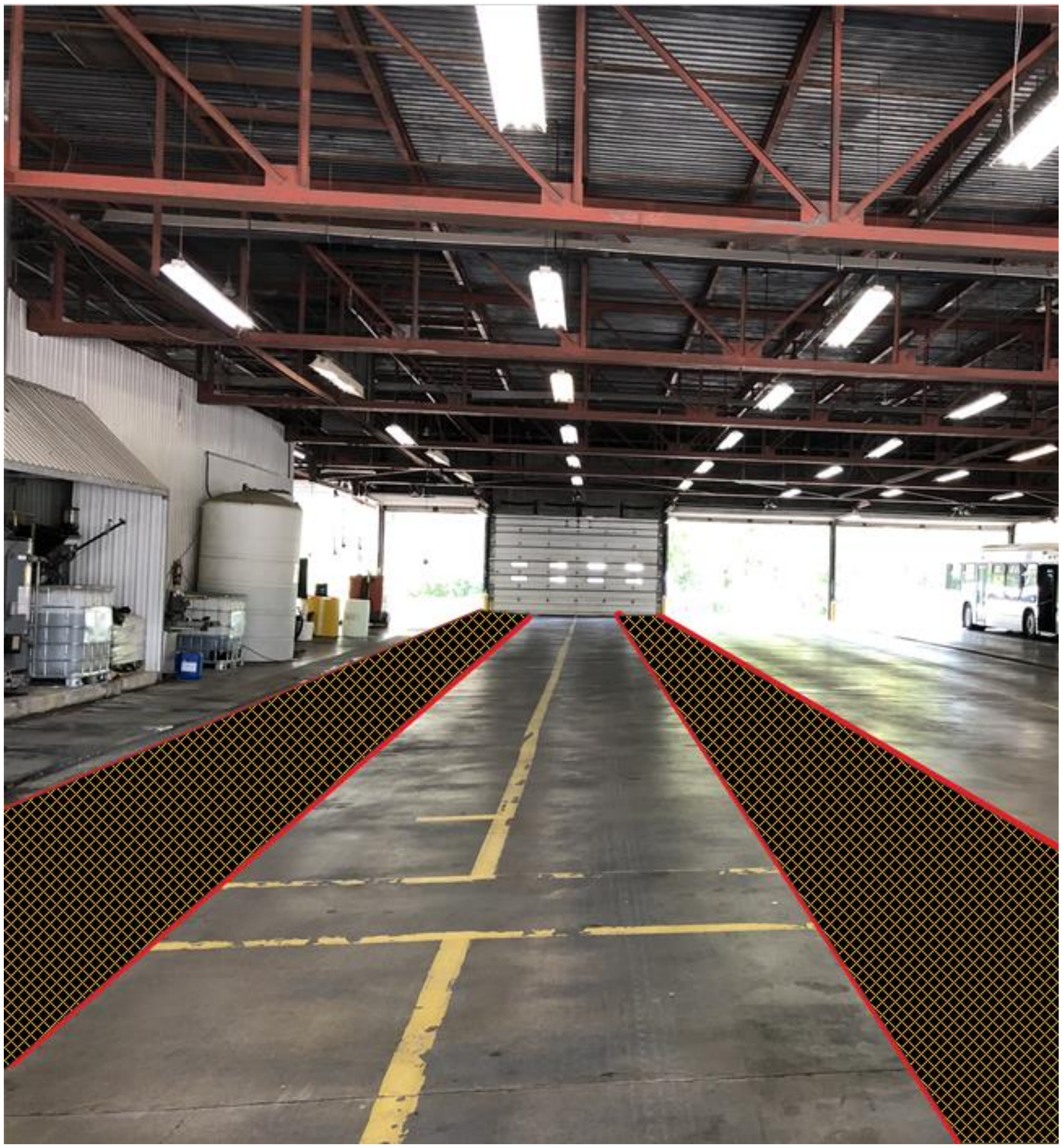


Exhibit 15: Visualization of Potential Lane Re-striping in the Storage Area to Accommodate Dispenser Placement



3 Fleet Transition Scenarios

Four scenarios have been included in this assessment, summarized in **Exhibit 16** below:

Exhibit 16: Fleet Transition Scenario Matrix

<table>
<tr><th>Scenario</th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>Business as Usual:
Do not pursue a BEB transition.
(Theoretical base case against which transition scenarios can be compared)</td><td>• Lowest cost and effort
• Avoids change management needs
• Avoids new infrastructure requirements</td><td>• Does not achieve project objectives
• Does not meet federal decarbonization targets</td></tr>
<tr><td>End-of-Life Replacement:
• Pursue a BEB transition in step with the expected end-of-life of the existing fleet beginning in 2024.
• Target 2030 for full conversion of the Lift fleet.
• Target 2037 for full conversion of the conventional fleet.</td><td>• Extracts maximum value from existing fleet assets
• Offers a maximum window for performance data gathering and change management</td><td>• Lowest cumulative GHG reduction potential associated with operations</td></tr>
<tr><td>Accelerated Replacement:
• Pursue a BEB transition at a pace faster than the expected end-of-life of the existing fleet, beginning in 2024.
• Target 2030 for full transition of both fleets.</td><td>• Improved cumulative GHG reduction potential associated with operations
• Offers a window for performance data gathering and change management</td><td>• Some potential disruption to operations
• Less opportunity to adjust procurements based on observed performance data</td></tr>
<tr><td>Flash Cut:
• Convert the entire conventional and Lift fleets simultaneously in 2024, regardless of remaining useful life.</td><td>• Maximized cumulative GHG reduction potential associated with operations</td><td>• Most potential disruption to operations
• No opportunity to adjust procurements based on observed performance data</td></tr>
</table>

In all transition scenarios, the date to introduce the first BEBs is projected to be 2024, based on the expected retirement date for Brantford Transit's oldest existing fleet as well as lead times to:

- Approve the transition strategy and associated budget;
- Manufacture and deliver the first vehicles; and
- Manufacture and install the first charging infrastructure.

The Flash Cut scenario is not considered likely to be feasible for cost and change management reasons. This is included primarily to establish a baseline for the maximum theoretically achievable GHG emissions reduction.

4 Conventional Transit Energy & Charging Analysis

4.1 Methodology & Setup

4.1.1 BEB Operating Constraints

Batteries currently available for BEB applications store less energy per unit of volume and unit of mass than a tank of diesel. As a result, full-size BEBs currently on the market tend to be heavier than equivalently sized diesel buses, and they have a lower maximum driving range between charges, compared with diesel driving range between fuelling.

Projecting energy consumption is important for BEBs because an agency's existing scheduling practices are typically based on the driving range of diesel buses. Schedules are broken into blocks – pieces of work that are pre-planned in the schedule, and that are each filled by one vehicle. Depending on variable energy consumption factors such as hill climbing and interior heating, BEBs often cannot perform a block lasting a full day without being swapped out midday or recharging on-route. This has implications on the overall fleet size required to run service, and the fixed infrastructure requirements to support the fleet.

The goal of energy modelling is to identify instances where the agency's existing schedules are incompatible with BEB range limitations, and then explore alternative strategies to achieve compatibility, such as blocking modifications and (if necessary) on-route charging sessions.

4.1.2 Modelling Process

The fixed-route energy use modelling conducted for Brantford Transit used the following steps:

1. **Building the BEB energy model** based on data from Brantford Transit, publicly available weather and terrain profiles, and Original Equipment Manufacturers (OEMs).
2. **Applying the model** to current Brantford Transit service blocks to identify compatibility gaps where the energy demand for a scheduled block exceeds typical ranges of available BEBs (as of late 2021).
3. **Applying mitigation strategies** to the current transit schedule to produce new theoretical blocks that achieve compatibility with BEBs, and to identify the fleet size required to run service. In Brantford Transit's case, the mitigation strategy was re-blocking the schedule.
4. **Re-validating the adjusted blocks** using the energy model.

4.1.2.1 Step 1: BEB Energy Model Parameters

The core of the fixed-route energy modelling analysis is the BEB energy consumption model, which computes the total energy required to operate each block based on several key factors influencing energy consumption:

- Horizontal propulsion, based on vehicle mass, block service and deadheading distances;
- Vertical propulsion, based on terrain elevation;
- Heating, ventilation, and air conditioning (HVAC), based on block durations.

In this model, total energy consumption is taken as the sum of consumption due to each of the three factors. Energy consumption is calculated at the trip level, as different trips may run different turn-by-turn directions (known as trip patterns) within the same block or route over the course of the day. This data can be further interpolated to the stop level, to provide finer energy consumption values and thus battery State-of-Charge (SOC) projections.

Additional potential factors in energy consumption such as driver behaviour and tire rolling resistance in various weather conditions have been built into the horizontal propulsion component as average assumed values. These factors are dependent on individual driving habits and pavement quality, which are not directly derivable from Brantford Transit planning data or bus OEM specifications. Driver training for BEB operation will be important for Brantford Transit when transitioning to BEBs, as driver behaviour from acceleration and braking can significantly impact driving range.

The three key factors influencing the energy consumption are discussed in detail below. The numerical values of all parameters used in the analysis are presented in **Section 4.1.3.3**.

Horizontal Propulsion

To calculate the horizontal propulsion energy, the total distance travelled in a trip is multiplied by a parameter representing the unit energy consumption per kilometre travelled. Energy consumption per kilometre is dependent on the vehicle mass and passenger loading, which vary by BEB model. For this analysis we have assumed an average vehicle mass based on 12-metre BEBs available in the Canadian market. Distance travelled was obtained from planning data supplied by Brantford Transit, and included revenue (customer carrying) trips and deadheads (out-of-service moves to/from the garage).

Vertical Propulsion

The impact of hill climbing on BEB energy consumption was included in the analysis. While Brantford is not characterized by particularly large hills or steep grades, the cumulative effect of repeatedly climbing the Grand River valley and surrounding rolling hills over the course of service contributes to battery energy consumption.

The calculation of vertical propulsion energy considers the cumulative positive vertical climb in elevation experienced by the vehicle throughout each trip. Energy consumed on vertical ascents is calculated as the cumulative difference in the gravitational potential energy, using the following equation:

$$E_{vert} = m_{BEB} \times g \times h_{climb}$$

m_{BEB} refers to the mass of the bus, g is the acceleration due to gravity (9.81 m/s^2), and h_{climb} is the cumulative positive vertical climb distance.

Potential energy consumption reductions through regenerative braking on descents are ignored to produce a more conservative estimate. This is due to the mechanism of regenerative braking and factors affecting its consistency in everyday use.

Regenerative braking operates by using the electric motor in reverse as a generator when the accelerator is not applied. This exerts a braking force on the wheels, with some of the lost rotational kinetic energy captured as generated electricity and routed back to the battery. Through this setup, some of the energy applied to move the vehicle forward or upwards could be recovered as the vehicle slows. However, the degree to which energy can be recovered to the battery using regenerative braking is highly variable.

Foremost, it is highly dependent on drivers adopting a quite different driving technique than with a conventional vehicle. Using the brakes in a conventional manner will eliminate most regenerative energy recovery, since brakes instead efficiently dissipate the rotational kinetic energy as heat. To gather much regenerative braking energy requires that drivers anticipate the need to slow early, and then let the regenerative braking slow the vehicle by stepping off the accelerator but not using the brake (sometimes referred to as "one pedal driving"). This is reportedly a very fundamental adjustment that some drivers find hard to make, so it is hard to plan operations in the foreseeable future around something that will vary some widely across the various drivers who will operate on a block.

Another big factor is that regenerative braking is set up to monitor traction and detect when the braking force effect would exceed the roadway traction (leading to wheel lock). In practice, this means that the regenerative braking will be mostly overridden whenever roads become slippery due to snow, ice, or water. Also, whenever the battery is mostly charged (i.e. over about 90%) the regenerative braking will be disabled since it would risk being harmful to the battery to force in more regenerative power.

For the reasons discussed, we do not recommend planning operations around expecting regenerative braking will be available to a consistent degree at this stage of transition.

Heating, Ventilation, and Air Conditioning

The energy consumed due to HVAC is dependent on the total block duration between pulling out of the garage at the beginning of service and pulling into the garage at the end of service. This duration is multiplied by a parameter representing the energy consumption rate of the HVAC system, which varies between seasons. Winter and summer represent the periods of highest energy demand due to HVAC, with winter heating creating the highest demand.

Importantly for winter heating, BEBs can be designed to either draw all heating energy from the battery, or to also carry a small diesel-powered heater to provide auxiliary heating below a threshold temperature setting. The analysis considered both heating scenarios, to determine whether full diesel heating could assist in reducing the fleet size requirements.

Under the **electric heating** scenario, all energy consumed for heating and air conditioning (and all other onboard components) come from the onboard battery. This approach provides the benefit of zero tailpipe GHG emissions, and minimal operational emissions overall, connected to electricity generation. The trade-off is that during cold weather conditions, a considerable portion of the battery charge would be used towards heating, impacting vehicle range. Winter operation is the limiting condition for year-round BEB performance in this scenario, as heating consumes more energy than air conditioning in the Brantford climate.

Under the **diesel heating** scenario, the onboard battery is assumed to not supply ongoing heating energy to the HVAC unit, extending vehicle range in the winter at the cost of some tailpipe GHG emissions. However, in the summertime when cooling is required, the energy still comes from the battery. Summer operation is the limiting condition for year-round BEB performance in this scenario, as air conditioning demand is highest.

4.1.2.2 Step 2: Current Schedule Compatibility with BEBs

After all energy consumption inputs are built into the model, the total energy consumption requirement for each block is compared against the available battery energy storage capacity of the BEB models whose performance data was used as part of the model inputs. Energy consumption varies by BEB model primarily based on vehicle weight (which the battery itself contributes to) and volume (for HVAC).

At this stage of the analysis, a minimum acceptable SOC is also applied, so that if the bus does approach the limit of its range, it will still have enough residual energy to return to the garage. If the total energy required for service would cross this threshold, the block is said to be incompatible with BEB operation as-is.

4.1.2.3 Step 3: Compatibility Mitigation through Re-Blocking

Re-blocking was approved by the City of Brantford as a mitigation strategy to investigate for blocks that are incompatible with BEBs. The process involves examining the energy requirements of all trips in each incompatible block, and trimming trips from the block to reduce its energy consumption to within BEB range constraints on a single charge. The trips trimmed off are then reallocated to other blocks. In some cases, the trips can be appended to other existing blocks with excess energy consumption headroom to retain compatibility, or the trimmed trips from one or more blocks can be formed into new blocks.

Often, re-blocking results in additional buses required to cover the same public-facing service, as blocks that could originally be operated by a single diesel bus are now shortened, and other buses need to cover the removed trips. Re-blocking needs to be conducted strategically such that the degree of fleet expansion required is minimized. An example of an approach to reduce fleet expansion requirements is to build two new blocks in the morning and the evening, and to use the midday time window for recharging in the garage, so that the same BEB can operate both blocks with a recharge in between.

It is important to note that the re-blocking conducted as part of this analysis does not represent an exact proposed future schedule for Brantford Transit – there are potentially many alternative re-blocking permutations with equivalent compatibility. Additionally, this re-blocking does not constitute a full revision of the schedule, as it does not include a parallel set of new runs (work assignments) for drivers. It is intended to estimate fleet size requirements and approximate midday recharging requirements only, without changing the public-facing trip times currently advertised by Brantford Transit. IBI Group recommends that a full revision of service blocks be performed by Brantford Transit scheduling staff as BEBs are delivered and performance data is gathered under local conditions, in conjunction with other service planning review activities.

Consideration of On-Route Charging

Depending on agency-specific factors (e.g. transit network layout, service frequency, scheduled layovers), re-blocking can sometimes be complemented or substituted by on-route charging. In Brantford Transit’s case, a schedule evaluation led IBI Group to recommend completing this analysis using re-blocking that was exclusively based on factors discussed in this section.

On a case-by-case basis, on-route chargers can provide benefits in the form of reduced fleet size and potentially staffing requirements, compared with in-garage charging. By charging outside the garage, the need to swap out buses is reduced, along with the staff hours associated with extra deadheading. However, trade-offs come in the forms of increased fixed infrastructure requirements (capital and maintenance), and reduced flexibility to re-route bus services relative to where the chargers are positioned in the network.

For Brantford Transit, the dominant candidate location for on-route charging would be the Downtown Terminal (at 64 Darling St.), as all routes pass through this facility, and all layovers between trips are currently scheduled at the Terminal. However, layovers are not very long (typically 5 min). Charging during short layovers typically involves “fast” charging at high power levels (300-450 kW), however such an interval still only provides a BEB with enough energy to complete one or two trips.

Trips converge at the Terminal on 30 min intervals. This timed transfer approach is important for the convenience of passengers making connections, however it would result in highly concentrated demand for charging buses: around half of the buses returning to the Terminal on each 30 min interval may need to charge in parallel, creating short burst loads of over 1 MW. These concentrated power demands would result in significant, long-term infrastructure requirements downtown and questionable feasibility for concentrating on-route charging at this location when using the current timed transfer approach. Under the current energy pricing model with Brantford Power, this site would be billable as a separate service from the existing garage.

Alternatively, on-route chargers could be distributed around the transit network. This would likely require changes to public-facing schedules to incorporate layovers, and the sites would still incur infrastructure upgrades and separate billing. Outside the scope of this study, Brantford Transit is exploring potential route modification opportunities and changes to satellite transfer facilities such as Lynden Park Mall and Brantford Commons. The uncertainty around potential future service changes and resulting impacts to charging locations effectively prevent this option from being further explored in this study. In the future once possible routing and facility modifications are better known, a clearer financial comparison of in-garage charging versus distributed on-route charging may become possible.

4.1.3 Input Data

4.1.3.1 Service Schedules

The service schedules used in this analysis, including all routes and block data, were based on Brantford Transit's Fall 2019 service plan, which reflected the most recent full schedule shortly before the onset of the COVID-19 pandemic. The schedule information received were in the form of internal block graphs supplemented by operator duty sheets and public-facing timetables. IBI's own Data Tools were used to encode that information into an integrated General Transit Feed Specification (GTFS) static feed. This standardized feed served as the input to the internal route modelling software used to run this analysis. Versions of the GTFS feed were created each time the schedule was modified for re-blocking.

Non-revenue service, including deadheads to/from the Brantford Transit Garage (at 400 Grand River Ave.) and for mid-block repositions were also considered. A pull-out deadhead was added to the beginning of every revenue service block, arriving at the starting stop of the first trip of the block two minutes before scheduled departure. A pull-in deadhead was added to the end of every revenue service block, departing from the last stop immediately after the last trip terminates. Most deadheads are between the garage and the Downtown Terminal, which was estimated to be roughly eight minutes in duration per direction based on the data provided by Brantford Transit. Deadheads to other locations on the network vary by driving distance.

Brantford Transit operates two distinct sets of service patterns: Monday to Saturday service, which begins at 6:00 a.m. and ends at 1:00 a.m. the next day, and Sunday service, which runs from 8:00 a.m. to 8:00 p.m. Modelling was conducted separately for both Monday to Saturday as well as Sunday. The baseline service schedule includes 17 blocks for Monday to Saturday service (mostly 15 to 19 hours in duration, with additional shorter industrial area services) and 8 blocks for Sunday service (all 12 hours in duration).

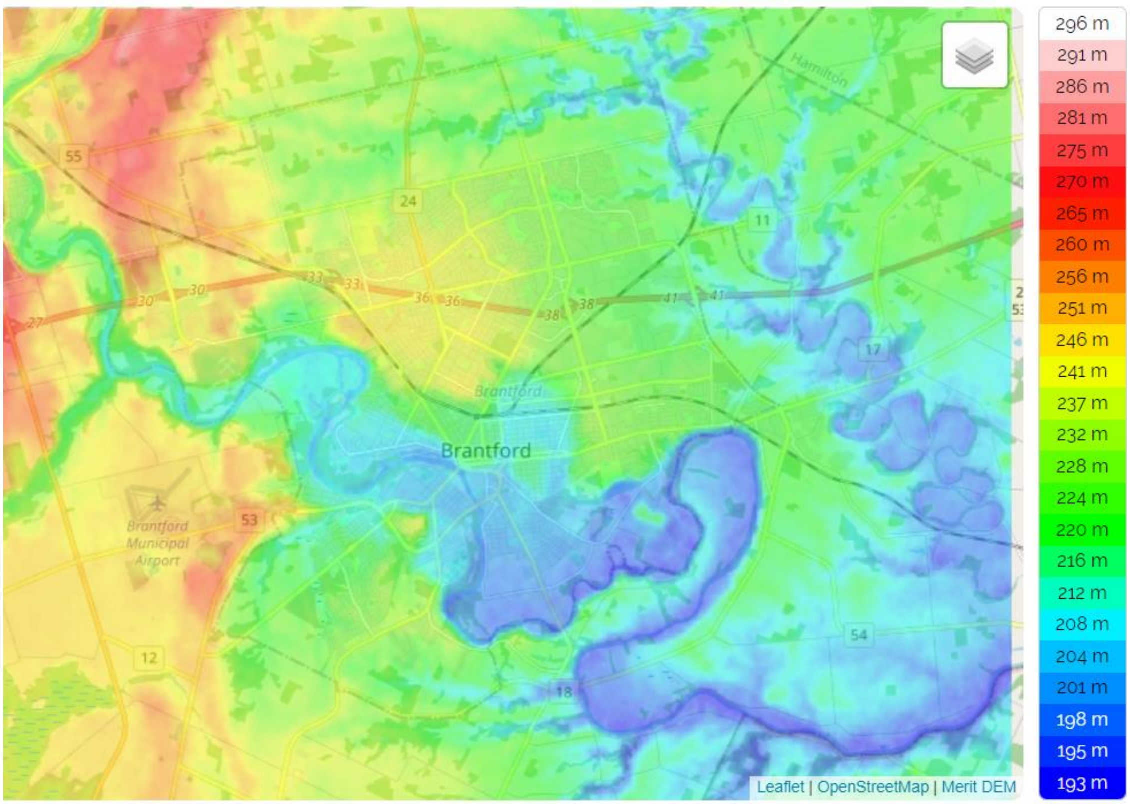
Brantford Transit also operates several rush-hour "tripper" blocks to supplement scheduled baseline service on Mondays to Saturdays. The number of trippers and their specific schedules tend to change more significantly between board periods than the baseline service, as they are intended to respond to seasonal fluctuations in ridership and are not advertised in the public schedules.

4.1.3.2 Terrain Data

Our modelling tool queried Google's Elevation API for the ground elevation of every point in the GTFS shapefile (example data visualization shown in **Exhibit 17**). Only point-to-point increases in elevation were factored into the vertical energy consumption (shown as h_{climb} in **Section 4.1.2.1**). Decreases in potential energy from downhill grades may be partly recovered with regenerative braking, but this has been excluded for a more conservative energy consumption estimate.

Google’s Elevation API only provides ground elevation data, not road elevation data. This is a meaningful difference when it comes to bridges and tunnels. The most prominent source of discrepancy between ground and road elevations in Brantford is the Grand River valley. When crossing the valley on bridges, the buses do not undergo as significant of a change in the road elevation as the ground elevation. Nevertheless, any differences between the road elevation and the ground elevations obtained only lead to a more conservative analysis due to larger vertical distances travelled. Other than bridges crossing the Grand River, most roads run directly on the ground.

Exhibit 17: Open-Source Brantford Elevations Data Visualization (Source: topographic-map.com)



4.1.3.3 Parameter Values

Key parameters were used to represent the characteristics of the BEB vehicle and its onboard systems, as well as other operational constraints. These parameters are summarized in **Exhibit 18** below with their values. During an actual future transition, phased BEB introduction would permit data collection in Brantford's local context, to confirm model assumptions and allow for adjustment to both capital procurement and service planning.

Exhibit 18: Energy Modelling Input Parameters

Parameter	Value	Rationale
Bus battery capacity		
Absolute	600 kWh	• Higher end of commercially available capacity for 40' and 60' BEBs in Canada as of late 2021 • Suitable for high-performance demands of urban fleets with long continuous utilization
Effective (85% of absolute)	510 kWh	• Minimum 15% capacity safety factor advised by OEMs to avoid habitual deep drawdown (which accelerates battery aging) • Can be counted as an emergency reserve for unplanned events such as long traffic delays
Bus mass (fully loaded)	20 tonnes	• Blended statistic from OEMs active in Canada
Horizontal propulsion energy conversion rate	1.38 kWh/km	• Efficiency built into parameter • Conservative, representing a full passenger load, a moderate frequency of stops and overall acceleration/deceleration cycling • Regenerative braking energy recovery on downhill slopes excluded in analysis (also to be conservative)
HVAC maximum energy conversion rate		
Electric Heater Scenario	11.3 kW	• Maximum battery usage by an all-electric HVAC system occurs during the winter due to heating • Value based on data from Edmonton Transit System, filtered for winter temperatures relevant to Brantford climate
Diesel Heater Scenario	9.27 kW	• Ventilation and air conditioning functions are powered by the battery. Maximum battery usage therefore occurs during the summer due to air conditioning

4.2 Existing Block Performance

Energy consumption modelling was conducted for the electric and diesel heater scenarios using the original baseline schedule to identify compatibility gaps. These gaps would then inform re-blocking to achieve full BEB compatibility for all service.

Among incompatible blocks, those with energy consumption values between the effective and absolute battery capacity values are classified as being “at risk”. BEBs operating those blocks would end with a SOC lower than the effective 15% threshold but higher than 0%. Those with energy consumption fully exceeding the total battery capacity are deemed “infeasible”.

4.2.1 Monday-Saturday Modelling Outputs

Monday-Saturday service consists of baseline and tripper blocks. A full graphical visualization of all existing Monday-Saturday blocks is provided in **Exhibit 33** (See **Section 4.3.3**).

Baseline blocks form the core of service and tend to have a duration of most/all of the service day. Tripper blocks are short-duration supplements to the baseline schedule, covering special industrial and school runs, and providing expanded service capacity on regular routes during peak periods. Most tripper blocks do not serve trips shown in the public-facing schedules, and they are subject to change with each board period in reaction to observed passenger volume fluctuations, changing needs for industrial and school service, and other potential factors.

Monday-Saturday Modelling results are summarized in **Exhibit 19**. All blocks under 5 hours in total duration (consisting of all trippers) are compatible, while none of the longer baseline blocks are compatible. Both electric and diesel heater scenarios resulted in the same breakdown of compatible and incompatible blocks. Reasons for this are discussed in **Section 4.2.3**.

Exhibit 19: Existing block compatibility summary statistics (Monday-Saturday service)

		Total Blocks	Compatible (< 510 kWh)	Incompatible	
				At Risk (510 to 600 kWh)	Infeasible (> 600 kWh)
Electric Heater Scenario (Winter Service)					
Block Count	Baseline	**15**	0	0	15
	Tripper	**12**	12	0	0
	Total	**27**	12	0	15
Percentage		**100%**	44.4%	0%	55.6%
Diesel Heater Scenario (Summer Service)					
Block Count	Baseline	**15**	0	0	15
	Tripper	**12**	12	0	0
	Total	**27**	12	0	15
Percentage		**100%**	44.4%	0%	55.6%

Histograms presented in **Exhibit 20** and **Exhibit 21** show the distribution of blocks by total electricity consumption. Line graphs presented in **Exhibit 22** and **Exhibit 23** plot the battery SOC for each block over time. In both sets of graphs, consumption and SOC readings are theoretical (i.e. plotted even if they are not achievable within actual battery capacity constraints).

In all graphs, the red dashed line represents the 510-kWh effective battery capacity, and the black solid line represents the 600-kWh absolute battery capacity. In the histograms only, green bars represent compatible blocks, amber bars represent blocks that exceed the effective battery capacity, and red bars represent blocks that exceed the absolute battery capacity.

Exhibit 20: Existing block electricity consumption histogram (electric heaters (winter), Monday-Saturday service)

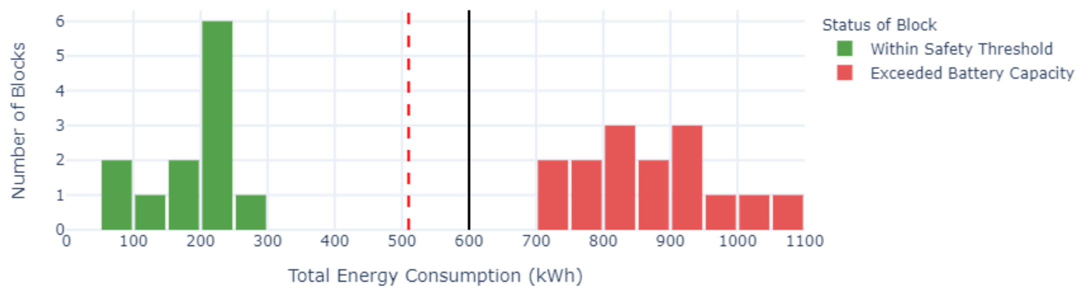


Exhibit 21: Existing block electricity consumption histogram (diesel heaters (summer), Monday-Saturday service)

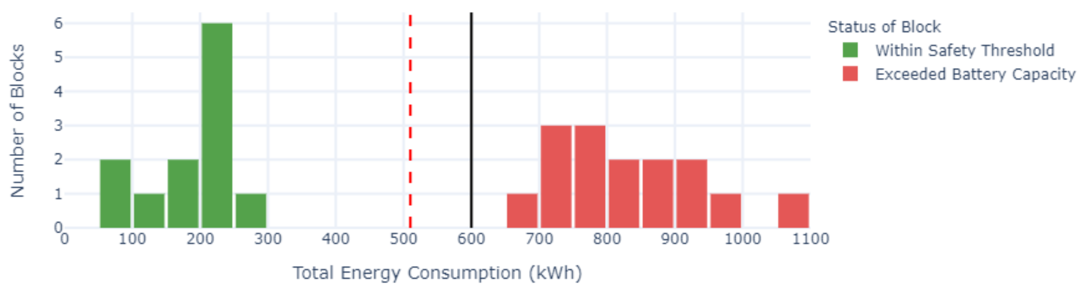


Exhibit 22: Existing block SOC profiles (electric heaters (winter), Monday-Saturday service)

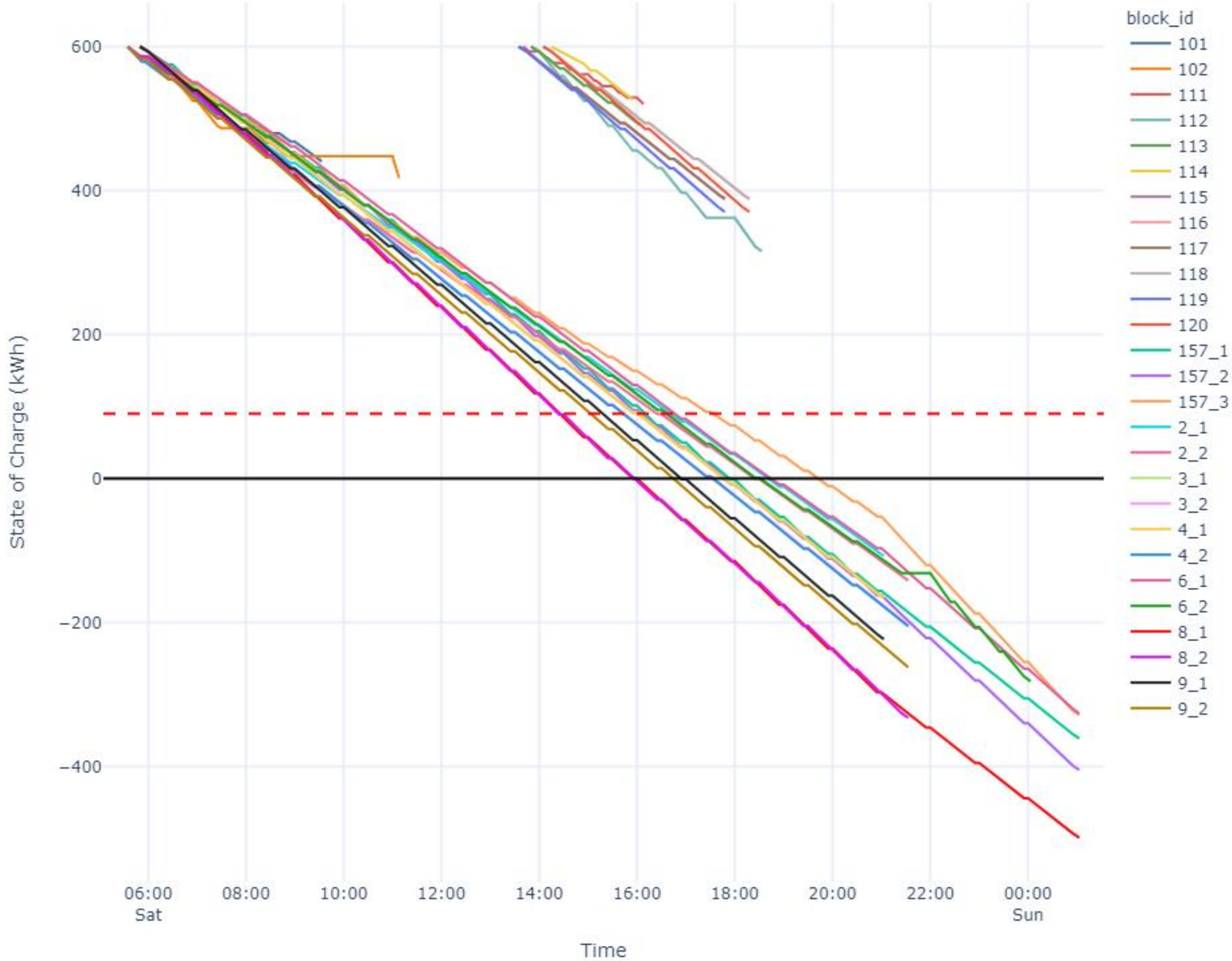
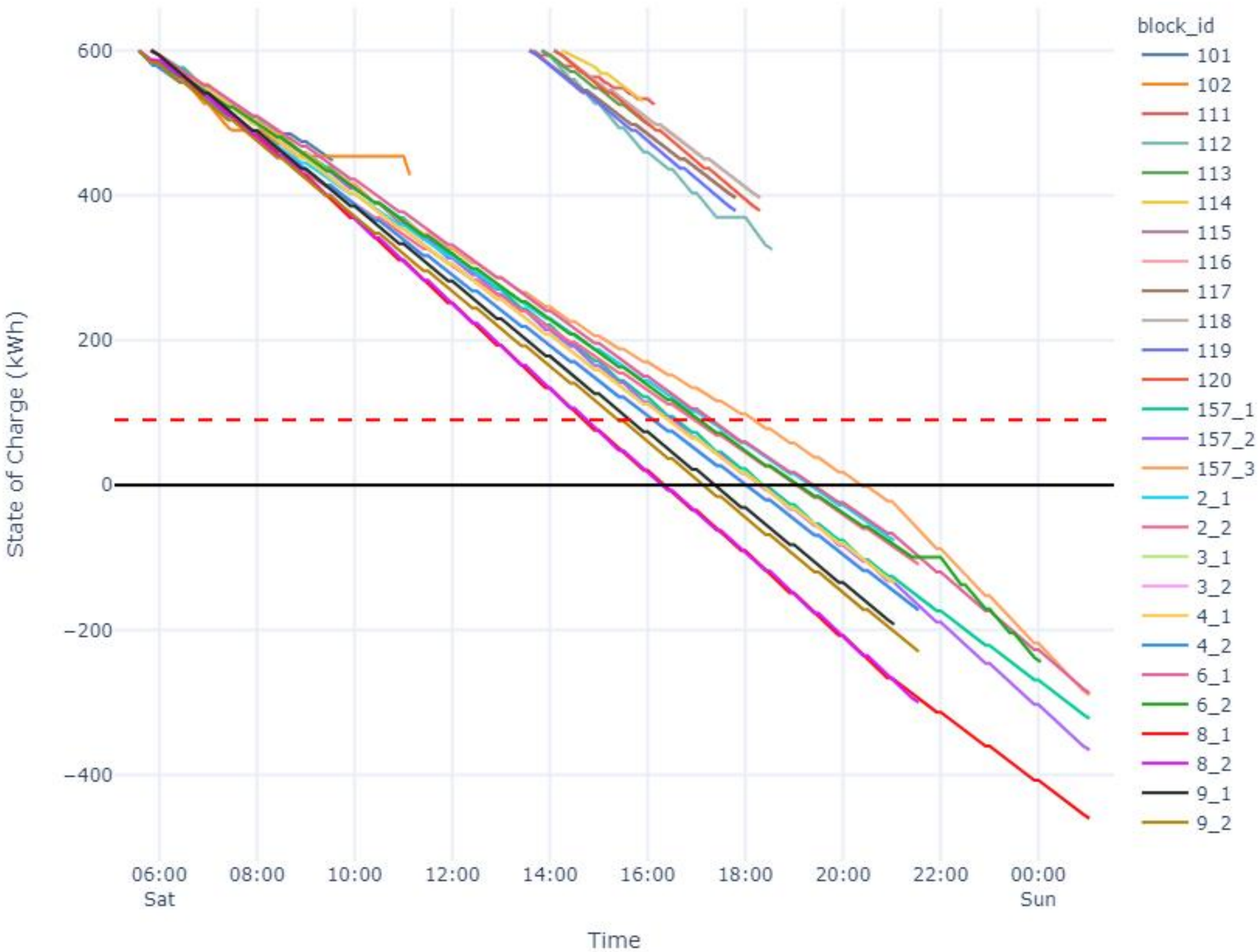


Exhibit 23: Existing block SOC profiles (diesel heaters (summer), Monday-Saturday service)



4.2.2 Sunday Modelling Outputs

Sunday service consists entirely of blocks providing service for the full day. A full graphical visualization of all existing Sunday blocks is provided in **Exhibit 35** (See **Section 4.3.3**).

All existing Sunday blocks are 12 hours in duration. Modelling results for the original service schedule under are summarized in **Exhibit 24**. In each heater scenario, a portion of blocks are considered "at risk" (i.e. consuming less energy than the absolute battery capacity, but more than the recommended effective capacity). No blocks were compatible outright.

Notably for Sunday service, the reduced battery energy consumption from diesel heaters resulted in two additional blocks improving in status from "infeasible" to "at risk", though none of the blocks achieved full compatibility.

Exhibit 24: Existing block compatibility summary statistics (Sunday service)

	Total Blocks	Compatible	Incompatible	
			At Risk	Infeasible
Electric Heater Scenario (Winter Service)				
Block Count	**8**	0	3	5
Percentage	**100%**	0%	37.5%	62.5%
Diesel Heater Scenario (Summer Service)				
Block Count	**8**	0	5	3
Percentage	**100%**	0%	62.5%	37.5%

Histograms presented in **Exhibit 25** and **Exhibit 26** show the distribution of blocks by total theoretical electricity consumption. Line graphs presented in **Exhibit 27** and **Exhibit 28** plot the theoretical battery SOC for each block over time.

Exhibit 25: Existing block electricity consumption histogram (electric heaters (winter), Sunday service)

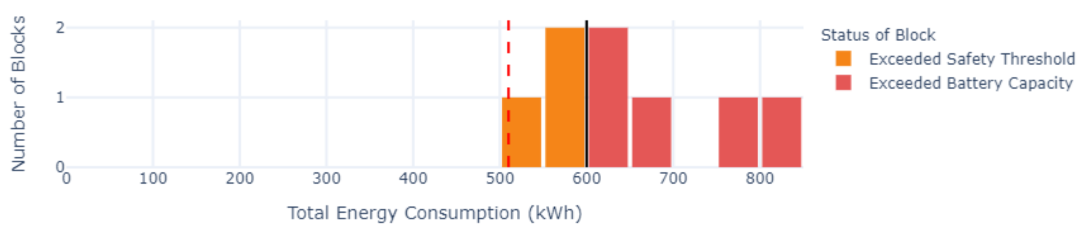


Exhibit 26: Existing block electricity consumption histogram (diesel heaters (summer), Sunday service)

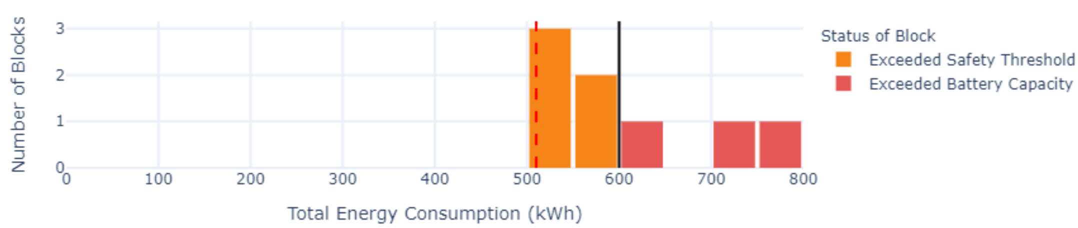


Exhibit 27: Existing block SOC profiles (electric heaters (winter), Sunday service)

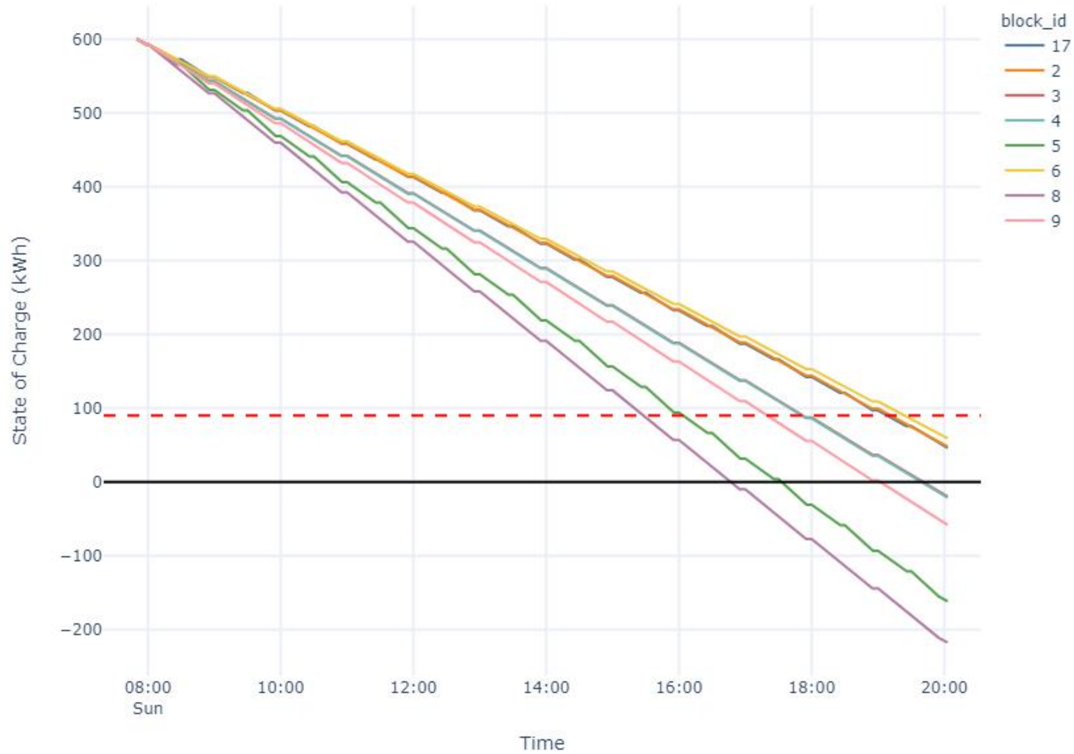
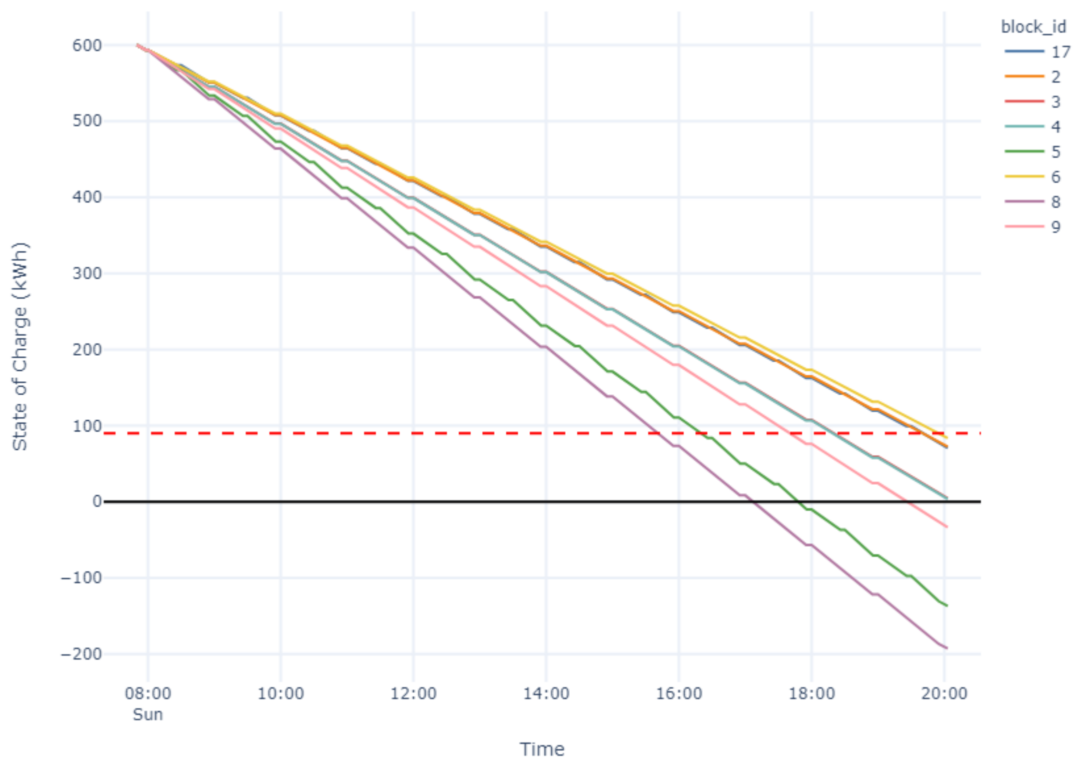


Exhibit 28: Existing block SOC profiles (diesel heaters (summer), Sunday service)



4.2.3 Impact of Heating Scenarios

Under the electric heating winter scenario, trips from the incompatible Monday-Saturday blocks that are left unsupported after each BEB has depleted its allowable charge totalled to **111.5 hours** in duration and **5815 kWh** in projected energy consumption, excluding deadheads. Under the diesel heating summer scenario, the total set of unsupported trips (excluding deadheads) prior to re-blocking summed to **102.5 hours** in duration and **5165 kWh** in energy consumption. This is **9 hours** and **650 kWh** lower than the electric heater scenario.

Under the electric heating winter scenario, three Sunday blocks finish with a SOC higher than 0%, however they are still considered “at risk”. The unsupported trips (excluding deadheads) totalled to **22 hours** in duration and **1239 kWh** in energy consumption. Under the diesel heating summer scenario, similar energy consumption savings were observed as Monday-Saturday service, resulting in each bus having the capacity to run approximately one additional trip before requiring relief. In aggregate, the remaining unsupported trips (excluding deadheads) totalled to **18.5 hours** in duration and **1022 kWh** in energy requirements.

The results of the existing block energy consumption modelling indicated that little improvement was achieved using diesel heaters, in terms of directly making existing blocks compatible with BEBs year-round. Modelling found that the maximum electricity consumption per block in the diesel heater summer scenario was approximately 30 kWh lower than the maximum electricity consumption in the electric heater winter scenario. This reflects a lower rate of electricity consumption from maximum summer air conditioning compared with electric winter heating. As a result, 10 out of the 15 incompatible blocks in the original Monday-Saturday blocking would have the capacity to run one extra trip before requiring relief.

Although diesel heaters would provide up to 11.3 kW in battery discharge savings during the winter, fleet sizing decisions need to account for year-round performance. During peak summer conditions, the peak energy consumption from air conditioning is projected to constrain bus ranges such that no additional blocks are brought into the compatible range. Based on these findings, the same re-blocking process was applied regardless of the heating scenario used. This re-blocked schedule would represent winter service requirements with electric heaters, or summer service requirements with diesel heaters.

4.3 Re-Blocking Process

Based on the energy consumption modelling, the existing baseline service schedule was re-blocked such that the energy requirement of each block would be within the specified effective battery capacity even under high-demand HVAC and passenger carrying scenarios. This blocking plan would not necessarily represent year-round requirements.

The primary strategy used in re-blocking was to break up blocks and swap out buses, without affecting passenger facing trip times. Trips were trimmed from existing blocks and either grouped into new blocks or appended to the few existing blocks that had sufficient energy consumption headroom to support additional trips. Deadheads to/from the garage were added or removed where required. Systematic strategies employed in the re-blocking process are described below.

4.3.1 Interlining

The route modelling analysis revealed a distribution in the energy consumption associated with trips on different routes lasting the same duration. These differences are due to both horizontal and vertical propulsion requirements. When blocks include the same trip pattern repeatedly, differences in energy requirements compound to make some blocks significantly more challenging to serve within one battery charge (**Exhibit 29**, **Exhibit 30**).

