City of Stratford

Energy Modelling Results

Battery Electric Bus Feasibility Study & Transition Plan

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INTRODUCTION

The City of Stratford is addressing climate change by collaborating with other local area municipalities in the Perth County Greenhouse Gas (GHG) Reduction Plan. The document states that a minimum reduction target 10% below the 2017 baseline year should be achieved by 2030. It also notes that the community is supportive of a 30% reduction target for 2030 and net zero by 2050.[1] There is no target for transit emissions but there is discussion of prioritizing an increase of use of the transit system by residents in the future to reduce local transportation GHG emissions. In October 2021, Stratford's council recommended that the Plan be adopted, and that the City set 2030 and 2050 targets that align with the Plan.

One way the City of Stratford is taking action is by transitioning its transit fleet to battery electric vehicles. Stratford has begun planning the transition to a zero emissions fleet by developing a Fleet Transition Plan that will act as a roadmap to guide the process. The Fleet Transition Plan will identify the feasible transition pathway(s), associated capital and operating costs, service impacts, and, ultimately, the preferred transition pathway. This Energy Modelling Results Memo will feed the larger fleet transition plan to provide a strategy for electrification of the transit fleet.

When planning for a transition to battery electric buses (BEBs), it is important for agencies to not only look at the vehicle requirements, but also the infrastructure changes and other operational changes required to operate and maintain those vehicles. For many Canadian transit agencies, current BEB technology cannot replace diesel buses at a one-to-one replacement ratio while maintaining the same service level primarily due to vehicle range limitations. To mitigate BEB range limitations, agencies may require additional vehicles, en-route charging infrastructure, or a combination of both. It may therefore also likely impact schedules for operations, peak vehicle requirements, infrastructure, capital and operating costs, training requirements for maintenance staff and vehicle operators, as well as customers. Understanding how the system will need to operate with BEBs and how those decisions will impact these variables are important in determining an optimum fleet transition pathway.

This memo documents the process and analysis involved in the development, assessment, and recommendations for a transition pathway for Stratford's fleet from diesel internal combustion engine buses to BEBs. The processes and analyses include:

- Review of current fleet composition, the existing capital replacement plan, and service operations for transit and paratransit services
- Estimation of energy consumption of the transit fleet using the Zero+ tool and the consolidation of the model results to identify feasible transition pathway(s)

[1] https://www.stratford.ca/en/live-here/resources/Climate-Change/Perth-County-and-Municipalities-Climate-Change-Plan-FINAL_cb.pdf

- Recommendation of the optimal vehicle battery size required for the BEB deployments based on the energy consumption modelling results
- Recommendation of a preferred transition pathway that will guide future analysis of Stratford's transition from diesel buses to BEBs
- Determination of charging infrastructure required to operate the vehicles based on the fleet's daily energy consumption profile

EXISTING CONDITIONS

The first step in exploring battery electric vehicles is to document existing conditions and evaluate the current routes and fleet vehicles used to provide service. Key data includes:

- Operator blocks for weekdays and weekends
- Block and bus-type assignments
- General Transit Feed Specifications (GTFS) data from pre-COVID service for transit blocks on weekdays and weekends
- Fleet Replacement Plan

Adding this data to the Zero+ model creates an accurate energy consumption profile unique to Stratford's existing service. Below is a summary of the fleet composition, fleet replacement plan, and fixed route and paratransit service operations information that feeds into the modelling effort and analysis that follows.

FLEET COMPOSITION AND REPLACEMENT PLAN

CURRENT TRANSIT FLEET COMPOSITION

Based on the existing fleet replacement plan, the current transit fleet includes a mix of full-size, 40' fixed route diesel buses and paratransit gasoline transit shuttles as shown in **Table 1**. Currently, there are a total of 15 fixed route transit buses in service. Two hybrid buses will likely be purchased within the next two years and will arrive in 2024 to replace the oldest two hybrid buses in the fleet. There are 5 paratransit buses.

Table 1: Current Fixed Route and Paratransit Fleet Composition

Fleet Count	Vehicle Type	Vehicle Make	Model Year(s)	Fuel Type	Facility Assignment
Fixed Route Transit Fleet					
15	LFS	40' Nova	1997-2022	Diesel	Stratford Transit Garage
Paratransit Fleet					
1	ETV	Chevrolet	2013	Gasoline	Stratford Transit Garage
1	G4500	Chevrolet	2015	Gasoline	Stratford Transit Garage
1	3500 CTV	Ford	2019	Gasoline	Stratford Transit Garage
1	G4500	GMC	2021	Gasoline	Stratford Transit Garage
1	G4500	GMC	2022	Gasoline	Stratford Transit Garage

Existing Fleet Replacement Plan: 2022 - 2040

Stratford's current fleet replacement plan outlines in which year(s) the current fleet will be replaced. The replacement of BEBs will follow this schedule. For fixed route transit buses, Stratford plans for 15 replacements between 2026 and 2042. The two 2024 buses are the replacements for the hybrid buses that Stratford plans to be in service in 2024. There is no service expansion planned in the near future. **Figure 1** shows the transit fleet replacement schedule. **Figure 2** shows the replacement schedule for Stratford's five paratransit buses.

For Stratford's fixed route transit fleet to transition to 100% zero emissions within an eight-to-ten-year timeframe, the agency will need to consider an accelerated replacement.