Exhibit 29: Block SOC profiles (electric heaters, Mon-Sat baseline service, original schedule)

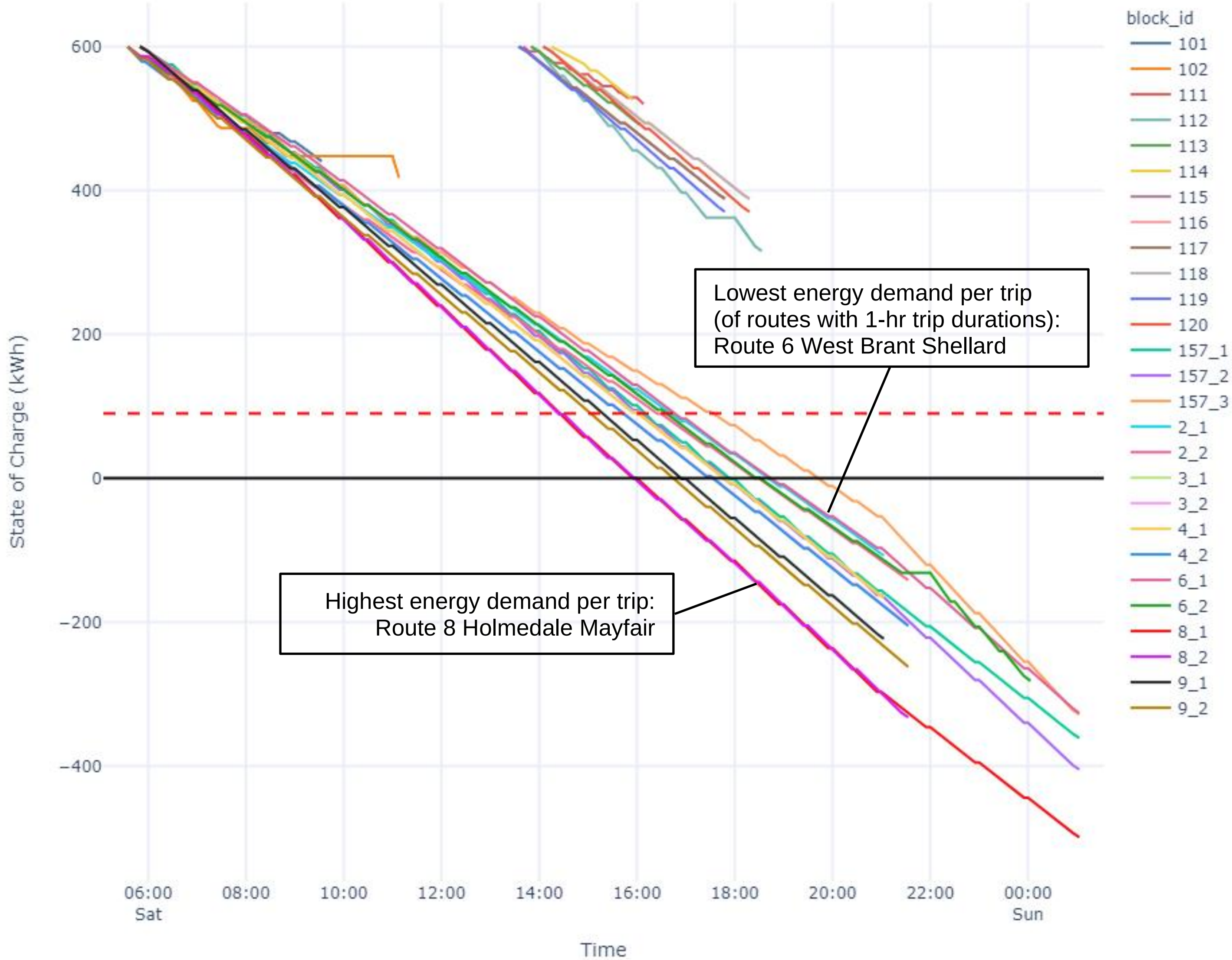
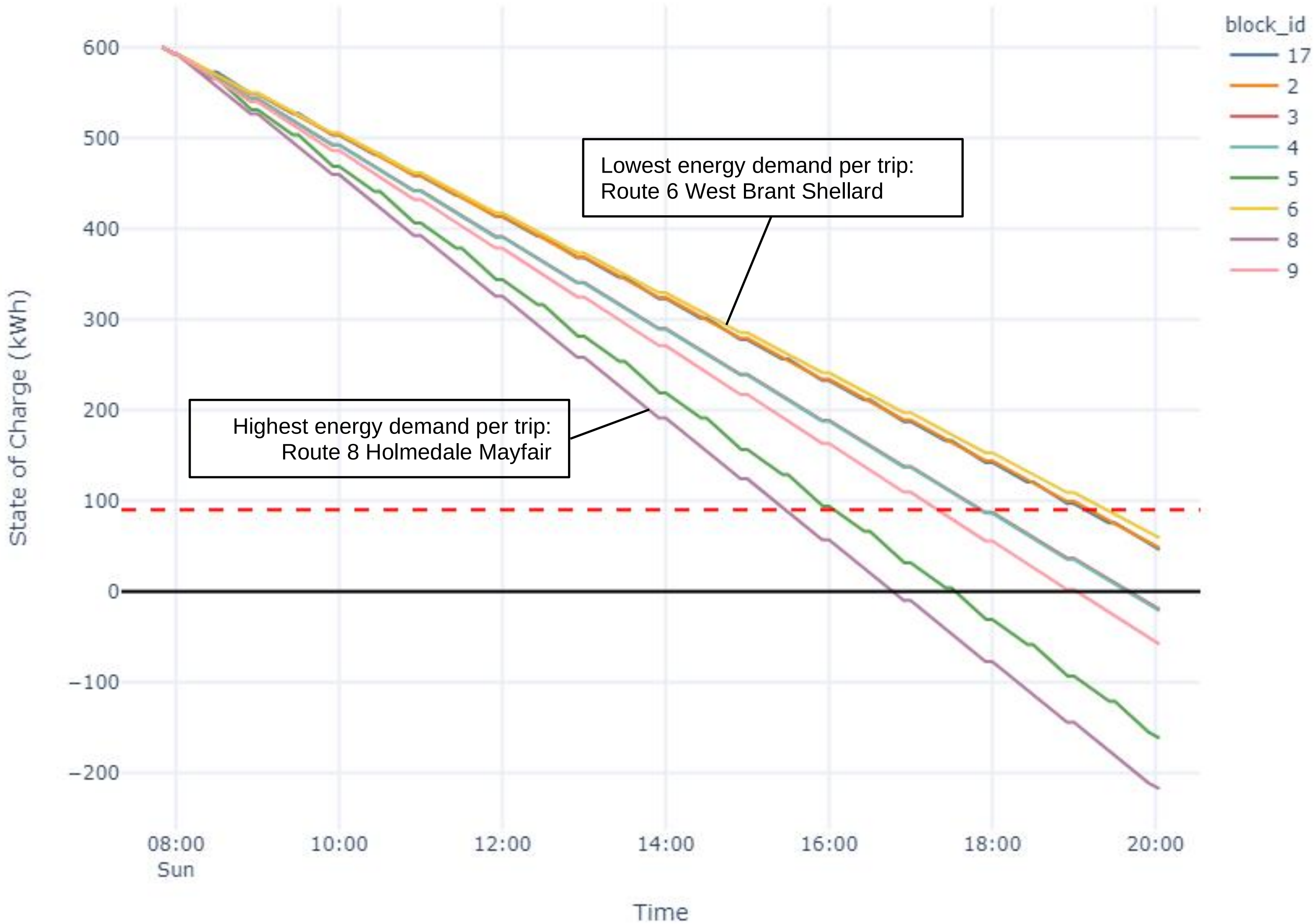


Exhibit 30: Block SOC profiles (electric heaters, Sun baseline service, original schedule)



To reduce the variation in overall block energy requirements, the re-blocking process included interlining routes with similar trip durations. Pairings were determined by matching routes with the highest and lowest energy demands, as presented in **Exhibit 31** below.

Exhibit 31: Interlining pairings based on per-trip energy demand, identified by public-facing route

High Energy Demand Trip Patterns (Descending Order)			Low Energy Demand Trip Patterns (Ascending Order)		Average Approx. Per-Trip Energy Consumption of Interlined Pair (kWh)
Route	Approx. Energy Per Trip (kWh)*		Route	Approx. Energy Per Trip (kWh)*	
8	60.84	+	6	47.36	54.10
2	55.14	+	4C	49.53	52.34
9	53.80	+	4A	50.65	52.22

*Note: To simplify the table, these estimates do not include midday/peak routing extensions

For Monday-Saturday service, trips on Route 8 and Route 6 were interlined in the service plan. For Sunday service, all pairings presented in **Exhibit 31** were interlined.

4.3.2 Charging Session Planning

Where possible, the re-blocked schedule minimizes the degree of fleet expansion required by enabling one bus to cover trips in the morning and evening, recharging midday in the depot. In turn, buses returning to service can then relieve other buses.

4.3.2.1 Additive and Subtractive Charge Management

Managing BEB states of charge can be considered from two primary approaches: additive or subtractive. In an additive approach, BEBs are provided with enough charge to run a specific block (or set of possible blocks) within the overall service plan. In a subtractive approach, a full charge is considered the baseline state for all BEBs. After expending a certain portion of this charge in service, each BEB is charged back to a full state. Each approach is best suited to different kinds of charging activities to help maintain reliable service.

Subtractive charge management results in buses that are substantially interchangeable for assigning to blocks, barring other differentiating factors like vehicle size/capacity. This provides an advantage for dispatchers since assignments can be more easily reworked if one bus experiences an issue at pull-out and requires substitution. It provides another advantage in the case of indoor charging in pull-though lanes, as maintenance staff and dispatchers do not need to ensure buses are parked in any specific order before pull-out.

Additive charge management is well-suited for charging midway through service, whether in the depot or on-route. In these cases, time is generally at a premium to charge the bus and send it back into service. The rest of the BEB's assigned service is already known, so a layover can be budgeted that provides time to charge the BEB just enough to continue in service. Additive charge management is less advisable for charging between services, as it requires pre-assigning buses to upcoming services before they charge. With the pull-through lane layout of Brantford Transit garage, this would necessitate careful coordination of movements and storage locations to ensure the availability of a specific bus when its assigned service is scheduled to pull out.

For these reasons, we have used a subtractive charge management approach to model overnight charging, and an additive approach to model midday charging.

4.3.2.2 Midday Charging Workflow

For blocks that have been split to introduce midday charging, the assigned BEB returns to the garage for charging only. Since it is returning to service, it does not receive maintenance or cleaning. Since the remainder of its service is known, an additive charge management approach was followed to provide the bus with just as much charge as required before returning to service.

As discussed in **Section 2.3.1**, in an indoor charging scenario, the constraints of the existing garage would require dispensers to be positioned length-wise along one or more pull-through lanes. In an optimized service plan, midday charging activities for multiple buses would be coordinated so as not to cause access conflicts to dispensers in the same lane. Charging sessions in the same lane would also optimally be scheduled to last similar durations when possible. Our approach to coordinating charging sessions is further discussed in **Section 4.4.1.1**.

4.3.2.3 Overnight Charging Workflow

At the end of service for a given block, the BEB assigned to the block returns to the garage for maintenance servicing and charging. In this analysis, typical cleaning and routine maintenance activities have been accounted for by applying a standard time buffer to each block, between the nominal pull-in time and the point at which the bus is considered available to charge. BEB charging is represented as a charging session appended onto the end of each block. Using a subtractive charge management approach, each bus is intended to reach a full charge before the following dispatch.

4.3.3 Re-Blocking Results

After implementing the identified re-blocking strategies, the estimated fleet count required for weekday pull-out under both heating scenarios is **32 BEBs.** Maintaining a recommended spare ratio of 20% would therefore result in 7 spares, for a total fleet size of **39 BEBs**. Summary statistics of the number of blocks and required fleet count at pull-out for baseline service only (i.e. excluding trippers, and accounting for paired blocks) are presented in **Exhibit 32** below.

Exhibit 32: Summary block statistics before and after re-blocking (electric heater scenario, baseline service)

Service Day	Blocks		Fleet at Pull-Out	
	Existing	Re-Blocked	Existing	Re-Blocked
Monday-Saturday	27	54	25	32
Sunday	8	16	8	10

The original and modified blockings for the baseline schedule are presented in **Exhibit 33** through **Exhibit 36** below. Newly created blocks have identification numbers based on the existing Brantford Transit format.

Monday to Saturday Service

Exhibit 33: Brantford Transit original block schedule for Monday to Saturday service

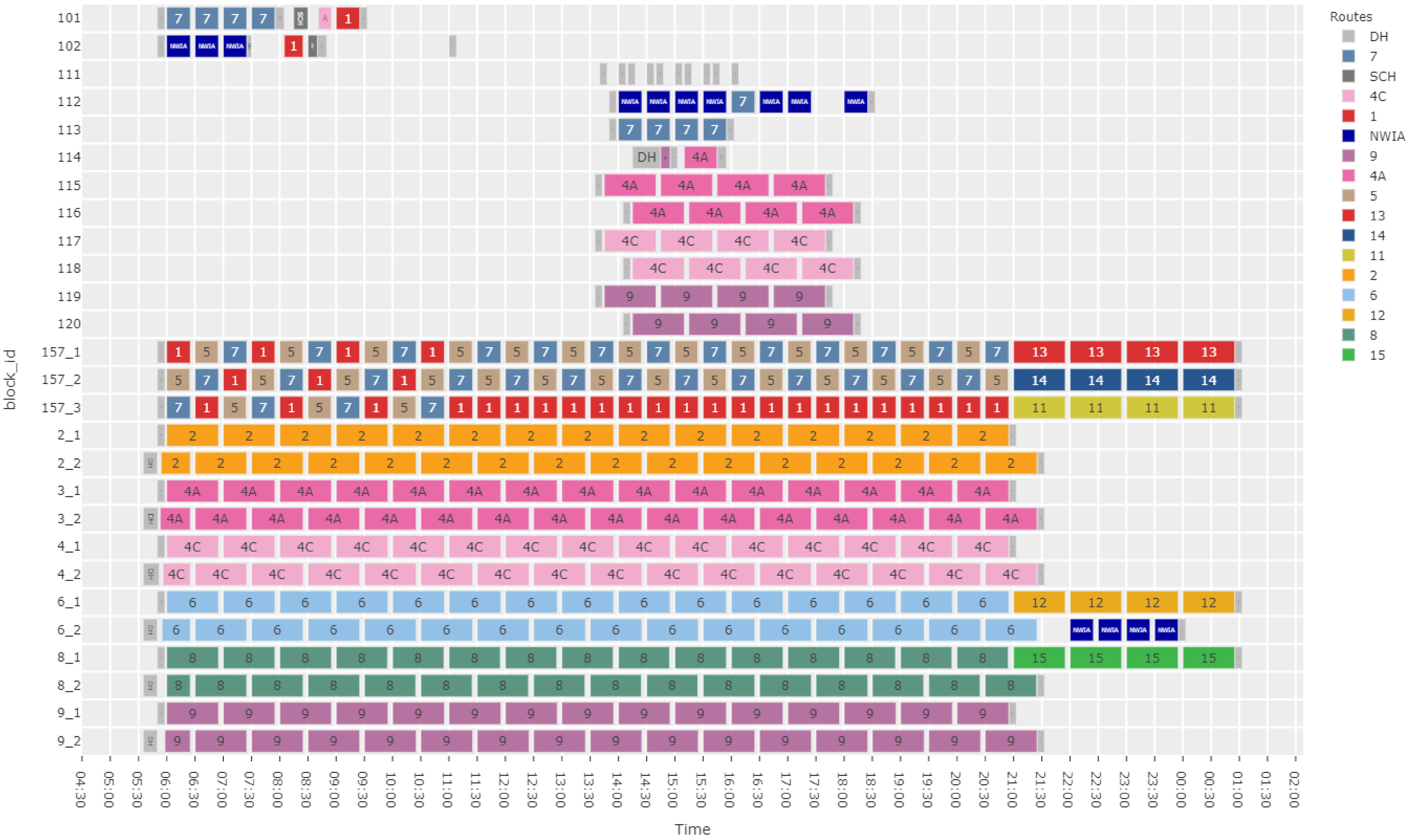
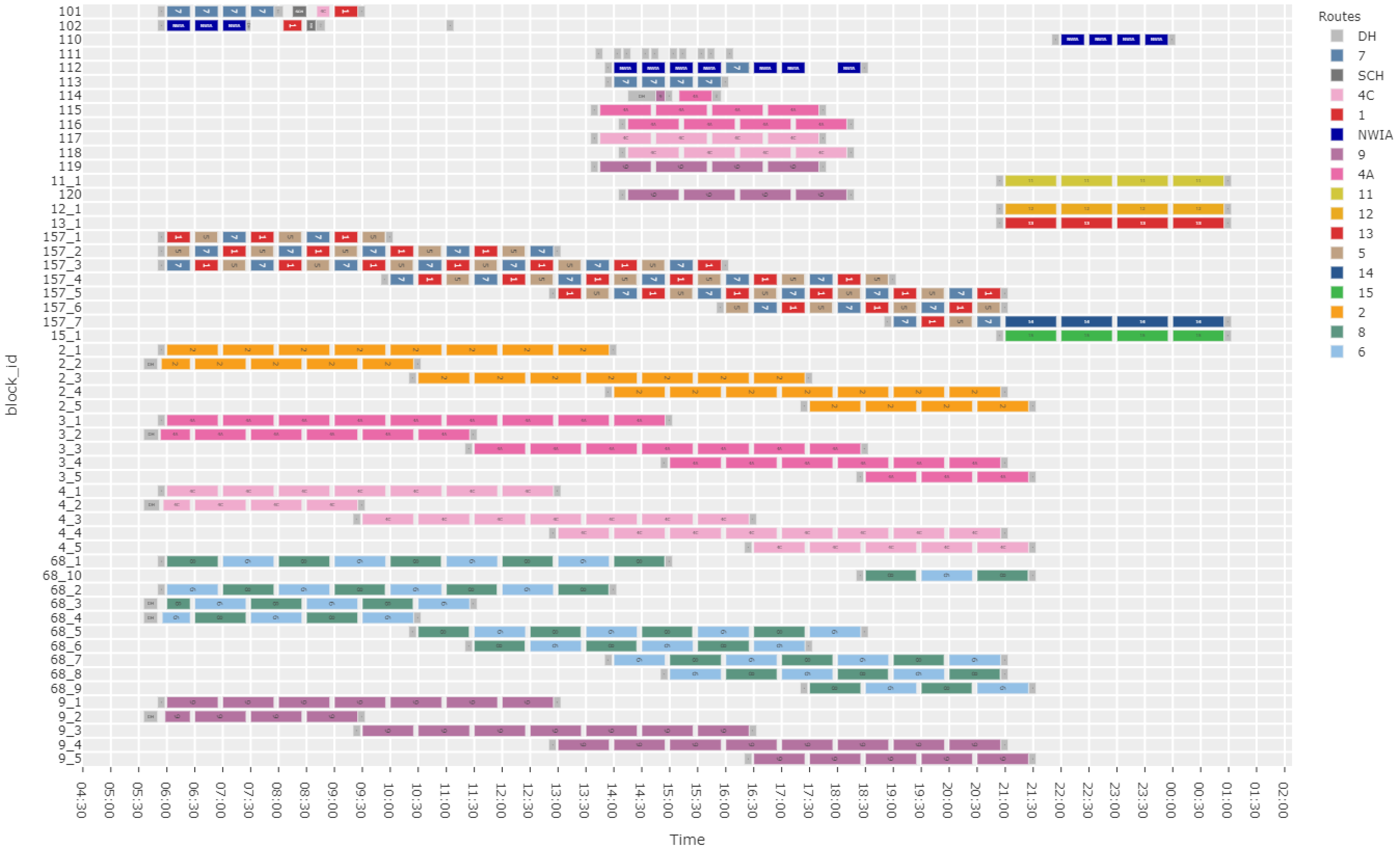


Exhibit 34: Brantford Transit modified block schedule for Monday to Saturday service



Sunday Service

Exhibit 35: Brantford Transit original block schedule for Sunday service

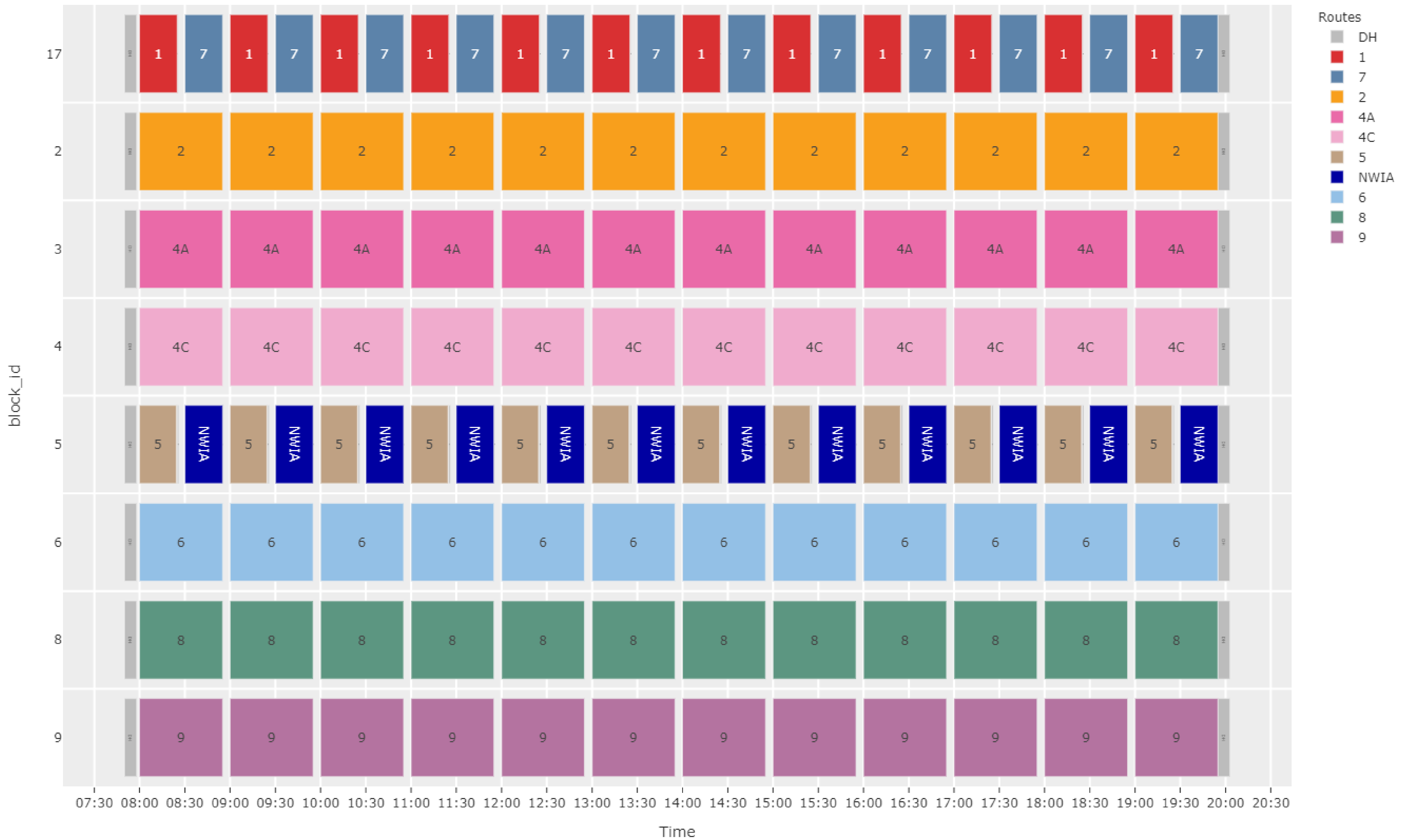
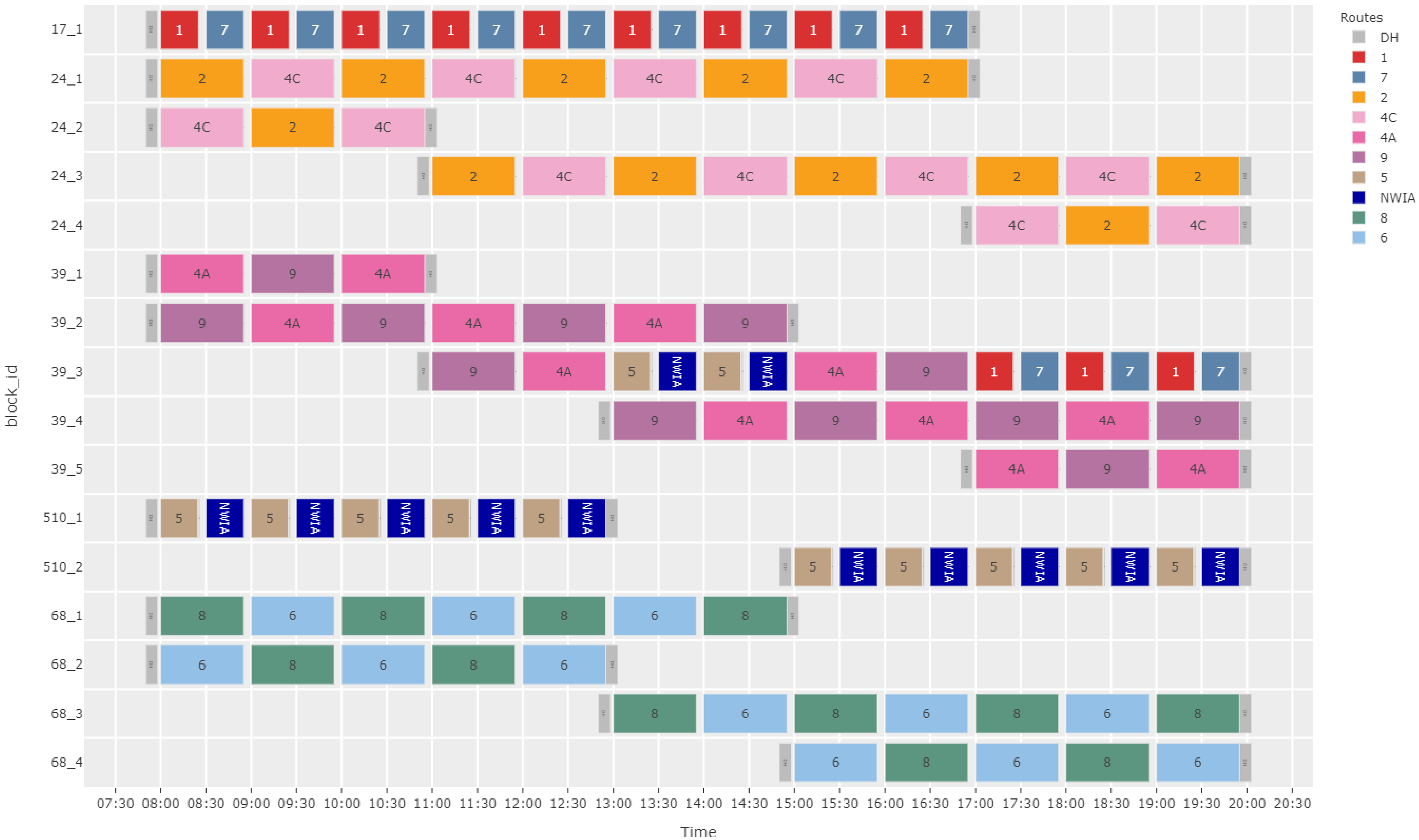


Exhibit 36: Brantford Transit modified block schedule for Sunday service



4.4 Charging Simulation

4.4.1 Simulated Scenarios

The IBI Group team simulated a selection of charging scenarios for Brantford Transit's conventional fleet, representing different charger layouts and operational workflows. For each scenario, escalating BEB and dispenser quantities were simulated to represent gradual progression of fleet transition. This escalation would continue until one of the following end constraints was reached:

1. The total parallel charging demand surpassed a global power cap of 1440 kW (representing a new transformer on an additional Brantford Power delivery point);
2. Not all conventional fleet (BEB and residual diesels) could be stored indoors; or
3. Full electrification of the fleet was successfully reached

Simulated charging scenarios are presented in **Exhibit 37** below.

Exhibit 37: Simulated charging scenarios for conventional transit

Scenario	Midday Charging		Overnight Charging	
	Location	Workflow	Location	Workflow
1	Indoor	Rotating batches	Indoor	Stationary
2	Indoor	Rotating batches	Indoor	Rotating batches
3	Outdoor	Individual	Outdoor	Individual

For Brantford Lift, charging is assumed to take place outdoors for all scenarios, due to space constraints within the storage building. This represents a suboptimal but necessary condition to achieving electrification of the conventional fleet.

4.4.1.1 Midday Charging Workflow

Indoor midday charging requires batching. Multiple buses would require charging at different, overlapping times of day, complicated by a first-in-first-out restriction on access to lanes with chargers. Batching allows buses to be first staged in storage lanes separate from the charging lanes, and then brought into the charge lane in a specific sequence, at similar times. Charging session volumes during the midday period are too low to be the governing factor in the quantity of chargers required, compared to overnight charging. Midday charging was simulated to validate the batching process, and to estimate final residual SOC values at pull-in.

4.4.1.2 Overnight Charging Workflow

Overnight charging followed three possible scenarios:

- **Indoor stationary charging:** after being cleaned and serviced, buses would remain parked in one storage + charging space for the duration of the overnight period.
- **Indoor batch charging:** after being cleaned and serviced, buses would be sorted into storage lanes without chargers. At planned times, groups of buses would be driven into the charging lanes and charged simultaneously as batches. After charging, buses would be removed and parked in storage lanes reserved for buses that are ready for pull-out.

- **Outdoor individual charging:** after being cleaned and serviced, buses would be parked indoors. Overnight, buses would be driven outdoors and charged, then returned to indoor storage in lanes reserved for buses that are ready for pull-out. This analysis assumes that an outdoor charging setup is relatively unconstrained for space, based on Brantford Transit having access to the backlot previously occupied by Brantford Power storage. Chargers would be arranged to allow free access.

4.4.2 Simulation Setup and Inputs

4.4.2.1 Global Power Cap

This analysis applies progressive global power supply caps to identify the lowest cap that still enables all charging to be completed in the time available. Simultaneously we consider what electrical infrastructure improvements would be required to achieve this level of supply.

Many Brantford Transit services terminate in waves: on Monday to Saturday, the largest pull-in waves occur at 9:00-9:30 PM and at 1:00 AM. There is not enough processing capacity at the garage to immediately clean and service each bus simultaneously, which helps to flatten the potential effect of these pull-in waves on charging. However, even taking this into account, if chargers were supplied so that every bus could charge as early as possible after servicing, the total power demand for the facility would quickly exceed all of the noted potential maximum supply thresholds. High peak energy usage could also negatively impact Brantford Transit’s electricity billing depending on the terms of a future supply contract. Capping demand instead spreads out charging through the overnight period.

4.4.2.2 Charging Equipment Capabilities

This analysis considers charging at a rate of 150 kW for conventional BEBs, and between 22 kW and 50 kW for Brantford Lift vehicles. These are standard commercial charging rates for each respective vehicle class. For standard BEBs, 150 kW is at the higher end of what is considered a balanced (or “slow”) charging rate. “Fast” charging at higher rates of around 300 kW is often possible, with certain BEB models accepting even higher rates of up to 450 kW. However, repeated and prolonged high-intensity charging can result in accelerated battery aging and reduced longevity. Containing charging rates to 150 kW avoids this effect.

BEB charger cabinets can be connected to multiple dispensers. The simplest equipment configuration would see one charger cabinet supporting two to four dispensers (maximum number of dispensers varies by model). With this arrangement, only one connected bus could be charged at full power at a time. Charging two or more connected buses would either need to take place in sequence, or in parallel but at lower rates. More recently, clustered cabinets with higher total power ratings have been developed to support more connected dispensers. This analysis considers charger/dispenser ratios for each scenario independently, as needs vary depending on operational workflow. This topic is further explored under each scenario.

4.4.2.3 Operational Workflow Buffers

The simulation used time buffers to reflect real-world operational constraints, such as maintenance and cleaning, repositioning buses around the facility, and (un)plugging dispensers. The following times were used:

- Servicing/cleaning: global 30 min buffer (actual servicing/cleaning times may vary per bus – conservative global buffer used to avoid over-specifying the simulation when real activities have highly variable durations)
- Repositioning and (un)plugging dispensers: 5 min buffer

Midday charging sessions were planned to not include tightly constrained garage repositioning movements, given that overall schedule adherence of buses returning to the garage for immediate charging is less controllable than the positions of buses already on premises overnight.

Where multiple bus movements simultaneously or in short succession could not be feasibly avoided during overnight charging, staffing implications would result. Our team will explore the potential financial considerations in the final costing analysis deliverable submitted to the City.

4.5 Simulation Findings

Simulation findings for each charging scenario include elements of operational workflow and physical layout to achieve a maximum degree of electrification possible for the conventional and Lift fleets.

4.5.1 Scenario 1: Indoor Stationary Charging Overnight + Indoor Batch Charging Midday

Indoor stationary charging was simulated for up to 24 BEBs, reaching end constraint #2:

1. The total parallel charging demand surpassed a global power cap of 1440 kW (representing a new transformer on an additional Brantford Power delivery point);
2. Not all conventional fleet (BEB and residual diesels) could be stored indoors; or
3. Full electrification of the fleet was successfully reached

This result is sufficient to electrify all Sunday service and all Monday-Saturday baseline service, but not all Monday-Saturday trippers. To achieve charging for the full fleet, an additional 8 dispensers for conventional BEBs would need to be installed outdoors.

4.5.1.1 Dispenser Layout and Deployment Sequencing

Scenario 1 requires removing indoor parking to accommodate charging equipment. Lane shifts have been assumed, as described in **Section 2.4**. This scenario can be rolled out in multiple stages of dispenser deployment, in conjunction with BEB procurement (See **Exhibit 38**).

Lane closure and shifting would take place at the outset to enable dispenser installation between Lane 2 and Lane 3, while making space available for later installation beside Lane 4. These initial stages are common between Scenario 1 and Scenario 2.

An important capital investment decision point would occur after Deployment Stage 3: Brantford Transit would need to decide whether to remove a second lane of parking and repeat the previous installation sequence with the former Brantford Power half of the storage space (proceeding with stationary charging), or instead implement operational workflow changes to charge additional BEBs in rotating batches (i.e. pursue Scenario 2 instead). Proceeding with removing a second lane of parking would push some of the Brantford Lift storage capacity out of the building, which is suboptimal but presents a trade-off to add more conventional BEBs.

The maximum constraint of 24 BEBs charging indoors occurs because of the facility layout constraints. Lanes 6 and 7 are divided by the partition wall between the current Brantford Transit and Brantford Power storage spaces. The available space between the wall and storage lanes is insufficient to recommend dispenser installation. Therefore, removal of a third parking lane would not enable dispenser installation up to the target of 32 parking spaces (the number of BEBs projected to be dispatched in a fully electrified fleet).

4.5.1.2 Maximized Charging Schedule and Energy Consumption

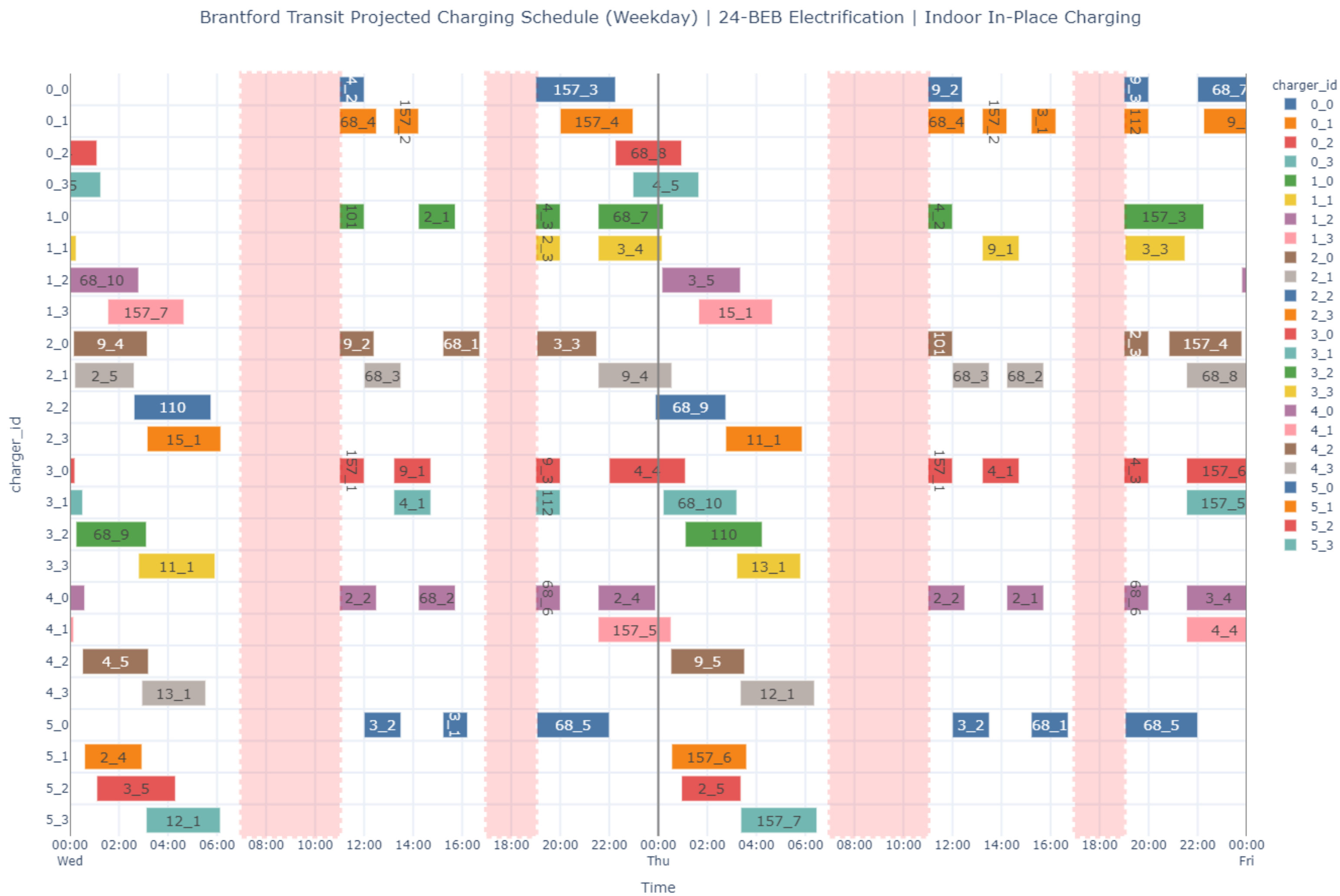
In a simulation with 24 BEBs dispatched in service (the maximum extent of conventional fleet electrification possible under this charging scenario), all 24 BEBs can be charged overnight without encountering potential peak electricity pricing periods on weekdays (See **Exhibit 39** and **Exhibit 40**). Midday charging is also fully supported using the re-blocked service plan (See **Exhibit 41** and **Exhibit 42** – vehicle SOC profiles for Mon-Sat and Sun service). Our simulation found that this was possible with 12 charging cabinets, each supporting 2 dispensers and charging in sequence. Important to note is that between Saturday night and Sunday night, the simulation results spread charging out, as fewer buses need to be ready to pull out on Sunday morning.

Maximum power demand was 1200 kW, which occurred during overnight charging (See **Exhibit 43** and **Exhibit 44** – facility power demand plots for a typical weekday and Sunday). This indicates that at minimum, the existing transformer would require replacement, before considering the contribution of Brantford Lift. This scenario also does not achieve full electrification of the conventional fleet (due to Monday-Saturday trippers).

4.5.1.3 Scenario 1 Exhibits

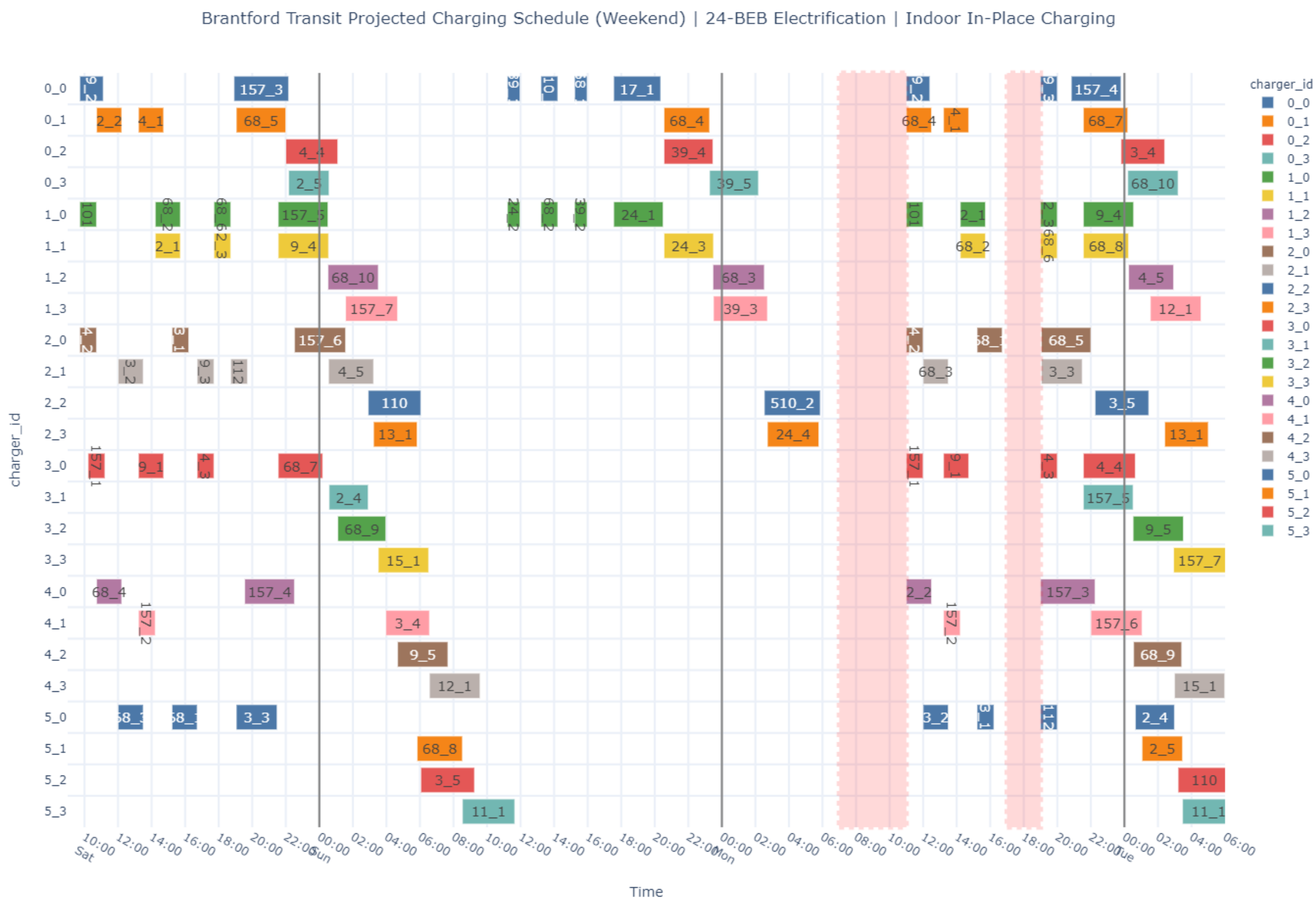
Exhibit 38: Garage dispenser layout and deployment stages (indoor stationary charging)

Exhibit 39: Charger schedule (Mon-Sat service, indoor stationary charging, 24 BEBs)



NOTE: In this exhibit, rows represent dispensers, and coloured fields represent charging sessions, which are labelled based on the block that the bus most recently completed. The red vertical bands represent times when charging is restricted due to electricity pricing peaks.

Exhibit 40: Charger schedule (Sun service, indoor stationary charging, 24 BEBs) – note Saturday overnight charging spreading into Sunday morning



NOTE: In this exhibit, rows represent dispensers, and coloured fields represent charging sessions, which are labelled based on the block that the bus most recently completed. The red vertical bands represent times when charging is restricted due to electricity pricing peaks.

Exhibit 41: Vehicle SOC profiles (Mon-Sat service, indoor stationary charging, 24 BEBs)

Exhibit 42: Vehicle SOC profiles (Sun service, indoor stationary charging, 24 BEBs)

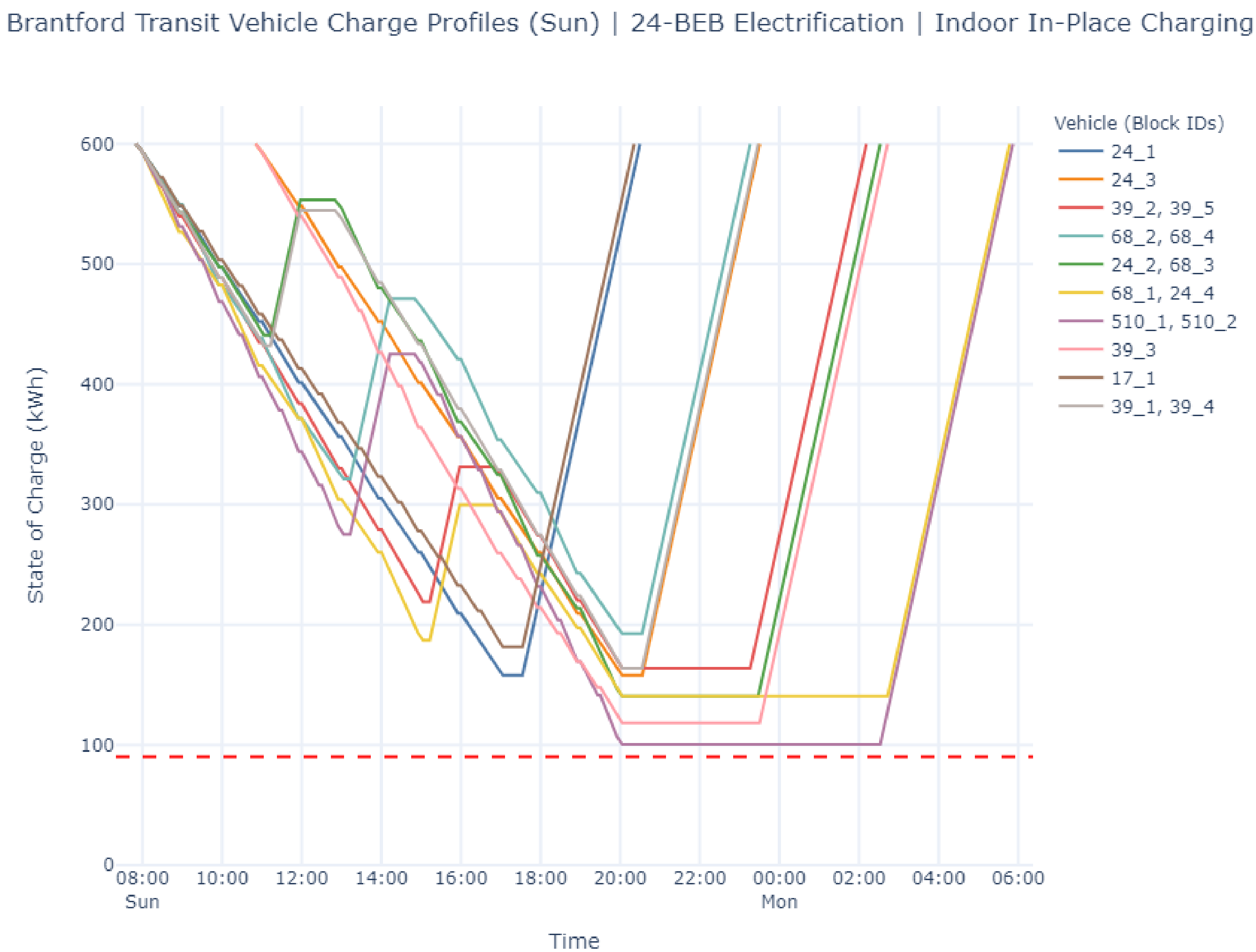


Exhibit 43: Charging power demand plot for fixed-route BEBs (Mon-Sat service, indoor stationary charging, 24 BEBs)

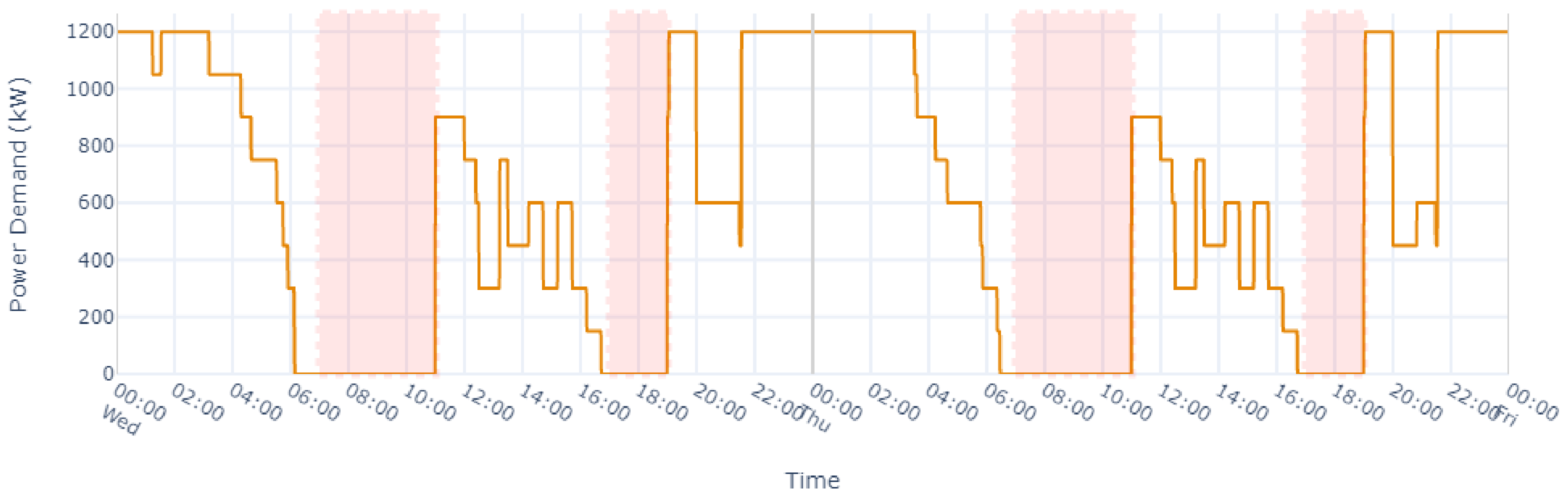
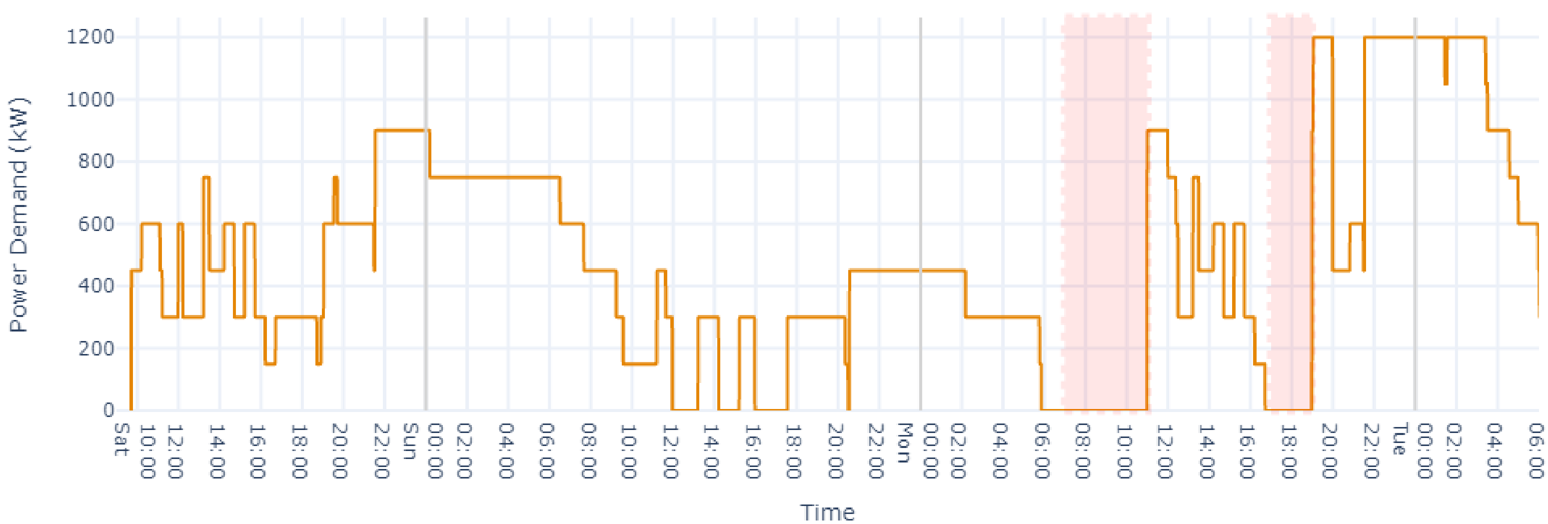


Exhibit 44: Charging power demand plot for fixed-route BEBs (Sun service, indoor stationary charging, 24 BEBs)



4.5.2 Scenario 2: Indoor Batch Charging (All Times)

Indoor batch charging was simulated for up to 32 BEBs, reaching end constraint #3:

1. The total parallel charging demand surpassed a global power cap of 1440 kW (representing a new transformer on an additional Brantford Power delivery point);
2. Not all conventional fleet (BEB and residual diesels) could be stored indoors; or
3. Full electrification of the fleet was successfully reached

4.5.2.1 Dispenser Layout and Deployment Sequencing

Scenario 2 requires removing indoor parking to accommodate charging equipment. Lane shifts have been assumed, as described in **Section 2.4**.. This scenario can be rolled out in two primary stages of dispenser deployment, in conjunction with BEB procurement (See **Exhibit 45**).

Lane closure and shifting would take place at the outset to enable dispenser installation between Lane 2 and Lane 3, while making space available for later installation beside Lane 4. These initial stages are common between Scenario 1 and Scenario 2. In Scenario 2, a backup row of dispensers would be recommended for installation facing Lane 3, as the dispensers in Lane 2 would be supporting a larger number of buses and any equipment failure could cause significant operational impacts.

In Scenario 2, our modelling indicated that with 32 BEBs, 8 storage lanes would be necessary to stage buses into batches which can then proceed with charging. This would push all Brantford Lift storage out of the building, which is suboptimal but necessary under this option to achieve charging for the full conventional fleet.

4.5.2.2 Maximized Charging Schedule and Energy Consumption

In a simulation with 24 BEBs dispatched in service (the maximum extent of conventional fleet electrification possible under this charging scenario), all 24 BEBs can be charged overnight without encountering potential peak electricity pricing periods on weekdays (See **Exhibit 46** and **Exhibit 47**). Midday charging is also fully supported using the re-blocked service plan (See **Exhibit 48** and **Exhibit 49** – vehicle SOC profiles for Mon-Sat and Sun service).

Our simulation found that this was possible with 8 charging cabinets, each supporting 1 dispenser. As with Scenario 1, between Saturday night and Sunday night, the simulation results spread charging out, as fewer buses need to be ready to pull out on Sunday morning.

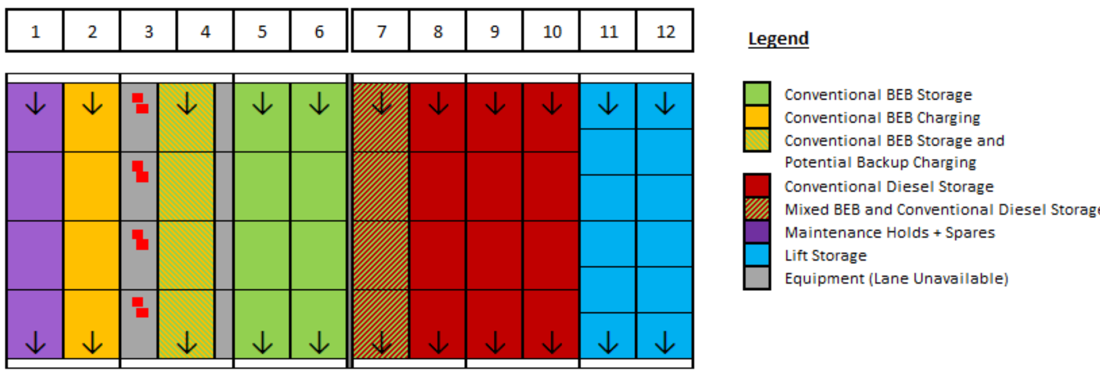
Maximum power demand was 1200 kW, which occurred during overnight charging (See **Exhibit 50** and **Exhibit 51**– facility power demand plots for a typical weekday and Sunday). This indicates that at minimum, the existing transformer would require replacement, before considering the contribution of Brantford Lift.

4.5.2.3 Scenario 2 Exhibits

Exhibit 45: Garage dispenser layout and deployment stages (indoor batch charging)

Indoor Batch Charging - Stage 1 Deployment (Maximum Feasible Indoor Storage for Conventional and Lift Fleets)

- 12 active conventional BEB storage spaces
- 12 active conventional diesel storage spaces
- 4 active conventional storage spaces shared by diesel and BEBs
- 4 conventional BEB charging spaces
- 12 active Brantford Lift storage spaces
- 4 standard bus equivalent spaces for spares/maintenance holds (mixed conventional/Lift)



Indoor Batch Charging - Stage 2 Deployment (Maximum Feasible Indoor Storage for Conventional Fleet Only)

- 32 active conventional BEB storage spaces
- 8 conventional BEB charging spaces
- 4 standard bus equivalent spaces for spares/maintenance holds (mixed conventional/Lift)

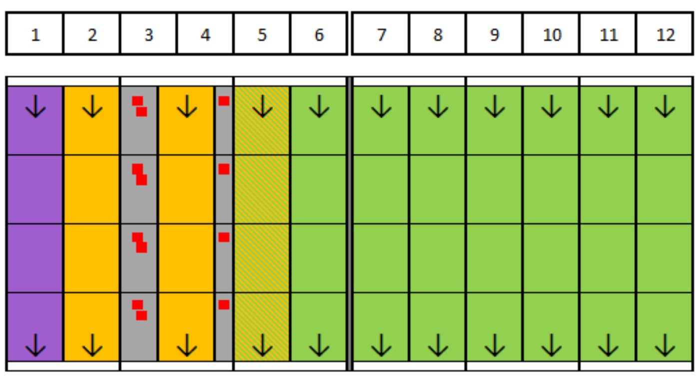
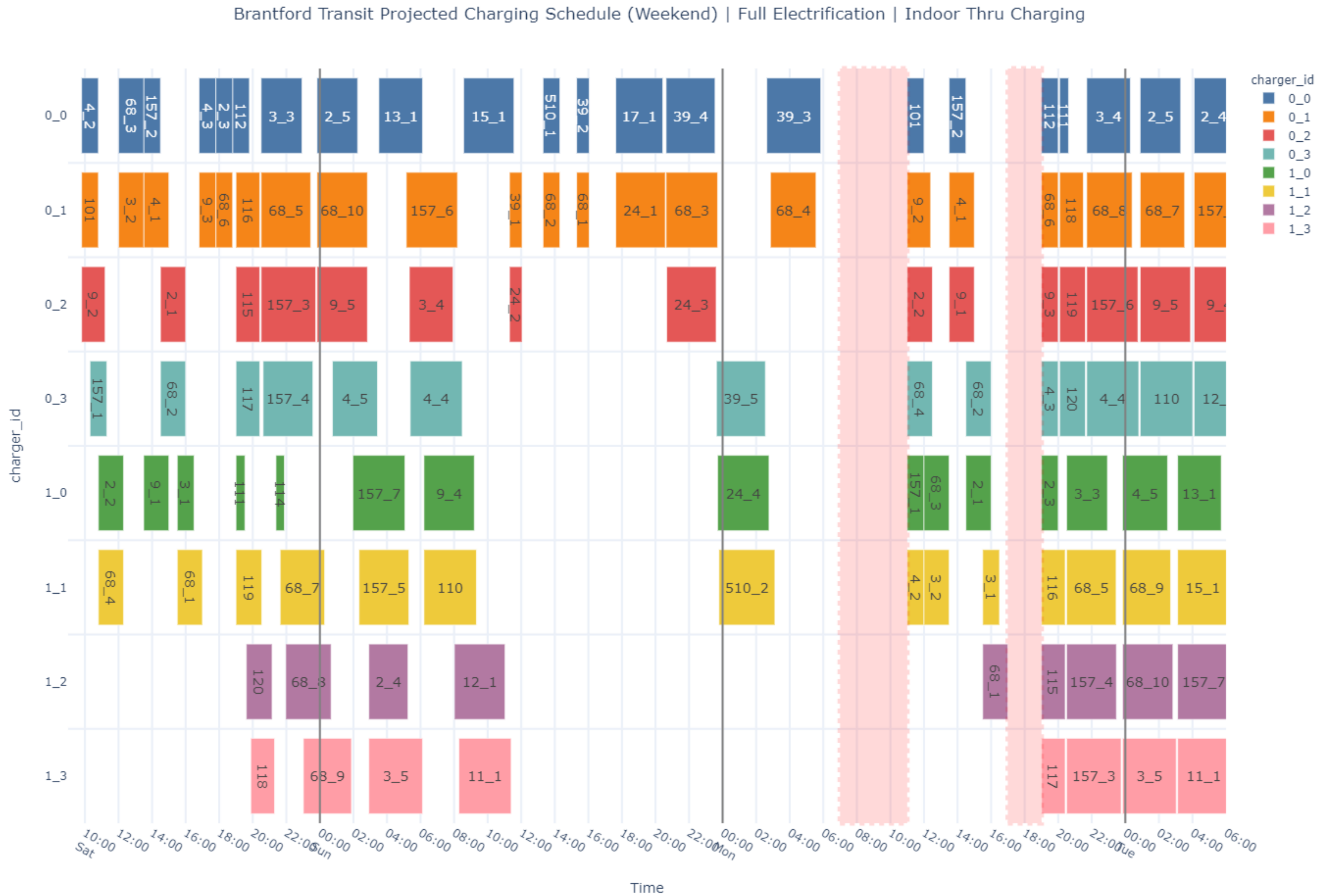


Exhibit 46: Charger schedule (Mon-Sat service, indoor batch charging, 32 BEBs (fully electrified service))

NOTE: In this exhibit, rows represent dispensers, and coloured fields represent charging sessions, which are labelled based on the block that the bus most recently completed. The red vertical bands represent times when charging is restricted due to electricity pricing peaks.

Exhibit 47: Charger schedule (Sun service, indoor batch charging, 32 BEBs (fully electrified service)) – note Saturday overnight charging spreading into Sunday morning



NOTE: In this exhibit, rows represent dispensers, and coloured fields represent charging sessions, which are labelled based on the block that the bus most recently completed. The red vertical bands represent times when charging is restricted due to electricity pricing peaks.

Exhibit 48: Vehicle SOC profiles (Mon-Sat service, indoor batch charging, 32 BEBs (fully electrified service))

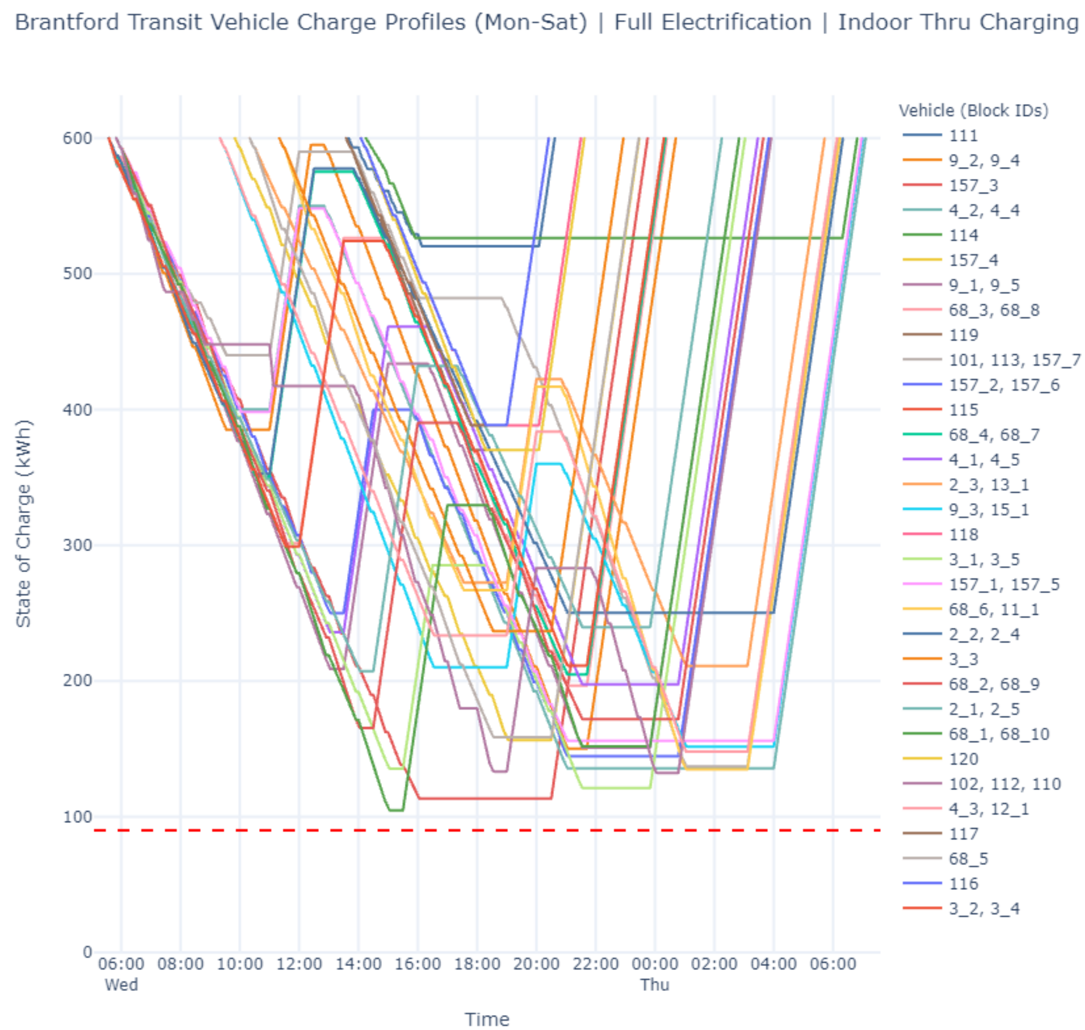


Exhibit 49: Vehicle SOC profiles (Sun service, indoor batch charging, 32 BEBs (fully electrified service))

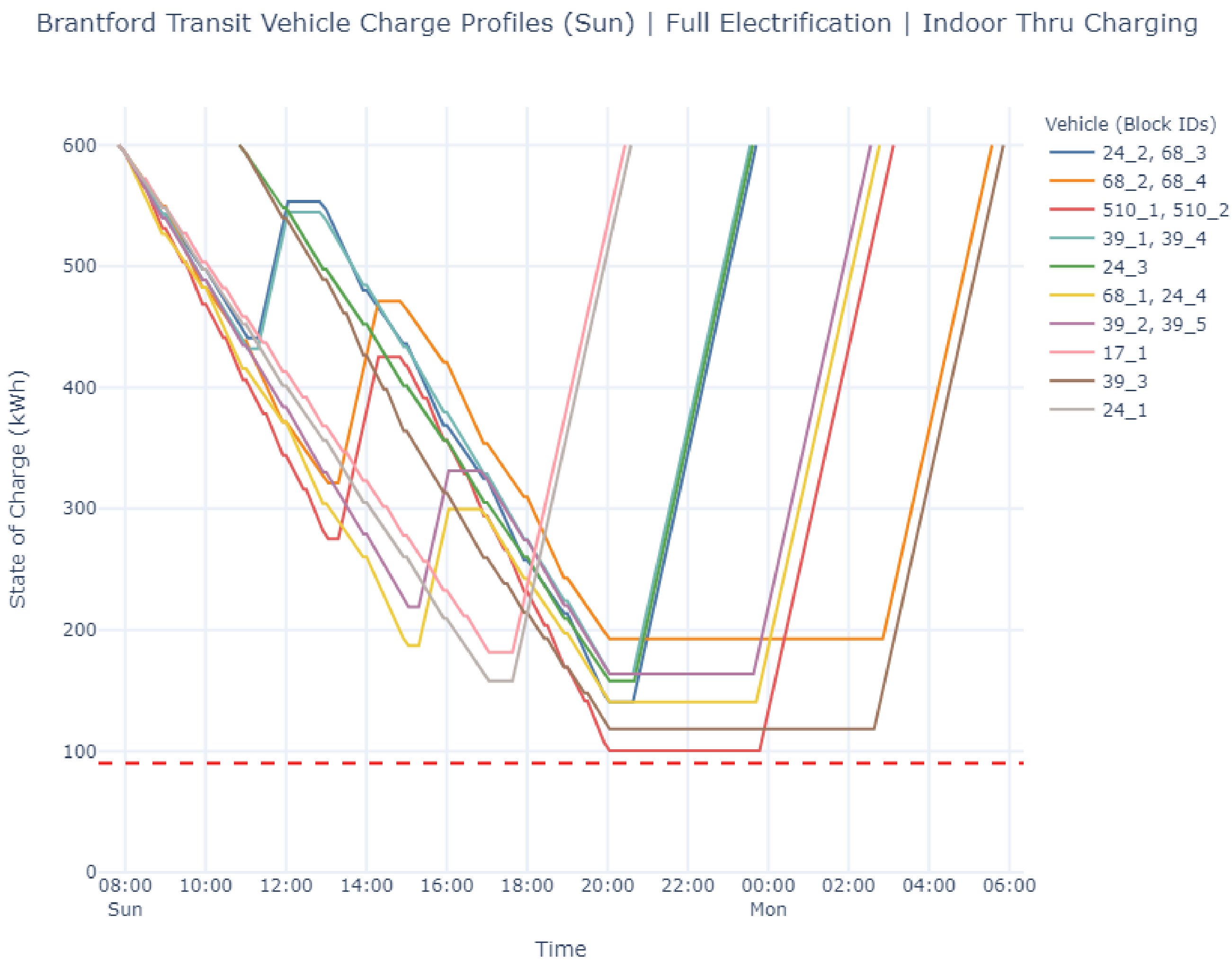


Exhibit 50: Power demand plot (Mon-Sat service, indoor batch charging, 32 BEBs (fully electrified service))

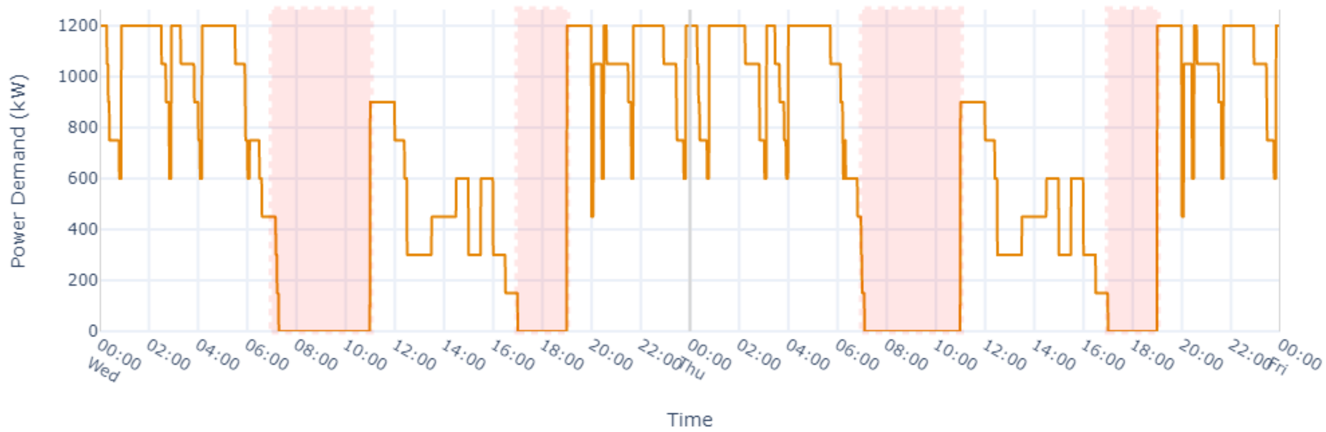
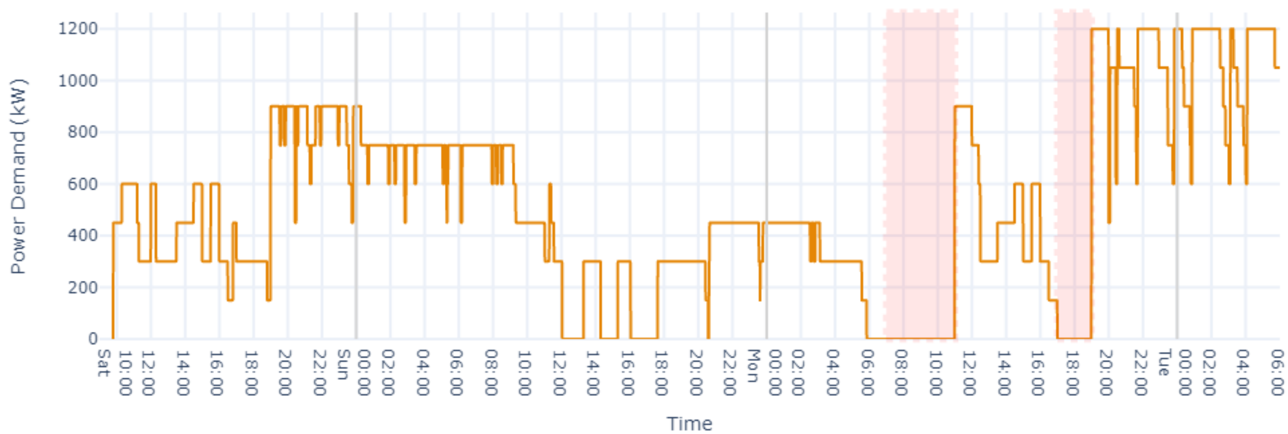


Exhibit 51: Power demand plot (Sun service, indoor batch charging, 32 BEBs (fully electrified service))



4.5.3 Scenario 3: Outdoor Individual Charging (All Times)

Outdoor individual charging was simulated for up to 32 BEBs, reaching end constraint #3:

1. The total parallel charging demand surpassed a global power cap of 1440 kW (representing a new transformer on an additional Brantford Power delivery point);
2. Not all conventional fleet (BEB and residual diesels) could be stored indoors; or
3. Full electrification of the fleet was successfully reached

4.5.3.1 Dispenser Layout and Deployment Sequencing

Full outdoor charging can be achieved with no impacts inside the garage. Precise dispenser layout was not evaluated, as it is estimated that enough space is available in the outdoor backlot to enable charging stations with free access to be installed. Indoor storage would be sufficient to accommodate all fleet types (**Exhibit 52**). Timing of charger and dispenser installation would be led by vehicle purchase timing decisions, rather than facility layout constraints.

4.5.3.2 Maximized Charging Schedule and Energy Consumption

In a simulation with 32 BEBs dispatched in service (representing full electrification of all services), all 32 BEBs can be charged overnight without encountering potential peak electricity pricing periods on weekdays (See **Exhibit 53** and **Exhibit 54**). Midday charging is also fully supported using the re-blocked service plan (See **Exhibit 55** and **Exhibit 56** – vehicle SOC profiles for Mon-Sat and Sun service).

Our simulation found that this was possible with 8 charging cabinets, each supporting 1 dispenser. As with Scenarios 1 and 2, between Saturday night and Sunday night, the simulation results spread charging out, as fewer buses need to be ready to pull out on Sunday morning.

Maximum power demand was 1200 kW, which occurred during overnight charging (See **Exhibit 57** and **Exhibit 58** – facility power demand plots for a typical weekday and Sunday). This indicates that at minimum, the existing transformer would require replacement, before considering the contribution of Brantford Lift.

4.5.3.3 Scenario 3 Exhibits

Exhibit 52: Garage storage layout (outdoor individual charging)

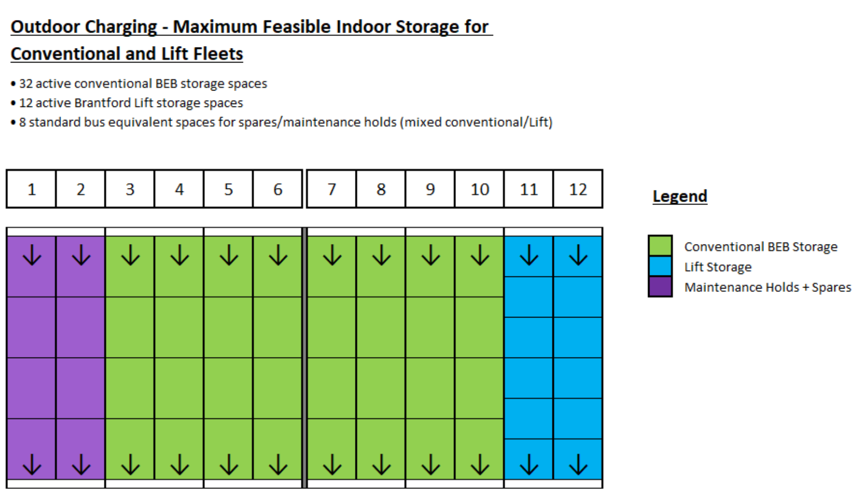
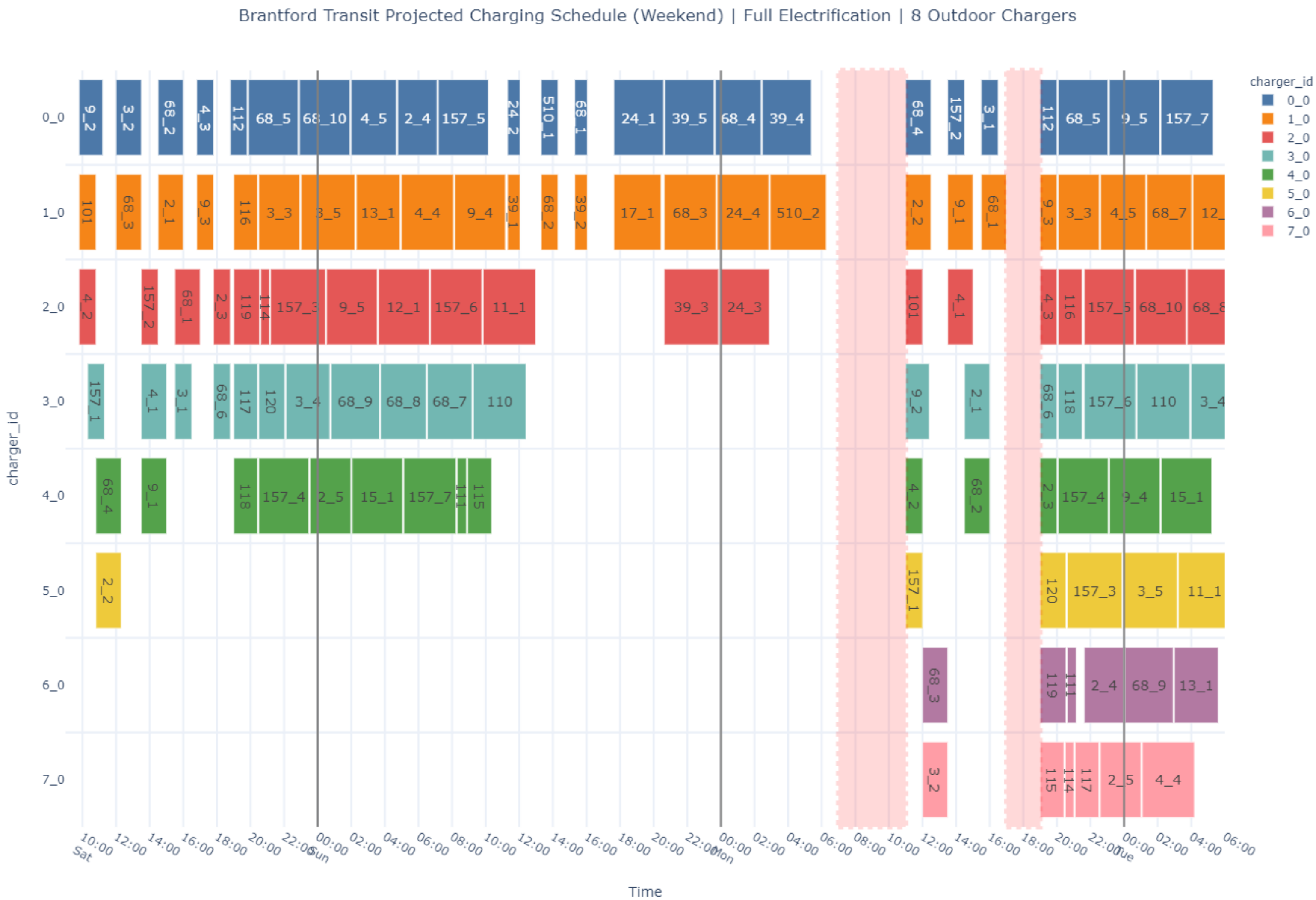


Exhibit 53: Charger schedule (Mon-Sat service, outdoor individual charging, 32 BEBs (fully electrified service))

NOTE: In this exhibit, rows represent dispensers, and coloured fields represent charging sessions, which are labelled based on the block that the bus most recently completed. The red vertical bands represent times when charging is restricted due to electricity pricing peaks.

Exhibit 54: Charger schedule (Sun service, outdoor individual charging, 32 BEBs (fully electrified service)) – note Saturday overnight charging spreading into Sunday morning



NOTE: In this exhibit, rows represent dispensers, and coloured fields represent charging sessions, which are labelled based on the block that the bus most recently completed. The red vertical bands represent times when charging is restricted due to electricity pricing peaks.

Exhibit 55: Vehicle SOC profiles (Mon-Sat service, outdoor individual charging, 32 BEBs (fully electrified service))

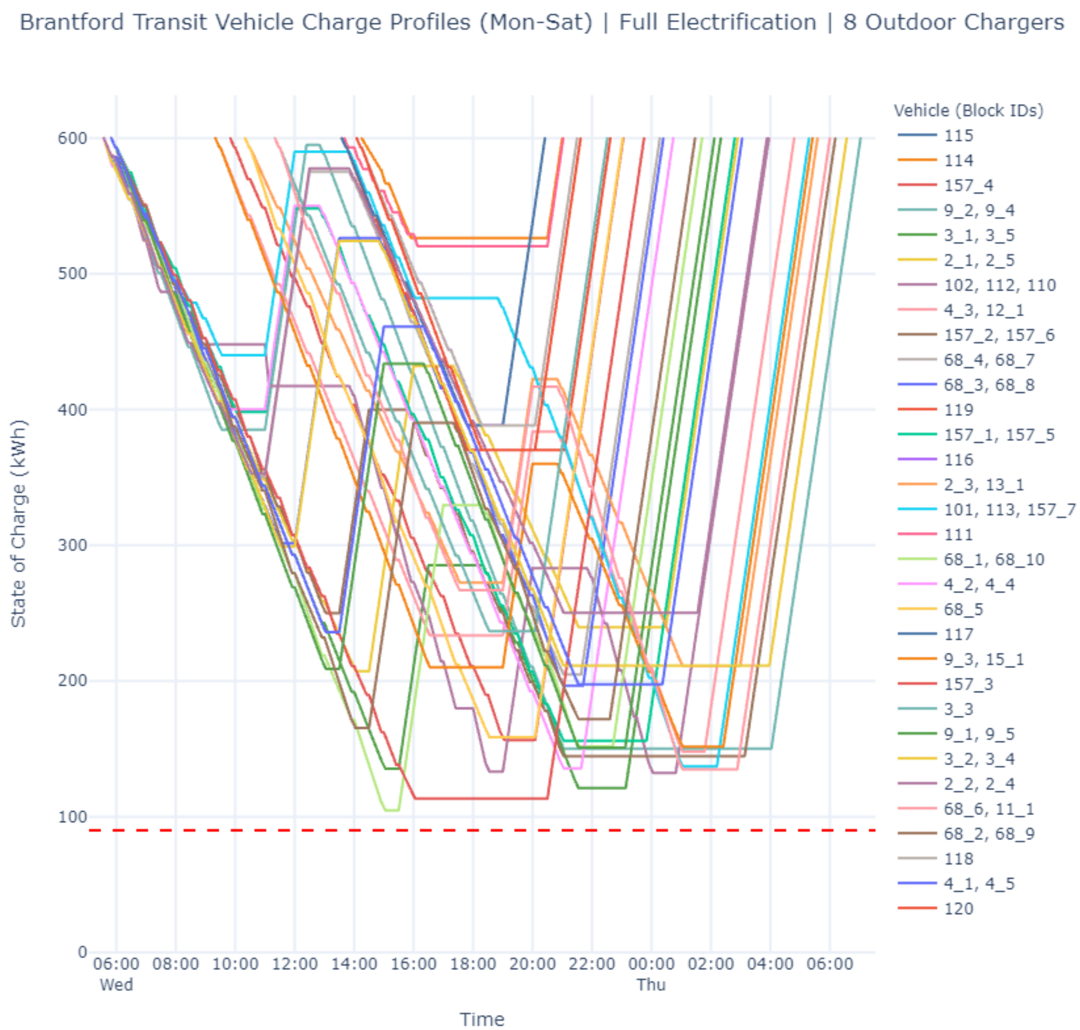


Exhibit 56: Vehicle SOC profiles (Sun service, outdoor individual charging, 32 BEBs (fully electrified service))

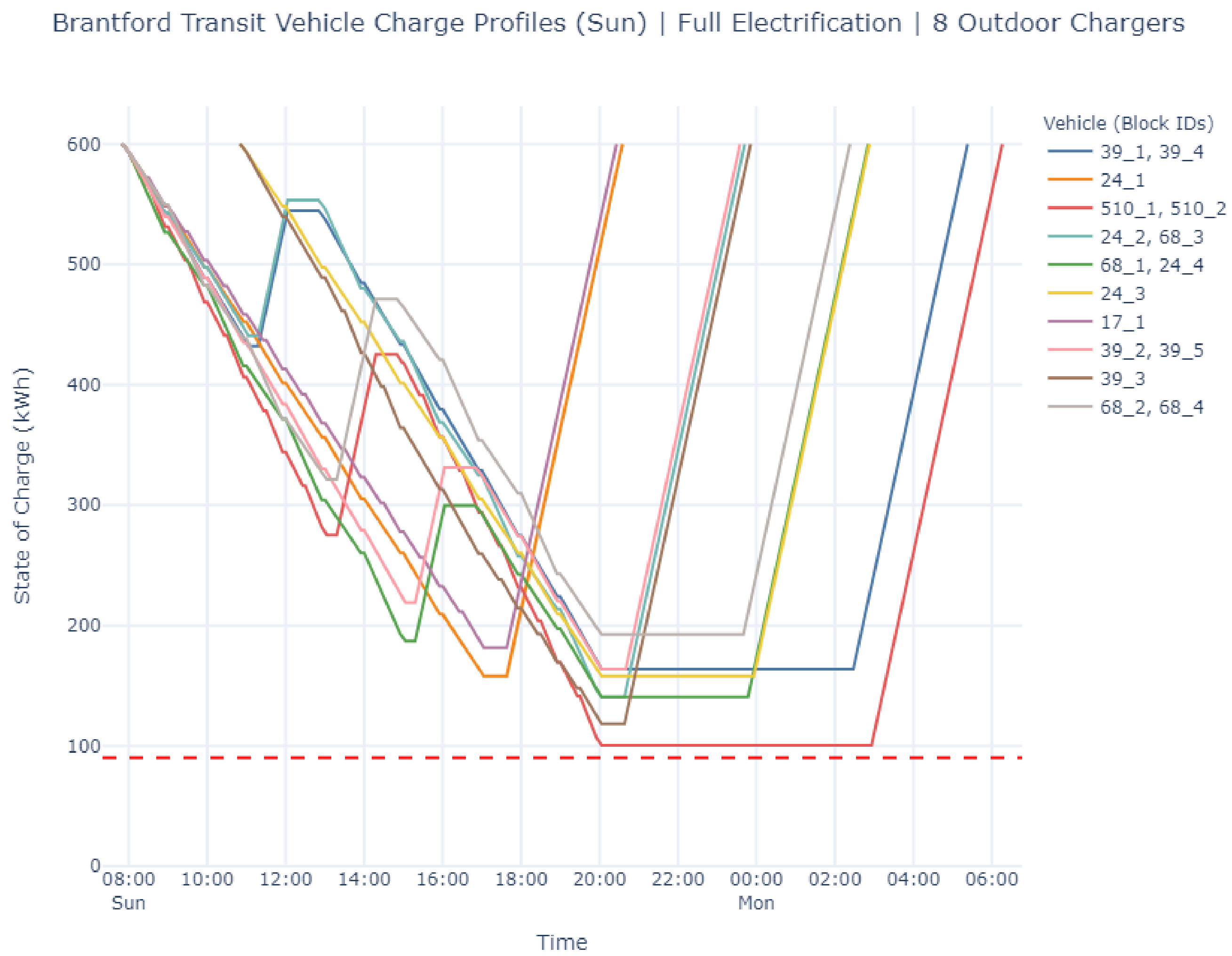


Exhibit 57: Power demand plot (Mon-Sat service, outdoor individual charging, 32 BEBs (fully electrified service))

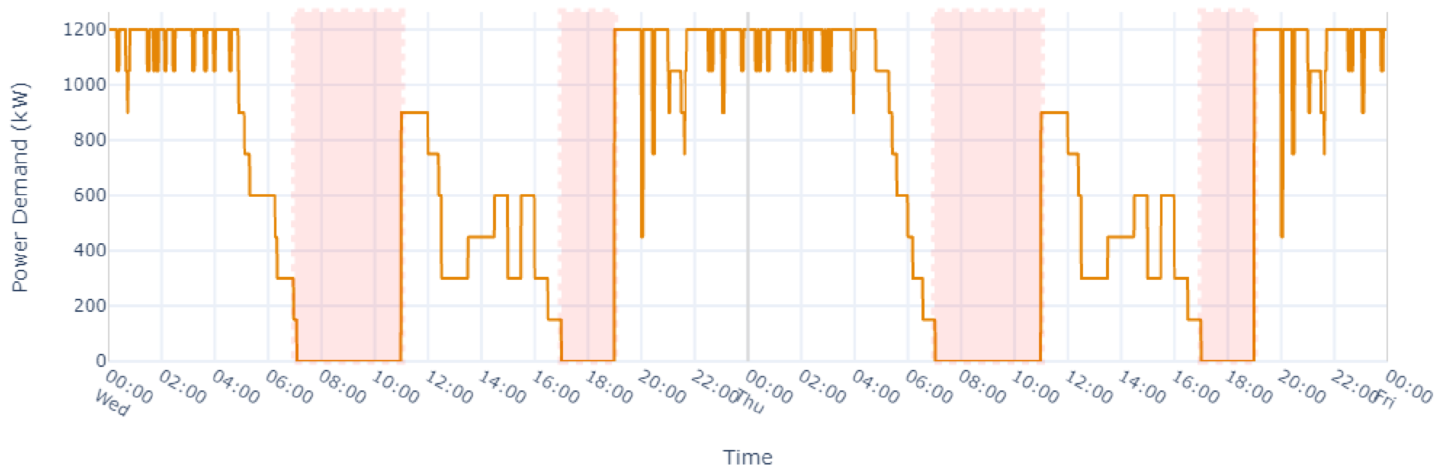
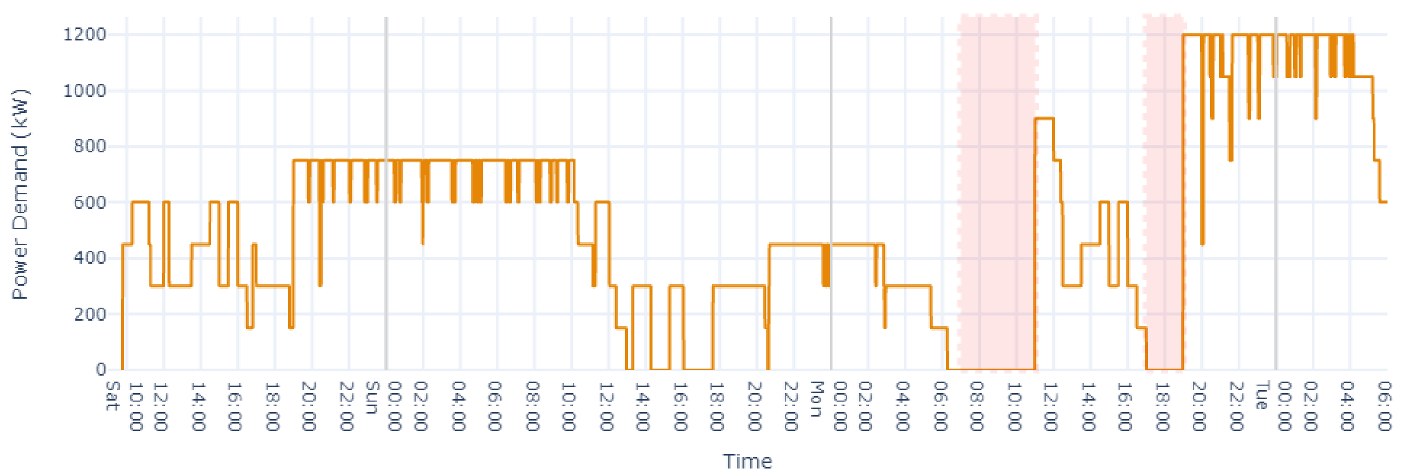


Exhibit 58: Power demand plot (Sun service, outdoor individual charging, 32 BEBs (fully electrified service))



5 Specialized Transit Energy & Charging Analysis

5.1 Methodology & Setup

5.1.1 Operations of Electric Specialized Transit Vehicles

Compared to standard BEBs designed for conventional transit, a zero-emission specialized transit fleet would consist of smaller cutaway buses and/or vans. These vehicles have smaller passenger capacity and are lighter than a conventional BEB. The battery capacity is smaller, typically between 110 and 160 kWh, but they also require less energy to operate over the same distance, with a nominal range of around 200 km as reported by manufacturers.

Operationally, specialized transit has no fixed routes, blocks, or published schedules. The operating mileage and locations the vehicles travel to on a given day are largely dependent on individual trip bookings by customers. As such, there is a greater degree of day to day variation in the level of service provided, vehicle manifests, and potentially driving factors such as distance and hill climbing, making it difficult to conduct route modelling for specialized transit at the same level of detail as was done for fixed-route transit. As a result, the modelling conducted focused on estimating energy use at an aggregate level based on daily vehicle mileage data. Mileage is collected for vehicle maintenance and mandatory inspection purposes, making it the most reliable data source for this assessment.

5.1.2 Modelling Process

The aggregate nature of the specialized transit modelling process meant that some factors affecting energy use of electric buses needed to be simplified and kept at a high level compared to fixed-route modelling. These include:

- HVAC energy consumption: typically, HVAC energy consumption is primarily dependent on seasonality and the duration of service, since air conditioning and heating need to be operational for the entire duration while the vehicle is out in service, whether the vehicle is stationary or in motion. As only vehicle mileage data are available for specialized transit, the energy consumption due to HVAC was consolidated into a single parameter of “unit energy consumption per kilometre travelled”.
- Terrain / vertical propulsion: since there is no fixed routing for specialized transit operations, the travel path variations from day to day would result in different topographical profiles experienced by each vehicle daily. As such, the impact of terrain on vertical propulsion energy consumption must also be generalized and grouped into the per-kilometre parameter mentioned above.

With a value determined for the “unit energy consumption per kilometre travelled” parameter, the projected energy consumption would be the product of that parameter and the daily mileage.

Our modelling examined these statistics on a per-vehicle basis as well as on a fleet-wide, aggregate basis based on the sum of individual vehicle mileages:

- For modelling on a **per-vehicle basis**, the maximum distance travelled on a single day for each vehicle across the duration of available data is used. The associated energy consumption estimate represents a “worst-case”, most conservative scenario for each individual vehicle, from which the compatibility is determined by comparing the estimated energy use against the allowable value based on the battery capacity and safety threshold.

- For modelling on a fleet-wide, **aggregate basis**, the maximum total distance travelled by all vehicles in the fleet on a single day is used. This represents a fleet-wide worst-case scenario. While compatibility of individual vehicles is not directly evaluated, this analysis yields a projection of minimum required fleet size by dividing the maximum total energy consumption of the entire fleet in a day by the maximum allowable energy consumption per vehicle based on the battery capacity. This projected fleet size is compared against the existing fleet size to project fleet expansion needs.

Aggregate usage considers how many vehicles would be required to cover the same total service distance for the day if the vehicle manifests were divided evenly between vehicles. This analysis is theoretical, as there are scheduling factors when building manifests that affect how evenly service may actually be divided among the fleet. For example, overlapping trips in similar parts of the city may result in greater operational efficiencies if one vehicle is remains in service. Specific manifest development techniques would need to be adjusted on a case-by-case basis in conjunction with electric vehicle deployment, as performance trends can be tracked.

For each of the two modelling processes, the data for weekdays, Saturdays, and Sundays are evaluated separately as service levels and demand vary between the three.

5.1.3 Input Data

5.1.3.1 Parameter Values

Current specialized transit cutaway buses on the market typically have a battery capacity around 110 to 160 kWh and a nominal range of around 200 km. The unit energy consumption parameter derived from the vehicle specifications ranges from 0.59 to 0.76 kWh/km. Values selected for modelling are presented in **Exhibit 59**.

Exhibit 59: Parameter values used in the modelling of specialized transit energy consumption

Unit Energy Consumption Per Kilometre (kWh/km)	Absolute Battery Capacity (kWh)	Minimum Battery Level Safety Threshold	Effective Battery Capacity (kWh)
0.75	120	15%	102

A high unit energy consumption value and a relatively low battery capacity were selected to achieve a more conservative analysis that leaves headroom for seasonal extremes and other factors influencing energy use such as terrain, traffic conditions, and variability of on-board devices such as lifts and ramps being deployed (which may vary based on passenger mobility).

5.1.3.2 Brantford Lift Operating Data

Brantford Lift, Brantford Transit's specialized transit service, has the same operating hours as conventional transit: 6:00 A.M.-1:00 A.M. the next day on Mondays to Saturdays, and 8:00 A.M.-8:00 P.M. on Sundays. Brantford Lift currently has a fleet of 17 vehicles, which are all cutaway buses. Not all vehicles are in service in parallel at a given time, as daily active fleet counts vary in response to trip booking volumes. On weekdays, there are a maximum of 12 to 13 vehicles in service before 3 p.m., after which the active fleet count decreases to around 2 to 3 in the evening (approximately up to 9:00 PM) and 1 to 2 late at night. On Saturdays and Sundays, there are typically 1 to 3 buses in service at a given time.

The daily vehicle mileage data available for modelling were from the month of September 2019, before the service and ridership decreases caused by the COVID-19 pandemic. There are 18 individual vehicles listed in the data, of which 15 logged non-zero mileage over the course of the month. Out of the 30 calendar days in September 2019, there were 5 Sundays, 4 Saturdays, 20 regular weekdays, and 1 holiday (Labour Day on September 2, 2019), the last of which was excluded from the analysis. Statistics were tallied separately for weekdays, Saturdays, and Sundays, which can be found in Appendix B.

5.2 Modelling Outputs

5.2.1 Daily Energy Consumption Statistics

The computed energy consumption projection statistics are presented below, based on the mileage data for Brantford Lift from September 2019. Some summary statistics of the raw mileage data (e.g. totals, averages) as well as breakdowns by individual vehicles are included in Appendix B.

5.2.1.1 Maximum Individual Daily Energy Consumption by Vehicle

The maximum daily energy consumption was determined for each vehicle's reported workload throughout the month of September 2019, presented in **Exhibit 60** below. Note that these maximum values did not all occur on the same day for all vehicles. The resulting compatibility of the reported workloads with electric propulsion is also indicated, based on an effective battery capacity of 102 kWh.

Exhibit 60: Maximum individual daily energy consumption projections and workload compatibility by vehicle

Vehicle ID	Maximum Workload by Service Day Type (kWh)			Compatibility Determination
	Weekday	Saturday	Sunday	
141	90	0	0	Compatible
142	87	0	0	Compatible
151	120.75	68.25	0	Incompatible
152	107.25	0	0	Incompatible
153	107.25	36.75	36.75	Incompatible
154	105.75	0	0	Incompatible
155	122.25	98.25	45	Incompatible
121701	124.5	101.25	78	Incompatible
121702	114	112.5	77.25	Incompatible
121703	102	0	53.25	Incompatible *
121704	106.5	147.75	96.75	Incompatible
121805	157.5	90.75	87	Incompatible
121839	163.5	0	0	Incompatible
121840	106.5	0	0	Incompatible
121841	94.5	0	0	Compatible
160	0	0	0	N/A
12105	0	0	0	N/A
121842	0	0	0	N/A

** Energy consumption exactly equals the modelled effective battery capacity (102 kWh), therefore classified as incompatible due to high risk of the threshold being exceeded.*

From the above table, out of the 15 vehicles that logged active mileage during September 2019, only 3 performed workloads that are directly compatible with electric propulsion as-is in the worst-case scenario operational days. However, this is partly a factor of uneven vehicle usage: in a single day, there is a considerable difference (of around 80 to 100 km on average) between the vehicle with the highest mileage and the vehicle with the lowest non-zero mileage.

5.2.1.2 Maximum Fleet-Wide Daily Total Energy Consumption

The maximum fleet-wide, aggregate daily total energy consumption was determined for each service day type in September 2019, as presented in **Exhibit 61** below. These figures represent the worst-case total daily energy consumption within the available dataset. The implications of these estimates on fleet size are discussed in the following section.

Exhibit 61: Maximum fleet-wide daily total energy consumption for Brantford Lift in September 2019

Service Day	Total Energy Consumption (kWh)
Weekday	1108.5
Saturday	429
Sunday	287.25

5.2.2 Fleet Size Requirements

From **Exhibit 61**, the maximum fleet-wide daily total energy consumption in the entire month of September 2019 was 1108.5 kWh. Dividing this value by the effective battery capacity of 102 kWh and rounding up yields 11 vehicles at the absolute minimum to satisfy all energy requirements from the vehicle manifests. Doing this for Saturday and Sunday yields 5 and 3 vehicles, respectively. In comparison, the maximum daily active vehicle counts for weekdays, Saturdays, and Sundays recorded in the September 2019 dataset were 12, 6, and 5 respectively. Assuming a minimum spare ratio of 20% on top of 11 active vehicles would imply a minimum required fleet size of 14 electric cutaway buses.

Based on these findings, we anticipate that changes to dispatching practices are likely to make a large difference in improving compatibility, by creating more balanced manifests for each vehicle that keep vehicle usage within the practical range of the battery. Our modelling indicates it is theoretically possible for all existing Brantford Lift service to be satisfied by electric buses without a major fleet expansion while also approximately retaining the current spare ratio, as long as dispatching optimizations are in place to ensure that no single vehicle manifest is too long for the vehicle battery to handle on a single charge.

This change in dispatching practices may have implications on driver staffing if swap-outs are required at busy times of day and ridership demand constrains the ability for drivers to return to the depot to change vehicles. Conclusively determining the potential impacts of this sort of operational challenge would require a more detailed optimization effort based on real observed vehicle performance data as vehicles are introduced.

5.2.3 Total Energy Consumption

Weekly total energy consumption projections for Brantford Lift are presented in **Exhibit 62** below. Two sets of values were computed:

- Consumption based on the **maximum daily total** energy consumption values (presented in **Exhibit 61** above)
- Consumption based on **average daily total** values across the entire month of September 2019.

These values contribute to overall energy consumption at the depot.

Exhibit 62: Total daily and weekly energy consumption projections for Brantford Lift using maximum daily total values and average daily total values (all values in kWh)

Source	Weekday Daily	Saturday Daily	Sunday Daily	Weekly
Maximum Daily Total	1108.5	429	287.25	**6258.75**
Average Daily Total	953.59	388.31	268.2	**5424.45**

5.3 Charging Analysis

As noted in **Section 4.4.1**, all charging for Brantford Lift is assumed to take place outdoors due to space constraints on indoor equipment installation. The results of the *Route Modelling Report* projected the following total daily charging requirements based on fuel consumption and kilometres travelled, as shown in **Exhibit 63**. Next to those figures are calculated aggregate durations to charge using charging rates of either 22 kW or 50 kW (as discussed in **Section 4.4.2.2**).

Exhibit 63: Maximum fleet-wide daily total energy consumption for Brantford Lift in September 2019

Service Day	Total Energy Consumption (kWh)	Total Charging Duration (h)	
		At 22 kW	At 50 kW
Weekday	1108.5	50.4	22.2
Saturday	429.0	19.5	8.6
Sunday	287.2	13.1	5.7

The window between the evening drawdown in Lift services (estimated around 3:00 PM) and pullout (at 6:00 AM) is 15 hours/day. If Brantford Transit's future electricity supply billing scheme is constrained by weekday peak energy pricing, the practical start time for charging would be delayed to 7:00 PM, for a total window of 11 hours/day.

Estimates from the *Route Modelling Report* indicate that if vehicle utilization is distributed evenly, approximately 11 electric Lift vehicles will be required for weekday service. An approximate battery capacity for current electric cutaway models is 102 kWh, corresponding to 4.6 h of charging at 22 kW, or 2.1 h of charging at 50 kW.

Weekday overnight charging will be the governing factor in projecting the average number of vehicles anticipated to charge simultaneously. Estimates for this are presented in **Exhibit 64**.

Exhibit 64: Average vehicles charging simultaneously given different daily charging windows

Charging Window	Average Vehicles Charging Simultaneously	
	At 22 kW	At 50 kW
11 hours	6	3
15 hours	4	2

Importantly, these *average* vehicle charging figures represent the most uniform distribution of charging overnight, and therefore the *minimum* required dispenser quantities. Uneven vehicle availability to charge will result in higher numbers of vehicles requiring simultaneous charging.

Given that Brantford Lift does not follow pre-scheduled blocks, consistent vehicle availability is not assured.

Due to this potential unpredictability, provisioning for charging at 50 kW is likely to be a more reliable and resilient approach than 22 kW. Charging at 22 kW requires more vehicles to be present earlier in the day/evening to begin charging, meaning that if a vehicle is late returning, potential charging time may be wasted with no vehicle present to take advantage of it. Charging at lower rates also allows less flexibility to react to unplanned events (e.g. a breakdown) to get a replacement vehicle charged quickly as needed. In an optimally stable scenario where an average of 3 Lift vehicles are charging at 50 kW at all times of the night, a total of 150 kW would be required for Lift.

To estimate the minimum number of dispensers required, we recommend assuming the more constrained case of 11-hour charging windows, and planning for a spare dispenser ratio of 50% (rounded up to 2 units), for a total of at least 5 dispensers.

6 Implementation Planning

6.1 Procurement Timelines

Procurement of a BEB fleet and supporting charging equipment should be considered as a coordinated timeline, with fleet replacement needs setting the pace and charger procurement responding to the fleet's needs.

6.1.1 Capital Investment Alternative Timelines

Theoretical investment timelines containing asset quantities for each of the 9 assessed alternative scenarios are provided in **Exhibit 65** through **Exhibit 73** below. For context, the corresponding retirement timeline for the existing fleet and the resulting net asset quantities are also presented. These replacement and capital investment timelines are designed to maintain a minimum 1.2 spare ratio (i.e. 1 spare vehicle for every 5 vehicles dispatched in service) for vehicles as the existing fleet is retired, as well as a minimum 1.2 spare ratio of charging equipment available in the garage at each transition stage.

Charging equipment quantities are also planned to correspond at minimum to the capacity required to charge all BEBs, with an additional 20% spare charging capacity, in terms of the total charging hours that the equipment can provide within the overnight period.

All timelines are shown to 2037 (the longest retirement timeline among vehicles in the existing fleet). Given replacement cycles of 12 years for conventional BEBs and 7 years for specialized BEBs, a second generation of BEB purchases occurs within the time horizon presented. These second-generation quantities are shown separately. Charging equipment is estimated to have a 15-year replacement cycle, and therefore a second generation does not appear in the exhibits.

More detailed breakdowns of fleet replacement timeline options are provided in **Section 6.1.2** below.

Exhibit 65: Capital Purchase and Retirement Quantities by Year – Alternative 1a (Stationary Charging, End-of-Life Fleet Replacement – SC/ER)

Item	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Total
Purchases																
Vehicles (First Generation BEB)																
Conventional (combined body & battery)		4	4	4	3		4	3		4			5	5	3	39
Specialized (combined body & battery)		5	4					5								14
Vehicles (Second Generation BEB)																
Conventional (combined body & battery)														4	4	8
Specialized (combined body & battery)									5	4					5	14
Charger Infrastructure																
Power conversion cabinet (150 kW)		2	1	1			3			1			1	1		10
Plug-in dispenser (150 kW)		4	4	4			8			4			4	4		32
Plug-in dispenser (50 kW)		3	2													5
Charge Management System (Lot)		1														1
Electrical Supply System Upgrade (Lot)		1														1
Retirements																
Vehicles (Existing Fleet)																
Conventional diesel/hybrid			4	4	2		3	2		3			5	5	3	31
Specialized gasoline			5	4				8								17
Vehicles (First Generation BEB)																
Conventional (combined body & battery)														4	4	8
Specialized (combined body & battery)									5	4					5	14
Net Asset Quantities																
Vehicles																
Conventional diesel/hybrid	31	31	27	23	21	21	18	16	16	13	13	13	8	3	0	
Conventional BEB	0	4	8	12	15	15	19	22	22	26	26	26	31	36	39	
Conventional (all propulsion)	31	35	35	35	36	36	37	38	38	39	39	39	39	39	39	
Specialized gasoline	17	17	12	8	8	8	8	0	0	0	0	0	0	0	0	
Specialized BEB	0	5	9	9	9	9	9	14	14	14	14	14	14	14	14	
Specialized (all propulsion)	17	22	21	17	17	17	17	14	14	14	14	14	14	14	14	
Charger Infrastructure																
Power conversion cabinet (150 kW)	0	2	3	4	4	4	7	7	7	8	8	8	9	10	10	
Plug-in dispenser (150 kW)	0	4	8	12	12	12	20	20	20	24	24	24	28	32	32	
Plug-in dispenser (50 kW)	0	3	5	5	5	5	5	5	5	5	5	5	5	5	5	
Charge Management System	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Electrical Supply System Upgrade	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Exhibit 66: Capital Purchase and Retirement Quantities by Year – Alternative 1b (Stationary Charging, Accelerated Fleet Replacement – SC/AR)

Item	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Total
Purchases																
Vehicles (First Generation BEB)																
Conventional (combined body & battery)		4	4	4	8	7	6	6								39
Specialized (combined body & battery)		5	4					5								14
Vehicles (Second Generation BEB)																
Conventional (combined body & battery)														4	4	8
Specialized (combined body & battery)									5	4					5	14
Charger Infrastructure																
Power conversion cabinet (150 kW)		2	1	1	3	1	1	1								10
Plug-in dispenser (150 kW)		4	4	4	8	4	4	4								32
Plug-in dispenser (50 kW)		3	2													5
Charge Management System (Lot)		1														1
Electrical Supply System Upgrade (Lot)		1														1
Retirements																
Vehicles (Existing Fleet)																
Conventional diesel/hybrid			4	4	6	6	6	5								31
Specialized gasoline			5	4				8								17
Vehicles (First Generation BEB)																
Conventional (combined body & battery)														4	4	8
Specialized (combined body & battery)									5	4					5	14
Net Asset Quantities																
Vehicles																
Conventional diesel/hybrid	31	31	27	23	17	11	5	0	0	0	0	0	0	0	0	
Conventional BEB	0	4	8	12	20	27	33	39	39	39	39	39	39	39	39	
Conventional (all propulsion)	31	35	35	35	37	38	38	39	39	39	39	39	39	39	39	
Specialized gasoline	17	17	12	8	8	8	8	0	0	0	0	0	0	0	0	
Specialized BEB	0	5	9	9	9	9	9	14	14	14	14	14	14	14	14	
Specialized (all propulsion)	17	22	21	17	17	17	17	14	14	14	14	14	14	14	14	
Charger Infrastructure																
Power conversion cabinet (150 kW)	0	2	3	4	7	8	9	10	10	10	10	10	10	10	10	
Plug-in dispenser (150 kW)	0	4	8	12	20	24	28	32	32	32	32	32	32	32	32	
Plug-in dispenser (50 kW)	0	3	5	5	5	5	5	5	5	5	5	5	5	5	5	
Charge Management System	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Electrical Supply System Upgrade	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Exhibit 67: Capital Purchase and Retirement Quantities by Year – Alternative 1c (Stationary Charging, Flash Cut Fleet Replacement – SC/FR)

Item	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Total
Purchases																
Vehicles (First Generation BEB)																
Conventional (combined body & battery)		39														39
Specialized (combined body & battery)		14														14
Vehicles (Second Generation BEB)																
Conventional (combined body & battery)														39		39
Specialized (combined body & battery)									14							14
Charger Infrastructure																
Power conversion cabinet (150 kW)		10														10
Plug-in dispenser (150 kW)		32														32
Plug-in dispenser (50 kW)		5														5
Charge Management System (Lot)		1														1
Electrical Supply System Upgrade (Lot)		1														1
Retirements																
Vehicles (Existing Fleet)																
Conventional diesel/hybrid		31														31
Specialized gasoline		17														17
Vehicles (First Generation BEB)																
Conventional (combined body & battery)														39		39
Specialized (combined body & battery)									14							14
Net Asset Quantities																
Vehicles																
Conventional diesel/hybrid	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Conventional BEB	0	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
Conventional (all propulsion)	31	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
Specialized gasoline	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Specialized BEB	0	14	14	14	14	14	14	14	14	14	14	14	14	14	14	
Specialized (all propulsion)	17	14	14	14	14	14	14	14	14	14	14	14	14	14	14	
Charger Infrastructure																
Power conversion cabinet (150 kW)	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
Plug-in dispenser (150 kW)	0	32	32	32	32	32	32	32	32	32	32	32	32	32	32	
Plug-in dispenser (50 kW)	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Charge Management System	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Electrical Supply System Upgrade	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Exhibit 68: Capital Purchase and Retirement Quantities by Year – Alternative 2a (Rotating Indoor Batch Charging, End-of-Life Fleet Replacement – RC/ER)

Item	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Total
Purchases																
Vehicles (First Generation BEB)																
Conventional (combined body & battery)		4	4	4	3		4	3		4			5	5	3	39
Specialized (combined body & battery)		5	4					5								14
Vehicles (Second Generation BEB)																
Conventional (combined body & battery)														4	4	8
Specialized (combined body & battery)									5	4					5	14
Charger Infrastructure																
Power conversion cabinet (150 kW)		2	1	1			1	2		1			1	1		10
Plug-in dispenser (150 kW)		4	4	4												12
Plug-in dispenser (50 kW)		3	2													5
Charge Management System (Lot)		1														1
Electrical Supply System Upgrade (Lot)		1														1
Retirements																
Vehicles (Existing Fleet)																
Conventional diesel/hybrid			4	4	2		3	2		3			5	5	3	31
Specialized gasoline			5	4				8								17
Vehicles (First Generation BEB)																
Conventional (combined body & battery)														4	4	8
Specialized (combined body & battery)									5	4					5	14
Net Asset Quantities																
Vehicles																
Conventional diesel/hybrid	31	31	27	23	21	21	18	16	16	13	13	13	8	3	0	
Conventional BEB	0	4	8	12	15	15	19	22	22	26	26	26	31	36	39	
Conventional (all propulsion)	31	35	35	35	36	36	37	38	38	39	39	39	39	39	39	
Specialized gasoline	17	17	12	8	8	8	8	0	0	0	0	0	0	0	0	
Specialized BEB	0	5	9	9	9	9	9	14	14	14	14	14	14	14	14	
Specialized (all propulsion)	17	22	21	17	17	17	17	14	14	14	14	14	14	14	14	
Charger Infrastructure																
Power conversion cabinet (150 kW)	0	2	3	4	4	4	5	7	7	8	8	8	9	10	10	
Plug-in dispenser (150 kW)	0	4	8	12	12	12	12	12	12	12	12	12	12	12	12	
Plug-in dispenser (50 kW)	0	3	5	5	5	5	5	5	5	5	5	5	5	5	5	
Charge Management System	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Electrical Supply System Upgrade	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Exhibit 69: Capital Purchase and Retirement Quantities by Year – Alternative 2b (Rotating Indoor Batch Charging, Accelerated Fleet Replacement – RC/AR)

Item	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Total
Purchases																
Vehicles (First Generation BEB)																
Conventional (combined body & battery)		4	4	4	8	7	6	6								39
Specialized (combined body & battery)		5	4					5								14
Vehicles (Second Generation BEB)																
Conventional (combined body & battery)														4	4	8
Specialized (combined body & battery)									5	4					5	14
Charger Infrastructure																
Power conversion cabinet (150 kW)		2	1	1	1	3	1	1								10
Plug-in dispenser (150 kW)		4	4	4												12
Plug-in dispenser (50 kW)		3	2													5
Charge Management System (Lot)		1														1
Electrical Supply System Upgrade (Lot)		1														1
Retirements																
Vehicles (Existing Fleet)																
Conventional diesel/hybrid			4	4	6	6	6	5								31
Specialized gasoline			5	4				8								17
Vehicles (First Generation BEB)																
Conventional (combined body & battery)														4	4	8
Specialized (combined body & battery)									5	4					5	14
Net Asset Quantities																
Vehicles																
Conventional diesel/hybrid	31	31	27	23	17	11	5	0	0	0	0	0	0	0	0	
Conventional BEB	0	4	8	12	20	27	33	39	39	39	39	39	39	39	39	
Conventional (all propulsion)	31	35	35	35	37	38	38	39	39	39	39	39	39	39	39	
Specialized gasoline	17	17	12	8	8	8	8	0	0	0	0	0	0	0	0	
Specialized BEB	0	5	9	9	9	9	9	14	14	14	14	14	14	14	14	
Specialized (all propulsion)	17	22	21	17	17	17	17	14	14	14	14	14	14	14	14	
Charger Infrastructure																
Power conversion cabinet (150 kW)	0	2	3	4	5	8	9	10	10	10	10	10	10	10	10	
Plug-in dispenser (150 kW)	0	4	8	12	12	12	12	12	12	12	12	12	12	12	12	
Plug-in dispenser (50 kW)	0	3	5	5	5	5	5	5	5	5	5	5	5	5	5	
Charge Management System	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Electrical Supply System Upgrade	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Exhibit 70: Capital Purchase and Retirement Quantities by Year – Alternative 2c (Rotating Indoor Batch Charging, Flash Cut Fleet Replacement – RC/FR)

Item	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Total
Purchases																
Vehicles (First Generation BEB)																
Conventional (combined body & battery)		39														39
Specialized (combined body & battery)		14														14
Vehicles (Second Generation BEB)																
Conventional (combined body & battery)														39		39
Specialized (combined body & battery)									14							14
Charger Infrastructure																
Power conversion cabinet (150 kW)		10														10
Plug-in dispenser (150 kW)		12														12
Plug-in dispenser (50 kW)		5														5
Charge Management System (Lot)		1														1
Electrical Supply System Upgrade (Lot)		1														1
Retirements																
Vehicles (Existing Fleet)																
Conventional diesel/hybrid		31														31
Specialized gasoline		17														17
Vehicles (First Generation BEB)																
Conventional (combined body & battery)														39		39
Specialized (combined body & battery)									14							14
Net Asset Quantities																
Vehicles																
Conventional diesel/hybrid	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Conventional BEB	0	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
Conventional (all propulsion)	31	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
Specialized gasoline	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Specialized BEB	0	14	14	14	14	14	14	14	14	14	14	14	14	14	14	
Specialized (all propulsion)	17	14	14	14	14	14	14	14	14	14	14	14	14	14	14	
Charger Infrastructure																
Power conversion cabinet (150 kW)	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
Plug-in dispenser (150 kW)	0	12	12	12	12	12	12	12	12	12	12	12	12	12	12	
Plug-in dispenser (50 kW)	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Charge Management System	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Electrical Supply System Upgrade	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Exhibit 71: Capital Purchase and Retirement Quantities by Year – Alternative 3a (Rotating Outdoor Charging, End-of-Life Fleet Replacement - OC/ER)

Item	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Total
Purchases																
Vehicles (First Generation BEB)																
Conventional (combined body & battery)		4	4	4	3		4	3		4			5	5	3	39
Specialized (combined body & battery)		5	4					5								14
Vehicles (Second Generation BEB)																
Conventional (combined body & battery)														4	4	39
Specialized (combined body & battery)									5	4					5	14
Charger Infrastructure																
Power conversion cabinet (150 kW)		2	1		1		1	1		1			1	2		10
Plug-in dispenser (150 kW)		2	1		1		1	1		1			1	2		10
Plug-in dispenser (50 kW)		3	2													5
Charge Management System (Lot)		1														1
Electrical Supply System Upgrade (Lot)		1														1
Retirements																
Vehicles (Existing Fleet)																
Conventional diesel/hybrid			4	4	2		3	2		3			5	5	3	31
Specialized gasoline			5	4				8								17
Vehicles (First Generation BEB)																
Conventional (combined body & battery)														4	4	39
Specialized (combined body & battery)									5	4					5	14
Net Asset Quantities																
Vehicles																
Conventional diesel/hybrid	31	31	27	23	21	21	18	16	16	13	13	13	8	3	0	
Conventional BEB	0	4	8	12	15	15	19	22	22	26	26	26	31	36	39	
Conventional (all propulsion)	31	35	35	35	36	36	37	38	38	39	39	39	39	39	39	
Specialized gasoline	17	17	12	8	8	8	8	0	0	0	0	0	0	0	0	
Specialized BEB	0	5	9	9	9	9	9	14	14	14	14	14	14	14	14	
Specialized (all propulsion)	17	22	21	17	17	17	17	14	14	14	14	14	14	14	14	
Charger Infrastructure																
Power conversion cabinet (150 kW)	0	2	3	3	4	4	5	6	6	7	7	7	8	10	10	
Plug-in dispenser (150 kW)	0	2	3	3	4	4	5	6	6	7	7	7	8	10	10	
Plug-in dispenser (50 kW)	0	3	5	5	5	5	5	5	5	5	5	5	5	5	5	
Charge Management System	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Electrical Supply System Upgrade	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Exhibit 72: Capital Purchase and Retirement Quantities by Year – Alternative 3b (Rotating Outdoor Charging, Accelerated Fleet Replacement – OC/AR)

Item	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Total
Purchases																
Vehicles (First Generation BEB)																
Conventional (combined body & battery)		4	4	4	8	7	6	6								39
Specialized (combined body & battery)		5	4					5								14
Vehicles (Second Generation BEB)																
Conventional (combined body & battery)														4	4	39
Specialized (combined body & battery)									5	4					5	14
Charger Infrastructure																
Power conversion cabinet (150 kW)		2	1		1	3	2	1								10
Plug-in dispenser (150 kW)		2	1		1	3	2	1								10
Plug-in dispenser (50 kW)		3	2													5
Charge Management System (Lot)		1														1
Electrical Supply System Upgrade (Lot)		1														1
Retirements																
Vehicles (Existing Fleet)																
Conventional diesel/hybrid			4	4	6	6	6	5								31
Specialized gasoline			5	4				8								17
Vehicles (First Generation BEB)																
Conventional (combined body & battery)														4	4	39
Specialized (combined body & battery)									5	4					5	14
Net Asset Quantities																
Vehicles																
Conventional diesel/hybrid	31	31	27	23	17	11	5	0	0	0	0	0	0	0	0	
Conventional BEB	0	4	8	12	20	27	33	39	39	39	39	39	39	39	39	
Conventional (all propulsion)	31	35	35	35	37	38	38	39	39	39	39	39	39	39	39	
Specialized gasoline	17	17	12	8	8	8	8	0	0	0	0	0	0	0	0	
Specialized BEB	0	5	9	9	9	9	9	14	14	14	14	14	14	14	14	
Specialized (all propulsion)	17	22	21	17	17	17	17	14	14	14	14	14	14	14	14	
Charger Infrastructure																
Power conversion cabinet (150 kW)	0	2	3	3	4	7	9	10	10	10	10	10	10	10	10	
Plug-in dispenser (150 kW)	0	2	3	3	4	7	9	10	10	10	10	10	10	10	10	
Plug-in dispenser (50 kW)	0	3	5	5	5	5	5	5	5	5	5	5	5	5	5	
Charge Management System	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Electrical Supply System Upgrade	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Exhibit 73: Capital Purchase and Retirement Quantities by Year – Alternative 3c (Rotating Outdoor Charging, Flash Cut Fleet Replacement – OC/FR)

Item	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Total
Purchases																
Vehicles (First Generation BEB)																
Conventional (combined body & battery)		39														39
Specialized (combined body & battery)		14														14
Vehicles (Second Generation BEB)																
Conventional (combined body & battery)														39		39
Specialized (combined body & battery)									14							14
Charger Infrastructure																
Power conversion cabinet (150 kW)		10														10
Plug-in dispenser (150 kW)		10														10
Plug-in dispenser (50 kW)		5														5
Charge Management System (Lot)		1														1
Electrical Supply System Upgrade (Lot)		1														1
Retirements																
Vehicles (Existing Fleet)																
Conventional diesel/hybrid		31														31
Specialized gasoline		17														17
Vehicles (First Generation BEB)																
Conventional (combined body & battery)														39		39
Specialized (combined body & battery)									14							14
Net Asset Quantities																
Vehicles																
Conventional diesel/hybrid	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Conventional BEB	0	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
Conventional (all propulsion)	31	39	39	39	39	39	39	39	39	39	39	39	39	39	39	
Specialized gasoline	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Specialized BEB	0	14	14	14	14	14	14	14	14	14	14	14	14	14	14	
Specialized (all propulsion)	17	14	14	14	14	14	14	14	14	14	14	14	14	14	14	
Charger Infrastructure																
Power conversion cabinet (150 kW)	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
Plug-in dispenser (150 kW)	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
Plug-in dispenser (50 kW)	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Charge Management System	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Electrical Supply System Upgrade	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

6.1.2 Detailed Fleet Replacement Breakdown

In each of the three fleet replacement timelines (end-of-life, accelerated, or flash cut), BEBs are planned for delivery beginning in 2024. As of the end of 2023 (before BEBs arrive), Brantford Transit is projected to have a conventional fleet of 31 conventional diesel (and diesel-electric hybrid) buses, and 18 Lift vehicles, of varying ages.

BEB purchases will need to be timed to replace retiring diesel buses as close as feasible to the planned end of their service lives (to minimize additional maintenance on old vehicles) and to establish a trend of fleet expansion. At the same time, IBI Group recommends that initial BEB procurements would be followed by a period of performance data gathering to inform adjustments to subsequent procurements. An initially slow uptake of BEBs may result in a limited number of existing diesel buses needing to be retained longer than Brantford Transit's typical 14-year replacement cycle to maintain fleet availability. BEB deliveries to North American transit systems are also experiencing backlogs of 12 to 18 months as a result of growing demand and supply chain challenges, adding to a risk of delayed retirements.

Exhibit 74 through **Exhibit 78** below present the existing Brantford Transit replacement timelines for the conventional and Lift fleets, in coordination with recommended BEB delivery timelines and suggested delayed retirements to support fleet availability, where applicable. Notes on interpreting these exhibits:

- Each row maps an existing bus to a replacement, sorted by proposed replacement year.
- Certain rows represent net fleet expansion or surplus, and are therefore not mapped to an existing or replacement bus, respectively.
- The future bus replacement cycle will likely need to shorten to 12 years with BEBs, down from Brantford Transit's existing 14-year cycle. As a result, in the end-of-life replacement timeline (**Exhibit 74**), first-generation BEBs appear for replacement beginning in 2036.

For comparison, the original fleet replacement timelines supplied by Brantford Transit as inputs for this analysis are provided Appendix C.

Exhibit 74: Proposed Conventional Fleet Replacement Timeline (End-of-Life Replacement Scenario)

Existing Vehicle	Purchase Year	Standard Replacement	Proposed BEB Purchase Year	Age of Existing Vehicle at Retirement
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
Diesel bus	2010	2024	2025	15
Diesel bus	2010	2024	2025	15
Diesel bus	2010	2024	2025	15
Diesel bus	2010	2024	2025	15
Diesel bus	2012	2026	2026	14
Diesel bus	2012	2026	2026	14
Diesel bus	2012	2026	2026	14
Diesel bus	2012	2026	2026	14
Diesel bus	2013	2027	2027	14
Diesel bus	2013	2027	2027	14
N/A - Expansion	N/A - Expansion	N/A - Expansion	2027	N/A - Expansion
Diesel bus	2015	2029	2029	14
Diesel bus	2015	2029	2029	14
Diesel bus	2015	2029	2029	14
N/A - Expansion	N/A - Expansion	N/A - Expansion	2029	N/A - Expansion
Diesel bus	2016	2030	2030	14
Diesel bus	2016	2030	2030	14
N/A - Expansion	N/A - Expansion	N/A - Expansion	2030	N/A - Expansion
Diesel bus	2018	2032	2032	14
Diesel bus	2018	2032	2032	14
Diesel bus	2018	2032	2032	14
N/A - Expansion	N/A - Expansion	N/A - Expansion	2032	N/A - Expansion
Diesel bus	2021	2035	2035	14
Diesel bus	2021	2035	2035	14
Diesel bus	2021	2035	2035	14
Diesel bus	2021	2035	2035	14
Diesel bus	2021	2035	2035	14
Diesel bus	2022	2036	2036	14
Diesel bus	2022	2036	2036	14
Diesel bus	2022	2036	2036	14
Diesel bus	2022	2036	2036	14
Diesel bus	2022	2036	2036	14
BEB	2024	2036	2036	12
BEB	2024	2036	2036	12
BEB	2024	2036	2036	12
BEB	2024	2036	2036	12
Diesel bus	2023	2037	2037	14
Diesel bus	2023	2037	2037	14
Diesel bus	2023	2037	2037	14
BEB	2025	2037	2037	12
BEB	2025	2037	2037	12
BEB	2025	2037	2037	12
BEB	2025	2037	2037	12

Exhibit 75: Proposed Conventional Fleet Replacement Timeline (Accelerated Replacement Scenario)

Existing Vehicle	Purchase Year	Standard Replacement	Proposed BEB Purchase Year	Age of Existing Vehicle at Retirement
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
Diesel bus	2010	2024	2025	15
Diesel bus	2010	2024	2025	15
Diesel bus	2010	2024	2025	15
Diesel bus	2010	2024	2025	15
Diesel bus	2012	2026	2026	14
Diesel bus	2012	2026	2026	14
Diesel bus	2012	2026	2026	14
Diesel bus	2012	2026	2026	14
Diesel bus	2013	2027	2027	14
Diesel bus	2013	2027	2027	14
Diesel bus	2015	2029	2027	12
Diesel bus	2015	2029	2027	12
Diesel bus	2015	2029	2027	12
Diesel bus	2016	2030	2027	11
N/A - Expansion	N/A - Expansion	N/A - Expansion	2027	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2027	N/A - Expansion
Diesel bus	2016	2030	2028	12
Diesel bus	2018	2032	2028	10
Diesel bus	2018	2032	2028	10
Diesel bus	2018	2032	2028	10
Diesel bus	2021	2035	2028	7
Diesel bus	2021	2035	2028	7
N/A - Expansion	N/A - Expansion	N/A - Expansion	2028	N/A - Expansion
Diesel bus	2021	2035	2029	8
Diesel bus	2021	2035	2029	8
Diesel bus	2021	2035	2029	8
Diesel bus	2022	2036	2029	7
Diesel bus	2022	2036	2029	7
Diesel bus	2022	2036	2029	7
Diesel bus	2022	2036	2030	8
Diesel bus	2022	2036	2030	18
Diesel bus	2023	2037	2030	7
Diesel bus	2023	2037	2030	7
Diesel bus	2023	2037	2030	7
N/A - Expansion	N/A - Expansion	N/A - Expansion	2030	N/A - Expansion

Exhibit 76: Proposed Conventional Fleet Replacement Timeline (Flash Cut Replacement Scenario)

Existing Vehicle	Purchase Year	Standard Replacement	Proposed BEB Purchase Year	Age of Existing Vehicle at Retirement
Diesel bus	2010	2024	2024	14
Diesel bus	2010	2024	2024	14
Diesel bus	2010	2024	2024	14
Diesel bus	2010	2024	2024	14
Diesel bus	2012	2026	2024	12
Diesel bus	2012	2026	2024	12
Diesel bus	2012	2026	2024	12
Diesel bus	2012	2026	2024	12
Diesel bus	2013	2027	2024	11
Diesel bus	2013	2027	2024	11
Diesel bus	2015	2029	2024	9
Diesel bus	2015	2029	2024	9
Diesel bus	2015	2029	2024	9
Diesel bus	2016	2030	2024	8
Diesel bus	2016	2030	2024	8
Diesel bus	2018	2032	2024	6
Diesel bus	2018	2032	2024	6
Diesel bus	2018	2032	2024	6
Diesel bus	2021	2035	2024	3
Diesel bus	2021	2035	2024	3
Diesel bus	2021	2035	2024	3
Diesel bus	2021	2035	2024	3
Diesel bus	2021	2035	2024	3
Diesel bus	2022	2036	2024	2
Diesel bus	2022	2036	2024	2
Diesel bus	2022	2036	2024	2
Diesel bus	2022	2036	2024	2
Diesel bus	2022	2036	2024	2
Diesel bus	2023	2037	2024	1
Diesel bus	2023	2037	2024	1
Diesel bus	2023	2037	2024	1
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion
N/A - Expansion	N/A - Expansion	N/A - Expansion	2024	N/A - Expansion

Exhibit 77: Proposed Specialized Fleet Replacement Timeline (End-of-Life Replacement Scenario)

Existing Vehicle	Purchase Year	Standard Replacement	Proposed BEB Purchase Year	Proposed Existing Vehicle Retirement Year	Age of Existing Vehicle at Retirement
Gasoline bus	2016	2023	N/A - Surplus	2023	7
Gasoline bus	2017	2024	2024	2025	8
Gasoline bus	2017	2024	2024	2025	8
Gasoline bus	2017	2024	2024	2025	8
Gasoline bus	2017	2024	2024	2025	8
Gasoline bus	2017	2024	2025	2025	8
Gasoline bus	2018	2025	2025	2026	8
Gasoline bus	2018	2025	2025	2026	8
Gasoline bus	2018	2025	2025	2026	8
Gasoline bus	2018	2025	2026	2026	8
Gasoline bus	2023	2030	2030	2030	7
Gasoline bus	2023	2030	2030	2030	7
Gasoline bus	2023	2030	2030	2030	7
Gasoline bus	2023	2030	2030	2030	7
Gasoline bus	2023	2030	2030	2030	7
Gasoline bus	2023	2030	N/A - Surplus	2030	7
Gasoline bus	2023	2030	N/A - Surplus	2030	7
Gasoline bus	2023	2030	N/A - Surplus	2030	7

Exhibit 78: Proposed Specialized Fleet Replacement Timeline (Flash Cut Replacement Scenario)

Existing Vehicle	Purchase Year	Standard Replacement	Proposed BEB Purchase Year	Proposed Existing Vehicle Retirement Year	Age of Existing Vehicle at Retirement
Gasoline bus	2016	2023	N/A - Surplus	2023	7
Gasoline bus	2017	2024	2024	2024	7
Gasoline bus	2017	2024	2024	2024	7
Gasoline bus	2017	2024	2024	2024	7
Gasoline bus	2017	2024	2024	2024	7
Gasoline bus	2017	2024	2024	2024	7
Gasoline bus	2018	2025	2024	2024	6
Gasoline bus	2018	2025	2024	2024	6
Gasoline bus	2018	2025	2024	2024	6
Gasoline bus	2018	2025	2024	2024	6
Gasoline bus	2023	2030	2024	2024	1
Gasoline bus	2023	2030	2024	2024	1
Gasoline bus	2023	2030	2024	2024	1
Gasoline bus	2023	2030	2024	2024	1
Gasoline bus	2023	2030	2024	2024	1
Gasoline bus	2023	2030	N/A - Surplus	2024	1
Gasoline bus	2023	2030	N/A - Surplus	2024	1
Gasoline bus	2023	2030	N/A - Surplus	2024	1

6.2 Charging Equipment Layout

As discussed in **Section 2.4**, accommodating charging equipment inside the existing garage will require removing parking space and strategically coordinating equipment layouts and installation phasing. This section presents a potential approach to implementing charging equipment to support reliable charging operations and contain financial risk.

6.2.1 Cabinet-to-Dispenser Ratio

Regardless of the number of connected dispensers, each power cabinet operating at full capacity can effectively recharge 4 BEBs during the overnight period, based on a maximum 150-kW charging rate and Brantford Transit's scheduled start and end of service.

The optimal number of dispensers connected to each cabinet will vary depending on the planned operational workflow. Connecting more dispensers to the same cabinet benefits a stationary charging scenario, as up to 4 connected buses can be charged without being physically moved. In a batch charging scenario, having a cabinet-to-dispenser ratio closer to 1:1 is more optimal, to minimize the number of redundant dispensers.

6.2.2 Equipment Deployment Stages

On the following pages, **Exhibit 80** through **Exhibit 82** present a series of suggested deployment stages for charging equipment under the two scenarios involving indoor charging:

- Scenario 1: Stationary Charging
- Scenario 2: Rotating Batch Charging

These deployment stages are broken down in detail due to the constrained nature of indoor charging, and the specific sets of theoretical conditions simulated and validated as part of the Energy & Charging Analysis. A similarly detailed set of stages was not produced for Scenario 3 (outdoor charging) as the layout of an outdoor charging setup would not face comparable constraints.

The first three deployment stages in this sequence have been intentionally planned in common between both equipment layout scenarios. Deploying an initial charger configuration that allows Brantford Transit to respond to observed BEB performance trends and charging needs is recommended, as it will reduce financial and operational risk associated with the initial implementation.

Each deployment stage includes a conceptual schematic of the garage storage area indicating where charging equipment would be installed. A legend to accompany the schematics is provided as **Exhibit 79** below.

Exhibit 79: Legend for Charging Equipment Layout Schematics

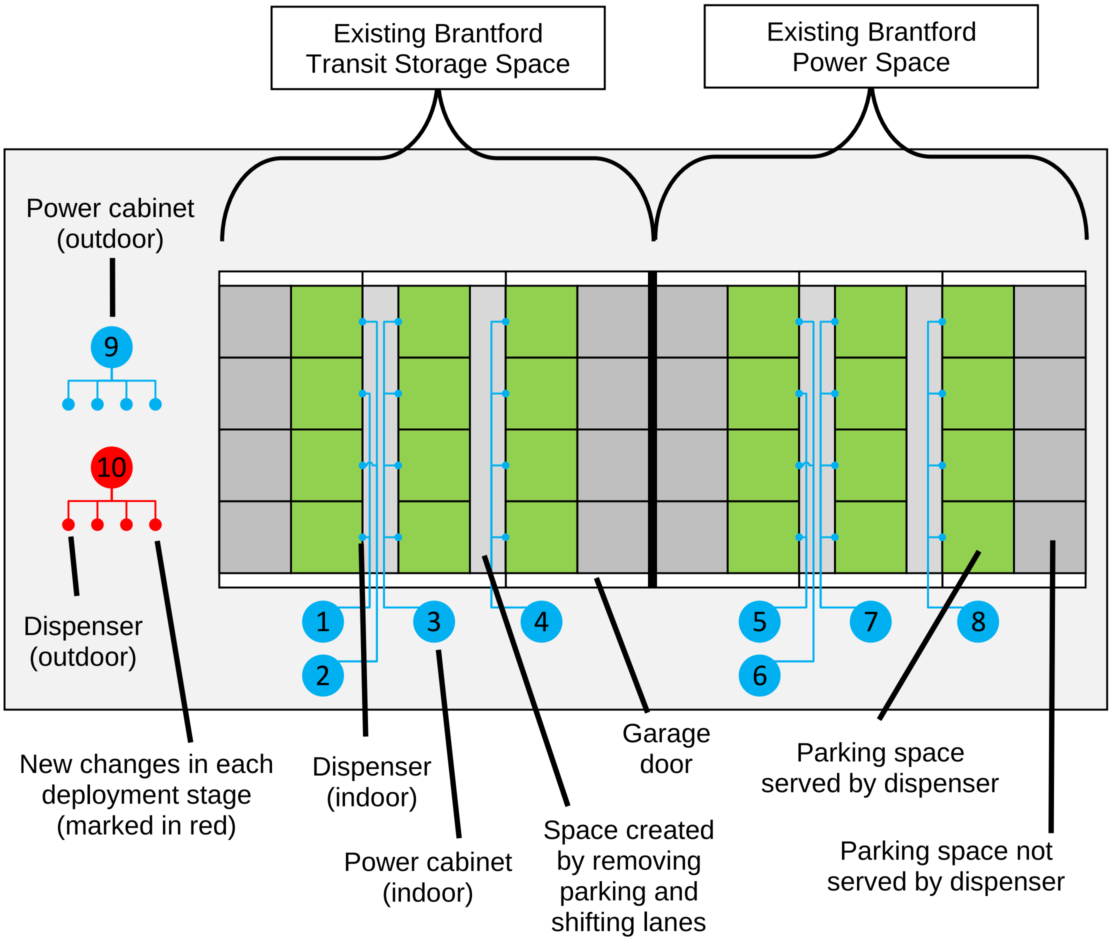
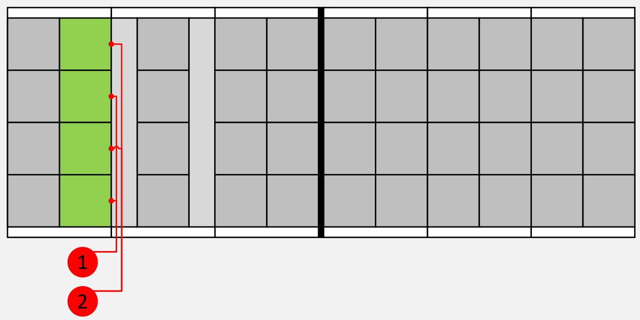
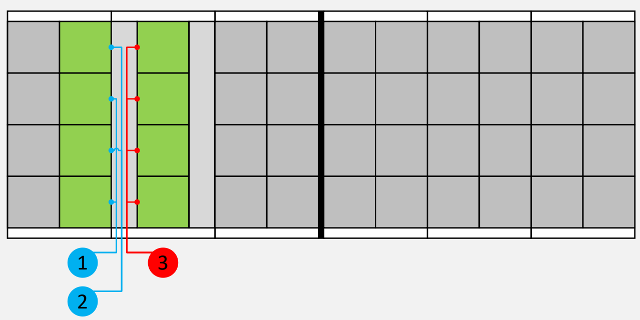


Exhibit 80: Early Deployment Stages for Indoor Charging Equipment (Common to Scenarios 1 and 2)

Early Deployment Stages (Common to Scenario 1 – Stationary Charging and Scenario 2 – Indoor Batch Charging)	
Cabinet & Dispenser Layout	**Description**
	**Transition Year 1: Installation Stage 1** New Infrastructure • 1 storage lane outfitted • 2 power converter cabinets • 4 dispensers (2 per cabinet) BEBs Accommodated Up to 4, stationary Notes A minimum of 2 cabinets is recommended for resiliency, in case of an equipment outage of 1 cabinet. Providing a 1:2 cabinet-to-dispenser ratio allows a full lane to be equipped for electric service.
	**Transition Year 2: Installation Stage 2** New Infrastructure • 1 additional power converter cabinet (#3) • 4 additional dispensers (1:4 ratio on new cabinet) BEBs Accommodated Up to 8, stationary Notes Results of the charging analysis indicate that 4 consecutive charging sessions can be accommodated overnight. Therefore, an additional lane can be outfitted with a single cabinet charging 4 buses in series. In case of an equipment outage of 1 cabinet (affecting 4 charging sessions), the affected sessions can be accommodated by using rotating batch charging on 2 cabinets with 2 dispensers (#1 and #2).

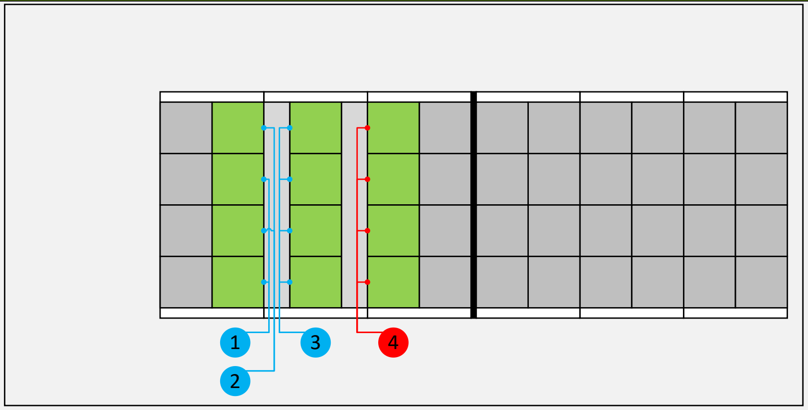
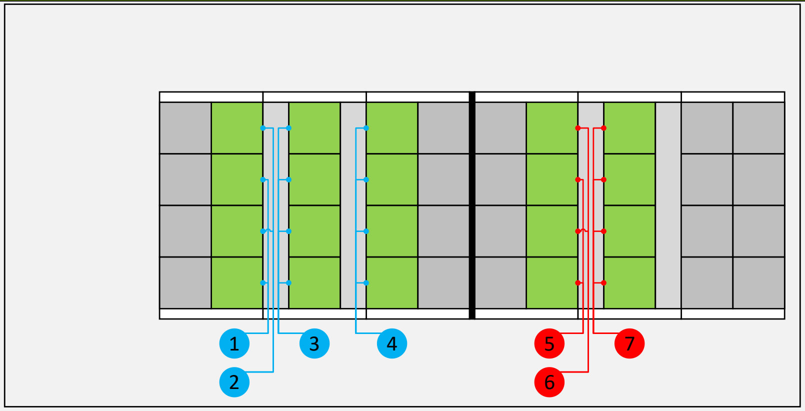
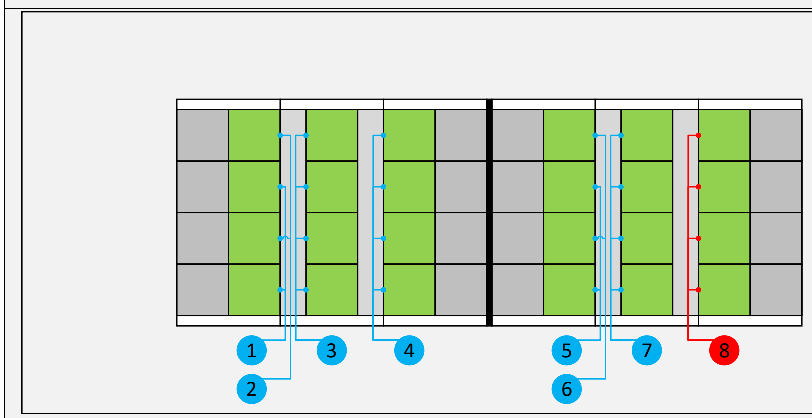
Early Deployment Stages (Common to Scenario 1 – Stationary Charging and Scenario 2 – Indoor Batch Charging)	
Cabinet & Dispenser Layout	**Description**
 	**Transition Year 3: Installation Stage 3** New Infrastructure • 1 additional power converter cabinet (#4) • 4 additional dispensers (1:4 ratio on new cabinet #4) BEBs Accommodated Up to 12, stationary Notes Similar to Stage 2, an additional lane can be outfitted with a single cabinet charging 4 buses in series. In case of an equipment outage of 1 cabinet (affecting 4 charging sessions), the affected sessions can be accommodated by using rotating batch charging on 2 cabinets with 2 dispensers (#1 and #2).
×× DECISION POINT: SCENARIO 1 (STATIONARY) OR SCENARIO 2 (INDOOR BATCH) ××	

Exhibit 81: Late Deployment Stages for Indoor Charging Equipment under Scenario 1 – Stationary Charging

Late Deployment Stages (Scenario 1 – Stationary Charging)	
Cabinet & Dispenser Layout	**Description**

	**Transition Year 6: Installation Stage 4 (Stationary Charging)**
	New Infrastructure
	• 3 additional power converter cabinets (#5, #6, #7)
	• 8 additional dispensers
	  ○ 1:2 ratio on cabinets #5 and #6
	  ○ 1:4 ratio on cabinet #7
	BEBs Accommodated
	Up to 20, stationary
	Notes
	Repeats the layout deployed in Stages 1 and 2 in the east half of the garage.
	In case of an equipment outage of 2 cabinets (affecting 8 charging sessions), the affected sessions can be accommodated by using rotating batch charging on 4 cabinets with 2 dispensers (#1, #2, #5, and #6).

	**Transition Year 9: Installation Stage 5 (Stationary Charging)** New Infrastructure • 1 additional power converter cabinet (#8) • 4 additional dispensers (1:4 ratio on new cabinet #8) BEBs Accommodated Up to 24, stationary Notes Repeats the layout deployed in Stage 3 in the east half of the garage. In case of an equipment outage of 2 cabinets (affecting 8 charging sessions), the affected sessions can be accommodated by using rotating batch charging on 4 cabinets with 2 dispensers (#1, #2, #5, and #6).

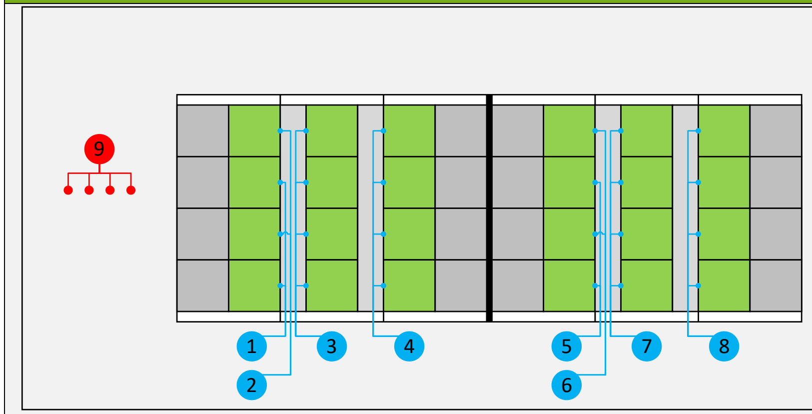
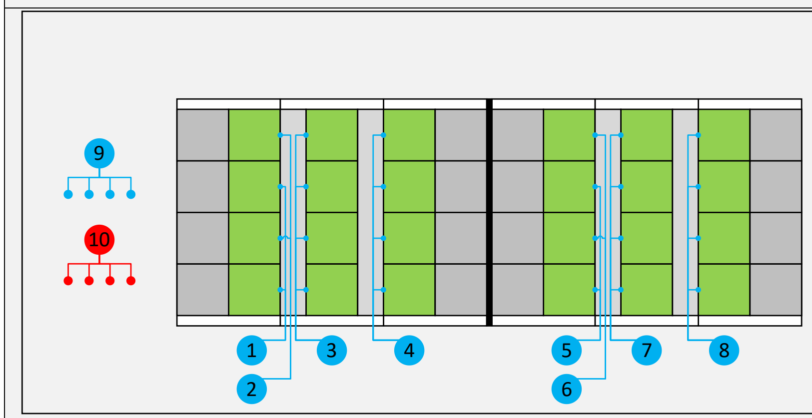
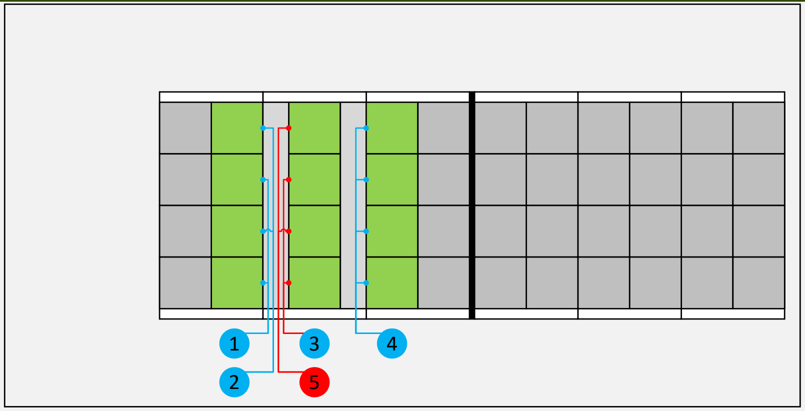
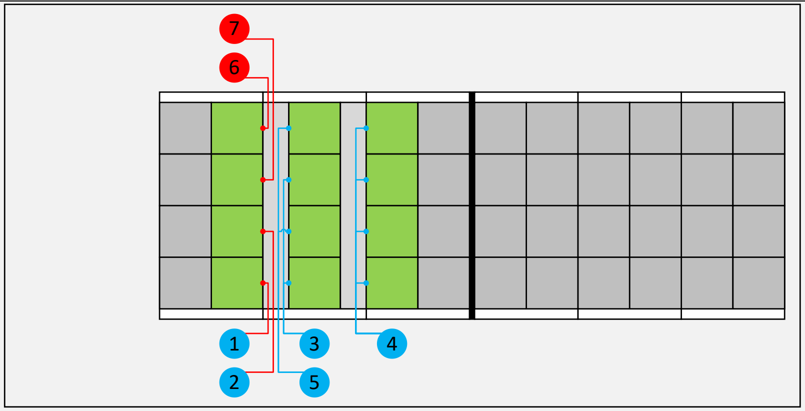
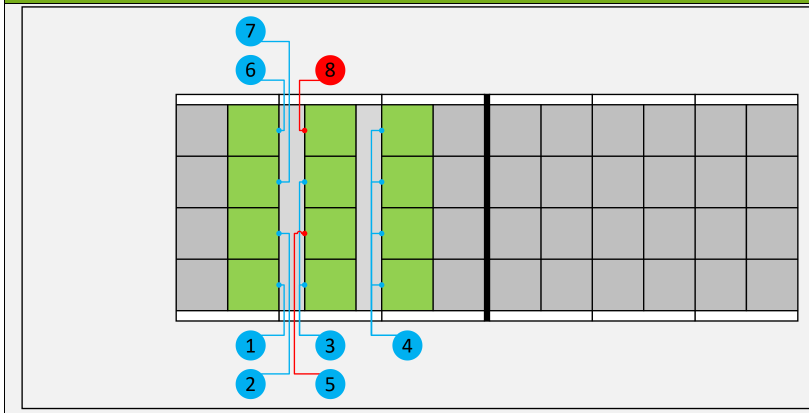
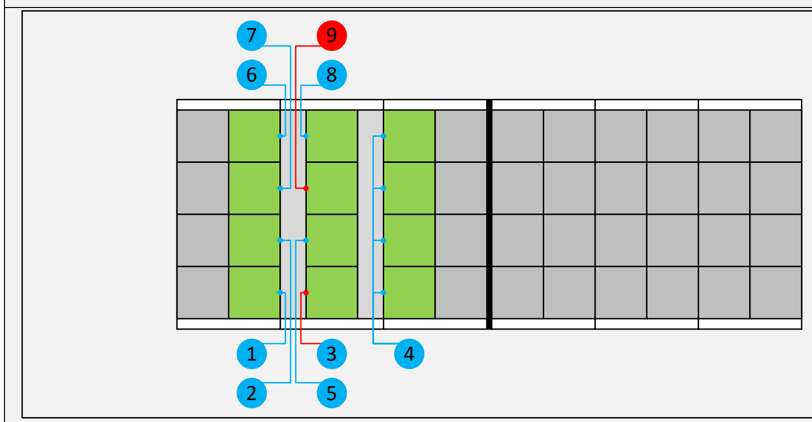
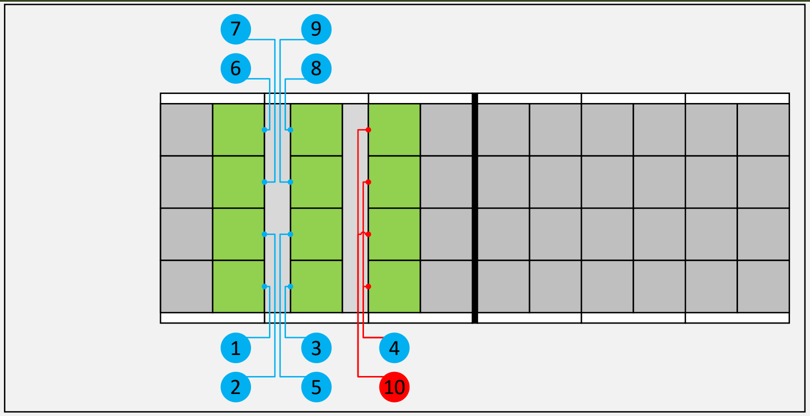
<table>
<tr><th colspan="2">Late Deployment Stages (Scenario 1 – Stationary Charging)</th></tr>
<tr><th>Cabinet & Dispenser Layout</th><th>Description</th></tr>
<tr><td>
</td><td>Transition Year 12: Installation Stage 6 (Stationary Charging)
<u>New Infrastructure</u>
• 1 additional power converter cabinet (#9) outdoors
• 4 additional dispensers (1:4 ratio on new cabinet #9)
<u>BEBs Accommodated</u>
Up to 28, stationary
<u>Notes</u>
New charging stalls positioned outdoors as indoor space is maximized.
In case of an equipment outage of up to 2 cabinets (affecting 8 charging sessions), the affected sessions can be accommodated by using rotating batch charging on 4 cabinets with 2 dispensers (#1, #2, #3, #5, #6, or #7).</td></tr>
<tr><td>
</td><td>Transition Year 13: Installation Stage 7 (Stationary Charging)
<u>New Infrastructure</u>
• 1 additional power converter cabinet (#10) outdoors
• 4 additional dispensers (1:4 ratio on new cabinet #9)
<u>BEBs Accommodated</u>
Up to 32, stationary
<u>Notes</u>
New charging stalls positioned outdoors as indoor space is maximized.
In case of an equipment outage of up to 3 cabinets (affecting 12 charging sessions), the affected sessions can be accommodated by using rotating batch charging on 6 cabinets with 2 dispensers (#1, #2, #3, #5, #6, and #7).</td></tr>
</table>

Exhibit 82: Late Deployment Stages for Indoor Charging Equipment under Scenario 2 – Indoor Batch Charging

Late Deployment Stages (Scenario 2 – Indoor Batch Charging)	
Cabinet & Dispenser Layout	**Description**
	**Transition Year 6: Installation Stage 4 (Indoor Batch Charging)** New Infrastructure • 1 additional power converter cabinet (#5) • 2 dispensers reconnected from cabinet #3 to cabinet #5 ○ Resulting 1:2 ratio on cabinets #1, #2, #3, and #5, and 1:4 ratio on cabinet #4 BEBs Accommodated Up to 16, in rotating batches Notes Decreasing the cabinet-to-dispenser ratio allows more buses to be charged simultaneously in the same lane, facilitating rotating batching. In case of an equipment outage of 1 cabinet (affecting 4 charging sessions), the affected sessions can be accommodated on the remaining 4 cabinets.
	**Transition Year 7: Installation Stage 5 (Indoor Batch Charging)** New Infrastructure • 2 additional power converter cabinets (#6 and #7) • 1 dispenser reconnected from cabinet #1 to cabinet #7 • 1 dispenser reconnected from cabinet #2 to cabinet #6 ○ Resulting 1:1 ratio on cabinets #1, #2, #6, and #7, 1:2 ratio on cabinets #3 and #5, and 1:4 ratio on cabinet #4 BEBs Accommodated Up to 20, in rotating batches Notes Further reduction in cabinet-to-dispenser ratio. In case of an equipment outage of 2 cabinets (affecting 8 charging sessions), the affected sessions can be accommodated on the remaining 5 cabinets.

<table>
<tr><th colspan="2">Late Deployment Stages (Scenario 2 – Indoor Batch Charging)</th></tr>
<tr><th>Cabinet & Dispenser Layout</th><th>Description</th></tr>
<tr><td>
</td><td>Transition Year 9: Installation Stage 6 (Indoor Batch Charging)
<u>New Infrastructure</u>
1 additional power converter cabinet (#8)
1 dispenser reconnected from cabinet #5 to cabinet #8
Resulting 1:1 ratio on cabinets #1, #2, #5, #6, #7, and #8, 1:2 ratio on cabinet #3, and 1:4 ratio on cabinet #4
<u>BEBs Accommodated</u>
Up to 24, in rotating batches
<u>Notes</u>
Further reduction in cabinet-to-dispenser ratio. In case of an equipment outage of 2 cabinets (affecting 8 charging sessions), the affected sessions can be accommodated on the remaining 6 cabinets.</td></tr>
<tr><td>
</td><td>Transition Year 12: Installation Stage 7 (Indoor Batch Charging)
<u>New Infrastructure</u>
1 additional power converter cabinet (#9)
1 dispenser reconnected from cabinet #3 to cabinet #9
Resulting 1:1 ratio on all cabinets except #4, and 1:4 ratio on cabinet #4
<u>BEBs Accommodated</u>
Up to 28, in rotating batches
<u>Notes</u>
Further reduction in cabinet-to-dispenser ratio. In case of an equipment outage of 2 cabinets (affecting 8 charging sessions), the affected sessions can be accommodated on the remaining 7 cabinets.</td></tr>
</table>

Late Deployment Stages (Scenario 2 – Indoor Batch Charging)	
Cabinet & Dispenser Layout	**Description**
 	**Transition Year 13: Installation Stage 8 (Indoor Batch Charging)** <u>New Infrastructure</u> • 1 additional power converter cabinet (#10) • 2 dispensers reconnected from cabinet #4 to cabinet #10 ○ Resulting 1:1 ratio on all cabinets except #4 and #10; 1:2 ratio on cabinets #4 and #10 <u>BEBs Accommodated</u> Up to 32, in rotating batches <u>Notes</u> Further reduction in cabinet-to-dispenser ratio. In case of an equipment outage of 3 cabinets (affecting 12 charging sessions), the affected sessions can be accommodated on the remaining 6 cabinets.

6.3 Electrical Upgrade Recommendations

Total power demand for charging the Brantford Transit fleet is projected at 1350 kW (composed of 1200 kW for conventional transit and 150 kW for Lift). This peak is stable for the majority of the overnight period, and it is consistent across all assessed scenarios for conventional transit.

As first discussed in **Section 2.3.2**, electricity can be delivered to the Brantford Transit garage through three primary options: using the current on-site transformer, upgrading to a new transformer serving all facility needs, or requesting an additional delivery point from Brantford Power dedicated to vehicle charging. If conventional and Lift power demands are counted together, an additional delivery point is the only effective option for supplying the required power demand, as presented in **Exhibit 83**.

Exhibit 83: Maximum power supply available for charging, by service type

Electrical Service	Maximum Available Power Supply for Charging (kW)	Residual Supply Capacity after Charging Requirements (kWh)
Current transformer on property	618	**-732**
Replacement transformer serving all facility uses	1338	**-12**
New, dedicated transformer for charging (additional delivery point from Brantford Power)	1440	**90**

7 Greenhouse Gas Emissions Assessment

This greenhouse gas (GHG) emission assessment compares the GHG emissions associated with alternative implementation timelines. Brantford's current fleet state and related GHG emissions are considered the baseline scenario against which future replacement scenarios and implementation timeline options are compared.

For the analysis of conventional transit, this study will also contrast the emissions differences between the baseline case and 2 heating scenarios – BEBs with electric heaters and BEBs with diesel interior space heaters. Specialized fleet replacement only compares the baseline case against 1 scenario, BEBs with electric heaters, as diesel heaters for specialized vehicles have limited market availability.

This environmental assessment focuses on the components of GHG emissions that are expected to change as a result of the fleet transition. Emissions components that are expected to remain relatively consistent regardless of the propulsion technology used will be largely excluded from the analysis.

7.1 Environmental Impact Assessment Methodology

7.1.1 Assumptions

This assessment uses fleet counts based on the findings from the energy and charging analyses for conventional and specialized service. The scenarios are:

- Conventional bus replacement using 39 BEBs with electric heaters;
- Conventional bus replacement using 39 BEBs with diesel heaters;

- Specialized vehicle replacement using BEBs with electric heaters.

Additional details about each scenario can be found in **Section 7.2**. This section outlines the global assumptions for these future emissions scenarios defined for the environmental analysis. The assumptions are listed below:

- It is assumed that levels of service do not decrease from current schedules. Decreased service would result in lower emissions from either fossil fuels or electricity generation.
- It is assumed that the upstream emissions produced by the BEB battery manufacturing processes do not significantly improve during the period when BEBs are manufactured and delivered. A significant improvement in the manufacturing process for BEB batteries would result in greater reductions in GHG emissions than identified by this analysis.
- It is assumed, in cases of early retirement of the existing fleet associated with an accelerated electrification timeline, that the existing vehicles are resold to another transit operator such that the annualized GHG emissions from their manufacturing process are partially transferred to the new owner and not attributable to Brantford Transit. Scrapping the existing vehicles before the end of their useful life would result in higher annualized manufacturing emissions.
- It is assumed that the Ontario electricity supply mix (the portions of Ontario's electricity generated by various renewable and non-renewable sources) will not significantly change. Changes to the electricity supply mix could result in an overestimate or underestimate of the GHG emissions reductions achieved by this fleet transition.
- Emissions figures are annualized based on the expected fleet composition on December 31 of the stated year. For diesel/gasoline vehicles identified as retiring in the stated year, their GHG emissions during that year are excluded, as their precise retirement dates within the year are uncertain. In reality, it is likely that there will be a period of overlap between BEB delivery and retirement of the corresponding diesel/gasoline vehicles.
- It is assumed that gross annual bus interior space heating will be equivalent to 20 weeks of heating at full intensity based on Brantford climate data. In practice, heating intensity will taper in the spring and fall, with a greater portion of the year requiring low-intensity heating in the early morning and late evening.

Some additional specific assumptions used within this analysis to quantify GHG emissions for the baseline and alternative transition timeline scenarios are discussed within relevant sections.

7.1.2 Emissions Assessment Boundary

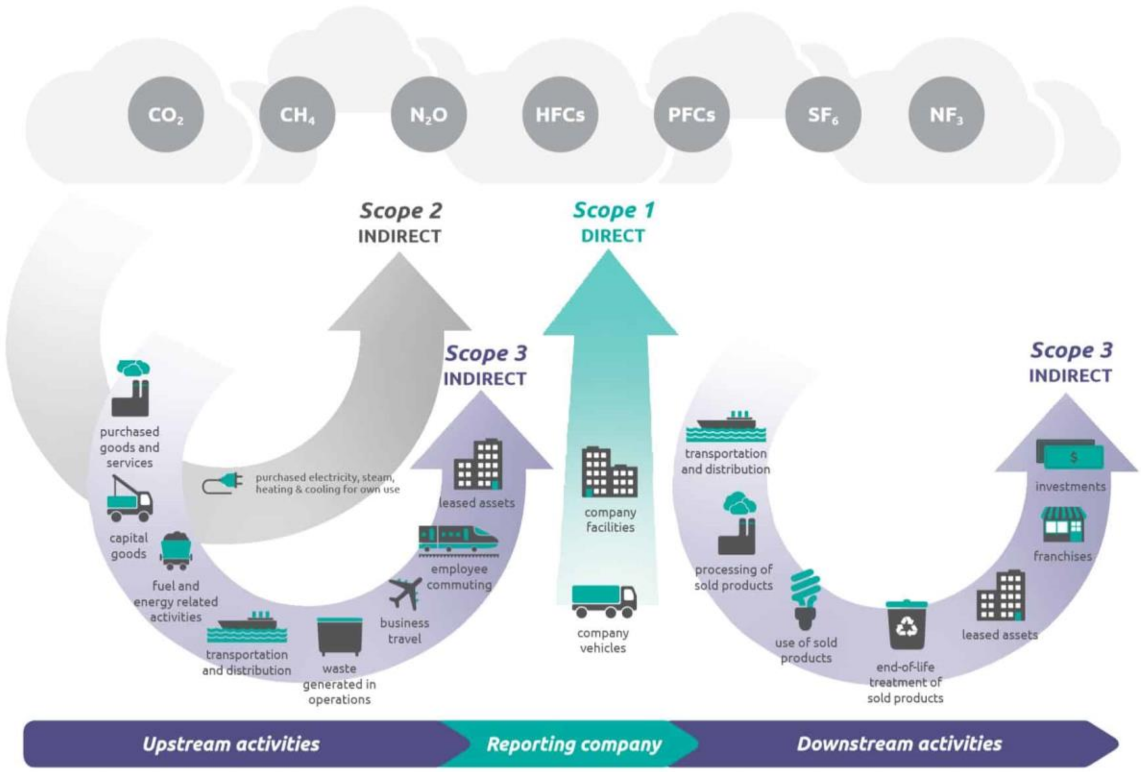
The boundaries define the scope of the environmental impact assessment. This analysis will consider all direct and indirect GHG emissions linked to the manufacturing and annual operation of diesel buses, gasoline buses and BEBs that will operate out of the current garage at 400 Grand River Avenue.

Our GHG emissions assessment methodology applies a focused version of the GHG Protocol (https://ghgprotocol.org/) – a broadly recognized international framework for describing and classifying emissions. At the centre of this framework is a classification of GHG emissions under three scopes, which are defined based on the level of control the reporting agency has over the specifics of the process (summarized below in **Exhibit 84**):

- **Scope 1:** Direct greenhouse (GHG) emissions that occur from sources that are controlled or owned by an organization
- **Scope 2:** Indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling

- **Scope 3:** Indirect emissions as the result of activities from assets not owned or controlled by the reporting organization, but that the organization indirectly impacts through its value chain purchasing decisions

Exhibit 84: GHG Emission Scopes as defined by the GHG Protocol. Extracted from WRI/WBCSD Corporate Value Chain (Scope 3) Accounting and Reporting Standard



As a result of the widespread adoption of these standards, expressing GHG emissions in terms of the above noted scopes has become an industry norm. For project specific GHG emissions accounting to city-wide inventories, GHG emissions are typically reported within each of the three categories.

Our methodology focuses on the most likely net changes in emissions under Scope 1 and Scope 2. Scope 1 emissions include direct vehicle use. Scope 2 emissions include electricity generation methods. We also consider select upstream Scope 3 emissions related to manufacturing the vehicles and the BEB batteries, which represent the largest single net change compared with components for a diesel or gasoline vehicle.

Other Scope 3 emissions related to the diesel and gasoline fuel supply chain are excluded (i.e. from the extraction, refinement and transportation of fuels used by either vehicles or electricity generation).

The detailed list for the included and excluded sources of direct and indirect emissions is depicted in **Exhibit 85** and a rationale is provided for where the emission was excluded from the GHG calculations and assessment. All production and manufacturing emissions considered under scope 3 are inclusive of extraction and production of materials, energy generation, fuel production, manufacturing process and treatment of materials consequent to end of life.

Exhibit 85: Identified Sources of Direct and Indirect Emissions

Source	Activity	Included/Excluded
Scope 1	Fuel use (fuelling of vehicles)	**Included**
	Refrigerant use	**Excluded:** Emissions from the baseline and transition scenarios are considered approximately equivalent
Scope 2	Electricity production (from fuel and renewable sources)	**Included**
Scope 3	BEB battery production and manufacturing	**Included**
	Powertrain production (Internal Combustion Engine (ICE) or electric motor) production and manufacturing	**Included:** Although emissions from producing ICEs and electric motors are considered approximately equivalent, fleet size changes result in a variance in total manufacturing emissions.[2]
	Bus frame, body, and wheel production and manufacturing	**Included:** Although emissions for diesel buses, gasolines buses and BEBs of equivalent size are considered approximately equivalent, fleet size changes result in a variance in total manufacturing emissions.
	BEB interior space heater production and manufacturing (diesel or electric units)	**Embedded:** built into bus body production. Emissions from producing either type of heater are considered approximately equivalent.

7.1.3 Greenhouse Gases in Scope

The greenhouse gases considered for inclusion in the environmental assessment were:

- Carbon Dioxide (CO_2)
- Methane (CH_4)
- Nitrous Oxide (N_2O)
- Fluorinated Gases (including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)

These gases are defined as GHGs by the United States Environmental Protection Agency and under the United Nations Intergovernmental Panel on Climate Change (IPCC).[3] Most emissions from the sources outlined in **Section 2.2** are CO_2 emissions, with smaller amounts of CH_4 and N_2O. Fluorinated gas emissions from vehicle operations are negligible. They may be produced during the manufacturing of bus bodies and electric batteries, however these emissions are projected to be low enough to be superseded by the variability in reporting quality on emissions from these manufacturing processes internationally, and are therefore excluded from this analysis.

[2] Nordelöf, A.; Romare, M.; Tivander, J. Life cycle assessment of city buses powered by electricity, hydrogenated vegetable oil or diesel. Transp. Res. Part D Transp. Environ. 2019, 75, 211–222.
[3] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

The magnitude of the impact of GHGs on climate change is calculated using Global Warming Potential (GWP), a standard scale to enable comparison of the effects of various emitted compounds in terms of tonnes-carbon-dioxide-equivalent, or t CO_2-eq. The GWP value reflects how long the GHG will remain in the atmosphere and how strongly it contributes to global warming compared with CO_2 (which has a GWP value of 1). This assessment uses GWP values from the IPCC 5th Assessment Report as provided in **Exhibit 86**.

Exhibit 86: GWP values of Three Relevant GHG Emissions Components

GHG Emissions Component	Global Warming Potential (GWP) (100 year)
Carbon Dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous Oxide (N_2O)	265

7.2 Projected Emissions

7.2.1 Per-Bus Emissions

The GHG calculations can be broken down into four groups:

- Manufacturing emissions from production of buses (all propulsion technologies) and BEB batteries;
- Emissions from fuel consumption of diesel/gasoline buses;
- Electricity and fuel consumption of BEBs with diesel heaters; and
- Electricity consumption of BEBs with electric heaters

The process for calculating each of these four groups of GHGs will be discussed in the following sub-sections.

7.2.1.1 Manufacturing

Vehicle body manufacturing is expected to produce approximately equivalent per-vehicle emissions for both diesel/gasoline and BEB categories when the vehicles are of similar size. The manufacturing process is broadly similar: the vehicle body is still largely made of the same raw materials using the same industrial processes, and similar transportation emissions are incurred during manufacturing and delivery[4]. The primary reason to consider vehicle body manufacturing emissions is the requirement for fleet size changes between the existing diesel/gasoline fleet and a future BEB fleet.

To account for new developments in manufacturing technology and supply chains, 2019 study data was referenced for GHG emissions of transit bus manufacturing. Estimated emissions are approximately 100 t CO_2-eq (tons of CO_2 equivalent) per 12-metre conventional transit bus. For specialized buses, a size ratio was taken to estimate the manufacturing emissions to be 60.82 t CO_2-eq per bus.

The production process of BEB batteries is a significant factor in comparing the production-related emissions for each transition scenario. The emissions difference in manufacturing between a diesel/gasoline bus and a BEB is primarily attributable to the battery.[4] BEBs are

[4] Nordelöf, A.; Romare, M.; Tivander, J. Life cycle assessment of city buses powered by electricity, hydrogenated vegetable oil or
diesel. Transp. Res. Part D Transp. Environ. 2019.

powered using large battery packs, the most popular type being lithium-ion batteries (LiB), due to their high specific energy, specific power, and energy density. Production of large battery packs in addition to the standard vehicle body and powertrain causes the total production phase GHG emissions for a BEB to be higher than for diesel buses and gasoline vehicles.

To determine the GHG emissions associated with battery production, we reviewed various studies on the GHG impact of BEB production and operation for data quality and alignment with the study boundaries. Since battery technology develops quickly, the final GHG emission factor was chosen from a 2019 study.[5] The study examined the life cycle energy consumption and GHG emissions from vehicle LiBs produced using a non-renewable electricity mix of 0.05–1 kg CO_2-eq per kWh consumed for production. This concluded that generally GHG emissions are 61–106 kg CO_2-eq per kWh of LiB energy storage capacity produced. However, this value can change depending on the electricity mix used in production. The study stated that the maximum value of 146 kg CO_2-eq/kWh could be used if transparent energy mix data is not available. The study also notes that these emissions estimates have decreased since 2017 due to improvements in manufacturing processes, and notes that production processes powered by greater proportions of renewable energy provides opportunities for these estimates to decrease further in the future.

Most global LiB production and manufacturing currently takes place in Asia, including batteries supplied to North American BEB manufacturers. In regions of Asia with concentrated LiB production, coal currently accounts for an average of approximately 60% of regional electricity generation.[6] In the absence of more granular regional reporting data, this analysis assumes the maximum value of 146 kg CO_2-eq/kWh of battery capacity to calculate GHG emissions, as the potential site of future BEB production is not yet known.

The BEB battery storage capacity is assumed to be 600 kWh for conventional BEBs and 120kWh for specialized BEBs, for consistency with the route modelling analysis. The fixed variables used in calculating manufacturing emissions are summarized in **Exhibit 87**.

Exhibit 87: Fixed Variables Used in Calculating Manufacturing Emissions of BEB Batteries

Variable	Value
Fixed Route BEB battery storage capacity (kWh)	600.00
Specialized transit BEB battery storage capacity (kWh)	120.00
LiB manufacturing GHG emissions (kg CO_2-eq per kWh LiB charge storage capacity)	146.00

BEB lifetime performance data is still growing in its availability and relevance to regional operating and environmental conditions, as the technology gains wider adoption. However, some early indications may be drawn from earlier experiences with hybrid diesel-electric bus fleets and early BEB adopters.

Initial deployments reported battery health decline trends that prompted replacement coinciding with typical mid-life vehicle overhauls (at around 6-7 years). Since that time, battery composition has improved, and battery health management techniques have become more sophisticated.

[5] Emilsson, E.; Dahllöf, L. Lithium-Ion Vehicle Battery Production Status 2019 on Energy Use, CO_2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling; IVL Swedish Environmental Research Institute: Stockholm, Sweden, 2019.
[6] Zhai Y. Q&A: A new energy policy to accelerate Asia's energy transition. Asian Development Bank. https://www.adb.org/news/features/qa-new-energy-policy-accelerate-asia-energy-transition. Published 2021.

These techniques concern both direct maintenance as well as dispatching practices that avoid overtaxing batteries and accelerating permanent deterioration. Battery longevity trends suggest that batteries may soon last the full lifetime of the bus – around 12 years. As a result, we have modelled this analysis on the assumption that batteries will be a one-time purchase per vehicle.[7]

To account for one-time GHG emissions related to manufacturing, this analysis compares manufacturing emissions for the three transition scenarios by annualizing emissions over a span of 12 years. The resulting total annual manufacturing GHG emissions figures therefore imply a steady, staggered replacement rate for new vehicles, which may not always be the case in practice (i.e. some years may incur more manufacturing related GHG emissions due to uneven sizes of new bus orders).

Exhibit 88 below presents estimated total bus and battery manufacturing emissions generated per vehicle, and the annualized emissions. Manufacturer warranty limits for BEBs tend to expire after 12 years, compared with Brantford Transit's existing 14-year replacement cycle for conventional diesel buses. Therefore, the annualization factors used in this analysis for manufacturing emissions are 14 years for diesel buses, and 12 years for BEBs.

Exhibit 88: Vehicle Manufacturing Emissions (Total and Annualized)[5]

GHG Emissions Component	Marginal Manufacturing Emissions Per Bus (t CO_2-eq)			
	Conventional Diesel	Conventional BEB	Specialized Gasoline	Specialized BEB
Bus body production	100.00	100.00	60.82	60.82
LiB production	--	87.60	--	17.52
Total production	**100.00**	**187.60**	**60.82**	**78.34**
Annualization Factor (Years)	14	12	7	7
Annualized Emissions	**7.14**	**15.63**	**8.69**	**11.19**

7.2.1.2 Fuel Consumption

The annual volume of diesel consumed by conventional buses in 2019 (1,174,217.90 L) and annual volume of gasoline consumed by specialized buses in 2019 (135,447.80 L) were provided by Brantford Transit as recorded operating statistics. Data from 2019 is expected to represent a more typical operating year than 2020 considering COVID-19 pandemic impacts. The current conventional fleet includes both diesel and hybrid-electric vehicles, which in practice have different fuel consumption. However, bulk annual data was not available in more granular figures by vehicle, so fuel consumption statistics were divided evenly among the fleet in terms of emissions produced per bus.

Fuel combustion generates significant GHG emissions. GHG emissions of CO_2, CH_4, and N_2O from diesel and gasoline consumption were quantified; as noted above, fluorinated gases are not produced during fuel combustion, and are omitted. Upstream emissions from diesel and gasoline fuel production are not considered.

The emissions calculations used the following equations and emissions factors from the Intergovernmental Panel on Climate Change (IPCC) and Environment and Climate Change Canada (ECCC):

$$\textit{GHG Emissions} = \textit{Mass or Volume of Fuel} \times \textit{Emission Factor x GWP}$$

[7] Electric Bus FAQ. Plug In Canada. https://www.plugincanada.ca/electric-bus-faq/#:~:text=The%20battery%20will%20be%20used,could%20last%2010%2D20%20years. Published 2021.

The emission factor and GWP from the equation above can be rolled up into a single Weighted Total Emissions Factor. This is presented in **Exhibit 89** below.

The projected annual emissions per diesel/gasoline bus based on the 2021 fleet quantities is presented in **Exhibit 90**.

The projected annual emissions per BEB produced by onboard diesel heaters (in the diesel heating scenario) is presented in **Exhibit 91**.

Exhibit 89: Derivation of Weighted Total Emissions Factors by Fuel Type[8]

Variable	GWP (100 year) (CO_2-eq)	ECCC GHG Emission Factor (kg/kL)	
		Diesel	Gasoline
CO_2	1	2681	2307
CH_4	28	0.073	0.100
N_2O	265	0.020	0.020
Weighted Total Emissions Factor (kg CO_2-eq/kL) (Emission Factor × GWP)		**2688**	**2315**

Exhibit 90: Annual GHG Emissions per Diesel/Gasoline Bus

Variable	Conventional Fleet (Diesel Fuel)		Specialized Fleet (Gasoline Fuel)	
Annual fuel consumption (L)		1,174,218		135,448
Fleet size (vehicles)	÷	31	÷	18
Annual fuel consumption per vehicle (L)	**=**	**37,878**	**=**	**7,525**
Weighted total emissions factor (kg CO_2-eq/kL)	÷	2,688	÷	2,315
Annual Emissions per vehicle (t CO_2-eq)	=	**101.83**	=	**17.42**

Exhibit 91: Projected BEB Onboard Diesel Heater Operation GHG Emissions per Vehicle[9] [10]

Variable	Value	
Fuel consumed by diesel heater per operational hour (L)		2.42
Conventional bus average operational hours per week (hours)	×	48.17
Annual duration that bus heating is required (equivalent weeks of heating at full power)	×	20.00
Total Projected Annual Fuel Consumption per Diesel Heater (L)	**=**	**2,331.43**
Weighted Total Emissions Factor (kg CO_2-eq/kL)	÷	2,688
Annual Emissions per vehicle (t CO_2-eq)	**=**	**6.27**

[8] ECCC, Canada's Greenhouse Gas Quantification Requirements, Version 4, 2021. Gatineau, ON.
[9] "Are buses with a diesel-powered heater true zero-emission buses?," Rupprecht Consult, 13-Dec-2017. [Online]. Available: https://www.rupprecht-consult.eu/news/news-detail/news/are-buses-with-a-diesel-powered-heater-true-zero-emission-buses.html. Accessed: 20-Jan-2022.
[10] F. Vojtisek-Lom, Dittrich, Fenkl, "Title of presentation," Measurement of emissions from independent bus heaters, June 28 – July 1, 2015. https://www.nanoparticles.ch/archive/2015_Fenkl_PO.pdf

7.2.1.3 Electricity Use

BEBs are categorized as zero-emission, as the vehicles produce no GHG emissions from vehicle propulsion at the point of operation (except when onboard diesel heaters are used). However, we have also accounted for the upstream GHG emissions associated with the electricity generation because all electricity generation methods emit GHGs at some point in their life cycle, whether through direct operation (e.g. burning fossil fuels) or through construction and maintenance (all methods). According to the International Energy Agency (IEA), the power sector accounted for nearly two-thirds of global GHG emissions growth in 2018,[11] and the burning of fossil fuels for electricity generation is responsible for over 40% of emissions related to the production and consumption of energy[12]. The GHG emissions resulting from electricity production will be calculated using the value provided by the ECCC's National Inventory Report: 30 g CO_2-eq/kWh[13].

The annual electricity consumed by the BEBs while in operation was calculated based on the weekly energy consumption from the block power requirements findings, scaled over the course of the year to account for fluctuations in HVAC requirements. This intentionally produces a conservative consumption estimate, since the baseline energy consumption values assume heavy passenger volumes and frequent stops. Reduced services on weeks containing holidays or school breaks were not considered.

7.2.1.4 Summary Annual Emissions per Bus

Based on the assumptions, data and calculation procedures outlined in **Section 7.1**, the annual GHG emissions per bus of each bus type and service is outlined in **Exhibit 92** below.

Exhibit 92: Projected Annual GHG Emissions per Bus

Bus Type	Approximate Energy Consumption (Per Bus)		Annual Emissions (t CO_2-eq/bus)		
	Diesel/Gasoline (By Bus Type) (L)	Electricity (kWh)	Manufacturing (Annualized)	Operating	Total
Conventional Transit					
Diesel Bus	37,878	--	7.14	101.83	*108.97*
BEB with Electric Heater	--	120,356	15.63	3.61	*19.24*
BEB with Diesel Heater	998	107,843	15.63	5.93	*21.56*
Specialized Transit (Brantford Lift)					
Gasoline Vehicle	7,525	--	8.69	18.45	*27.14*
BEB	--	26,707	11.19	0.80	*11.89*

[11] "Data overview - IEA", International Energy Agency. [Online]. Available: https://www.iea.org/data-and-statistics.
[12] "Carbon Dioxide Emissions From Electricity", World Nuclear Association. [Online]. Available: https://www.world-nuclear.org/information-library/energy-and-the-environment/carbon-dioxide-emissions-from-electricity.aspx.
[13] Environment and Climate Change Canada, "National inventory report: greenhouse gas sources and sinks in Canada - Part 3", Environment and Climate Change Canada, 2019.

7.2.2 Fleet-Wide Emissions

This section presents the calculated annual GHG emissions for the conventional and specialized fleets as follows:

- Conventional bus replacement using 39 BEBs with electric heaters;
- Conventional bus replacement using 39 BEBs with diesel heaters;
- Specialized vehicle replacement using 14 BEBs with electric heaters (diesel heaters were not considered due to market availability)

Alternative analyses were generated for each fleet replacement timeline introduced in **Section 3**, and following the specific year-by-year fleet replacement timeline alternatives presented in **Section 6.1**. Detailed emissions calculations used in this analysis are provided in Appendix D.

7.2.3 Analysis 1: Conventional BEBs with Electric Heaters

This analysis projects the annual GHG emissions from conventional vehicles for the three alternative implementation timelines if electric heaters are used on BEBs. Estimated emissions are broken down by diesel and BEB fleets in terms of absolute t CO_2-eq and as a percentage of total annual emissions.

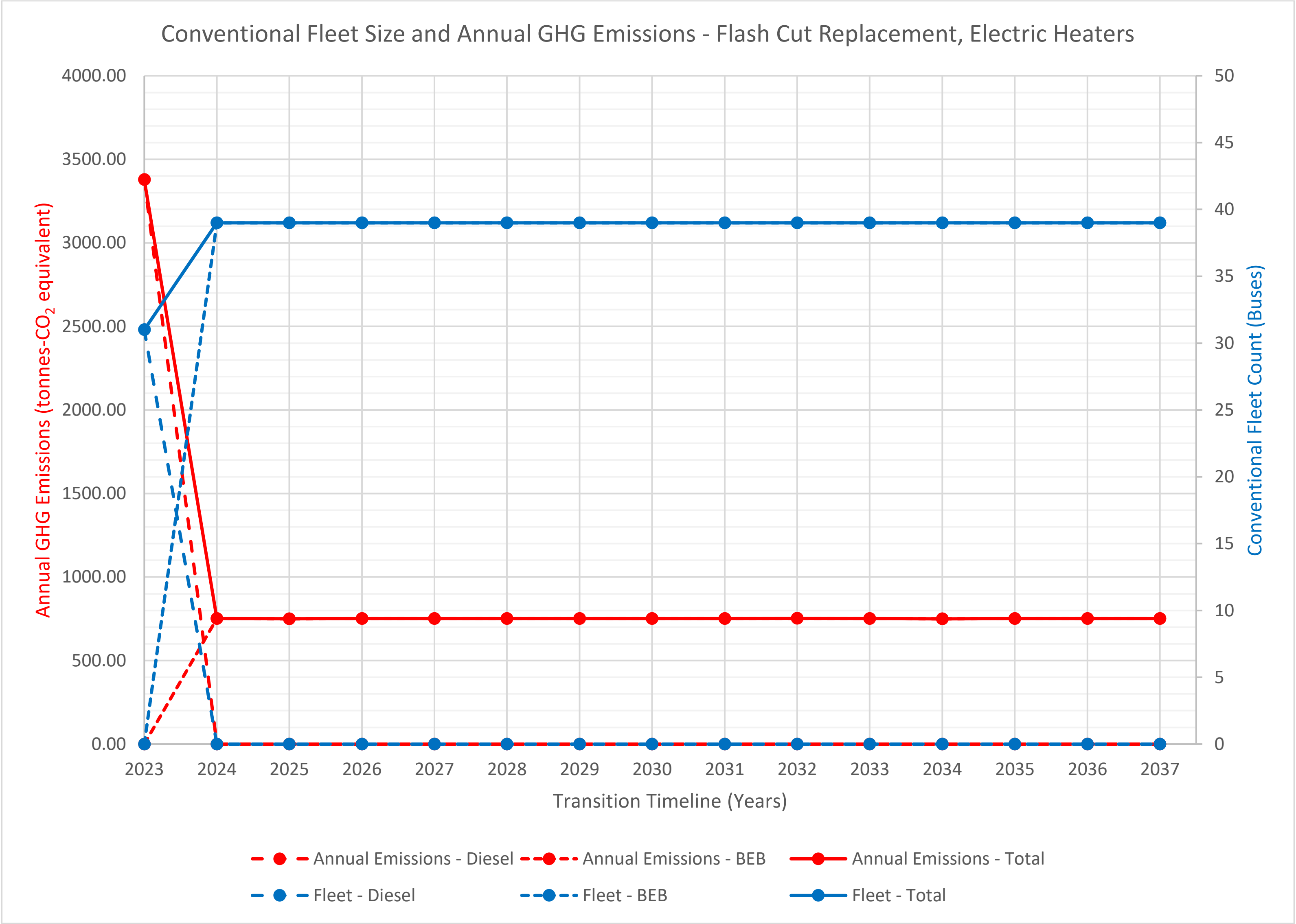
7.2.3.1 Implementation Timeline 1: 2024 Flash Fleet Replacement Timeline

Implementation timeline 1 replaces the current fleet, inclusive of spares, with 39 BEBs in 1 year, 2024, instead of spreading out implementation over multiple years. The emissions analysis is presented in **Exhibit 93** below. **Exhibit 94** depicts how emissions drop upon transition to a BEB fleet.

Exhibit 93: Flash Cut Implementation Timeline Annual GHG Emissions – Conventional BEBs, Electric Heaters

YEAR	FLEET COUNT			ANNUAL EMISSIONS – TOTAL FLEET								
				Diesel Bus Annual Emissions (t CO_2-eq)			BEB Annual Emissions (t CO_2-eq)			Total Annual Emissions (t CO_2-eq)		
	Diesel Vehicles	BEBs	Total Fleet Count	Manufacturing (annualized)	Operating	Diesel Subtotal	Manufacturing (annualized)	Operating	BEB Subtotal	Total Annual Emissions	Percentage Diesel Buses Contribution	Percentage BEB Contribution
2023	31	0	31	221	3157	3378	0	0	0	3378	100%	0%
2024	0	39	39	0	0	0	610	141	751	751	0%	100%
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2037	0	39	39	0	0	0	610	141	751	751	0%	100%
Total	**N/A**	**N/A**	**N/A**	**221**	**3157**	**3378**	**8536**	**1974**	**10510**	**13888**	**24%**	**76%**

Exhibit 94: Correlation between Changes in Fleet Composition and Annual GHG Emissions – Conventional Fleet, Flash Cut Replacement, Electric Heaters



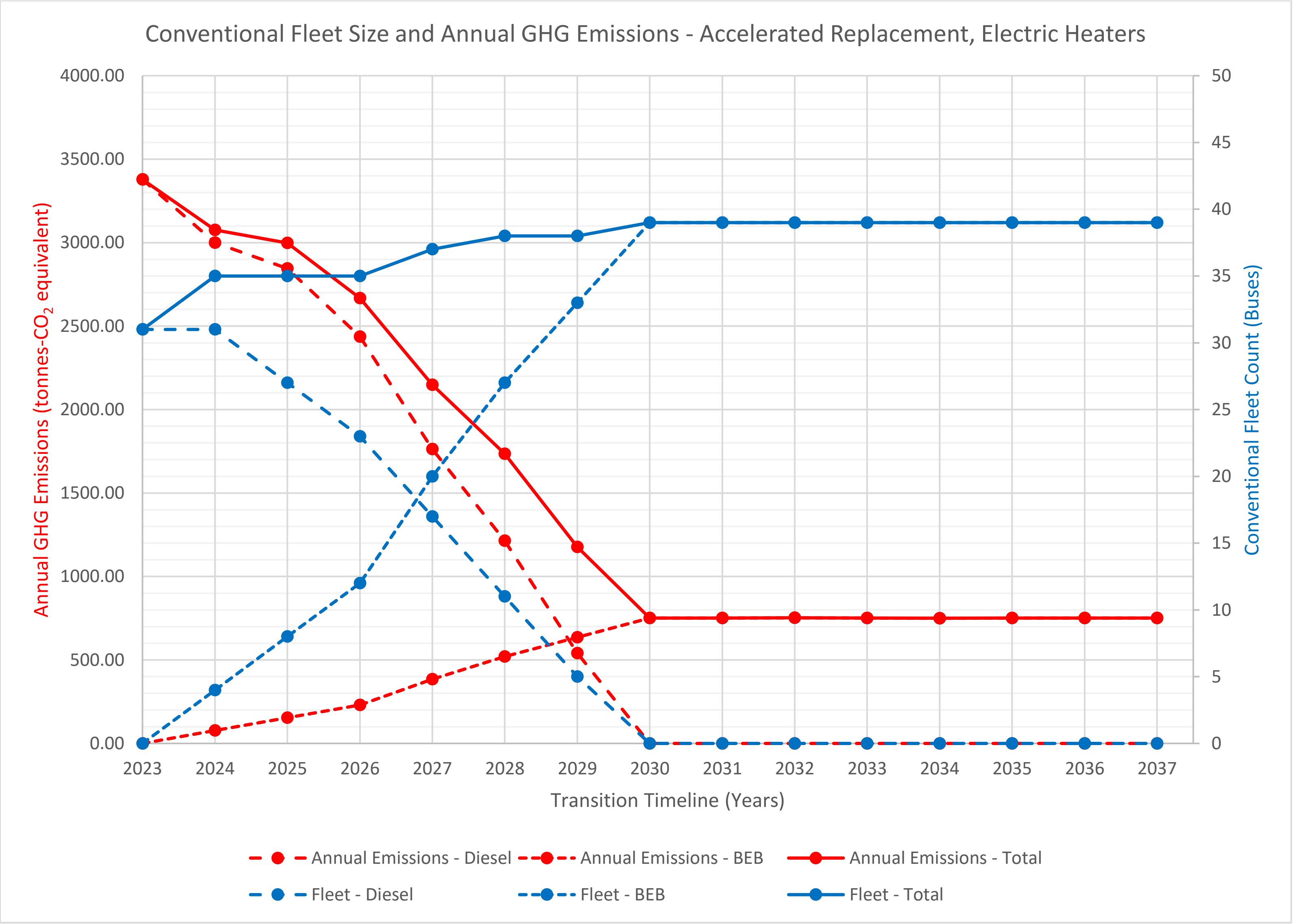
7.2.3.2 Implementation Timeline 2: 2030 Accelerated Fleet Replacement Timeline

Implementation timeline 2 replaces the current fleet with 39 BEBs by 2030. Starting in 2023, BEBs are introduced at a rate of 4 to 8 vehicles per year while diesel vehicles are retired at a rate of 2 to 8 vehicles per year. The emissions analysis is presented in **Exhibit 95** below. **Exhibit 96** depicts how emissions drop as the fleet composition changes.

Exhibit 95: Accelerated Implementation Timeline Annual GHG Emissions – Conventional BEBs, Electric Heaters

YEAR	FLEET COUNT			ANNUAL EMISSIONS – TOTAL FLEET								
				Diesel Bus Annual Emissions (t CO_2-eq)			BEB Annual Emissions (t CO_2-eq)			Total Annual Emissions (t CO_2-eq)		
	Diesel Vehicles	BEBs	Total Fleet Count	Manufacturing (annualized)	Operating	Diesel Subtotal	Manufacturing (annualized)	Operating	BEB Subtotal	Total Annual Emissions	Percentage Diesel Buses Contribution	Percentage BEB Contribution
2023	31	0	31	221	3157	3378	0	0	0	3378	100%	0%
2024	31	4	35	221	2778	2999	63	14	77	3076	97%	3%
2025	27	8	35	193	2652	2844	125	29	154	2998	95%	5%
2026	23	12	35	164	2273	2437	188	43	231	2668	91%	9%
2027	17	20	37	121	1641	1763	313	72	385	2148	82%	18%
2028	11	27	38	79	1136	1215	422	98	520	1735	70%	30%
2029	5	33	38	36	505	541	516	120	635	1176	46%	54%
2030	0	39	39	0	0	0	610	141	751	751	0%	100%
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2037	0	39	39	0	0	0	610	141	751	751	0%	100%
Total	**N/A**	**N/A**	**N/A**	**1036**	**14142**	**15178**	**6503**	**1505**	**8008**	**23186**	**65%**	**35%**

Exhibit 96: Correlation between Changes in Fleet Composition and Annual GHG Emissions – Conventional Fleet, Accelerated Replacement, Electric Heaters



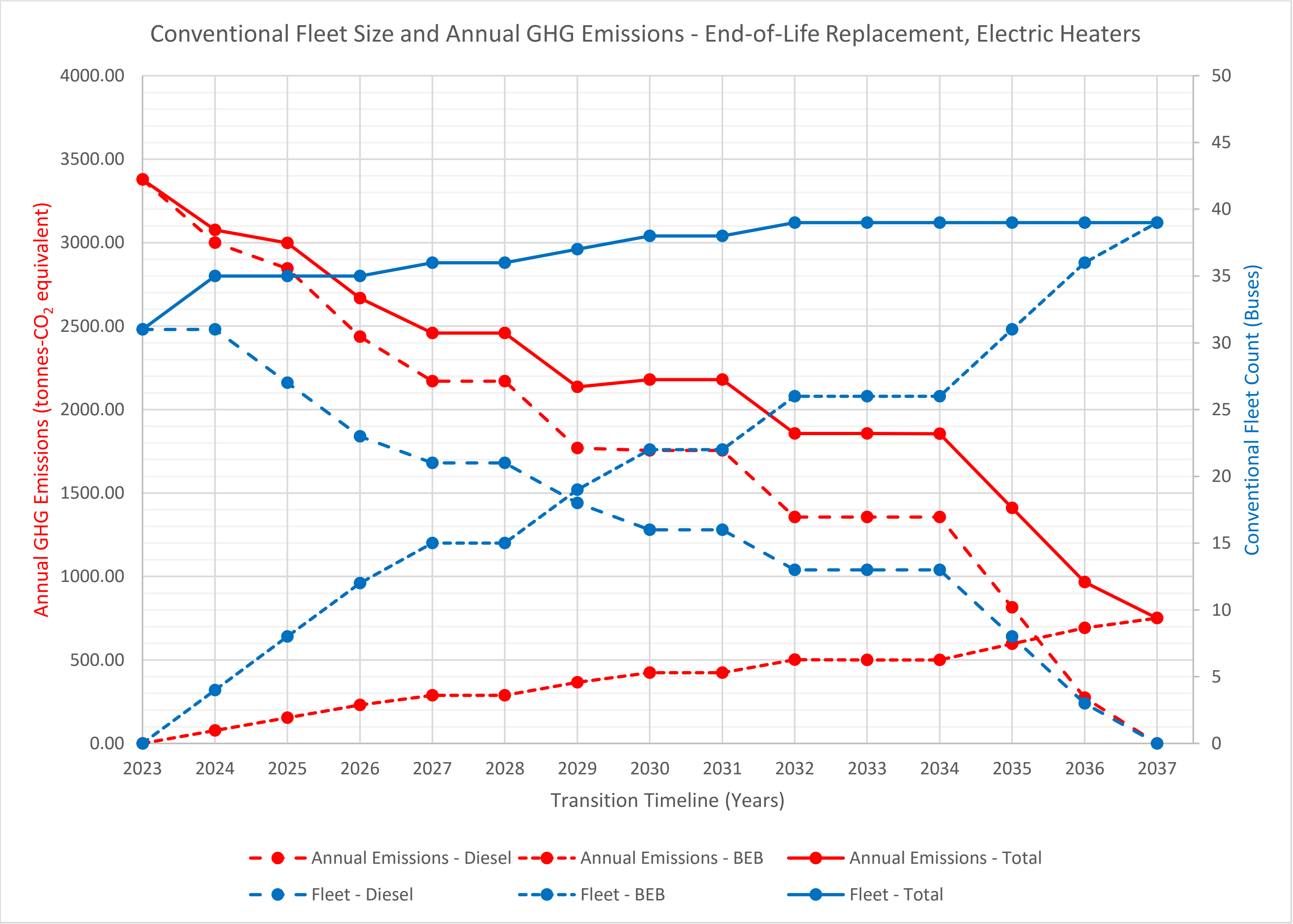
7.2.3.3 Implementation Timeline 3: 2036 End-of-Life Fleet Replacement Timeline

Implementation timeline 3 replaces the current fleet with 39 BEBs, inclusive of spare vehicles, by 2036. Starting in 2023, BEBs are introduced at a rate of 3 to 4 vehicles every 1 to 2 years while diesel vehicles are retired at a rate of 1 to 5 vehicles every 1 to 2 years. The emissions analysis is presented in **Exhibit 97** below. **Exhibit 98** depicts how emissions drop as the fleet composition changes.

Exhibit 97: End-of-Life Implementation Timeline Annual GHG Emissions – Conventional BEBs, Electric Heaters

YEAR	FLEET COUNT			ANNUAL EMISSIONS – TOTAL FLEET								
				Diesel Bus Annual Emissions ($t\ CO_2$-eq)			BEB Annual Emissions ($t\ CO_2$-eq)			Total Annual Emissions ($t\ CO_2$-eq)		
	Diesel Vehicles	BEBs	Total Fleet Count	Manufacturing (annualized)	Operating	Diesel Subtotal	Manufacturing (annualized)	Operating	BEB Subtotal	Total Annual Emissions	Percentage Diesel Buses Contribution	Percentage BEB Contribution
2023	31	0	31	221	3157	3378	0	0	0	3378	100%	0%
2024	31	4	35	221	2778	2999	63	14	77	3076	97%	3%
2025	27	8	35	193	2652	2844	125	29	154	2998	95%	5%
2026	23	12	35	164	2273	2437	188	43	231	2668	91%	9%
2027	21	15	36	150	2020	2170	235	54	289	2459	88%	12%
2028	21	15	36	150	2020	2170	235	54	289	2459	88%	12%
2029	18	19	37	129	1641	1770	297	69	366	2136	83%	17%
2030	16	22	38	114	1641	1756	344	79	423	2179	81%	19%
2031	16	22	38	114	1641	1756	344	80	424	2179	81%	19%
2032	13	26	39	93	1263	1356	406	95	501	1857	73%	27%
2033	13	26	39	93	1263	1356	406	94	501	1856	73%	27%
2034	13	26	39	93	1263	1356	406	94	500	1856	73%	27%
2035	8	31	39	57	758	815	485	112	597	1411	58%	42%
2036	3	36	39	21	253	274	563	130	693	967	28%	72%
2037	0	39	39	0	0	0	610	141	751	751	0%	100%
Total	N/A	N/A	N/A	1814	24622	26437	4706	1088	5794	32231	82%	18%

Exhibit 98: Correlation between Changes in Fleet Composition and Annual GHG Emissions – Conventional Fleet, End-of-Life Replacement, Electric Heaters



7.2.4 Analysis 2: Conventional BEBs with Diesel Heaters

This analysis projects the annual GHG emissions from conventional vehicles for the three alternative implementation timelines if diesel heaters are used on BEBs. Estimated emissions are broken down by diesel and BEB fleets in terms of absolute t CO_2-eq and as a percentage of total annual emissions.

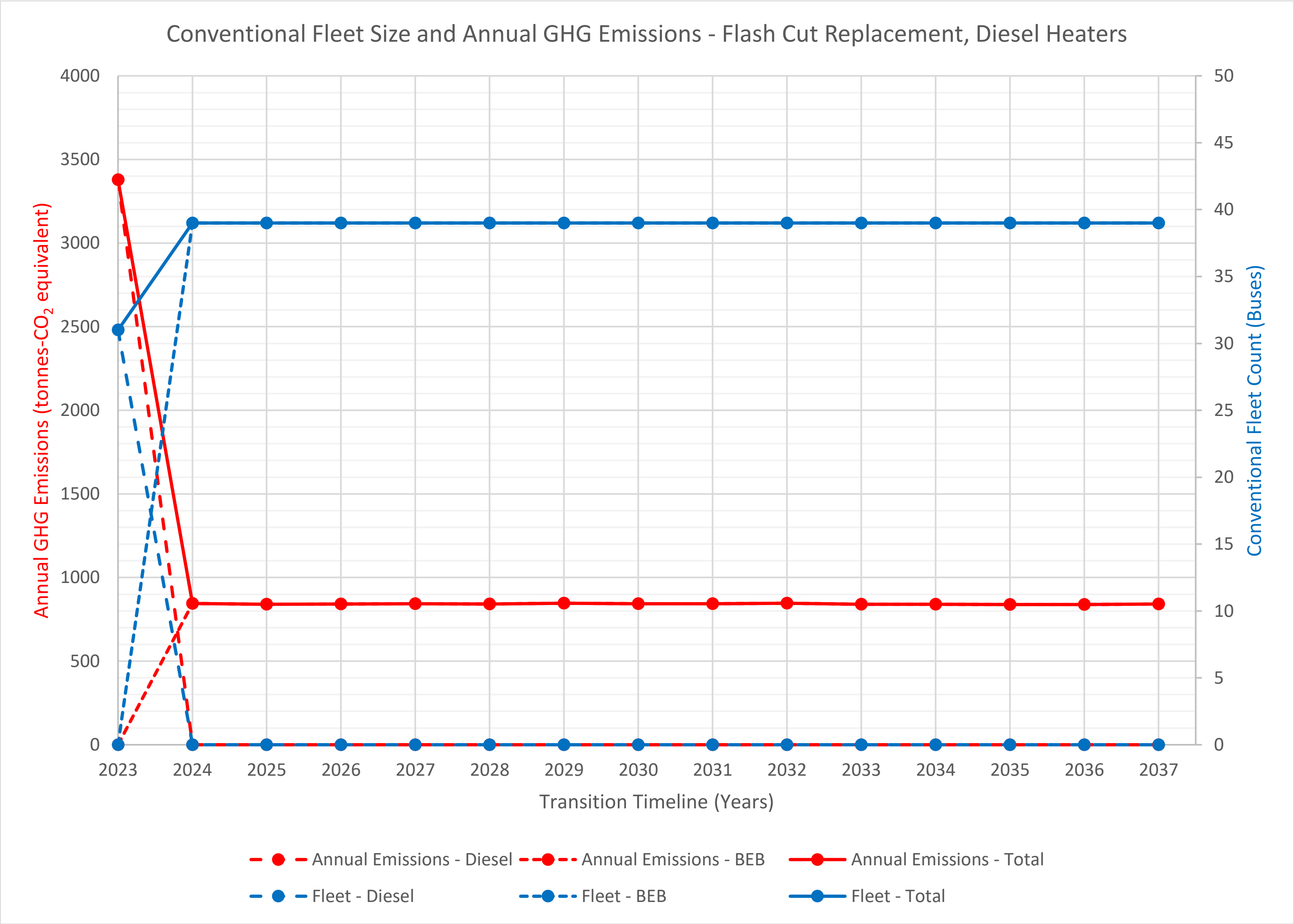
7.2.4.1 Implementation Timeline 1: 2024 Flash Fleet Replacement Timeline

Implementation timeline 1 replaces the current fleet with 39 BEBs, inclusive of spare vehicles in 1 year, 2024, instead of spreading out implementation over multiple years. The emissions analysis is presented in **Exhibit 99** below. **Exhibit 100** depicts how emissions drop upon transition to a BEB fleet.

Exhibit 99: Flash Cut Implementation Timeline Annual GHG Emissions – Conventional BEBs, Diesel Heaters

YEAR	FLEET COUNT			ANNUAL EMISSIONS – TOTAL FLEET										
				Diesel Bus Annual Emissions (t CO_2-eq)			BEB Annual Emissions (t CO_2-eq)				Total Annual Emissions (t CO_2-eq)			
								Operating					Percentage BEB Contribution	
	Diesel Vehicles	BEBs	Total Fleet Count	Manufacturing (annualized)	Operating	Diesel Subtotal	Manufacturing (annualized)	Electric Component	Diesel Heater Component	BEB Subtotal	Total Annual Emissions	Percentage Diesel Buses Contribution	Electric Component (incl. Annualized Manufacturing)	Diesel Heater Component (Operation Only)
2023	31	0	31	221	3157	3378	0	0	0	0	3378	100%	0%	0%
2024	0	39	39	0	0	0	610	126	108	844	844	0%	87%	13%
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2037	0	39	39	0	0	0	610	127	105	841	841	0%	88%	12%
Total	N/A	N/A	N/A	221	3157	3378	8536	1775	1475	11786	15164	22%	68%	10%

Exhibit 100: Correlation between Changes in Fleet Composition and Annual GHG Emissions – Conventional Fleet, Flash Cut Replacement, Diesel Heaters



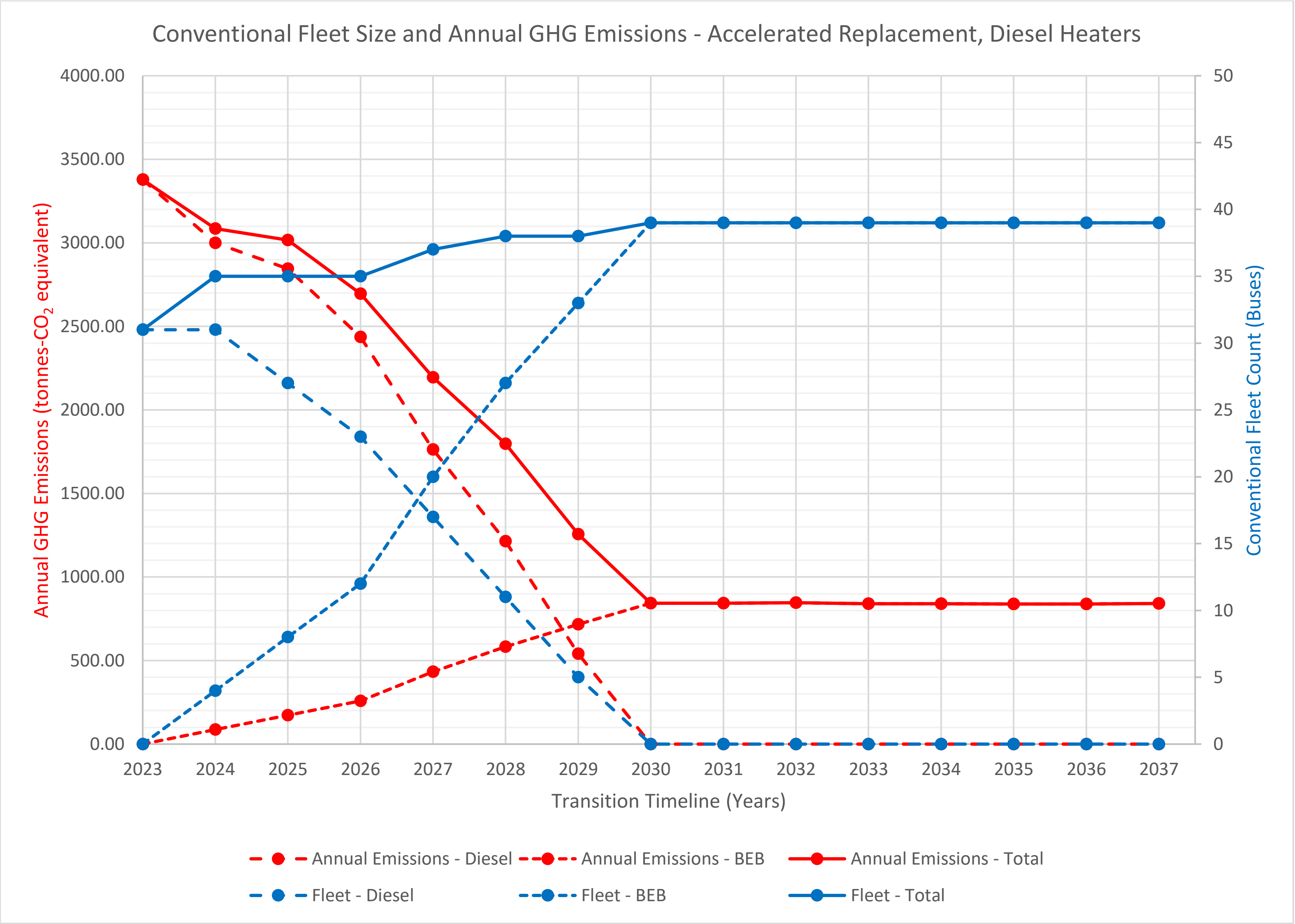
7.2.4.2 Implementation Timeline 2: 2030 Accelerated Fleet Replacement Timeline

Implementation timeline 2 replaces the current fleet with 39 BEBs, inclusive spare vehicles, by 2030. Starting in 2023, BEBs are introduced at a rate of 4 to 8 vehicles per year while diesel vehicles are retired at a rate of 2 to 8 vehicles per year. The emissions analysis is presented in **Exhibit 101** below. **Exhibit 102** depicts how emissions drop as the fleet composition changes.

Exhibit 101: Accelerated Implementation Timeline Annual GHG Emissions – Conventional BEBs, Diesel Heaters

YEAR	FLEET COUNT			ANNUAL EMISSIONS – TOTAL FLEET										
				Diesel Bus Annual Emissions (t CO_2-eq)			BEB Annual Emissions (t CO_2-eq)				Total Annual Emissions (t CO_2-eq)			
								Operating					Percentage BEB Contribution	
	Diesel Vehicles	BEBs	Total Fleet Count	Manufacturing (annualized)	Operating	Diesel Subtotal	Manufacturing (annualized)	Electric Component	Diesel Heater Component	BEB Subtotal	Total Annual Emissions	Percentage Diesel Buses Contribution	Electric Component (incl. Annualized Manufacturing)	Diesel Heater Component (Operation Only)
2023	31	0	31	221	3157	3378	0	0	0	0	3378	100%	0%	0%
2024	31	4	35	221	2778	2999	63	13	11	87	3086	97%	2%	0%
2025	27	8	35	193	2652	2844	125	26	21	172	3017	94%	5%	1%
2026	23	12	35	164	2273	2437	188	39	32	259	2696	90%	8%	1%
2027	17	20	37	121	1641	1763	313	65	55	432	2195	80%	17%	3%
2028	11	27	38	79	1136	1215	422	88	72	582	1797	68%	28%	4%
2029	5	33	38	36	505	541	516	107	93	716	1257	43%	50%	7%
2030	0	39	39	0	0	0	610	127	106	842	842	0%	87%	13%
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2037	0	39	39	0	0	0	610	127	105	841	841	0%	88%	12%
Total	**N/A**	**N/A**	**N/A**	**1036**	**14142**	**15178**	**6503**	**1354**	**1122**	**8979**	**24157**	**63%**	**33%**	**5%**

Exhibit 102: Correlation between Changes in Fleet Composition and Annual GHG Emissions – Conventional Fleet, Accelerated Replacement, Diesel Heaters



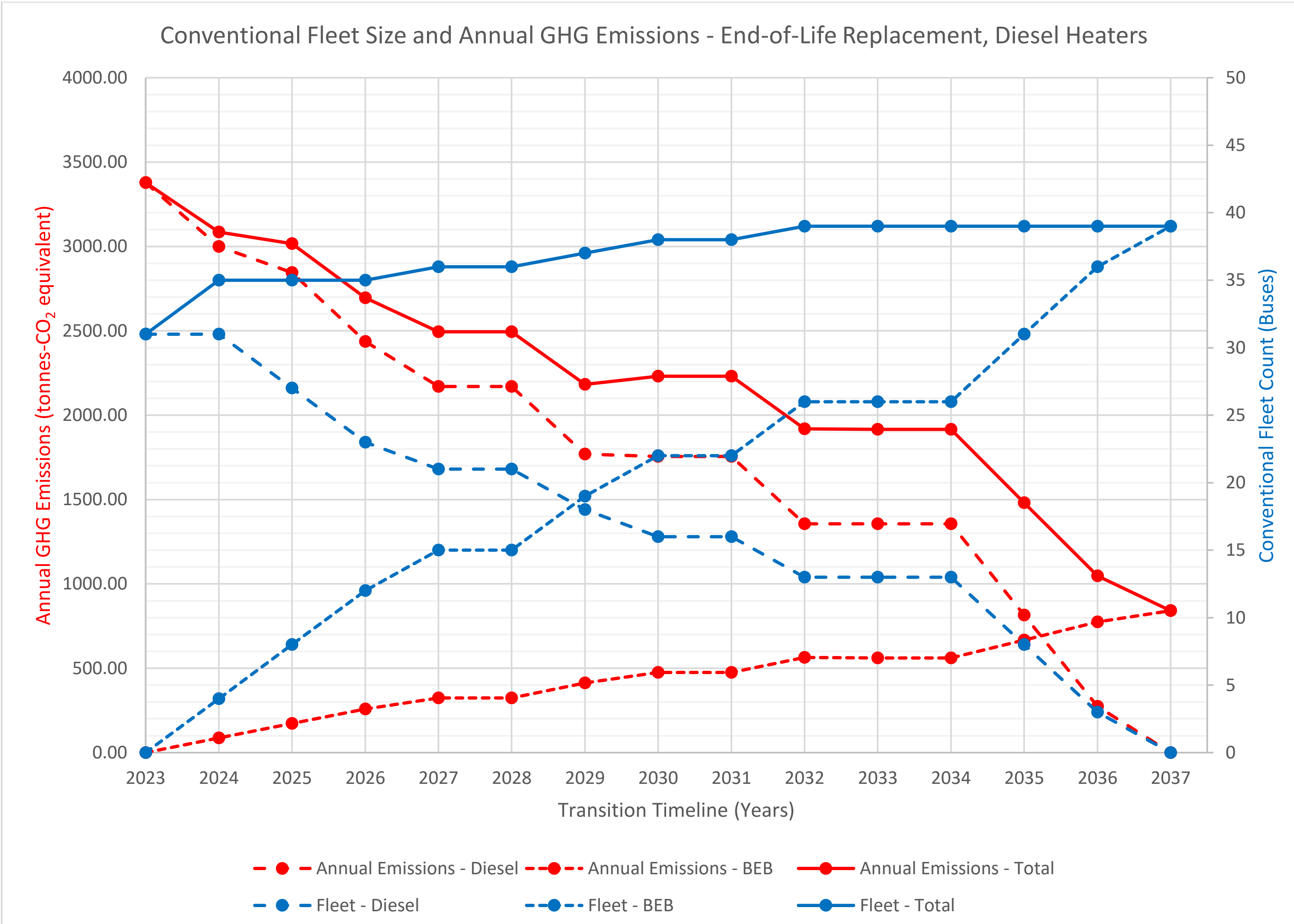
7.2.4.3 Implementation Timeline 3: 2036 End-of-Life Fleet Replacement Timeline

Implementation timeline 3 replaces the current fleet with 39 BEBs, inclusive of spare vehicles by 2036. Starting in 2023, BEBs are introduced at a rate of 3 to 4 vehicles per year while diesel vehicles are retired at a rate of 1 to 5 vehicles every 1 to 2 years. The emissions analysis is presented in **Exhibit 103** below. **Exhibit 104** depicts how emissions drop as the fleet composition changes.

Exhibit 103: End-of-Life Implementation Timeline Annual GHG Emissions – Conventional BEBs, Diesel Heaters

YEAR	FLEET COUNT			ANNUAL EMISSIONS – TOTAL FLEET										
				Diesel Bus Annual Emissions (t CO_2-eq)			BEB Annual Emissions (t CO_2-eq)				Total Annual Emissions (t CO_2-eq)			
								Operating					Percentage BEB Contribution	
	Diesel Vehicles	BEBs	Total Fleet Count	Manufacturing (annualized)	Operating	Diesel Subtotal	Manufacturing (annualized)	Electric Component	Diesel Heater Component	BEB Subtotal	Total Annual Emissions	Percentage Diesel Buses Contribution	Electric Component (incl. Annualized Manufacturing)	Diesel Heater Component (Operation Only)
2023	31	0	31	221	3157	3378	0	0	0	0	3378	100%	0%	0%
2024	31	4	35	221	2778	2999	63	13	11	87	3086	97%	2%	0%
2025	27	8	35	193	2652	2844	125	26	21	172	3017	94%	5%	1%
2026	23	12	35	164	2273	2437	188	39	32	259	2696	90%	8%	1%
2027	21	15	36	150	2020	2170	235	49	41	324	2495	87%	11%	2%
2028	21	15	36	150	2020	2170	235	49	40	324	2494	87%	11%	2%
2029	18	19	37	129	1641	1770	297	62	54	412	2182	81%	16%	2%
2030	16	22	38	114	1641	1756	344	71	60	475	2231	79%	19%	3%
2031	16	22	38	114	1641	1756	344	72	60	475	2231	79%	19%	3%
2032	13	26	39	93	1263	1356	406	85	72	564	1919	71%	26%	4%
2033	13	26	39	93	1263	1356	406	85	69	560	1916	71%	26%	4%
2034	13	26	39	93	1263	1356	406	84	69	560	1916	71%	26%	4%
2035	8	31	39	57	758	815	485	101	81	667	1481	55%	40%	5%
2036	3	36	39	21	253	274	563	117	94	774	1048	26%	65%	9%
2037	0	39	39	0	0	0	610	127	105	841	841	0%	88%	12%
Total	**N/A**	**N/A**	**N/A**	**1814**	**24622**	**26437**	**4706**	**979**	**810**	**6495**	**32931**	**80%**	**17%**	**2%**

Exhibit 104: Correlation between Changes in Fleet Composition and Annual GHG Emissions – Conventional Fleet, End-of-Life Replacement, Diesel Heaters



7.2.5 Analysis 3: Specialized BEBs

This analysis shows the breakdown of the annual GHG emissions from Lift vehicles for each year of the two implementation plans relevant to Lift (2024 flash cut and 2030 end-of-life). All BEBs considered in these implementation scenarios utilize electric heaters, due to market availability. Estimated emissions are broken down by gasoline and BEB fleets in terms of absolute t CO_2-eq and as a percentage of total annual emissions.

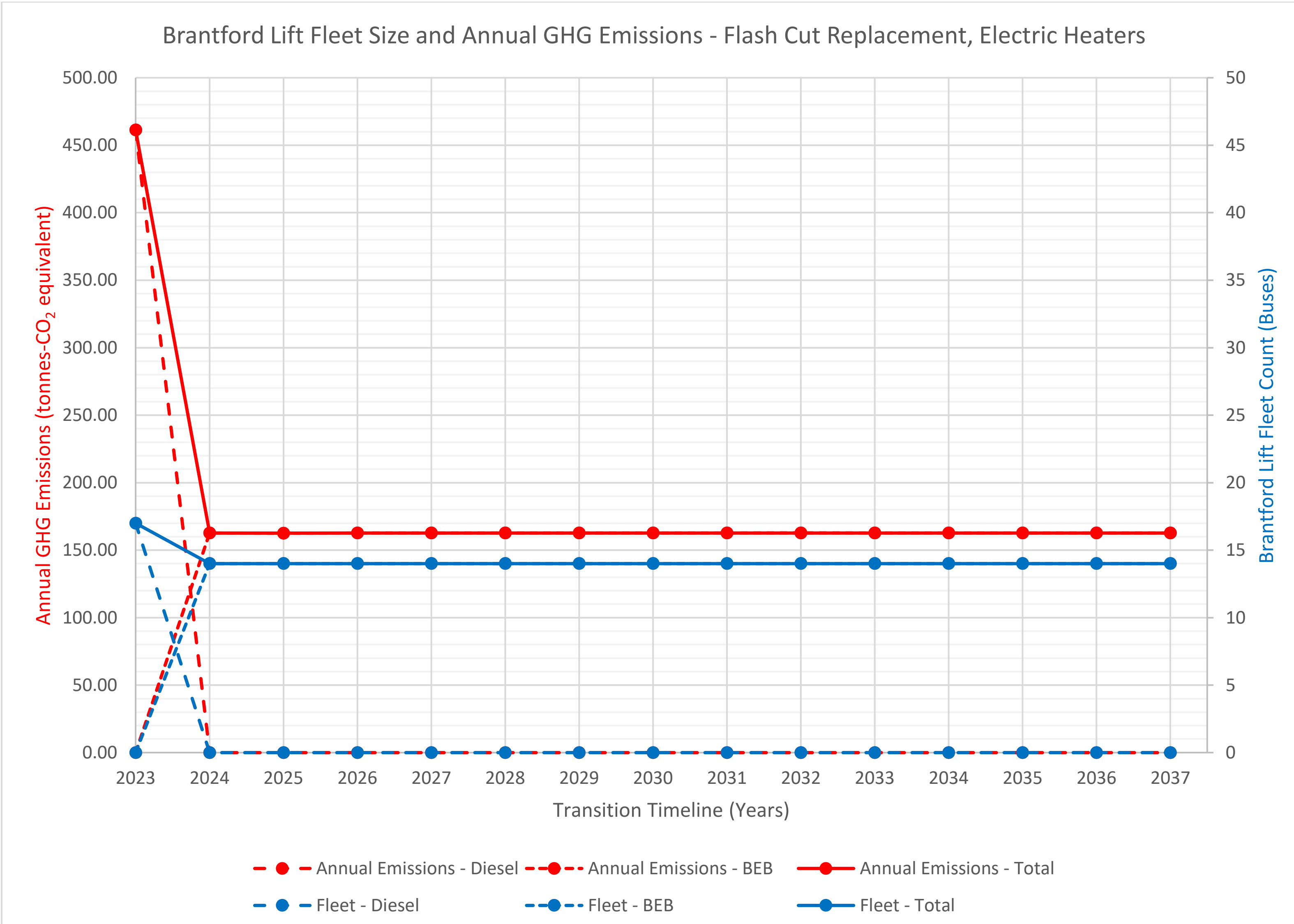
7.2.5.1 Implementation Timeline 1: 2024 Flash Fleet Replacement Timeline

Implementation timeline 1 replaces the current fleet with 14 BEBs in 1 year, 2024, instead of spreading out implementation over multiple years. The emissions analysis is presented in Table 17 below. Lift BEBs produce much less GHG emissions compared to conventional BEBs because Lift bus batteries have 1/6 of the capacity of full-size BEB batteries and utilize less electricity, resulting in lower manufacturing emissions and operating emissions from electricity consumption. The emissions analysis is presented in **Exhibit 105** below. **Exhibit 106** depicts how emissions drop upon transition to a BEB fleet.

Exhibit 105: Flash Cut Implementation Timeline Annual GHG Emissions – Specialized BEBs

YEAR	FLEET COUNT			ANNUAL EMISSIONS – TOTAL FLEET								
				Gasoline Bus Annual Emissions (t CO_2-eq)			BEB Annual Emissions (t CO_2-eq)			Total Annual Emissions (t CO_2-eq)		
	Gasoline Vehicles	BEBs	Total Fleet Count	Manufacturing (annualized)	Operating	Gasoline Subtotal	Manufacturing (annualized)	Operating	BEB Subtotal	Total Annual Emissions	Percentage Gasoline Buses Contribution	Percentage BEB Contribution
2023	17	0	17	148	314	461	0	0	0	461	100%	0%
2024	0	14	14	0	0	0	151	11	163	163	0%	100%
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2037	0	14	14	0	0	0	151	11	163	163	0%	100%
Total	**N/A**	**N/A**	**N/A**	**148**	**314**	**461**	**2120**	**157**	**2277**	**2738**	**17%**	**83%**

Exhibit 106: Correlation between Changes in Fleet Composition and Annual GHG Emissions – Specialized Fleet, Flash Cut Replacement



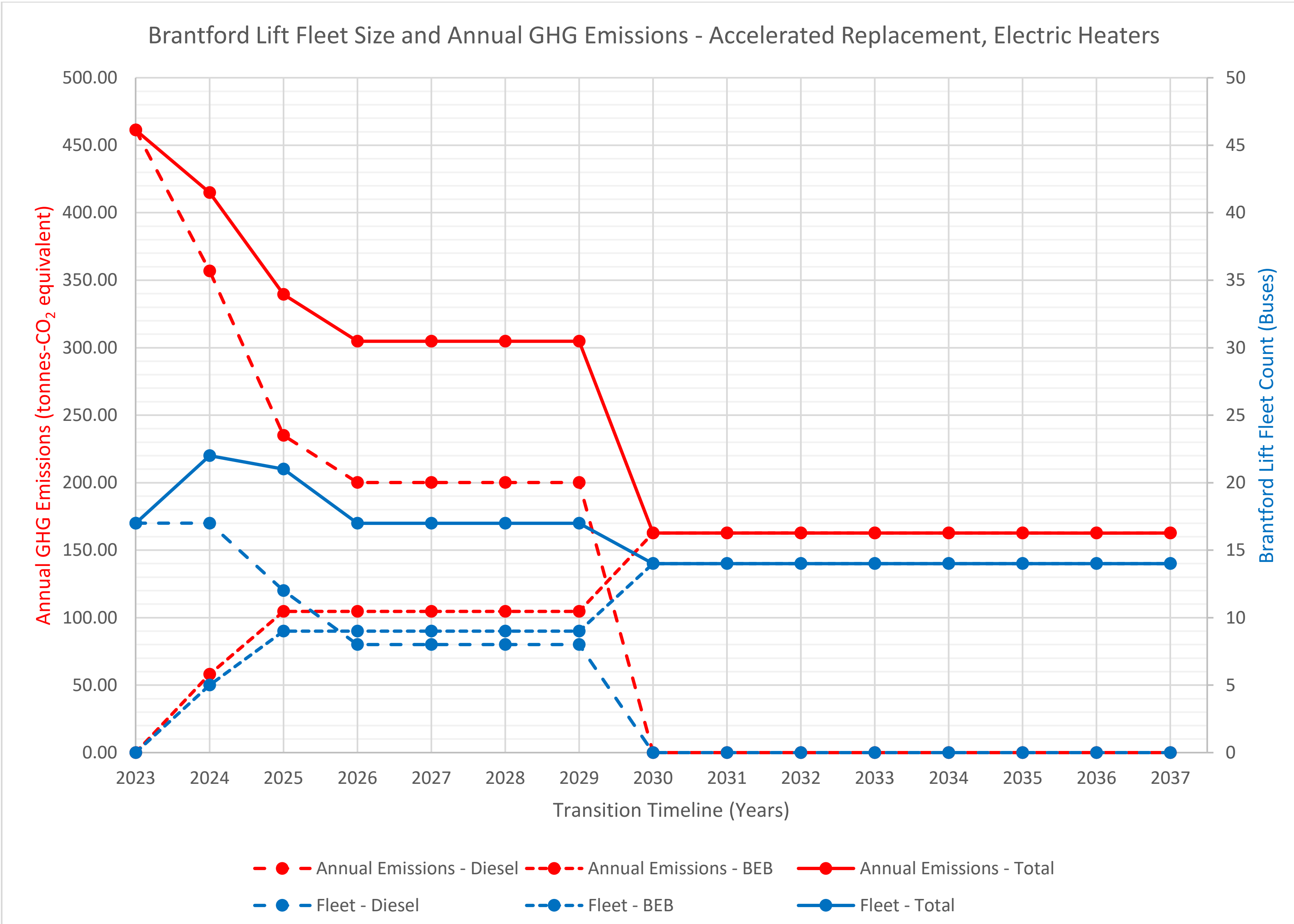
7.2.5.2 Implementation Timeline 2: 2030 End-of-Life Fleet Replacement Timeline

Implementation timeline 2 replaces the current fleet with 14 BEBs by 2030. Starting in 2022, BEBs are introduced at a rate of 2 to 4 vehicles every 1 to 3 years while diesel vehicles are retired at a rate of 2 to 6 vehicles every 1 to 2 years. The emissions analysis is presented in **Exhibit 107** below. **Exhibit 108** depicts how emissions drop as the fleet composition changes.

Exhibit 107: End-of-Life Implementation Timeline Annual GHG Emissions – Specialized BEBs

YEAR	FLEET COUNT			ANNUAL EMISSIONS – TOTAL FLEET								
				Gasoline Bus Annual Emissions (t CO_2-eq)			BEB Annual Emissions (t CO_2-eq)			Total Annual Emissions (t CO_2-eq)		
	Gasoline Vehicles	BEBs	Total Fleet Count	Manufacturing (annualized)	Operating	Gasoline Subtotal	Manufacturing (annualized)	Operating	BEB Subtotal	Total Annual Emissions	Percentage Gasoline Buses Contribution	Percentage BEB Contribution
2023	17	0	17	148	314	461	0	0	0	461	100%	0%
2024	17	5	22	148	209	357	54	4	58	415	86%	14%
2025	12	9	21	104	131	235	97	7	105	339	69%	31%
2026	8	9	17	70	131	200	97	7	105	305	66%	34%
2027	8	9	17	70	131	200	97	7	105	305	66%	34%
2028	8	9	17	70	131	200	97	7	105	305	66%	34%
2029	8	9	17	70	131	200	97	7	105	305	66%	34%
2030	0	14	14	0	0	0	151	11	163	163	0%	100%
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2037	0	14	14	0	0	0	151	11	163	163	0%	100%
Total	N/A	N/A	N/A	678	1176	1854	1752	130	1882	3736	50%	50%

Exhibit 108: Correlation between Changes in Fleet Composition and Annual GHG Emissions – Specialized Fleet, End-of-Life Replacement



7.3 Environmental Assessment Findings

Within each heating scenario, all fleet replacement options effectively involve transitioning from the same initial state to the same final, in terms of typical annual emissions, with electric heating producing fewer annual GHG emissions (total and at the tailpipe) post-transition.

It is important to restate that these projections are based on an assumption that Brantford Transit would sell diesel/gasoline vehicles to other transit systems if they are not yet at economic end-of-life, which would allow Brantford to externalize the remaining annualized manufacturing emissions after sale. If diesel/gasoline buses could not be resold to other transit systems after early retirement, the annualized embodied emissions from their production would be significantly higher, reducing the benefit of an earlier transition.

The projected annualized GHG emissions of each fleet type before and after transition is presented in **Exhibit 109** below, including each alternative heating scenario for conventional BEBs.

Exhibit 109: Summary of Projected Annual Emissions by Fleet Type before and after-Transition

Bus Fleet	Projected Annual GHG Emissions (t CO_2-eq)			
	Manufacturing (Annualized)	Operating		Total
		Electricity	Diesel/ Gasoline	
Conventional Transit				
31 Buses, Diesel Fuelled (2022)	221	--	3157	3378
39 BEBs, Electric Heaters (Post-Transition)	610	141	--	751
39 BEBs, Diesel Heaters (Post-Transition)	610	126	105	844
Specialized Transit (Brantford Lift)				
18 Vehicles, Gasoline Fuelled (2022)	156	--	332	488
14 Battery-Electric Vehicles (Post-Transition)	151	11	--	163

A head-to-head comparison of the total projected GHG emissions from all 6 transition scenarios (when conventional and Lift fleets are combined) and a business-as-usual case is presented in **Exhibit 110** (table) and **Exhibit 111** (graphed).

A similar comparison depicting only operating emissions is presented in **Exhibit 112** (table) and **Exhibit 113** (graphed) below. Notable in this comparison, the selection of heating method for conventional buses has the largest impact on future operating emissions, with diesel heaters resulting in approximately 60% higher annual operating emissions than electric heaters.

Exhibit 110: Head-to-Head Comparison of Annual GHG Emissions (Manufacturing and Operating, t CO_2-eq, rounded to 10s) for All Transition Scenarios

Year	Business as Usual	With Electric-Heated Conventional BEBs			With Diesel-Heated Conventional BEBs		
		End-of-Life Replacement	Accelerated Replacement	Flash Cut Replacement	End-of-Life Replacement	Accelerated Replacement	Flash Cut Replacement
2023	3839	3839	3839	3839	3839	3839	3839
2024	3839	3491	3491	913	3501	3501	1007
2025	3839	3338	3338	913	3356	3356	1002
2026	3839	2973	2973	913	3001	3001	1004
2027	3839	2764	2453	913	2799	2500	1006
2028	3839	2764	2040	913	2799	2102	1004
2029	3839	2441	1481	914	2487	1562	1009
2030	3839	2342	913	913	2394	1005	1005
2031	3839	2342	914	914	2394	1005	1005
2032	3839	2020	915	915	2082	1009	1009
2033	3839	2019	913	913	2078	1003	1003
2034	3839	2018	913	913	2078	1003	1003
2035	3839	1574	913	913	1644	1001	1001
2036	3839	1129	913	913	1211	1001	1001
2037	3839	913	913	913	1004	1004	1004
Total	**57591**	**35966**	**26922**	**16626**	**36667**	**27892**	**17903**

Exhibit 111: Progression of Annual GHG Emissions (Manufacturing and Operating, t CO_2-eq) under each Transition Scenario (combined Conventional and Lift)

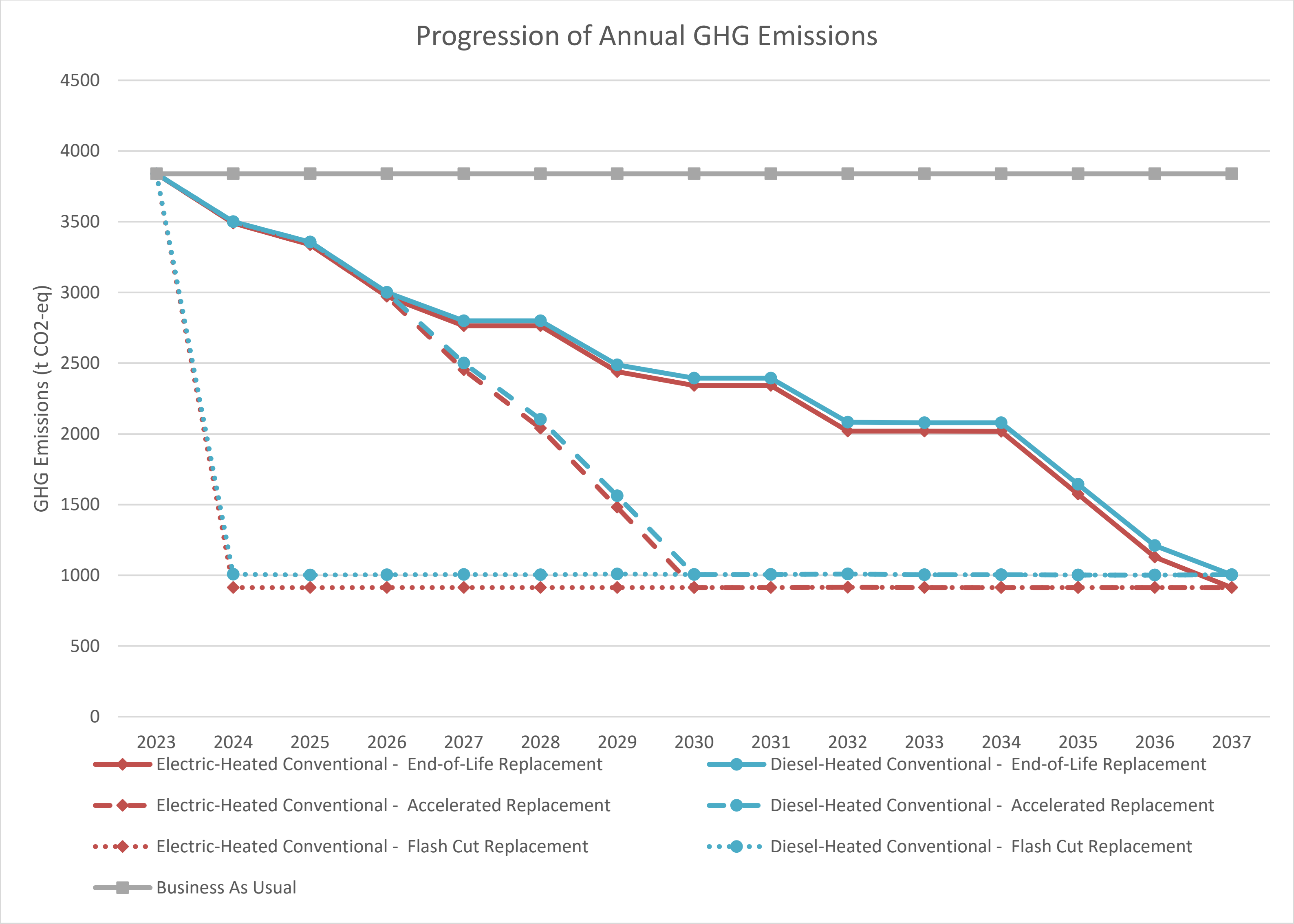
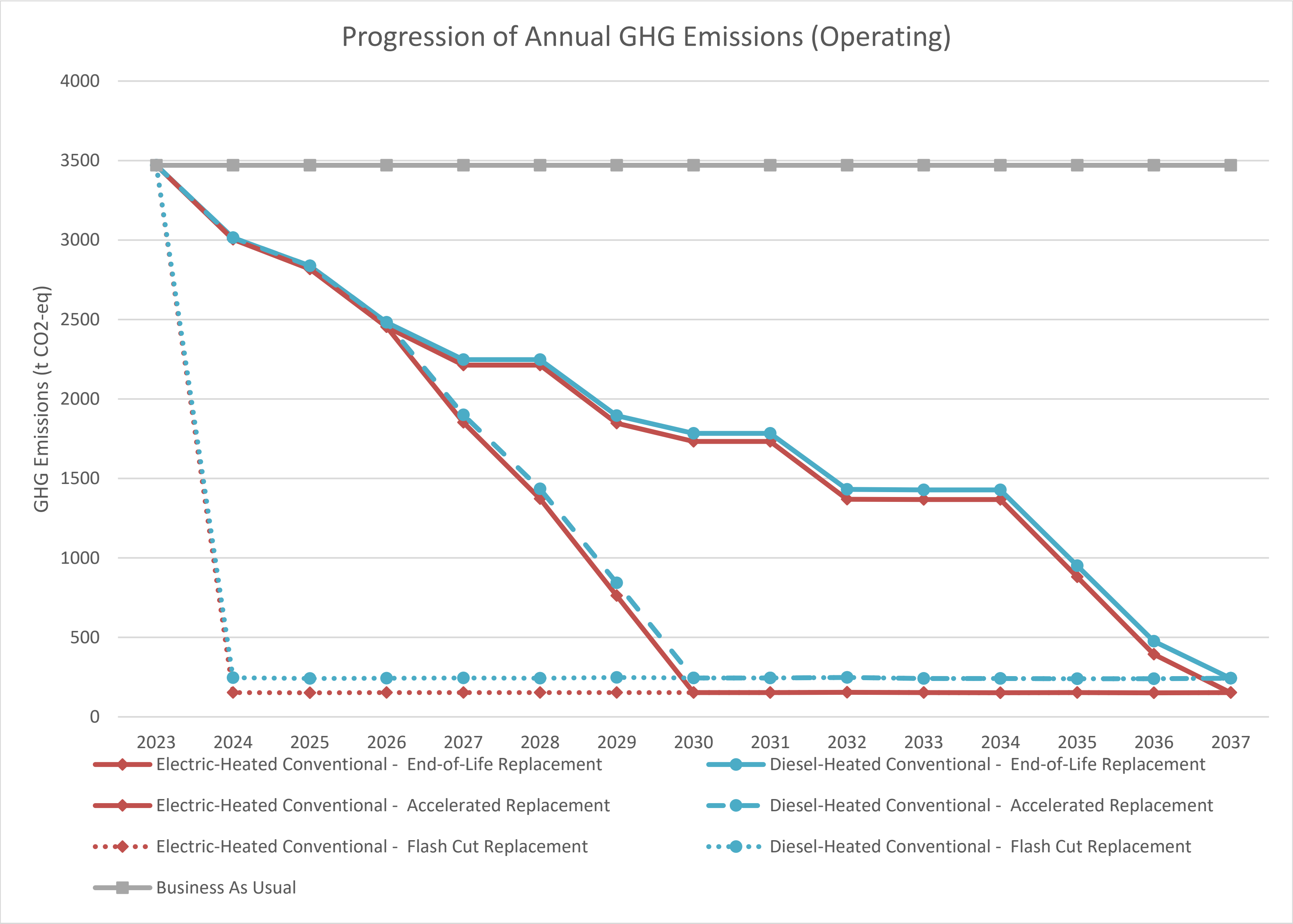


Exhibit 112: Head-to-Head Comparison of Annual GHG Emissions (Operating Only, t CO_2-eq, rounded to 10s) for All Transition Scenarios

Year	Business as Usual	With Electric-Heated Conventional BEBs			With Diesel-Heated Conventional BEBs		
		End-of-Life Replacement	Accelerated Replacement	Flash Cut Replacement	End-of-Life Replacement	Accelerated Replacement	Flash Cut Replacement
2023	3470	3470	3470	3470	3470	3470	3470
2024	3470	3005	3005	152	3015	3015	246
2025	3470	2818	2818	151	2837	2837	241
2026	3470	2454	2454	152	2482	2482	242
2027	3470	2212	1852	152	2248	1899	245
2028	3470	2212	1372	152	2247	1435	243
2029	3470	1848	762	153	1895	843	248
2030	3470	1732	152	152	1784	244	244
2031	3470	1732	152	152	1784	244	244
2032	3470	1369	154	154	1431	248	248
2033	3470	1368	152	152	1428	242	242
2034	3470	1368	152	152	1428	242	242
2035	3470	881	152	152	951	240	240
2036	3470	394	152	152	475	240	240
2037	3470	152	152	152	243	243	243
Total	**52054**	**27017**	**16953**	**5601**	**27717**	**17923**	**6878**

Exhibit 113: Progression of Annual GHG Emissions (Operating Only, t CO_2-eq) under each Transition Scenario (combined Conventional and Lift)



Operating emissions were confirmed to be significantly lower for a BEB fleet than a diesel/gasoline bus fleet. This is largely due to the relatively clean composition of Ontario's electricity supply mix. Although annualized manufacturing emissions are projected to be much higher for the future BEB fleet than the existing diesel fleet (due to the increased fleet size and battery production impacts), this is more than fully offset by operating emissions reductions. Projected emissions reductions are summarized in **Exhibit 114** below.

Exhibit 114: Projected GHG Emissions Reductions from BEB Transition

BEB Fleet	Projected Annual Total GHG Emissions Reduction from Diesel/Gasoline Vehicles	
	Operating Only	Total
39 Conventional BEBs, Electric Heaters	96%	78%
39 Conventional BEBs, Diesel Heaters	93%	75%
14 Specialized BEBs at Maximum Projected Energy Consumption	96%	65%

From the perspective of relative impacts of each fleet type, for both conventional and specialized vehicles, even at a point in the transition when diesel/gasoline vehicles make up around 25% of the fleet, they continue to contribute between 50% to 60% of total emissions. The disproportionate ratio between the GHG impact of diesel and gasoline vehicles to BEBs highlights the positive projected environmental impact of a BEB fleet transition. **Exhibit 115** summarizes the total GHG emissions accumulated in each implementation timeline from 2021 to 2036 inclusive.

Exhibit 115: Total GHG emissions accumulated in each implementation timeline from 2024 to 2037 inclusive.

Transition Scenario	Year of Complete Transition	Total Emissions to 2037 (t CO_2-eq)		
		Diesel/Gasoline Vehicles	BEBs	Total
Conventional BEBs with Electric Heaters	2024	3,378	10,510	13,888
	2030	15,178	8,008	23,186
	2037	26,437	5,794	32,231
Conventional BEBs with Diesel Heaters	2024	3,378	11,786	15,164
	2030	15,178	8,979	24,157
	2037	26,437	6,495	32,931
Specialized Transit BEBs	2024	461	2,277	2,738
	2030	1,854	1,882	3,736

8 Cost of Ownership

8.1 Capital Costs

8.1.1 In-Scope Items and Unit Costs

In-scope capital cost items are presented in **Exhibit 116**, along with unit cost estimates. These estimates are based on a combination of academic and industry research and observed costs from past IBI Group projects.

Exhibit 116: Capital Cost Items and Estimated Unit Costs (CAD)

Item	Purchase Unit Cost	Installation Unit Cost	Total Unit Cost (Rounded up to 000s)
Vehicles			
Conventional BEB (Body)	$ 648,960	$ -	$ 649,000
Conventional BEB (Battery)	$ 540,000	$ -	$ 540,000
Specialized BEB (combined body and battery)	$ 390,000	$ -	$ 390,000
Charger Infrastructure			
Power conversion cabinet	$ 66,500	$ 19,700	$ 67,000
Plug-in dispenser (150 kW)	$ 16,000	$ 8,000	$ 16,000
Plug-in dispenser (50 kW)	$ 33,500	$ 8,000	$ 34,000
Charge Management System	$ 180,000	$ 170,000	$ 180,000
Electrical Supply System Upgrades	$ 180,000	$ 65,000	$ 180,000

While these costs are likely to shift as electrification becomes more widespread, the net change in cost will be influenced by countervailing factors. Typically, cost evolution seen in new technology adoption trends downward, benefitting the purchaser. However, the rapidly escalating pressure on many transit systems and other industries to adopt electric vehicle technology in support of emissions reduction targets may contribute to capital costs remaining higher than in an adoption scenario driven purely by innovation. Supply chain challenges associated with every production step from raw material extraction/recycling to manufacturing and delivery are likely to be implicated in this. Construction costs are also liable to increase as part of a general escalation in cost-of-living in southern Ontario.

8.1.2 Capital Cost of Ownership

Based on the alternative capital investment timelines presented in **Section 6.1.1**, a summarized comparison of the annual capital costs of each electrification option and a Business-as-Usual case through 2037 is presented in **Exhibit 117**, including only costs for first-generation equipment and vehicle purchases. A similar comparison showing costs including first- and second-generation purchases is presented in **Exhibit 118** below.

Exhibit 117: Capital Cost of Ownership – Cash Flow Comparison to 2037
(2023 Present Value, First Generation Purchases Only)

Year	Business as Usual	Alternative 1a (SC/ER)	Alternative 1b (SC/AR)	Alternative 1c (SC/FR)	Alternative 2a (BC/ER)	Alternative 2b (BC/AR)	Alternative 2c (BC/FR)	Alternative 3a (OC/ER)	Alternative 3b (OC/AR)	Alternative 3c (OC/FR)
2024	$ 2,748	$ 7,102	$ 7,102	$ 53,679	$ 7,102	$ 7,102	$ 53,199	$ 7,054	$ 7,054	$ 53,151
2025	$ 758	$ 6,583	$ 6,583	$ -	$ 6,583	$ 6,583	$ -	$ 6,511	$ 6,511	$ -
2026	$ 3,202	$ 4,939	$ 4,939	$ -	$ 4,939	$ 4,939	$ -	$ 4,756	$ 4,756	$ -
2027	$ 1,298	$ 3,567	$ 9,965	$ -	$ 3,567	$ 9,599	$ -	$ 3,678	$ 9,623	$ -
2028	$ -	$ -	$ 8,506	$ -	$ -	$ 8,584	$ -	$ -	$ 8,656	$ -
2029	$ 1,947	$ 5,209	$ 7,317	$ -	$ 4,843	$ 7,221	$ -	$ 4,867	$ 7,356	$ -
2030	$ 2,510	$ 5,517	$ 9,267	$ -	$ 5,691	$ 9,171	$ -	$ 5,628	$ 9,195	$ -
2031	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2032	$ 1,947	$ 4,939	$ -	$ -	$ 4,843	$ -	$ -	$ 4,867	$ -	$ -
2033	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2034	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2035	$ 3,245	$ 6,128	$ -	$ -	$ 6,032	$ -	$ -	$ 6,056	$ -	$ -
2036	$ 3,245	$ 6,128	$ -	$ -	$ 6,032	$ -	$ -	$ 6,167	$ -	$ -
2037	$ 1,947	$ 3,567	$ -	$ -	$ 3,567	$ -	$ -	$ 3,567	$ -	$ -
Total	**$ 22,847**	**$ 53,679**	**$ 53,679**	**$ 53,679**	**$ 53,199**	**$ 53,199**	**$ 53,199**	**$ 53,151**	**$ 53,151**	**$ 53,151**

Exhibit 118: Capital Cost Projection – Cash Flow Comparison, 2024-2037
(First- and Second-Generation Purchases, 2023 Present Value, 000s)

Year	Business as Usual	Alternative 1a (SC/ER)	Alternative 1b (SC/AR)	Alternative 1c (SC/FR)	Alternative 2a (BC/ER)	Alternative 2b (BC/AR)	Alternative 2c (BC/FR)	Alternative 3a (OC/ER)	Alternative 3b (OC/AR)	Alternative 3c (OC/FR)
2024	$ 2,748	$ 7,102	$ 7,102	$ 53,679	$ 7,102	$ 7,102	$ 53,199	$ 7,054	$ 7,054	$ 53,151
2025	$ 758	$ 6,583	$ 6,583	$ -	$ 6,583	$ 6,583	$ -	$ 6,511	$ 6,511	$ -
2026	$ 3,202	$ 4,939	$ 4,939	$ -	$ 4,939	$ 4,939	$ -	$ 4,756	$ 4,756	$ -
2027	$ 1,298	$ 3,567	$ 9,965	$ -	$ 3,567	$ 9,599	$ -	$ 3,678	$ 9,623	$ -
2028	$ -	$ -	$ 8,506	$ -	$ -	$ 8,584	$ -	$ -	$ 8,656	$ -
2029	$ 1,947	$ 5,209	$ 7,317	$ -	$ 4,843	$ 7,221	$ -	$ 4,867	$ 7,356	$ -
2030	$ 2,510	$ 5,517	$ 9,267	$ -	$ 5,691	$ 9,171	$ -	$ 5,628	$ 9,195	$ -
2031	$ 152	$ 1,950	$ 1,950	$ 5,460	$ 1,950	$ 1,950	$ 5,460	$ 1,950	$ 1,950	$ 5,460
2032	$ 2,704	$ 6,499	$ 1,560	$ -	$ 6,403	$ 1,560	$ -	$ 6,427	$ 1,560	$ -
2033	$ 606	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2034	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2035	$ 3,245	$ 6,128	$ -	$ -	$ 6,032	$ -	$ -	$ 6,056	$ -	$ -
2036	$ 3,245	$ 10,884	$ 4,756	$ 46,371	$ 10,788	$ 4,756	$ 46,371	$ 10,923	$ 4,756	$ 46,371
2037	$ 3,159	$ 10,273	$ 6,706	$ -	$ 10,273	$ 6,706	$ -	$ 10,273	$ 6,706	$ -
Total	**$ 25,574**	**$ 68,651**	**$ 68,651**	**$ 105,510**	**$ 68,171**	**$ 68,171**	**$ 105,030**	**$ 68,123**	**$ 68,123**	**$ 104,982**

8.2 Operating Costs

8.2.1 In-Scope Items and Unit Costs

In-scope operating cost items are presented in **Exhibit 119**, along with unit cost estimates. These estimates are based on a combination of existing Brantford Transit data, Collective Agreements, academic and industry research, and observed costs from past IBI Group projects. Specific sources of each value are noted.

Exhibit 119: Operating Cost Items and Estimated Unit Costs (2023 Present Value)

Item	Rate (CAD)	Per Unit
Maintenance and Energy		
Legacy Fleet (Combined Labour, Fuel, Parts and Material)[14]	$ 68,960.20	vehicle-year
Conventional BEB Maintenance[15]	$ 0.12	km
Specialized BEB Maintenance[2]	$ 0.12	km
Electricity	(variable)*	kWh
Driving		
Driving in service and shuttling in depot (fully burdened, 1.4 multiplier)[16]	$ 46.48	h

*Electricity pricing is based on various factors related to time-of-use and peak consumption, and is therefore discussed separately

While these costs are likely to shift as electrification becomes more widespread, the net change in cost will be influenced by countervailing factors. Typically, cost evolution seen in new technology adoption trends downward, benefitting the purchaser. However, the rapidly escalating pressure on many transit systems and other industries to adopt electric vehicle technology in support of emissions reduction targets may contribute to capital costs remaining higher than in an adoption scenario driven purely by innovation. Supply chain challenges associated with every production step from raw material extraction/recycling to manufacturing and delivery are likely to be implicated in this. Construction costs are also liable to increase as part of a general escalation in cost-of-living in southern Ontario.

8.2.1.1 Electricity Costs

All discussion of electricity pricing assumes that Brantford Transit chooses to obtain its electricity from the local utility (currently Brantford Power, Inc.; rebranding as GrandBridge Energy) under the Independent Electricity System Operator (IESO) for Ontario, rather than enter into a private retailer contract.

One of the most important drivers for operating costs will be Brantford Transit's ability to plan around electricity pricing trends, and to manage power consumption accordingly. When optimally managed, electricity on average is a much less expensive energy source for bus propulsion than

[14] Data provided by the City of Brantford, escalated to 2023
[15] Foothill Transit Battery Electric Bus Demonstration Results: Second Report. https://www.nrel.gov/docs/fy17osti/67698.pdf
[16] Based on rate data from the Collective Agreement between the Corporation of the City of Brantford and the Amalgamated Transit Union Local 685

fossil fuels, per unit of distance travelled. However, uncontrolled charging can quickly offset these potential cost savings due to Ontario's electricity pricing regime.

Based on IBI Group's previous Electrical Service and Charging Analysis, Brantford Transit's total peak electricity consumption at the maintenance and storage garage is projected to multiply by approximately 13.75 times the existing peak load (from approximately 106 kW to 1456 kW on two delivery points, with an incremental peak load from charging of 1350 kW). The Electrical Service and Charging Analysis recommended supplying the 1350-kW peak charging load via a separate delivery point to avoid alteration to the existing electrical infrastructure. As a result, this costing analysis concerns only the new delivery point, which would be separately metered.

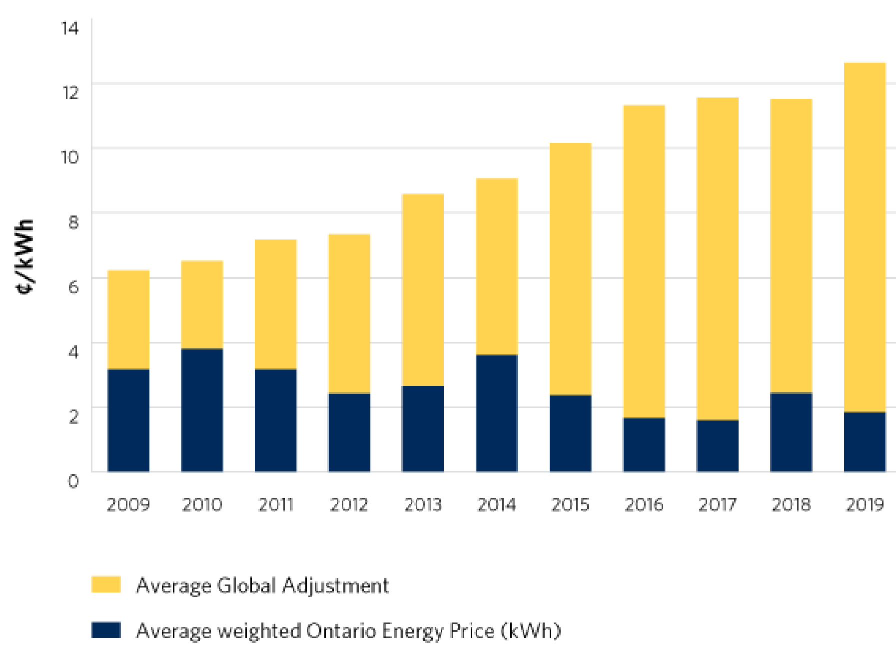
As a result of this demand increase, electrification will cause Brantford Transit's relationship to the local electrical utility to fundamentally change. The peak electricity consumption of 1350 kW for vehicle charging will classify Brantford Transit as a large commercial consumer under the IESO-defined regime implemented by local utilities. Pricing will be determined by a combination of:

- Hourly Ontario Electricity Price (HOEP)
- Global Adjustment (GA) charges (As discussed further below, consumption greater than 1 MW automatically classifies Brantford Transit as Class B, with opt-in to Class A pricing available)
- Utility charges

The effects of these pricing components are discussed in the subsections below.

Over time, GA charges have shifted to form an increasing portion of customer electricity bills, as shown in **Exhibit 120** (obtained from IESO).

Exhibit 120: Trend in Average HOEP and GA Charges[17]



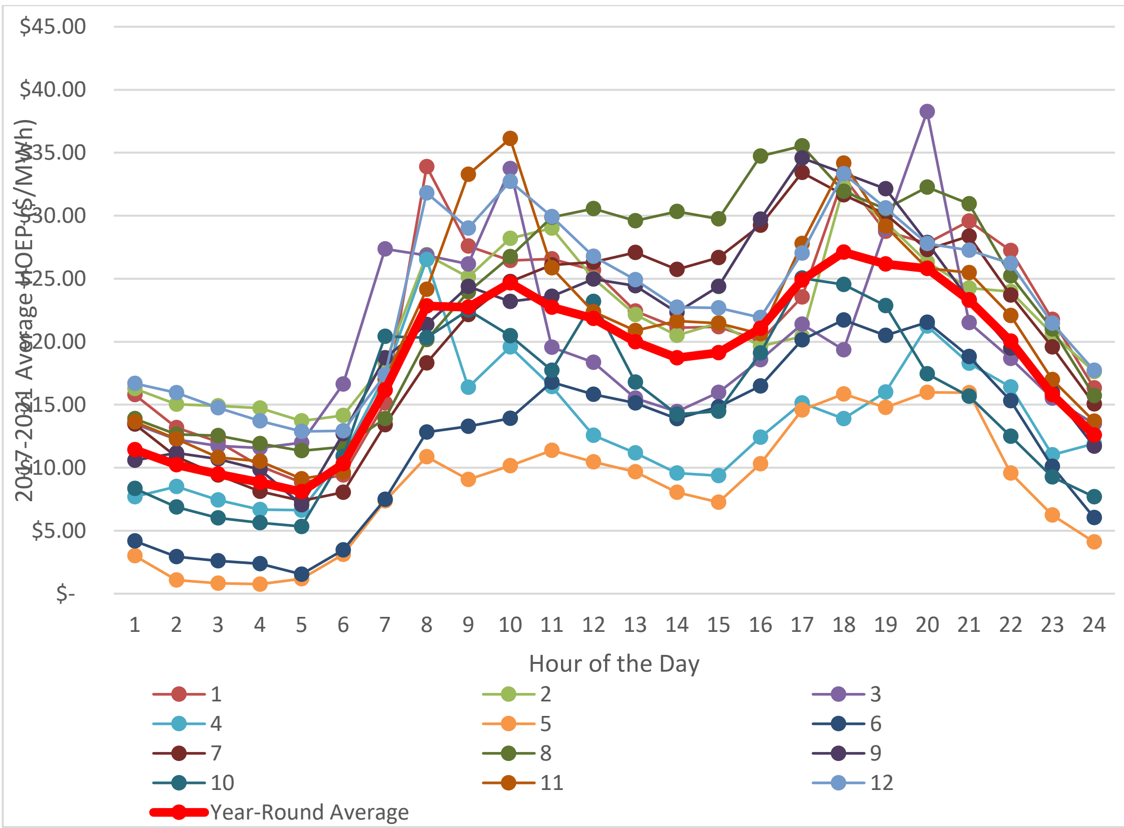
[17] https://www.ieso.ca/en/Power-Data/Price-Overview/Global-Adjustment

8.2.1.1.1 Hourly Ontario Electricity Price

The HOEP changes hourly, however it follows predictable daily trends in terms of the times of day with the highest prices, which correlate with consumption. Average HOEP values throughout the year (2017-2021) are presented in **Exhibit 121** below.

As of 2021, distinct peaks occur during the mid-morning and mid-afternoon. As battery electric vehicle adoption grows in various transportation sectors, energy use in the evening and overnight hours for charging may rise. Projections of this growth and resulting potential cost increase depending on energy policy are outside the scope of this study.

Exhibit 121: 2017-2021 Average HOEP Values by Month



8.2.1.1.2 Global Adjustment

GA charges are based on each consumer's contribution to the Top 5 annual overall Ontario-wide peak consumption hours (calculated May 1 through April 30). Charges are calculated after the fact and then applied to customers' bills for the following year.

All consumers pay GA charges, however for small consumers these charges are embedded in overall monthly bills and are typically less directly influenced by the individual consumer's power saving actions. For large consumers, GA charges can be more directly influenced, especially for participants in the Industrial Conservation Initiative (ICI), who are also known as Class A consumers. Class A consumers benefit the most if they can shift their demand outside of the hours during which Top 5 annual peaks typically occur.

Recent historical annual Top 5 electricity consumption peaks and their timing are presented in **Exhibit 122** and **Exhibit 123** below. Electricity consumption figures are in terms of Allocated Quantity of Energy Withdrawn (AQEW).

Exhibit 122: Ontario Electricity Usage Peaks by Date and Consumption (MWh)

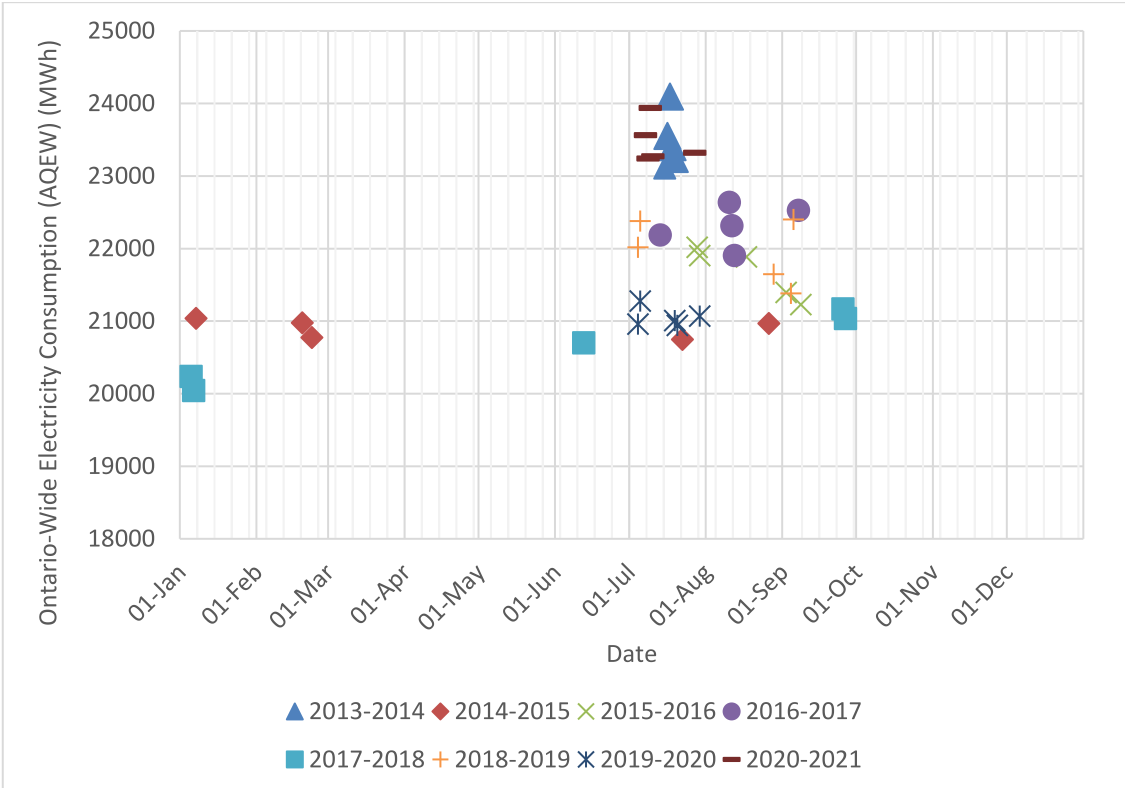
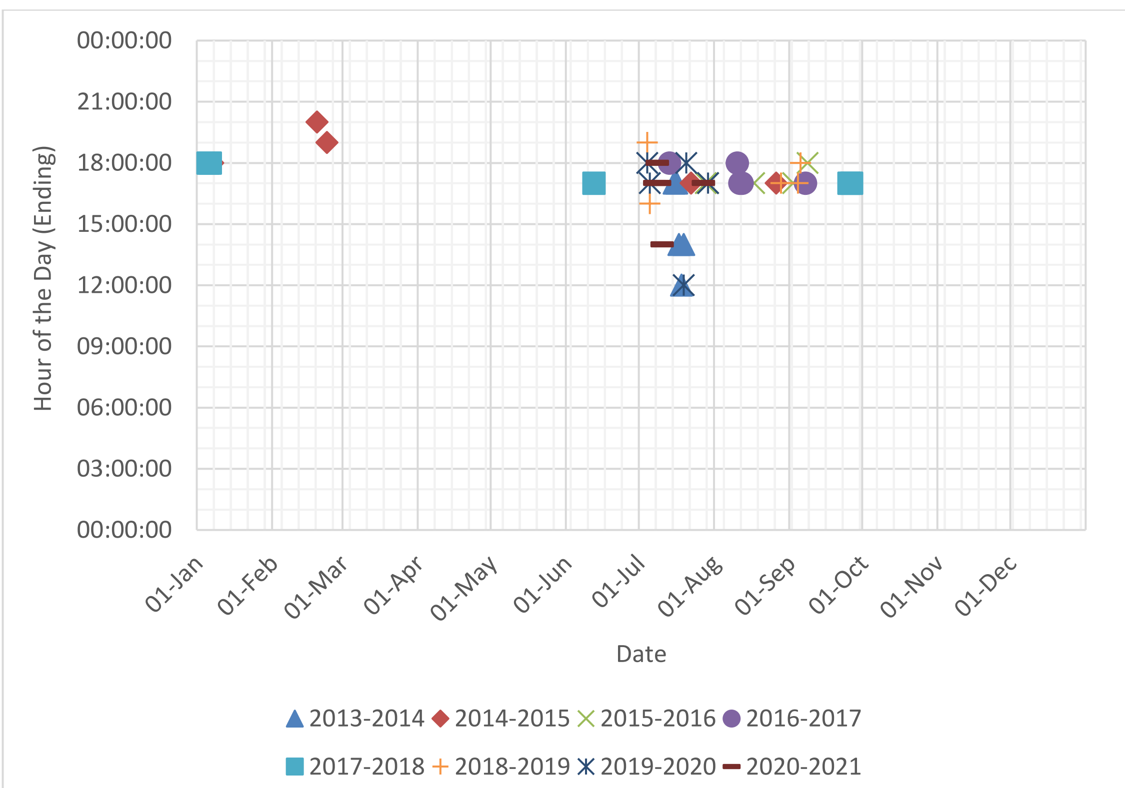


Exhibit 123: Ontario Electricity Usage Peaks by Date and Time of Day



As shown in these exhibits, Top 5 annual electricity consumption peaks historically tend to cluster in summer afternoon hours. This trend is primarily attributable to air conditioning power demand. A similar cluster is not currently observed in the winter due to Ontario's dominant reliance on natural gas for heating (making up 67% of residential heating demand[18]), however this is likely to shift with adoption of heat pump technology as decarbonization efforts advance through the mid-century.

The relative predictability of both transit service scheduling and the electricity consumption peak hours can be used by Brantford Transit to lower its overall electricity costs. If Brantford Transit were to opt into Class A pricing, and plan charging to avoid typical hours during which Top 5 peaks occur. Class A consumers can manage their electricity costs to a greater extent by adjusting their own consumption, whereas Class B consumers (to which Brantford Transit would automatically belong unless it opted into Class A) pay rates that are reckoned monthly based on the collective electricity-saving behaviour of the provincial market. For this reason, we have developed cost projections on the assumption that Brantford Transit opts into Class A, and we would encourage Brantford Transit to investigate this option.

8.2.1.1.3 Utility Charges

The local utility will also collect delivery and regulatory charges. Going forward from the time of this study the local entity will be GrandBridge Energy, forming from a merger of Brantford Power and Energy+. These organizations previously applied different utility charges, and it is unclear exactly what actions may be taken to harmonize these rates going forward, or what a large commercial user may expect to pay. To provide a conservative cost estimate, the rate structure of Energy+ was used in this study. These utility charges are presented in **Exhibit 124** below. Assumptions regarding the nature of Brantford Transit's future contract are noted.

Exhibit 124: Energy+ Large Commercial Utility Charges (Effective May 1, 2022)[19]

Item	Rate (CAD)	Per Unit
Delivery Charge		
Service Charge	926.75	Month
Rate Rider (Fixed)	241.31	Month
Local Distribution Charge	4.0891	kW
Low Voltage Service Rate	0.1010	kW
~~Rate Rider (Non-Wholesale Market Participants)~~ [Not Applicable]*	~~0.1500~~	~~kW~~
Rate Rider for Disposition of Global Adjustment	0.0016	kWh
Rate Riders (Variable)	0.4491	kW
Provincial Network Transmission	3.3532	kW
Provincial Line & Transformation Connection	1.8574	kW
Regulatory Charge		
Admin Fee - Standard Supply Service	0.2500	Month
Wholesale Market & RRRP	0.0035	kWh
~~Capacity Based Recovery - Class B~~ [Not Applicable]**	~~0.0004~~	~~kWh~~
~~Transformer Allowance~~ [Not Applicable]***	~~(0.6000)~~	~~kW~~

* Rate Rider (Non-Wholesale Market Participants) is only applicable to retail contract customers
** Capacity Based Recovery - Class B is not applicable if Brantford Transit opts into ICI / Class A
*** Transformer Allowance is not applicable until/unless Brantford Transit's future peak consumption necessitates purchasing a transformer (e.g. as a result of service growth).

[18] https://www.cer-rec.gc.ca/en/data-analysis/energy-commodities/natural-gas/report/canadian-residential-natural-gasbill/index.html
[19] https://www.energyplus.ca/en/business/electricity-rates-commercial-large-commercial.aspx#ProvincialLineTransmissionConnection

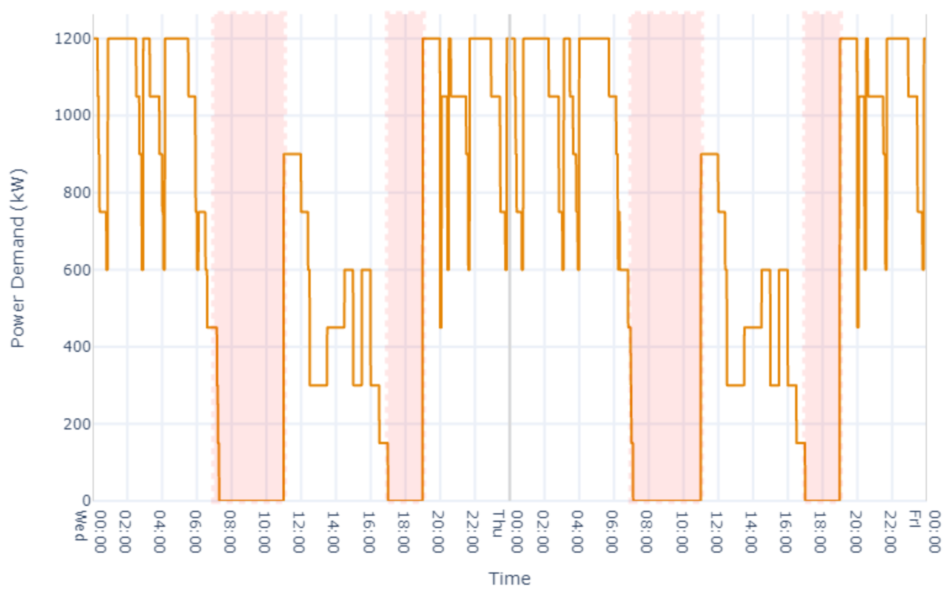
8.2.1.1.4 Impact to Brantford Transit

The dominant factors in calculating electricity prices for Brantford Transit will be peak consumption mapped against time-of-use, relative to all other electricity consumers in Ontario. The theoretical schedule re-blocking process and charging schedule development that IBI Group undertook for Brantford Transit and documented in the Electrical Service and Charging Analysis accounted for these factors by:

- Avoiding charging during historical peak hours to the extent possible while still delivering the same passenger-facing service with as few total vehicles as possible
- Flattening overnight charging to avoid sudden consumption spikes (also beneficial for electrical infrastructure needs)

Exhibit 125 below presents a projected power demand profile over a 48-h period for charging the conventional transit fleet, resulting from IBI Group's theoretical re-blocking process. In this graph, the orange line shows instantaneous power consumption to charge a fully electric fleet, and the vertical shaded bands represent "blackout" times when charging would be heavily discouraged due to historically predictable peak pricing trends (in terms of HOEP and GA).

Exhibit 125: Facility Power Consumption Profile (Conventional Transit Fleet Only)



A summary of the projected annual electricity costs for BEB charging (i.e. not for other facility functions at the garage) under each transition scenario is presented in the following exhibits:

- Electric heaters: **Exhibit 126** (table) and **Exhibit 127** (graphed)
- Diesel heaters: **Exhibit 128** (table) and **Exhibit 129** (graphed)

In **Exhibit 127** and **Exhibit 129**, the average values from the 3 equipment implementation scenarios are shown, given that the cost figures are highly similar.

Notably, costs are projected to rise at an accelerating rate through 2037, due to the established trend of rising GA costs. It is not yet clear how factors such as increasing adoption of electric vehicles may change consumption patterns and conservation incentives. Any effects that would drastically change the times of peak use, or that would cause the IESO pricing regime to change, would affect this cost projection.

Exhibit 126: Electricity Cost Projection – Cash Flow Comparison, 2024-2037
(Including Conventional BEBs with Electric Heaters; 2023 Present Value, 000s)

Year	Alternative 1a (SC/ER)	Alternative 1b (SC/AR)	Alternative 1c (SC/FR)	Alternative 2a (BC/ER)	Alternative 2b (BC/AR)	Alternative 2c (BC/FR)	Alternative 3a (OC/ER)	Alternative 3b (OC/AR)	Alternative 3c (OC/FR)
2024	$ 48	$ 48	$ 506	$ 48	$ 48	$ 508	$ 48	$ 48	$ 508
2025	$ 100	$ 100	$ 529	$ 100	$ 100	$ 531	$ 100	$ 100	$ 531
2026	$ 174	$ 174	$ 556	$ 175	$ 175	$ 558	$ 175	$ 175	$ 558
2027	$ 220	$ 293	$ 585	$ 220	$ 294	$ 587	$ 220	$ 294	$ 587
2028	$ 232	$ 425	$ 618	$ 233	$ 426	$ 619	$ 233	$ 426	$ 619
2029	$ 306	$ 551	$ 653	$ 307	$ 553	$ 655	$ 307	$ 553	$ 655
2030	$ 390	$ 692	$ 692	$ 391	$ 694	$ 694	$ 391	$ 694	$ 694
2031	$ 414	$ 736	$ 736	$ 415	$ 738	$ 738	$ 415	$ 738	$ 738
2032	$ 515	$ 785	$ 785	$ 517	$ 787	$ 787	$ 517	$ 787	$ 787
2033	$ 550	$ 838	$ 838	$ 551	$ 839	$ 839	$ 551	$ 839	$ 839
2034	$ 588	$ 896	$ 896	$ 589	$ 898	$ 898	$ 589	$ 898	$ 898
2035	$ 751	$ 961	$ 961	$ 753	$ 963	$ 963	$ 753	$ 963	$ 963
2036	$ 969	$ 1,033	$ 1,033	$ 970	$ 1,035	$ 1,035	$ 970	$ 1,035	$ 1,035
2037	$ 1,113	$ 1,113	$ 1,113	$ 1,114	$ 1,114	$ 1,114	$ 1,115	$ 1,115	$ 1,115
Total	**$ 6,370**	**$ 8,645**	**$ 10,501**	**$ 6,383**	**$ 8,664**	**$ 10,526**	**$ 6,384**	**$ 8,665**	**$ 10,527**

Exhibit 127: Electricity Cost Projection – Cash Flow Comparison, 2024-2037
(Including Conventional BEBs with Electric Heaters; 2023 Present Value, Average of All Equipment Implementation Scenarios, 000s)

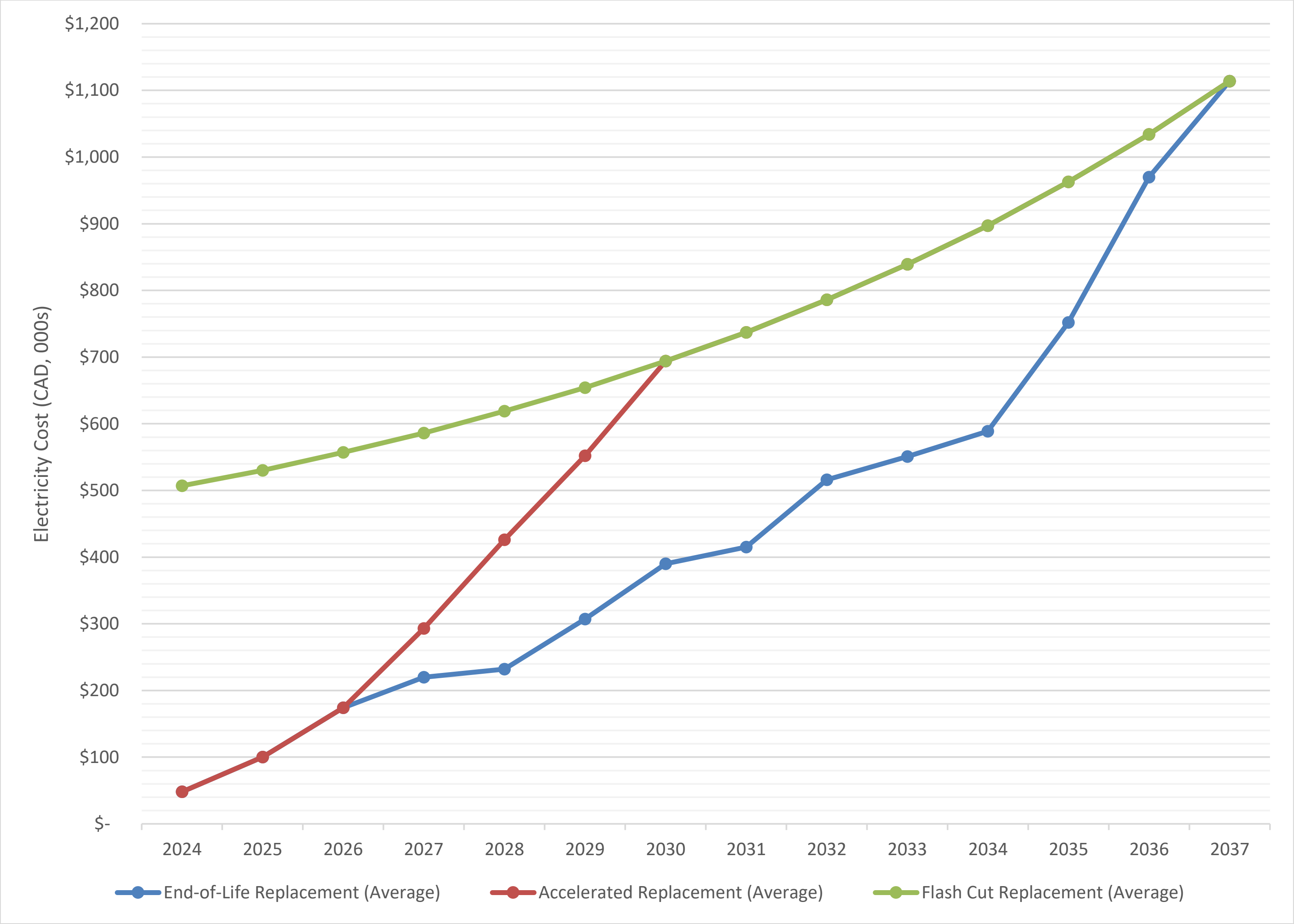
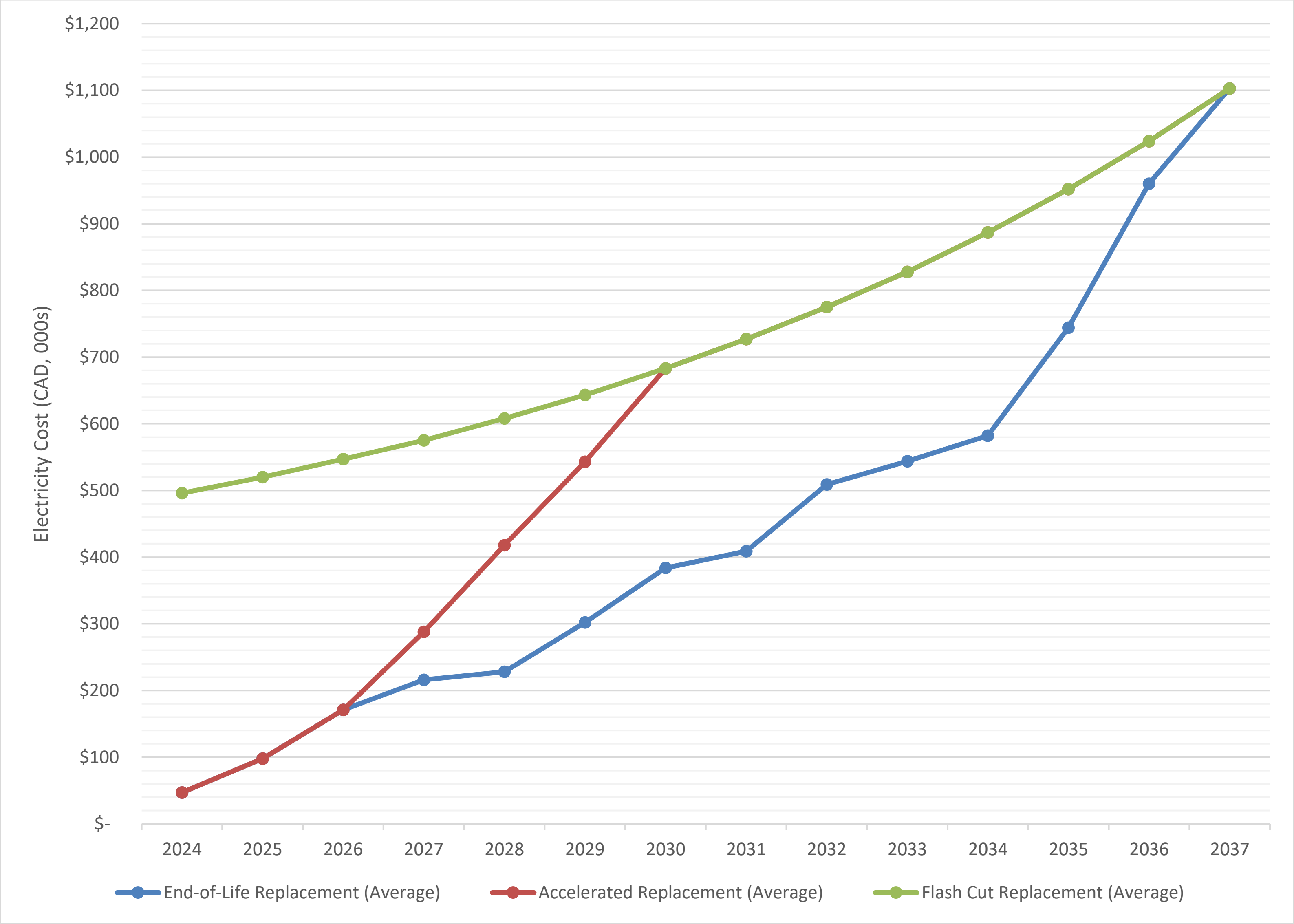


Exhibit 128: Electricity Cost Projection – Cash Flow Comparison, 2024-2037
(Including Conventional BEBs with Diesel Heaters; 2023 Present Value, 000s)

Year	Alternative 1a (SC/ER)	Alternative 1b (SC/AR)	Alternative 1c (SC/FR)	Alternative 2a (BC/ER)	Alternative 2b (BC/AR)	Alternative 2c (BC/FR)	Alternative 3a (OC/ER)	Alternative 3b (OC/AR)	Alternative 3c (OC/FR)
2024	$ 47	$ 47	$ 495	$ 47	$ 47	$ 496	$ 47	$ 47	$ 497
2025	$ 98	$ 98	$ 518	$ 98	$ 98	$ 520	$ 98	$ 98	$ 521
2026	$ 171	$ 171	$ 545	$ 171	$ 171	$ 547	$ 172	$ 172	$ 548
2027	$ 216	$ 287	$ 574	$ 216	$ 288	$ 576	$ 217	$ 289	$ 577
2028	$ 228	$ 417	$ 607	$ 228	$ 418	$ 608	$ 229	$ 419	$ 610
2029	$ 301	$ 542	$ 642	$ 302	$ 543	$ 643	$ 302	$ 544	$ 645
2030	$ 383	$ 681	$ 681	$ 384	$ 683	$ 683	$ 385	$ 684	$ 684
2031	$ 408	$ 725	$ 725	$ 409	$ 727	$ 727	$ 410	$ 728	$ 728
2032	$ 508	$ 774	$ 774	$ 509	$ 775	$ 775	$ 510	$ 777	$ 777
2033	$ 543	$ 827	$ 827	$ 544	$ 828	$ 828	$ 545	$ 830	$ 830
2034	$ 581	$ 885	$ 885	$ 582	$ 887	$ 887	$ 583	$ 888	$ 888
2035	$ 743	$ 951	$ 951	$ 744	$ 952	$ 952	$ 745	$ 954	$ 954
2036	$ 959	$ 1,023	$ 1,023	$ 960	$ 1,024	$ 1,024	$ 961	$ 1,025	$ 1,025
2037	$ 1,102	$ 1,102	$ 1,102	$ 1,104	$ 1,104	$ 1,104	$ 1,105	$ 1,105	$ 1,105
Total	**$ 6,288**	**$ 8,530**	**$ 10,349**	**$ 6,298**	**$ 8,545**	**$ 10,370**	**$ 6,309**	**$ 8,560**	**$ 10,389**

Exhibit 129: Electricity Cost Projection – Cash Flow Comparison, 2024-2037
(Including Conventional BEBs with Diesel Heaters; 2023 Present Value, Average of All Equipment Implementation Scenarios, 000s)



8.2.1.2 Driving Costs

Driving cost is considered for hours in service, as well as additional movements within the garage as needed for charging. Both sources of operating cost will experience a degree of increase associated with electrification, due to the addition of charging operations and movements.

In-service hours are not projected to substantially increase, as presented in **Exhibit 130** below.

Exhibit 130: Projected Change in Daily and Weekly Service Hours

Item	Daily Service Hours		% Change in Daily Service Hours
	Before Re-Blocking	After Re-Blocking	
Monday-Saturday Service			
Conventional Transit	297	306	3 %
Specialized Transit (M-F)	100	100	0 %
Specialized Transit (Sat)	38	38	0 %
Sunday Service			
Conventional Transit	98	99	1 %
Specialized Transit	24	24	0 %
Weekly Total			
Conventional Transit	1880	1935	3 %
Specialized Transit	562	562	0 %

Although the re-blocked service plan developed for the Charging Analysis includes a significant expansion in the number of blocks, this is due to existing blocks being broken up and vehicles swapping out. All swap-outs in the service plan are coordinated at the downtown terminal. As a result, this costing analysis assumes that these swap-out operations are assigned to new dedicated operator shifts, while the drivers running in passenger service would change over between vehicles at the terminal and carry on to the next trip. This approach minimizes additional costs due to operator downtime.

The in-garage shuttling component is present for indoor batch and outdoor rotating charging, since each vehicle would require at least two relocations (one round trip between storage and charging locations). The increased volume of movements in the facility, and the need to coordinate some of these movements in parallel to maximize utilization of the charging equipment overnight, would require additional staffing. Our analysis estimated that with full electrification, an equivalent of up to 5 additional general service technician shifts would be required through the midday and overnight periods, to support Brantford Transit and Brantford Lift needs in these operational scenarios. These would be distributed as 1.5 shifts in the midday, and 3.5 shifts in the evening and overnight.

In all operating costs, a rate multiplier of 1.4 is assumed for staff driving buses, based on the most recent available Collective Agreement between the Corporation of the City of Brantford and the Amalgamated Transit Union Local 685, accounting for average benefits and administrative costs.

8.2.2 Operating Cost of Ownership

Summarized comparison of the incremental annual operating costs of each electrification option relative to the Business-as-Usual case are presented in **Exhibit 131** (including conventional BEBs with electric heaters) and **Exhibit 133** (including conventional BEBs with diesel heaters). This calculation considers costs regardless of equipment generation (i.e. it has not been separated into costs incurred to maintain first- versus second-generation vehicles and equipment). Figures for the Business-as-Usual case are based on current Brantford Transit operating costs projected to 2023 present value with a 4% discount rate. Annual costs in this scenario are assumed to be roughly stable due to the existing distribution of vehicle ages and states of repair contributing to maintenance costs.

Exhibit 131: Operating Cost of Ownership – Cash Flow Comparison, 2024-2037
(Including Conventional BEBs with Electric Heaters; 2023 Present Value, 000s)

Year	Business as Usual	Alternative 1a (SC/ER)	Alternative 1b (SC/AR)	Alternative 1c (SC/FR)	Alternative 2a (BC/ER)	Alternative 2b (BC/AR)	Alternative 2c (BC/FR)	Alternative 3a (OC/ER)	Alternative 3b (OC/AR)	Alternative 3c (OC/FR)
2024	$ 9,026	$ 9,206	$ 9,206	$ 7,051	$ 9,206	$ 9,206	$ 7,596	$ 9,206	$ 9,206	$ 7,596
2025	$ 9,026	$ 9,007	$ 9,007	$ 7,074	$ 9,007	$ 9,007	$ 7,619	$ 9,143	$ 9,143	$ 7,619
2026	$ 9,026	$ 8,633	$ 8,633	$ 7,101	$ 8,634	$ 8,634	$ 7,646	$ 8,770	$ 8,770	$ 7,646
2027	$ 9,026	$ 8,501	$ 8,392	$ 7,130	$ 8,501	$ 8,665	$ 7,675	$ 8,637	$ 8,665	$ 7,675
2028	$ 9,026	$ 8,513	$ 8,339	$ 7,162	$ 8,514	$ 8,748	$ 7,707	$ 8,650	$ 8,748	$ 7,707
2029	$ 9,026	$ 8,316	$ 7,944	$ 7,198	$ 8,589	$ 8,489	$ 7,743	$ 8,589	$ 8,489	$ 7,743
2030	$ 9,026	$ 8,159	$ 7,237	$ 7,237	$ 8,432	$ 7,782	$ 7,782	$ 8,432	$ 7,782	$ 7,782
2031	$ 9,026	$ 8,184	$ 7,281	$ 7,281	$ 8,456	$ 7,826	$ 7,826	$ 8,457	$ 7,826	$ 7,826
2032	$ 9,026	$ 8,014	$ 7,330	$ 7,330	$ 8,422	$ 7,875	$ 7,875	$ 8,422	$ 7,875	$ 7,875
2033	$ 9,026	$ 8,048	$ 7,382	$ 7,382	$ 8,457	$ 7,927	$ 7,927	$ 8,457	$ 7,927	$ 7,927
2034	$ 9,026	$ 8,087	$ 7,441	$ 7,441	$ 8,495	$ 7,986	$ 7,986	$ 8,495	$ 7,986	$ 7,986
2035	$ 9,026	$ 7,821	$ 7,506	$ 7,506	$ 8,230	$ 8,051	$ 8,051	$ 8,230	$ 8,051	$ 8,051
2036	$ 9,026	$ 7,756	$ 7,578	$ 7,578	$ 8,301	$ 8,123	$ 8,123	$ 8,301	$ 8,123	$ 8,123
2037	$ 9,026	$ 7,658	$ 7,658	$ 7,658	$ 8,202	$ 8,202	$ 8,202	$ 8,203	$ 8,203	$ 8,203
Total	**$ 126,364**	**$ 115,903**	**$ 110,934**	**$ 102,129**	**$ 119,446**	**$ 116,521**	**$ 109,758**	**$ 119,992**	**$ 116,794**	**$ 109,759**

Exhibit 132: Operating Cost of Ownership – Cash Flow Comparison, 2024-2037
(Including Conventional BEBs with Diesel Heaters; 2023 Present Value, 000s)

Year	Business as Usual	Alternative 1a (SC/ER)	Alternative 1b (SC/AR)	Alternative 1c (SC/FR)	Alternative 2a (BC/ER)	Alternative 2b (BC/AR)	Alternative 2c (BC/FR)	Alternative 3a (OC/ER)	Alternative 3b (OC/AR)	Alternative 3c (OC/FR)
2024	$ 9,026	$ 9,293	$ 9,293	$ 7,109	$ 9,293	$ 9,293	$ 7,654	$ 9,293	$ 9,293	$ 7,655
2025	$ 9,026	$ 8,824	$ 8,824	$ 7,130	$ 8,825	$ 8,825	$ 7,675	$ 8,961	$ 8,961	$ 7,676
2026	$ 9,026	$ 8,437	$ 8,437	$ 7,157	$ 8,437	$ 8,437	$ 7,702	$ 8,573	$ 8,573	$ 7,703
2027	$ 9,026	$ 8,389	$ 8,265	$ 7,188	$ 8,390	$ 8,537	$ 7,733	$ 8,526	$ 8,538	$ 7,734
2028	$ 9,026	$ 8,401	$ 8,092	$ 7,219	$ 8,401	$ 8,501	$ 7,764	$ 8,538	$ 8,502	$ 7,765
2029	$ 9,026	$ 8,333	$ 7,909	$ 7,258	$ 8,605	$ 8,454	$ 7,803	$ 8,605	$ 8,455	$ 7,804
2030	$ 9,026	$ 7,818	$ 7,295	$ 7,295	$ 8,090	$ 7,840	$ 7,840	$ 8,091	$ 7,841	$ 7,841
2031	$ 9,026	$ 7,843	$ 7,338	$ 7,338	$ 8,115	$ 7,883	$ 7,883	$ 8,116	$ 7,884	$ 7,884
2032	$ 9,026	$ 7,799	$ 7,389	$ 7,389	$ 8,207	$ 7,934	$ 7,934	$ 8,208	$ 7,935	$ 7,935
2033	$ 9,026	$ 7,832	$ 7,439	$ 7,439	$ 8,240	$ 7,983	$ 7,983	$ 8,241	$ 7,984	$ 7,984
2034	$ 9,026	$ 7,870	$ 7,497	$ 7,497	$ 8,278	$ 8,042	$ 8,042	$ 8,279	$ 8,043	$ 8,043
2035	$ 9,026	$ 7,771	$ 7,561	$ 7,561	$ 8,179	$ 8,106	$ 8,106	$ 8,180	$ 8,107	$ 8,107
2036	$ 9,026	$ 7,728	$ 7,633	$ 7,633	$ 8,273	$ 8,178	$ 8,178	$ 8,274	$ 8,179	$ 8,179
2037	$ 9,026	$ 7,714	$ 7,714	$ 7,714	$ 8,259	$ 8,259	$ 8,259	$ 8,260	$ 8,260	$ 8,260
Total	**$ 126,364**	**$ 114,052**	**$ 110,686**	**$ 102,927**	**$ 117,592**	**$ 116,272**	**$ 110,556**	**$ 118,145**	**$ 116,555**	**$ 110,570**

8.3 Administrative Costs

Projected administration costs examined in this analysis focus on training and re-certification efforts. These would be geared toward enabling employees to facilitate a transition to operating and maintaining BEBs. Programs would include safety training in bus operation and high voltage environments, maintenance courses for employed mechanics, and familiarization for drivers. In addition, a degree of change to general labour resourcing and practices may be expected.

Bus fleet electrification presents significant changes to many areas of Brantford Transit's personnel, especially in terms of staff interaction with the new fleet and infrastructure. Electrification will necessitate changes in fleet maintenance, work procedures and safety training, as well as significant changes in how buses are operated and dispatched.

Bus and facility maintenance staff will be most affected by training and recertification requirements. First and foremost, new safety training will be required. Personal protective equipment (PPE) will change based on the specific tasks being performed and many tasks will require a safety observer (where one might not be needed for analogous diesel/gas vehicle maintenance tasks).

Likewise, the technical expertise required to service BEBs over diesel/gas vehicles requires new training. The bulk of this training would take place as electrification is phased in, to equip existing employees with necessary skills for the transition. However, some level of ongoing training can be expected as existing staff change positions, and for topics that are specialized to the agency and not externally available to be expected of new hires.

BEB manufacturers will offer training for maintenance personnel, but this typically requires prerequisite skills in electrical theory, high voltage safety, PPE for high-voltage environments, use of specialized tools, and basic computer skills. These skills may be acquired for existing employees through offsite EV maintenance training courses offered at some Ontario community colleges and staff may be rotated through the off-site training courses. Colleges in the region including Mohawk College, Niagara College, and Centennial College appear to offer courses in electric vehicle maintenance. Brantford Transit may consider designating skills that are available through external programs as prerequisites for any new hires, or coordinating with these Colleges to deliver training after hiring.

Beyond maintenance changes, more moderate changes to work procedures will affect a broader distribution of staff and require their own training procedures (mostly as group sessions):

- Familiarization with operating BEBs for all operators and mechanics who are permitted or required to drive a bus. As of 2022, the rollout of BEBs is still limited enough in North America that it may not be feasible to expect BEB familiarity as a prerequisite for new hires.
- Rigorous high voltage (HV) safety training for facility employees, including emphasis on lock-out/tag-out procedures and correct use of HV PPE. This can be expected as an ongoing expense, as continuous, periodic retraining in HV safety is generally required for existing staff.
- Less extensive HV safety training for management staff and visitors to the maintenance area. This can be expected as an ongoing expense, as it may not be practical to include HV safety training as prerequisites for management positions or for personnel requiring limited/temporary site access such as external contractors.

This analysis assumes that Brantford Transit will familiarize all applicable staff with BEBs and train all mechanical staff in EV maintenance with both the partial and full BEB scenarios.

A breakdown of projected time requirements, frequency of repetition (if applicable) and fixed cost of various training activities is presented in **Exhibit 133** below.

Exhibit 133: Training Activity Projected Time Requirements and Fixed Costs (Burdened)

Training Item	Affected Employees	2023 Flat Fee Per Trainee (CAD)	Training Time (h)	2023 Projected Average Staff Rate (CAD/h, Burdened)	One-Time Transition Cost Estimate	Recurrence Intensity (% of Initial Transition Effort per Month)	Monthly Ongoing Cost Estimate
BEB Familiarization Training	89	$ -[20]	3	$ 46.48	$ 12,410	1%	$ 24
High Voltage Safety Training	15	$ 1,435[21]	16	$ 54.31	$ 34,558	3%	$ 323
EV Maintenance Training for Existing Employees	15	$ 433[22]	42	$ 54.31	$ 40,708	0%	$ -
Management and Visitor HV Safety Training	5	$ 38[23]	4	$ 140.00	$ 2,990	100%	$ 249
Subtotal Costs					**$ 90,666**		**$ 696**

A breakdown of assumptions used in this table is as follows:

- Projected workforce numbers and staff rates are based on information provided by Brantford Transit.
- Recurrence is estimated from IBI Group past projects.

[20] Assumed to be offered by bus manufacturer as part of bus procurement
[21] Inflated to 2023 costs, from https://www.canada-training-group.ca/course/12167050391/arc-flash-high-voltage-safety-qualified-electrical-worker-certification
[22] Average of certification fees from colleges in the Brantford area
[23] Inflated to 2023 costs, from https://worksitesafety.ca/product/training/online/electrical-safety/

8.4 Cost of Ownership

Summarized comparisons of the annual cash flow for each electrification option and a Business-as-Usual case through 2037 are presented in the following exhibits:

- Including conventional BEBs with electric heaters:
  - Considering first-generation capital purchases only: **Exhibit 134**;
  - Including capital costs for first- and second-generation purchases: **Exhibit 135**;
- Including conventional BEBs with diesel heaters:
  - Considering first-generation capital purchases only: **Exhibit 136**;
  - Including capital costs for first- and second-generation purchases: **Exhibit 137**.

Exhibit 134: Total Cost of Ownership – Cash Flow Comparison, 2024-2037
(Including Conventional BEBs with Electric Heaters; First Generation Capital Purchases Only, 2023 Present Value, 000s)

Year	Business as Usual	Alternative 1a (SC/ER)	Alternative 1b (SC/AR)	Alternative 1c (SC/FR)	Alternative 2a (BC/ER)	Alternative 2b (BC/AR)	Alternative 2c (BC/FR)	Alternative 3a (OC/ER)	Alternative 3b (OC/AR)	Alternative 3c (OC/FR)
2024	$ 11,773	$ 16,410	$ 16,410	$ 60,832	$ 16,410	$ 16,410	$ 60,897	$ 16,362	$ 16,362	$ 60,849
2025	$ 9,783	$ 15,598	$ 15,598	$ 7,082	$ 15,598	$ 15,598	$ 7,627	$ 15,662	$ 15,662	$ 7,627
2026	$ 12,227	$ 13,581	$ 13,581	$ 7,109	$ 13,581	$ 13,581	$ 7,654	$ 13,534	$ 13,534	$ 7,654
2027	$ 10,323	$ 12,076	$ 18,366	$ 7,138	$ 12,077	$ 18,272	$ 7,683	$ 12,324	$ 18,296	$ 7,683
2028	$ 9,026	$ 8,521	$ 16,853	$ 7,171	$ 8,522	$ 17,340	$ 7,716	$ 8,658	$ 17,412	$ 7,716
2029	$ 10,972	$ 13,534	$ 15,269	$ 7,206	$ 13,440	$ 15,718	$ 7,751	$ 13,464	$ 15,853	$ 7,751
2030	$ 11,535	$ 13,685	$ 16,512	$ 7,245	$ 14,131	$ 16,961	$ 7,790	$ 14,068	$ 16,986	$ 7,791
2031	$ 9,026	$ 8,192	$ 7,289	$ 7,289	$ 8,465	$ 7,834	$ 7,834	$ 8,465	$ 7,834	$ 7,834
2032	$ 10,972	$ 12,961	$ 7,338	$ 7,338	$ 13,274	$ 7,883	$ 7,883	$ 13,298	$ 7,883	$ 7,883
2033	$ 9,026	$ 8,057	$ 7,391	$ 7,391	$ 8,465	$ 7,936	$ 7,936	$ 8,465	$ 7,936	$ 7,936
2034	$ 9,026	$ 8,095	$ 7,449	$ 7,449	$ 8,503	$ 7,994	$ 7,994	$ 8,504	$ 7,994	$ 7,994
2035	$ 12,270	$ 13,957	$ 7,515	$ 7,515	$ 14,270	$ 8,060	$ 8,060	$ 14,294	$ 8,060	$ 8,060
2036	$ 12,270	$ 13,893	$ 7,586	$ 7,586	$ 14,342	$ 8,131	$ 8,131	$ 14,477	$ 8,131	$ 8,131
2037	$ 10,972	$ 11,233	$ 7,666	$ 7,666	$ 11,778	$ 8,211	$ 8,211	$ 11,778	$ 8,211	$ 8,211
Total	**$ 149,201**	**$ 169,793**	**$ 164,823**	**$ 156,017**	**$ 172,856**	**$ 169,929**	**$ 163,167**	**$ 173,353**	**$ 170,154**	**$ 163,120**

Exhibit 135: Total Cost of Ownership – Cash Flow Comparison, 2024-2037
(Including Conventional BEBs with Electric Heaters; First- and Second- Generation Capital Purchases, 2023 Present Value, 000s)

Year	Business as Usual	Alternative 1a (SC/ER)	Alternative 1b (SC/AR)	Alternative 1c (SC/FR)	Alternative 2a (BC/ER)	Alternative 2b (BC/AR)	Alternative 2c (BC/FR)	Alternative 3a (OC/ER)	Alternative 3b (OC/AR)	Alternative 3c (OC/FR)
2024	$ 11,773	$ 16,410	$ 16,410	$ 60,832	$ 16,410	$ 16,410	$ 60,897	$ 16,362	$ 16,362	$ 60,849
2025	$ 9,783	$ 15,598	$ 15,598	$ 7,082	$ 15,598	$ 15,598	$ 7,627	$ 15,662	$ 15,662	$ 7,627
2026	$ 12,227	$ 13,581	$ 13,581	$ 7,109	$ 13,581	$ 13,581	$ 7,654	$ 13,534	$ 13,534	$ 7,654
2027	$ 10,323	$ 12,076	$ 18,366	$ 7,138	$ 12,077	$ 18,272	$ 7,683	$ 12,324	$ 18,296	$ 7,683
2028	$ 9,026	$ 8,521	$ 16,853	$ 7,171	$ 8,522	$ 17,340	$ 7,716	$ 8,658	$ 17,412	$ 7,716
2029	$ 10,972	$ 13,534	$ 15,269	$ 7,206	$ 13,440	$ 15,718	$ 7,751	$ 13,464	$ 15,853	$ 7,751
2030	$ 11,535	$ 13,685	$ 16,512	$ 7,245	$ 14,131	$ 16,961	$ 7,790	$ 14,068	$ 16,986	$ 7,791
2031	$ 9,177	$ 10,142	$ 9,239	$ 12,749	$ 10,415	$ 9,784	$ 13,294	$ 10,415	$ 9,784	$ 13,294
2032	$ 11,730	$ 14,521	$ 8,898	$ 7,338	$ 14,834	$ 9,443	$ 7,883	$ 14,858	$ 9,443	$ 7,883
2033	$ 9,631	$ 8,057	$ 7,391	$ 7,391	$ 8,465	$ 7,936	$ 7,936	$ 8,465	$ 7,936	$ 7,936
2034	$ 9,026	$ 8,095	$ 7,449	$ 7,449	$ 8,503	$ 7,994	$ 7,994	$ 8,504	$ 7,994	$ 7,994
2035	$ 12,270	$ 13,957	$ 7,515	$ 7,515	$ 14,270	$ 8,060	$ 8,060	$ 14,294	$ 8,060	$ 8,060
2036	$ 12,270	$ 18,649	$ 12,342	$ 53,957	$ 19,098	$ 12,887	$ 54,502	$ 19,233	$ 12,887	$ 54,502
2037	$ 12,184	$ 17,939	$ 14,372	$ 7,666	$ 18,484	$ 14,917	$ 8,211	$ 18,484	$ 14,917	$ 8,211
Total	**$ 151,927**	**$ 184,765**	**$ 179,795**	**$ 207,848**	**$ 187,828**	**$ 184,901**	**$ 214,998**	**$ 188,325**	**$ 185,126**	**$ 214,951**

Exhibit 136: Total Cost of Ownership – Cash Flow Comparison, 2024-2037
(Including Conventional BEBs with Diesel Heaters; First Generation Capital Purchases Only, 2023 Present Value, 000s)

Year	Business as Usual	Alternative 1a (SC/ER)	Alternative 1b (SC/AR)	Alternative 1c (SC/FR)	Alternative 2a (BC/ER)	Alternative 2b (BC/AR)	Alternative 2c (BC/FR)	Alternative 3a (OC/ER)	Alternative 3b (OC/AR)	Alternative 3c (OC/FR)
2024	$ 11,773	$ 16,498	$ 16,498	$ 60,891	$ 16,498	$ 16,498	$ 60,956	$ 16,450	$ 16,450	$ 60,909
2025	$ 9,783	$ 15,416	$ 15,416	$ 7,138	$ 15,416	$ 15,416	$ 7,683	$ 15,480	$ 15,480	$ 7,684
2026	$ 12,227	$ 13,384	$ 13,384	$ 7,166	$ 13,385	$ 13,385	$ 7,711	$ 13,338	$ 13,338	$ 7,712
2027	$ 10,323	$ 11,965	$ 18,238	$ 7,196	$ 11,965	$ 18,145	$ 7,741	$ 12,212	$ 18,169	$ 7,742
2028	$ 9,026	$ 8,409	$ 16,607	$ 7,228	$ 8,410	$ 17,093	$ 7,772	$ 8,546	$ 17,166	$ 7,773
2029	$ 10,972	$ 13,550	$ 15,234	$ 7,266	$ 13,456	$ 15,683	$ 7,811	$ 13,481	$ 15,819	$ 7,812
2030	$ 11,535	$ 13,343	$ 16,570	$ 7,303	$ 13,790	$ 17,019	$ 7,848	$ 13,727	$ 17,044	$ 7,849
2031	$ 9,026	$ 7,851	$ 7,347	$ 7,347	$ 8,123	$ 7,892	$ 7,892	$ 8,124	$ 7,893	$ 7,893
2032	$ 10,972	$ 12,746	$ 7,397	$ 7,397	$ 13,059	$ 7,942	$ 7,942	$ 13,083	$ 7,943	$ 7,943
2033	$ 9,026	$ 7,840	$ 7,447	$ 7,447	$ 8,248	$ 7,992	$ 7,992	$ 8,249	$ 7,993	$ 7,993
2034	$ 9,026	$ 7,878	$ 7,506	$ 7,506	$ 8,287	$ 8,050	$ 8,050	$ 8,288	$ 8,052	$ 8,052
2035	$ 12,270	$ 13,907	$ 7,570	$ 7,570	$ 14,220	$ 8,115	$ 8,115	$ 14,244	$ 8,116	$ 8,116
2036	$ 12,270	$ 13,865	$ 7,642	$ 7,642	$ 14,314	$ 8,186	$ 8,186	$ 14,450	$ 8,188	$ 8,188
2037	$ 10,972	$ 11,290	$ 7,723	$ 7,723	$ 11,834	$ 8,267	$ 8,267	$ 11,836	$ 8,269	$ 8,269
Total	**$ 149,201**	**$ 167,942**	**$ 164,579**	**$ 156,820**	**$ 171,005**	**$ 169,683**	**$ 163,966**	**$ 171,508**	**$ 169,920**	**$ 163,935**

Exhibit 137: Total Cost of Ownership – Cash Flow Comparison, 2024-2037
(Including Conventional BEBs with Diesel Heaters; First- and Second- Generation Capital Purchases, 2023 Present Value, 000s)

Year	Business as Usual	Alternative 1a (SC/ER)	Alternative 1b (SC/AR)	Alternative 1c (SC/FR)	Alternative 2a (BC/ER)	Alternative 2b (BC/AR)	Alternative 2c (BC/FR)	Alternative 3a (OC/ER)	Alternative 3b (OC/AR)	Alternative 3c (OC/FR)
2024	$ 11,773	$ 16,498	$ 16,498	$ 60,891	$ 16,498	$ 16,498	$ 60,956	$ 16,450	$ 16,450	$ 60,909
2025	$ 9,783	$ 15,416	$ 15,416	$ 7,138	$ 15,416	$ 15,416	$ 7,683	$ 15,480	$ 15,480	$ 7,684
2026	$ 12,227	$ 13,384	$ 13,384	$ 7,166	$ 13,385	$ 13,385	$ 7,711	$ 13,338	$ 13,338	$ 7,712
2027	$ 10,323	$ 11,965	$ 18,238	$ 7,196	$ 11,965	$ 18,145	$ 7,741	$ 12,212	$ 18,169	$ 7,742
2028	$ 9,026	$ 8,409	$ 16,607	$ 7,228	$ 8,410	$ 17,093	$ 7,772	$ 8,546	$ 17,166	$ 7,773
2029	$ 10,972	$ 13,550	$ 15,234	$ 7,266	$ 13,456	$ 15,683	$ 7,811	$ 13,481	$ 15,819	$ 7,812
2030	$ 11,535	$ 13,343	$ 16,570	$ 7,303	$ 13,790	$ 17,019	$ 7,848	$ 13,727	$ 17,044	$ 7,849
2031	$ 9,177	$ 9,801	$ 9,297	$ 12,807	$ 10,073	$ 9,842	$ 13,352	$ 10,074	$ 9,843	$ 13,353
2032	$ 11,730	$ 14,306	$ 8,957	$ 7,397	$ 14,619	$ 9,502	$ 7,942	$ 14,643	$ 9,503	$ 7,943
2033	$ 9,631	$ 7,840	$ 7,447	$ 7,447	$ 8,248	$ 7,992	$ 7,992	$ 8,249	$ 7,993	$ 7,993
2034	$ 9,026	$ 7,878	$ 7,506	$ 7,506	$ 8,287	$ 8,050	$ 8,050	$ 8,288	$ 8,052	$ 8,052
2035	$ 12,270	$ 13,907	$ 7,570	$ 7,570	$ 14,220	$ 8,115	$ 8,115	$ 14,244	$ 8,116	$ 8,116
2036	$ 12,270	$ 18,621	$ 12,398	$ 54,013	$ 19,070	$ 12,942	$ 54,557	$ 19,206	$ 12,944	$ 54,559
2037	$ 12,184	$ 17,996	$ 14,429	$ 7,723	$ 18,540	$ 14,973	$ 8,267	$ 18,542	$ 14,975	$ 8,269
Total	**$ 151,927**	**$ 182,914**	**$ 179,551**	**$ 208,651**	**$ 185,977**	**$ 184,655**	**$ 215,797**	**$ 186,480**	**$ 184,892**	**$ 215,766**

9 Evaluation and Recommendation

9.1 Projected Trends

Key observations from this analysis include the total cost of all transition options compared with Business-as-Usual, and the patterns in overall cost difference related to the timeline of fleet replacement. The projected incremental costs of all options are presented in a matrix in **Exhibit 138** and **Exhibit 139** below, to highlight these patterns. As with the annual breakdown tables provided in previous sections, costs for electrification alternatives are shown as the increment relative to the BAU alternative.

Exhibit 138: Comparison Matrix of Total Cost of Ownership, 2024-2037
(Including First Generation Capital Purchases Only, 2023 Present Value, 000s)

		(1) Stationary Charging	(2) Rotating Indoor Batch Charging	(3) Rotating Outdoor Charging
(a) End-of-Life Replacement	Electric Heat	$ 178,811	$ 181,875	$ 182,372
	Diesel Heat	$ 180,118	$ 183,181	$ 183,685
(b) Accelerated Replacement	Electric Heat	$ 173,843	$ 178,949	$ 179,174
	Diesel Heat	$ 176,754	$ 181,859	$ 182,095
(c) Flash Cut Replacement	Electric Heat	$ 165,037	$ 172,186	$ 172,140
	Diesel Heat	$ 168,996	$ 176,143	$ 176,111
Business-as-Usual (No Replacement)				$ 161,378

Exhibit 139: Comparison Matrix of Total Cost of Ownership, 2024-2037
(Including First- and Second-Generation Capital Purchases, 2023 Present Value, 000s)

		(1) Stationary Charging	(2) Rotating Indoor Batch Charging	(3) Rotating Outdoor Charging
(a) End-of-Life Replacement	Electric Heat	$ 196,942	$ 200,006	$ 200,502
	Diesel Heat	$ 195,090	$ 198,153	$ 198,657
(b) Accelerated Replacement	Electric Heat	$ 191,973	$ 197,080	$ 197,305
	Diesel Heat	$ 191,726	$ 196,831	$ 197,067
(c) Flash Cut Replacement	Electric Heat	$ 220,026	$ 227,176	$ 227,130
	Diesel Heat	$ 220,827	$ 227,974	$ 227,942
Business-as-Usual (No Replacement)				$ 164,104

As can be seen in these comparisons, of all scenarios the Business-as-Usual approach produces the lowest total costs. Of the transition options to BEBs, all 2024 flash cut alternatives theoretically outperform longer transition timeframes on cost, when considering the first-generation capital purchases only. This would be a result of transitioning away from fossil fuels in the shortest possible timeframe, as operating costs are anticipated to reduce significantly with a switch to electric power. The much higher apparent cost of a flash cut presented in **Exhibit 138** and **Exhibit 139** is a result of purchasing an entire second generation of conventional vehicles within the analysis horizon.

The specific approach to charging had limited impact on projected cost in terms of 2023 present value, with a spread of $3.5 million to $7.2 million within the same transition timeframe. At the scale of deployment expected at Brantford Transit, the additional equipment deployment costs to facilitate stationary charging produce savings compared with additional labour to shuttle buses around the garage for charging.

9.2 Excluded Options

Despite the overall low cost of maintaining Business-as-Usual, this approach is recommended for exclusion as it fails to meet federal emissions reductions targets or the City's own climate emergency declaration.

Scenarios involving a 2024 flash cut incur the lowest total costs, assuming all elements of the transition unfold to plan. However, as BEB technology and deployments are still not at a fully mature state of development in North America, risks of technical challenges associated with an immediate 2024 conversion are high:

- Converting the entire fleet at once provides no opportunity to collect performance data and refine technical requirements based on lessons learned;
- Staff would have limited opportunity for exposure to the new technology before having to rely on it to deliver service;
- This strategy would incur high up-front capital costs, and it would set up a pattern of heavily concentrated costs in subsequent replacement cycles.

For these reasons, a flash cut is also recommended for exclusion.

9.3 Recommended Path Forward

9.3.1 Fleet Replacement

Key Recommendation:

IBI Group recommends that Brantford Transit pursue an end-of-life replacement timeline for the current fleet.

The end-of-life and accelerated replacement timeframes carry higher transition costs than a flash cut. An accelerated fleet replacement, in which all vehicles would transition by 2030, produces lower total costs than an end-of-life transition, due to lower energy costs from electricity compared with fossil fuels. This variation is due to higher labour costs for indoor batch and outdoor rotating charging, which partially offset fuel cost savings from an accelerated transition.

However, the lower theoretical cost of an accelerated transition is accompanied by higher risk, as Brantford Transit would still need to pursue an accelerated procurement process in which there is little opportunity for lessons learned from the first order of buses and chargers to inform later orders. If major changes need to be made to procurement schedules or specifications, the relatively low marginal cost between the end-of-life and accelerated transition timelines could quickly be eclipsed by the cost of midstream changes.

As of 2022, BEB orders are facing an anticipated backlog of 12 to 18 months due to accelerating customer demand and overarching global supply chain challenges. If ordered before the end of 2022, the first delivery of BEBs could be anticipated to occur between the late 2023 and mid-2024, with all-season data gathering not being complete for at least 12 months. These findings would not translate into lessons learned for vehicle and charger specifications until at least late 2025, only affecting vehicles to be delivered from late 2026 or mid-2027 onward. Coordinating these milestones with an accelerated replacement target would result either in multiple procurements that miss opportunities to benefit from lessons learned with the initial order, or in a delayed procurement followed by a rush to fully replace the fleet between 2027 and 2030.

9.3.2 Vehicle Heating

Key Recommendation:

IBI Group recommends purchasing first-generation BEBs with auxiliary diesel heaters for resiliency purposes in extreme cold weather. We encourage Brantford Transit to consider pursuing heat pump technology as the technology develops and becomes available on the North American market, because of potential savings in energy consumption.

The energy and charging analysis included in this study indicated that fleet expansion savings from exclusively using diesel heating would be minimal, due to the power draw of summer air conditioning on the battery. Typical Brantford winters do not tend to involve prolonged running at extreme low temperatures. However, diesel heaters may be important for resiliency in cold snaps when battery performance would be threatened.

Heat pump technology has not yet made major commercial entry in North America, however this is an anticipated market requirement for dealing with large seasonal temperature variations typical to many Canadian and US cities. When it becomes available, it may offer considerable energy savings over heating based on diesel combustion or electrical resistance, and the consolidation of heating and cooling capabilities in one unit may reduce maintenance requirements.

9.3.3 Charging Equipment Configuration

Key Recommendation:

In the near term, IBI Group recommends that Brantford Transit install initial charging equipment indoors, in a configuration that supports a near-future decision between stationary charging and rotating batch charging. That decision would be based on deploying an initial order of BEBs and observing performance. Initial operations would use stationary charging to avoid additional labour cost while BEB performance is evaluated.

In the medium term, IBI Group recommends that the City of Brantford investigate options for a new or relocated facility for transit operations, given the constraints at the existing garage.

Each charging option is projected to incur varying costs from the charging equipment and labour. Of the three equipment configurations, stationary charging incurs the lowest cost due to avoided extra labour. This analysis projects that rotating outdoor charging would theoretically incur the highest cost in an end-of-life replacement timeline, however the margin compared with indoor batch charging (under $1m total to 2037 – 2023 present value) is within a plausible margin of error based on the potential for unforeseen fluctuation in future resource and labour costs.

In the early stages of rollout, alternatives 1 and 2 (stationary and indoor batch charging) start with the same equipment, before diverging at Transition Year 6 (approx. 2029; see **Section 6.2.2**). IBI Group recommends selecting between the alternatives by Transition Year 3 (approx. 2026) to provide time to plan operations and capital purchases.

In a new-build facility, stationary charging would be the dominant recommendation, carrying approximately $5m less cost (2023 present value). However, in the existing Brantford Transit garage, stationary charging carries the notable disadvantage of requiring spillover to outdoor stalls. Lift vehicles would not be accommodated indoors, and supplementary conventional fleet chargers would be required outdoors by Transition Year 11 (approx. 2034), as there is not enough space within the garage building to accommodate chargers for all vehicles.

Based on these constraints and Brantford Transit's stated preference to consider indoor charging, proceeding with an initial charger layout that supports either alternative 1 or 2 would provide the most flexibility to react to performance data findings and possible further investigation of a new facility as the transition progresses.

9.3.4 Recommended Options Summary

A summary of the projected total costs for both finalist options is presented in

Exhibit 140 (showing costs using electric heaters only) and **Exhibit 141** (showing costs using diesel heaters only) below. As noted in **Section 9.3.1**, it is recommended that Brantford Transit procure BEBs with diesel auxiliary heaters and calibrate their use according to reliability needs. As a result, final cost projections could be projected to fall between the values presented in these tables.

Also provided for context are the projected GHG emissions corresponding to the recommended fleet replacement timelines, and GHG emissions savings expressed in terms of "cars taken off the road" (based on emissions statistics from Natural Resources Canada[24]).

Annual costs vary from year to year compared with the Business-as-Usual case, as a result of somewhat shifted procurement cycles for BEBs and equipment. GHG emissions projections rise slightly during 2024 because the impact of BEB manufacturing has not yet been offset by replacing fossil fuels in daily operations, during the initial rollout.

[24] https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/calculator/ghg-calculator.cfm#results

Exhibit 140: Recommended Options Summary of Incremental Costs and GHG Savings Comparison
(Including Conventional BEBs with Electric Heaters; First- and Second-Generation Capital Purchases)

Year	Annual Costs (2023 Present Value, 000s)						Annual GHG Emissions (t CO2-eq)		GHG Emissions Savings (“Cars off the Road”)
	Business as Usual		Alternative 1a (Stationary Charging, End-of-Life Replacement)		Alternative 2a (Indoor Batch, End-of-Life Replacement)		Business as Usual	BEB Transition (Either Equipment Layout)	
	Capital	Operating	Capital	Operating	Capital	Operating			
2024	$ 2,748	$ 9,026	$ 7,102	$ 9,293	$ 7,102	$ 9,293	3839	3501	103
2025	$ 758	$ 9,026	$ 6,583	$ 8,824	$ 6,583	$ 8,824	3839	3356	148
2026	$ 3,202	$ 9,026	$ 4,939	$ 8,437	$ 4,939	$ 8,437	3839	3001	257
2027	$ 1,298	$ 9,026	$ 3,567	$ 8,389	$ 9,965	$ 8,265	3839	2799	318
2028	$ -	$ 9,026	$ -	$ 8,401	$ 8,506	$ 8,092	3839	2799	318
2029	$ 1,947	$ 9,026	$ 5,209	$ 8,333	$ 7,317	$ 7,909	3839	2487	414
2030	$ 2,510	$ 9,026	$ 5,517	$ 7,818	$ 9,267	$ 7,295	3839	2394	442
2031	$ 152	$ 9,026	$ 1,950	$ 7,843	$ 1,950	$ 7,338	3839	2394	442
2032	$ 2,704	$ 9,026	$ 6,499	$ 7,799	$ 1,560	$ 7,389	3839	2082	538
2033	$ 606	$ 9,026	$ -	$ 7,832	$ -	$ 7,439	3839	2078	539
2034	$ -	$ 9,026	$ -	$ 7,870	$ -	$ 7,497	3839	2078	539
2035	$ 3,245	$ 9,026	$ 6,128	$ 7,771	$ -	$ 7,561	3839	1644	672
2036	$ 3,245	$ 9,026	$ 10,884	$ 7,728	$ 4,756	$ 7,633	3839	1211	805
2037	$ 3,159	$ 9,026	$ 10,273	$ 7,714	$ 6,706	$ 7,714	3839	1004	868
Total	**$ 25,574**	**$ 126,364**	**$ 68,651**	**$ 114,052**	**$ 68,651**	**$ 110,686**	**53752**	**32828**	

Exhibit 141: Recommended Options Summary of Incremental Costs and GHG Savings Comparison
(Including Conventional BEBs with Diesel Heaters; First- and Second-Generation Capital Purchases)

Year	Annual Costs (2023 Present Value, 000s)						Annual GHG Emissions (t CO2-eq)		GHG Emissions Savings ("Cars off the Road")
	Business as Usual		Alternative 1a (Stationary Charging, End-of-Life Replacement)		Alternative 2a (Indoor Batch, End-of-Life Replacement)		Business as Usual	BEB Transition (Either Equipment Layout)	
	Capital	Operating	Capital	Operating	Capital	Operating			
2024	$ 2,748	$ 9,026	$ 7,102	$ 9,206	$ 7,102	$ 9,206	3839	3491	106
2025	$ 758	$ 9,026	$ 6,583	$ 9,007	$ 6,583	$ 9,007	3839	3338	153
2026	$ 3,202	$ 9,026	$ 4,939	$ 8,633	$ 4,939	$ 8,633	3839	2973	265
2027	$ 1,298	$ 9,026	$ 3,567	$ 8,501	$ 9,965	$ 8,392	3839	2764	329
2028	$ -	$ 9,026	$ -	$ 8,513	$ 8,506	$ 8,339	3839	2764	329
2029	$ 1,947	$ 9,026	$ 5,209	$ 8,316	$ 7,317	$ 7,944	3839	2441	428
2030	$ 2,510	$ 9,026	$ 5,517	$ 8,159	$ 9,267	$ 7,237	3839	2342	458
2031	$ 152	$ 9,026	$ 1,950	$ 8,184	$ 1,950	$ 7,281	3839	2342	458
2032	$ 2,704	$ 9,026	$ 6,499	$ 8,014	$ 1,560	$ 7,330	3839	2020	557
2033	$ 606	$ 9,026	$ -	$ 8,048	$ -	$ 7,382	3839	2019	557
2034	$ -	$ 9,026	$ -	$ 8,087	$ -	$ 7,441	3839	2018	557
2035	$ 3,245	$ 9,026	$ 6,128	$ 7,821	$ -	$ 7,506	3839	1574	694
2036	$ 3,245	$ 9,026	$ 10,884	$ 7,756	$ 4,756	$ 7,578	3839	1129	830
2037	$ 3,159	$ 9,026	$ 10,273	$ 7,658	$ 6,706	$ 7,658	3839	913	896
Total	**$ 25,574**	**$ 126,364**	**$ 68,651**	**$ 115,903**	**$ 68,651**	**$ 110,934**	**53752**	**32127**	

9.3.5 Funding and Financing Opportunities

As shown in **Exhibit 140** and **Exhibit 141**, operating costs are projected to achieve net savings in either BEB transition option by the study horizon of 2037, due to replacing fossil fuel costs with electricity costs. The net cost increase from transition is due to higher capital costs from fleet expansion as well as higher unit costs per vehicle.

In the long-term, it is possible that BEB manufacturing costs may decrease as the technology matures. Improved performance may also reduce the need for fleet expansion to provide the same level of service as the current fossil fuel fleet, freeing the additional fleet for network expansion.

In the short-term, funding and financing opportunities are available to assist Brantford in offsetting the capital cost increase compared with purchasing fossil fuel vehicles. The Canadian Infrastructure Bank (CIB) Zero Emission Buses (ZEB) Initiative[25] offers flexible financing for BEBs and related charging infrastructure. This takes the form of direct loans with interest rates at or below market rates, to cover high up-front capital costs. Repayment is sourced solely from the actual savings generated by the lower operating costs of electric buses. Typically, the CIB will finance the difference between the cost of purchasing traditional diesel buses and BEBs. Financing is available in multiple draws over the project implementation period (1-5 years) with repayment over the financing term (12-18 years). The CIB ZEB Initiative fund has been used so far on electrification projects in cities including Edmonton ($14.4 million), Ottawa ($400 million), and Brampton ($400 million). Eligibility for funding is determined by the CIB through enquiry, but the City of Brantford appears to meet typical criteria.

Infrastructure Canada also launched the Zero Emissions Transit Funding (ZETF) funding program in 2021, for which agencies are considered in coordination with the CIB financing. Agencies can be funded for up to 50% of capital costs for buses and charging infrastructure once sufficient transition planning has been completed.

Ontario municipalities can also apply for funding through the Investing in Canada Infrastructure Program[26] (ICIP), in which the Canadian federal government covers 40% of the total eligible cost of a new transit project, the province 33.33%, and the municipality 26.67%. To be eligible, a municipality must fulfill the criteria set out in the grant program guide[27] which includes receiving provincial gas tax funding and having reported their ridership data to the Canadian Urban Transit Association (CUTA) for 2015. Beyond municipal eligibility, project-specific eligibility is determined by the following required criteria:

- Capital components are owned by the applicant;
- Project will be substantially completed by October 31, 2027;
- Project must meet the highest accessibility standards in Ontario; and.
- Other project-specific criteria set out in the program guide.

Municipalities may use other sources of provincial funding like the provincial gas tax toward their contribution, but the federal contribution level is a maximum regardless of the source of federal funding.

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[25] CIB Growth Plan: Overview of $1.5B Zero Emission Buses Initiative. https://cib-bic.ca/wp-content/uploads/2021/03/ZEB-initiative.pdf
[26] *INVESTING IN CANADA INFRASTRUCTURE PROGRAM: PUBLIC TRANSIT STREAM: Program Guide.* Ministry of Transportation, Ontario. Urban and Rural Infrastructure Policy Branch. June, 2021.
[27] Investing in Canada Infrastructure Program: Public Transit Stream

Appendix A
Facility Field Review Report

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Facility Field Review Report

Project Name	RFP 2021-34 “Electric Bus Needs Assessment & Feasibility Study”	**Report No.**	**FFRR-001**
Client Name	City of Brantford	**Report Date**	Aug 27 2021
Project No.	134803	**Date of Visit**	Aug 05 2021
Permit No.	N/A	**Time of Visit**	2:00PM
Location	400 Grand River Ave., ON N3T 5A3	**Reviewer**	Tony Shen
Weather Conditions	Sunny		

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A- PURPOSE

1. To review the existing facility and assess the possibility for the planning of the current fleet electrification.
2. Review the garage size and available space for infrastructure and equipment related to charging the electrical busses.
3. Review existing electrical and IT spaces and determine available space for expansions related to the fleet electrification initiative.
4. Review the available space on site for new hydro transformer or customer-owned substation.

B- OBSERVATION

B.1- Architectural observations

1. The existing building is around 65000 sq ft in total area, with a maximum length of around 300 ft and maximum width of 215 ft. It is divided into two city operations: Brantford Power Inc (BPI) and Brantford Transit (BT). BPI occupies the east part of the bus garage (with 3 overhead doors) and part of the west building area (storage space). BT occupies the middle (Garage) and west part of the bus garage (maintenance & repair), as well as the west building area. (see photos 003 and 004)
2. Vehicles in the Brantford Transit Repair area are parked at a 45-degree angle. The busses in the garage are parked in a longitudinal arrangement, 2 bus lanes per overhead door (bay). If the Transit garage expands into the Brantford Power space, additional space will be available for the bus electrification system.
3. The 14’-3” interior height of the bus garage and the unknown status of the overhead structural trusses do not allow for pantographs, floor mounted chargers/dispensers must be used instead. The former type of chargers may require extensive structural assessment and reinforcement which is not advisable due to the age of the facility.

4. There is not enough space between the bus parking and the sidewalk (about 800mm) for the implementation of chargers/dispensers per current bus parking arrangement (see Photo 010).
5. Potential solar panel farm can be located on the roof and on-site plan in the space west of the building (current Hydro Yard). Solar panel assembly on the garage roof would require complete structural system assessment by structural engineer, as the structure of the building is more than 50 years old.

B.2- Architectural Conclusion:

1. It appears that the current facility layout will allow the owner to perform full fleet electrification without major expansion to the building. The acquisition of the Brantford Power space will add to the space availability and allow for chargers and dispensers installation indoors.
2. The site plan has potential space for expanding the electrical system that is required for full fleet electrification.

B.3- Electrical observations:

1. Existing Hydro service for the City of Brantford Transit facility is provided by a pad mounted three-phase transformer located inside the north-east corner of hydro yard, which is fed from an adjacent hydro dip pole via overhead line (OHL). As per follow up information received from Brantford Power Inc (BPI), the current utility provider, transformer size is 750 kVA, with 27.6KV primary and 347/600V (secondary)
2. This 750 kVA pad mount Hydro transformer is currently providing power for both Brantford Transit Garage and Brantford Power Store. The demand load per latest available meter data is:

   Transit garage: 102 kW average

   Power Store: 200 kW average
3. The existing main electrical switchboard (1200A, 600V, 3P/3W) c/w main hydro meter is located in the backhouse of the Transit Garage shop parts storage area, fed from Hydro transformer via underground conduits. The main breaker is 1200A/3P. This switchboard is shared by both Transit Garage and Power Store, each has its own hydro revenue meter.
4. The switchboard is feeding following power panels and services

   Transit garage: PP #2 (225A), PP #3 (100A), PP #6 (150A), PP #8 (?), Shop Splitter #1 (?)

   Power Store: PP #7 (400A)
5. Inside main switchboard, there are two (2) 600A/3P spare breakers, and three (3) spaces for future breakers
6. The Power Store main panel PP #7 is located inside its storage area, c/w hydro meter cabinet and downstream transformer and panels, all wall mounted.
7. The existing IT cabinet, phone terminal blocks and security panels are located in the same area on the north wall.
8. There is no outdoor emergency backup generator

B.4- Electrical Conclusion:

6. The Brantford Power Store is moving out. After that, the whole site, including the current hydro service (750 kVA) and main switchboard will be available dedicated for Brantford Transit Garage.

   The average Transit Garage power demand load is 102 kW, equal to 106 kVA calculated based on 96% power factor per latest hydro bill (Jun.16/2021), which leaves 644 kVA spare power capacity for bus electric charging.

   Bus charging power cabinet would be based on 150 kW capacity each (c/w 1, 2, or 3 charging dispensers). As per data from ABB and SIEMENS, the two major BEB charger market players, the required input power load varies from 170 kVA to 186 kVA

7. Per current existing 750 kVA hydro transformer, without hydro service upgrade, maximum of 4 -150 kW charging power cabinets (up to 12 charging dispensers) can be accommodated.

   New dedicated BEB power distribution panel(s) will be added

   Existing switchboard has 2 spare 600A breakers which might be utilized for the new BEB power distribution panel feeders as required.

8. Existing hydro service upgrade might be required to accommodate the full transition to Battery Electric Bus (BEB) fleet if more than 4 charging power cabinet required per study.

   In the situation when more than 4 charging power cabinets are required, Hydro service upgrade will be required.

   Per Brantford Power Inc's Conditions of Service (March 2020 edition), for any new transformer provided by BPI, the max pad mounted capacity 1.5 MVA before the connection is transferred from General Service (Section 3.3.4) to Customer Owned Substation (section 3.3.5).

   As per e-mail conversation with Ryan Hantz (rhantz@brantford.ca) from BPI, the largest transformer that Brantford Power supplies is 2500 kVA (2.5MVA).

   Customer Owned Substation will involve extra infrastructure capital cost. Further clarification with BPI will be required.

   Based on current Transit Garage demand load 106 kVA,

   - Upgrade hydro service to 1500 kVA (1.5MVA) transformer can accommodate up to 8 BEB 150 kW charging power cabinet (up to 24 charging dispensers).
   - Upgrade hydro service to 2500 kVA (2.5MVA) transformer can accommodate up to 14 charging power cabinet (up to 42 charging dispensers)

9. If hydro server upgrade is required per study, to reduce the power interruption to minimum, installing a new main switchboard is recommended while keep the existing one intact for facility operation during the service upgrade. After the new hydro transformer and switchboard being installed, the existing facility switchboard will be re-fed from the new main switchboard after disconnecting it from existing hydro feeder during power cut-over. The rest of existing power distribution system for the facility would remain the same. Hydro meter tapping (CT/PT) will need to be upgraded to accommodate.

   The new hydro pad mount transformer can be installed in the yard close to the existing hydro transformer and hydro dip pole.

   The new main switchboard can be installed either inside the current shop parts storage area by removing some storage racks to have space, or inside current Power Store area adjacent to where existing panels located. New duct bank/conduits will be required for new hydro service feeder cables.

   The new BEB power distribution panel fed from new main switchboard can be installed either by the new main switchboard or in bus storage area where the BEB Charger Power Cabinets located.

1. For the data connection required for the BEB chargers for management, to reduce operation cost, local LAN (wired or wireless network) is preferred than 4G cellular network which has monthly cost.

2. Currently, no emergency backup generator is provided for reliability of the facility service. This is another issue to discuss for the fleet electrification study

C- COMMENTS

None

Prepared

Anwar Ktecha	August 27, 2021
Signed	Date
Tony Shen	August 27, 2021
Signed	Date

Approved:

Nicolas Al Nakhl	August 27, 2021
Signed	Date

Existing Site Photos

Architectural Aspects

External

Photo 001– Hydro Dip Pole Near Transformer

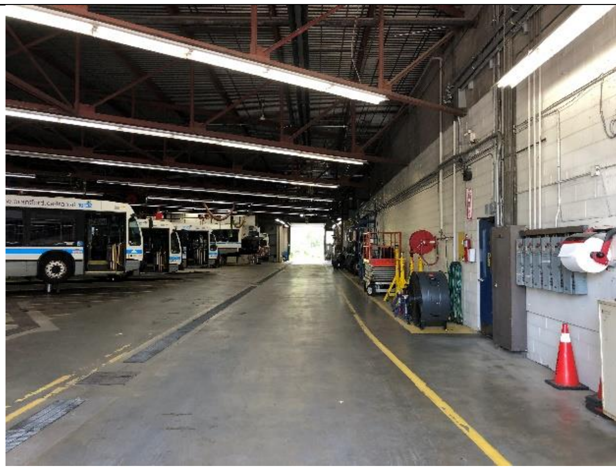
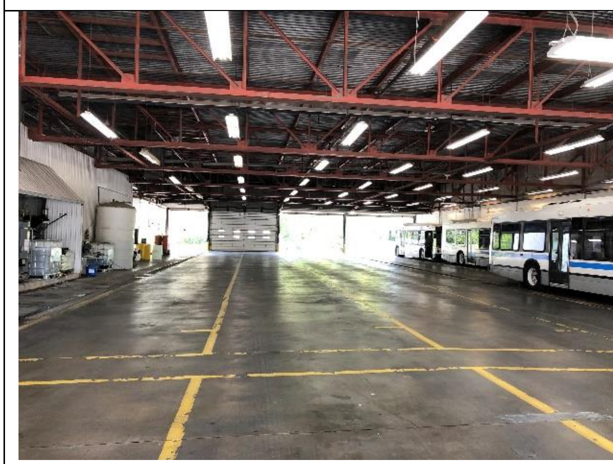
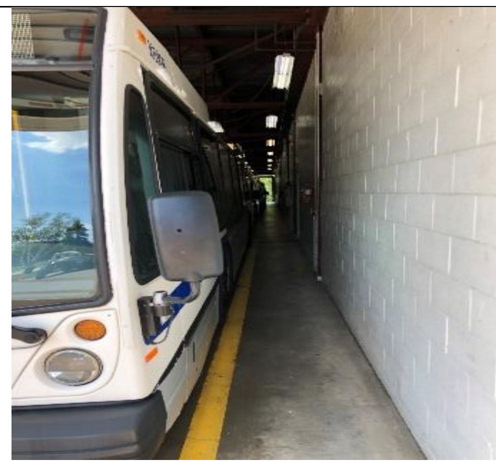
Photo 002 – 750 KV Pad Mounted hydro Transformer

Photo 003 - Overhead doors to Brantford Transit (BT).

Photo 004 –Overhead doors to Brantford Power Inc (BPI)

Photo 005 - Overhead doors to Brantford Transit and Brantford Power Inc-South elevation.

Photo 006 – Office area-main entrance

Architectural Aspects	Internal		
		Photo 007 – Maintenance garage	Photo 008 -Bus wash bay
			
		Photo 009 – Brantford Transit Bus garage	Photo 010 – Available space between bus and masonry wall on BT bus garage side.
			
		Photo 011 - Available space between buses at BT bus garage.	Photo 012 - Brantford Power garage.

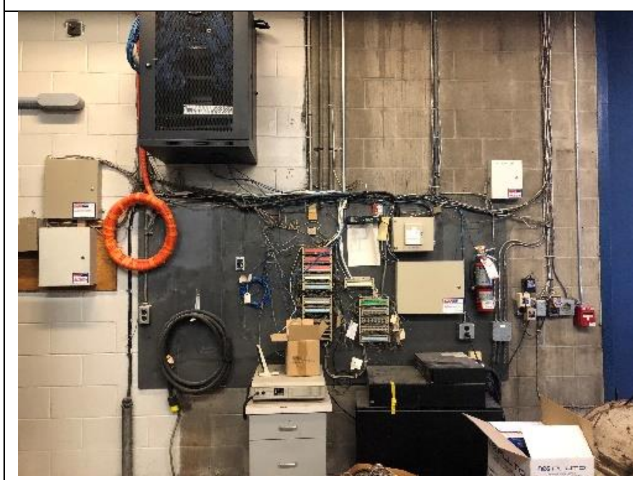
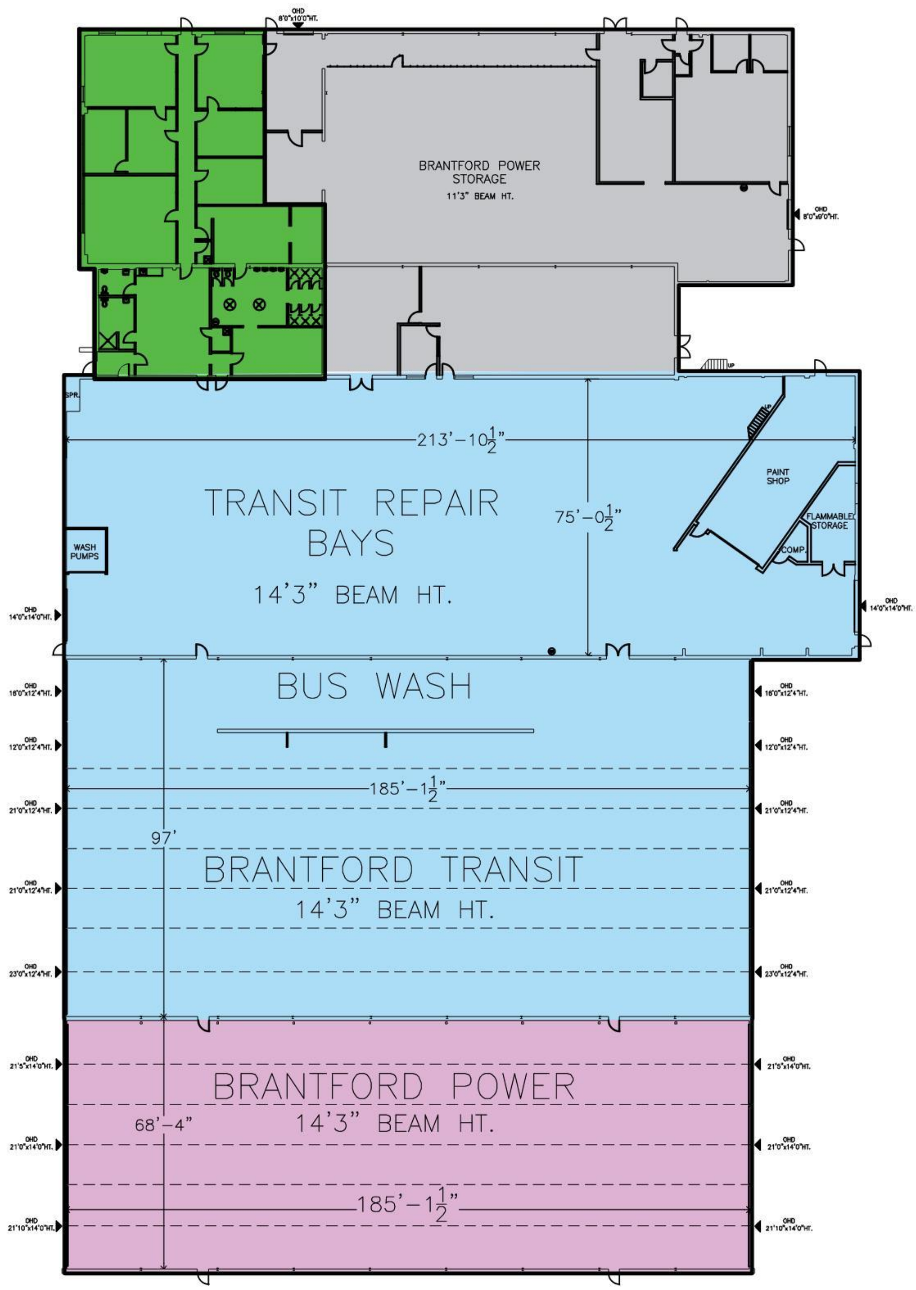
<table>
<tr><td rowspan="4">Electrical Aspects</td><td rowspan="4"></td><td></td><td></td></tr>
<tr><td>Photo 013 – Existing electic main switchboard in Transit Garage parts storage area</td><td>Photo 014 – Existing Electic main switchboard integrated power distribution panel</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Photo 015 – Existing IT cabinet, security panels and telephone terminal blocks in Transit Garage parts storage area</td><td>Photo 016 - Existing electic panel/transformer in Power Store storage area</td></tr>
</table>

Figure 001– 3D View of the facility

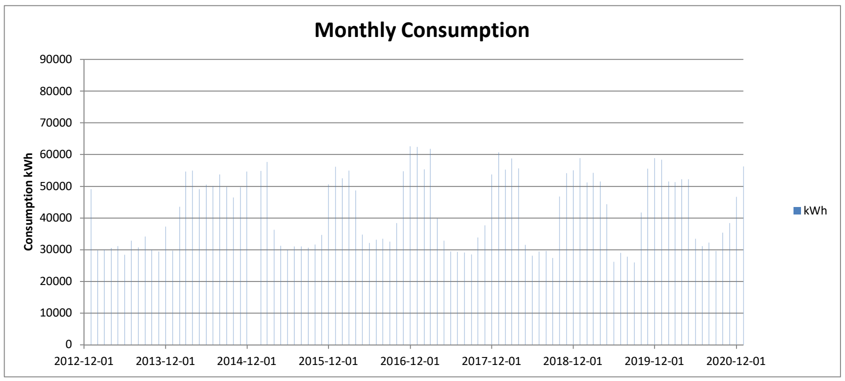


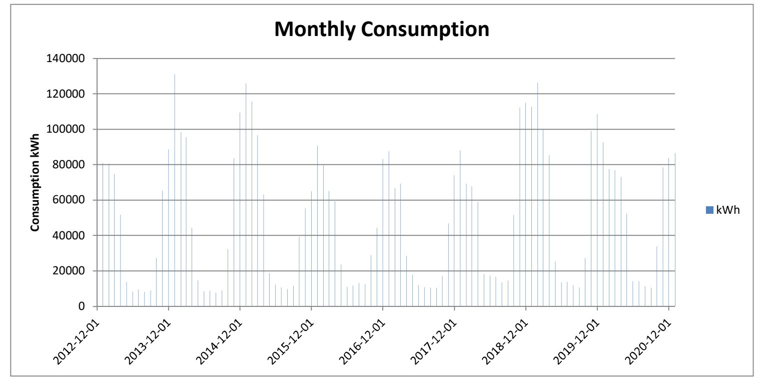
OFFICE AREA:	5,418 SQ.FT.
BRANTFORD POWER STORAGE:	11,676 SQ.FT.
BRANTFORD TRANSIT AREA:	35,110 SQ.FT.
BRANTFORD POWER AREA:	12,786 SQ.FT.
TOTAL AREA:	64,990 SQ.FT.

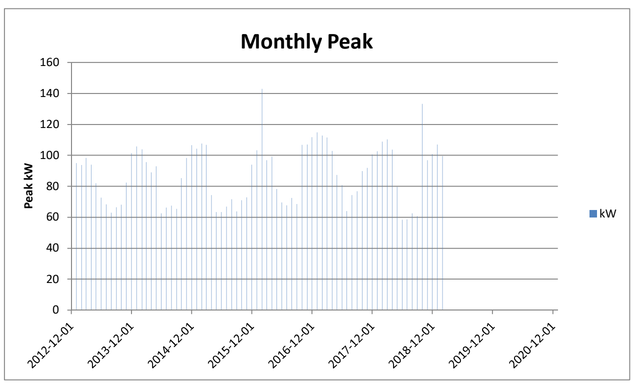
Figure 002– Layout of the facility

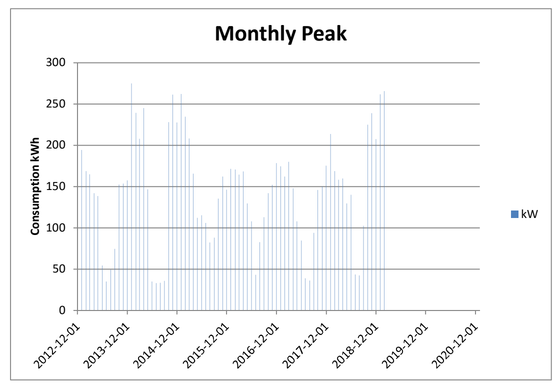
Back to ELEC Summary

Operational Services GARAGE		TRANSIT GARAGE 400 GRAND RIVER AVE 218899-2						POWER STORES 400 GRAND RIVER AVE 218895-3						TOTAL		
YEAR	HDD	Months	kWh	kW Avg	kW Max	kW Min	$	Months	kWh	kW Avg	kW Max	kW Min	$	kWh	$	
2014	0	12	586273	87	106	63	$ 82,025	12	643037	164	275	33	$ 97,599	1229310	$ 179,625	
2015	0	12	418986	80	107	63	$ 63,291	12	622896	151	262	82	$ 97,238	1041882	$ 160,529	
2016	0	12	533507	94	143	68	$ 92,628	12	522764	135	178	43	$ 95,738	1056271	$ 188,366	
2017	0	12	493311	92	115	64	$ 84,130	12	450624	125	180	36	$ 79,399	943935	$ 163,529	
2018	0	12	531715	90	133	58	$ 86,911	12	642228	152	239	42	$ 111,801	1173943	$ 198,712	
2019	0	12	525000	17	107	0	$ 83,884	12	733675	44	265	0	$ 114,958	1258675	$ 198,843	
2020	0	12	511977	0	0	0	$ 86,816	12	617891	0	0	0	$ 107,135	1129868	$ 193,951	
Insert Row Above																
2019	0	12	525000	17	107	0	$ 83,884	12	733675	43.89333333	265	0	$ 114,958	1258675	$ 198,843	<--- YTD
AVERAGE	***0***	***12***	***514396***	***66***	***102***	***45***	***$ 82,812***	***12***	***604731***	***110***	***200***	***34***	***$ 100,553***	***1119126***	***$ 183,365***	









Appendix B
Mileage Statistics for Brantford Lift

The computed statistics of the Brantford Lift daily operating mileage data from September 2019 are presented in tables below. The energy consumption estimates in Section **Error! Reference source not found.** were based on these results.

Exhibit 142:Total mileage statistics by vehicle for Brantford Lift in Sept. 2019 (all values in km)

Vehicle ID	Weekdays	Saturdays	Sundays	Total
12105	0	0	0	**0**
141	241	0	0	**241**
142	482	0	0	**482**
151	2476	91	0	**2567**
152	1687	0	0	**1687**
153	1271	49	49	**1369**
154	1126	0	0	**1126**
155	2340	198	131	**2669**
160	0	0	0	**0**
121701	2474	434	317	**3225**
121702	1958	472	331	**2761**
121703	1853	0	108	**1961**
121704	2072	523	556	**3151**
121805	2692	304	296	**3292**
121839	1392	0	0	**1392**
121840	2081	0	0	**2081**
121841	1284	0	0	**1284**
121842	0	0	0	**0**
Total	**25429**	**2071**	**1788**	**29288**

Exhibit 143: Month average Lift mileage statistics in Sept. 2019 (all values in km except vehicle count)

Data Category		Weekdays	Saturdays	Sundays
Average Daily Mileage by Vehicle	12105	0	0	0
	141	80.33	0	0
	142	80.33	0	0
	151	130.32	91	0
	152	120.5	0	0
	153	90.79	49	49
	154	86.62	0	0
	155	123.16	99	43.67
	160	0	0	0
	121701	130.21	108.5	79.25
	121702	122.38	118	66.2
	121703	115.81	0	54
	121704	115.11	130.75	111.2
	121805	134.6	76	59.2
	121839	116	0	0
	121840	115.61	0	0
	121841	98.77	0	0
	121842	0	0	0
Month Average of Daily Total Mileage		1271.45	517.75	357.6
Month Average of Daily Active Vehicle Count		11 vehicles	5 vehicles	5 vehicles
Month Average of Daily Average Vehicle Mileage		115.91	106.75	71.52

Exhibit 144: Maximum Lift mileage logged in one day by individual vehicle in Sept. 2019 (all values in km)

Vehicle ID	Weekdays	Saturdays	Sundays
12105	0	0	0
141	120	0	0
142	116	0	0
151	161	91	0
152	143	0	0
153	143	49	49
154	141	0	0
155	163	131	60
160	0	0	0
121701	166	135	104
121702	152	150	103
121703	136	0	71
121704	142	197	129
121805	210	121	116
121839	218	0	0
121840	142	0	0
121841	126	0	0
121842	0	0	0

Exhibit 145: Maximum fleet-wide total mileage in one day for Brantford Lift in Sept. 2019

	Weekday	Saturday	Sunday
Day Total Mileage (km)	1478	572	383
Date Logged	2019-09-24	2019-09-28	2019-09-08

Appendix C
Original Fleet Replacement Timelines

Exhibit 146: Brantford Transit Conventional Fleet Replacement Timeline (June 2021)

Unit #	Year	Unit Description Make/Model	Life Cycle	Replacement Year	Other Info
10081	2008	NOVA 40FT LFS COACH	14	2022	
10083	2008	NOVA 40FT LFS COACH	14	2022	
10084	2008	NOVA 40FT LFS COACH	14	2022	
10102	2010	NOVA 40FT LFS HYBRID	12	2024	
10103	2010	NOVA 40FT LFS HYBRID	12	2024	
10104	2010	NOVA 40FT LFS HYBRID	12	2024	
10105	2010	NOVA 40FT LFS HYBRID	12	2024	
10121	2012	NOVA 40FT LFS COACH	14	2026	
10123	2012	NOVA 40FT LFS COACH	14	2026	
10124	2012	NOVA 40FT LFS COACH	14	2026	
10125	2012	NOVA 40FT LFS COACH	14	2026	
10131	2013	NOVA 40FT LFS COACH	14	2027	
10132	2013	NOVA 40FT LFS COACH	14	2027	
10151	2015	NOVA 40FT LFS COACH	14	2029	
10152	2015	NOVA 40FT LFS COACH	14	2029	
10153	2015	NOVA 40FT LFS COACH	14	2029	
10161	2016	NOVA 40FT LFS COACH	14	2030	
10162	2016	NOVA 40FT LFS COACH	14	2030	
101808	2018	NOVA 40FT LFS COACH	14	2032	
101809	2018	NOVA 40FT LFS COACH	14	2032	
101810	2018	NOVA 40FT LFS COACH	14	2032	
102105	2021	NOVA 40FT LFS COACH	14	2035	New bus expected in Q3 2021
102106	2021	NOVA 40FT LFS COACH	14	2035	New bus expected in Q3 2021
102107	2021	NOVA 40FT LFS COACH	14	2035	New bus expected in Q3 2021
102108	2021	NOVA 40FT LFS COACH	14	2035	New bus expected in Q3 2021
102109	2021	NOVA 40FT LFS COACH	14	2035	New bus expected in Q3 2021
TBD	2022	NOVA 40FT LFS COACH	14	2036	On order, delivery in Q2 2022
TBD	2022	NOVA 40FT LFS COACH	14	2036	On order, delivery in Q2 2022
TBD	2022	NOVA 40FT LFS COACH	14	2036	On order, delivery in Q2 2022
TBD	2022	NOVA 40FT LFS COACH	14	2036	On order, delivery in Q2 2022
TBD	2022	NOVA 40FT LFS COACH	14	2036	On order, delivery in Q2 2022

Exhibit 147: Brantford Lift Fleet Replacement Timeline (June 2021)

Unit #	Year	Unit Description Make/Model	Life Cycle	Replacement Year	Other Info
12105	2010	CHEV EXPRESS/Goshen	7	2017	Replacement ordered Q1 2022 - Delivery in 2023
12141	2014	CHEV EXPRESS/Goshen	7	2021	Replacement ordered Q1 2022 - Delivery in 2023
12142	2014	CHEV EXPRESS/Goshen	7	2021	Replacement ordered Q1 2022 - Delivery in 2023
12151	2015	CHEV EXPRESS/Goshen	7	2022	Replacement ordered Q1 2022 - Delivery in 2023
12152	2015	CHEV EXPRESS/Goshen	7	2022	Replacement ordered Q1 2022 - Delivery in 2023
12153	2015	CHEV EXPRESS/Goshen	7	2022	Replacement ordered Q1 2022 - Delivery in 2023
12154	2015	CHEV EXPRESS/Goshen	7	2022	Replacement ordered Q1 2022 - Delivery in 2023
12155	2015	CHEV EXPRESS/Goshen	7	2022	Replacement ordered Q1 2022 - Delivery in 2023
12160	2016	MV-1	7	2023	
121701	2017	GMC 4500 Glaval	7	2024	
121702	2017	GMC 4500 Glaval	7	2024	
121703	2017	GMC 4500 Glaval	7	2024	
121704	2017	GMC 4500 Glaval	7	2024	
121805	2017	GMC 4500 Glaval	7	2024	
121839	2018	Ford Champion LF	7	2025	
121840	2018	Ford Champion LF	7	2025	
121841	2018	Ford Champion LF	7	2025	
121842	2018	Ford Champion LF	7	2025	

Appendix D
GHG Emissions Formulas

This appendix outlines the equations and variables used in calculating GHG emissions from all bus operations, and from marginal emissions from BEB manufacturing. The values used in these equations can be found in **Section 7.2** of the report.

Battery Electric Buses

$$Operation\ Emissions\ Per\ Year\ \left(\frac{t\ CO_2eq}{year}\right) = \frac{\text{Ontario energy mix }\left(\frac{\text{g CO}_2\text{eq}}{kWh}\right) \times \text{BEB fleet annual electricity consumption}\left(\frac{\text{kWh}}{year}\right)}{1000000\ g/tonne}$$

$$LiB\ Manufacturing\ Emissions\ per\ Bus\ (Annualized)\ \left(\frac{t\ CO_2eq}{year}\right) = \frac{\text{LiB manufacturing emissions }\left(\frac{\text{kg CO}_2\text{eq}}{kWh\ of\ LiB\ capacity}\right) \times \text{LiB Capacity }(kWh)}{\text{Projected useful life }(years) \times\ 1000\ kg/tonne}$$

$$\begin{aligned} Ontario\ energy\ supply\ mix\ \left(\frac{g\ CO_2eq}{kWh}\right) \\ = 0.6 \times nuclear\ emissions\left(\frac{g\ CO_2eq}{kWh}\right) + 0.26 \times hydro\ emissions\left(\frac{g\ CO_2eq}{kWh}\right) + 0.07 \times wind\ emissions\left(\frac{g\ CO_2eq}{kWh}\right) + 0.02 \times solar\ emissions\left(\frac{g\ CO_2eq}{kWh}\right) \\ + 0.05 \times natural\ gas\ emissions\left(\frac{g\ CO_2eq}{kWh}\right) \end{aligned}$$

Diesel Buses

$$Operation\ Emissions\ Per\ Year\ \left(\frac{t\ CO_2eq}{year}\right) = \left(\text{CO}_2\text{ emissions }\left(\frac{t\ CO_2eq}{diesel\ bus}\right) + \text{CH}_4\text{ emissions }\left(\frac{t\ CO_2eq}{diesel\ bus}\right) + \text{ N}_2\text{O emissions }\left(\frac{t\ CO_2eq}{diesel\ bus}\right)\right) \times \text{Diesel fleet size}$$

Gasoline Buses

$$Operation\ Emissions\ Per\ Year\ \left(\frac{t\ CO_2eq}{year}\right) = \left(\text{CO}_2\text{ emissions }\left(\frac{t\ CO_2eq}{diesel\ bus}\right) + \text{CH}_4\text{ emissions }\left(\frac{t\ CO_2eq}{diesel\ bus}\right) + \text{ N}_2\text{O emissions }\left(\frac{t\ CO_2eq}{diesel\ bus}\right)\right) \times \text{Diesel fleet size}$$