Figure 1: Fixed Route Transit Fleet Replacement Schedule

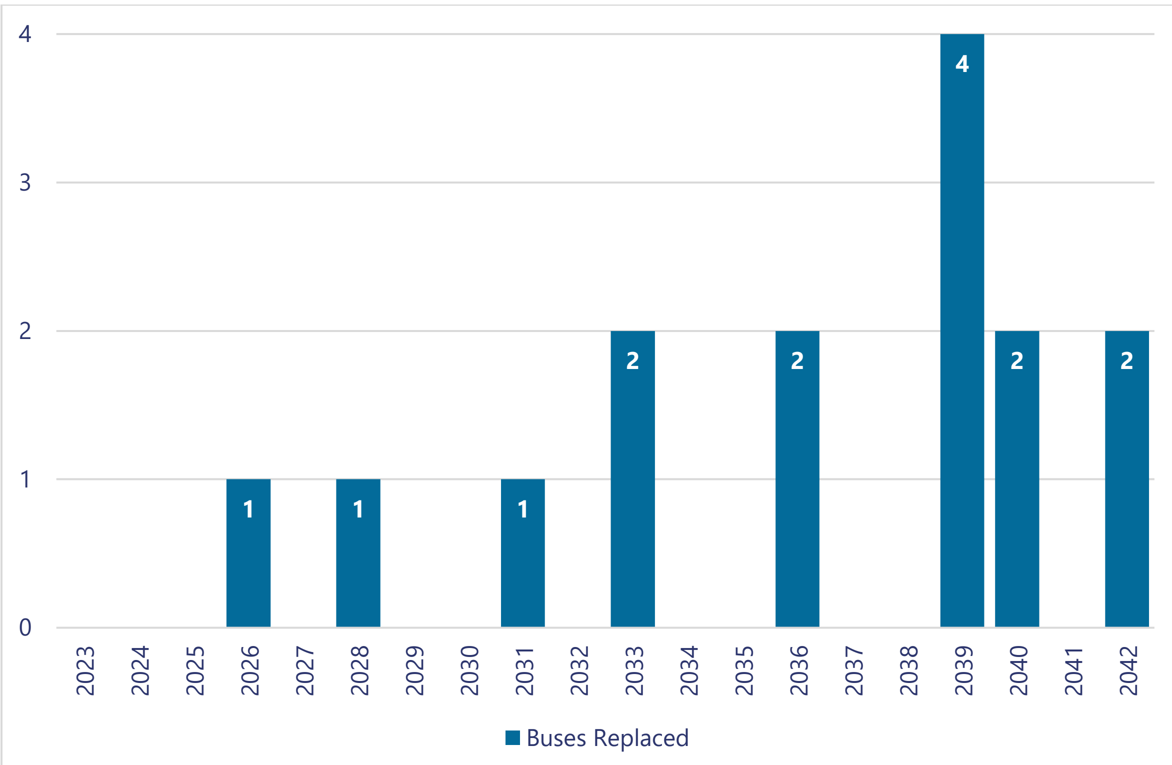
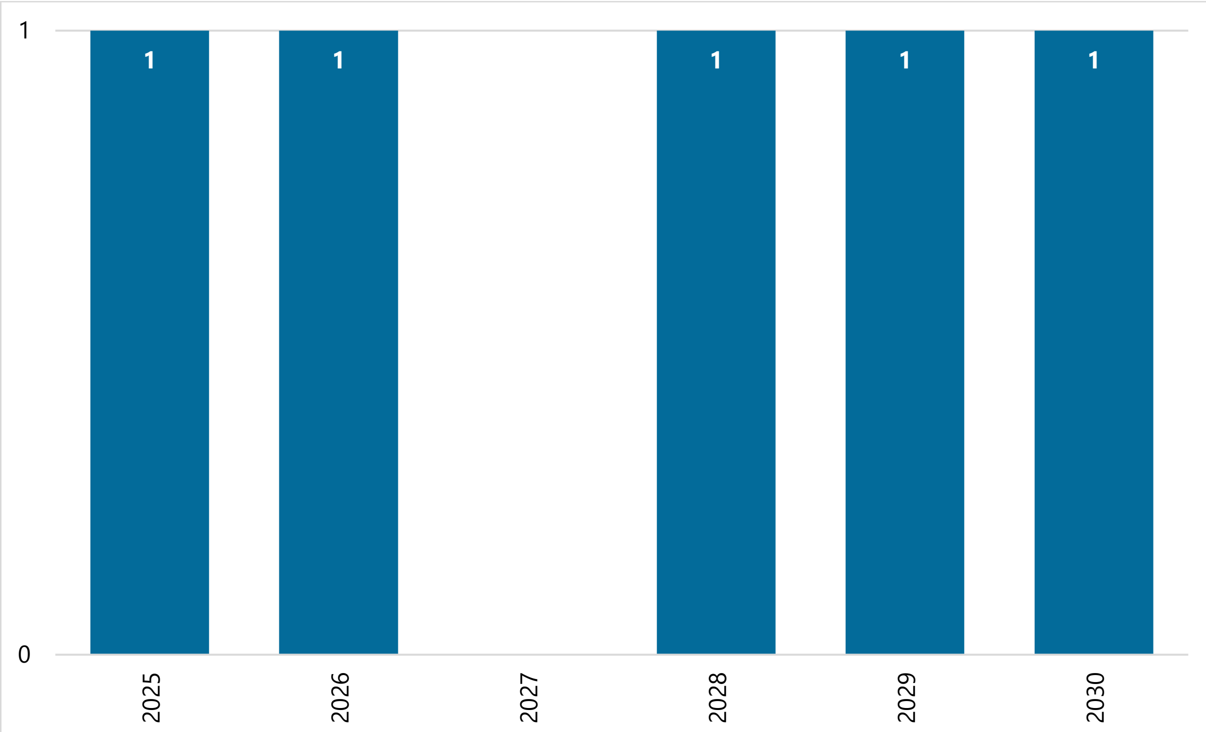


Figure 2: Paratransit Fleet Replacement Schedule



FIXED ROUTE & PARATRANSIT SERVICE OPERATIONS

OPERATING SCHEDULES

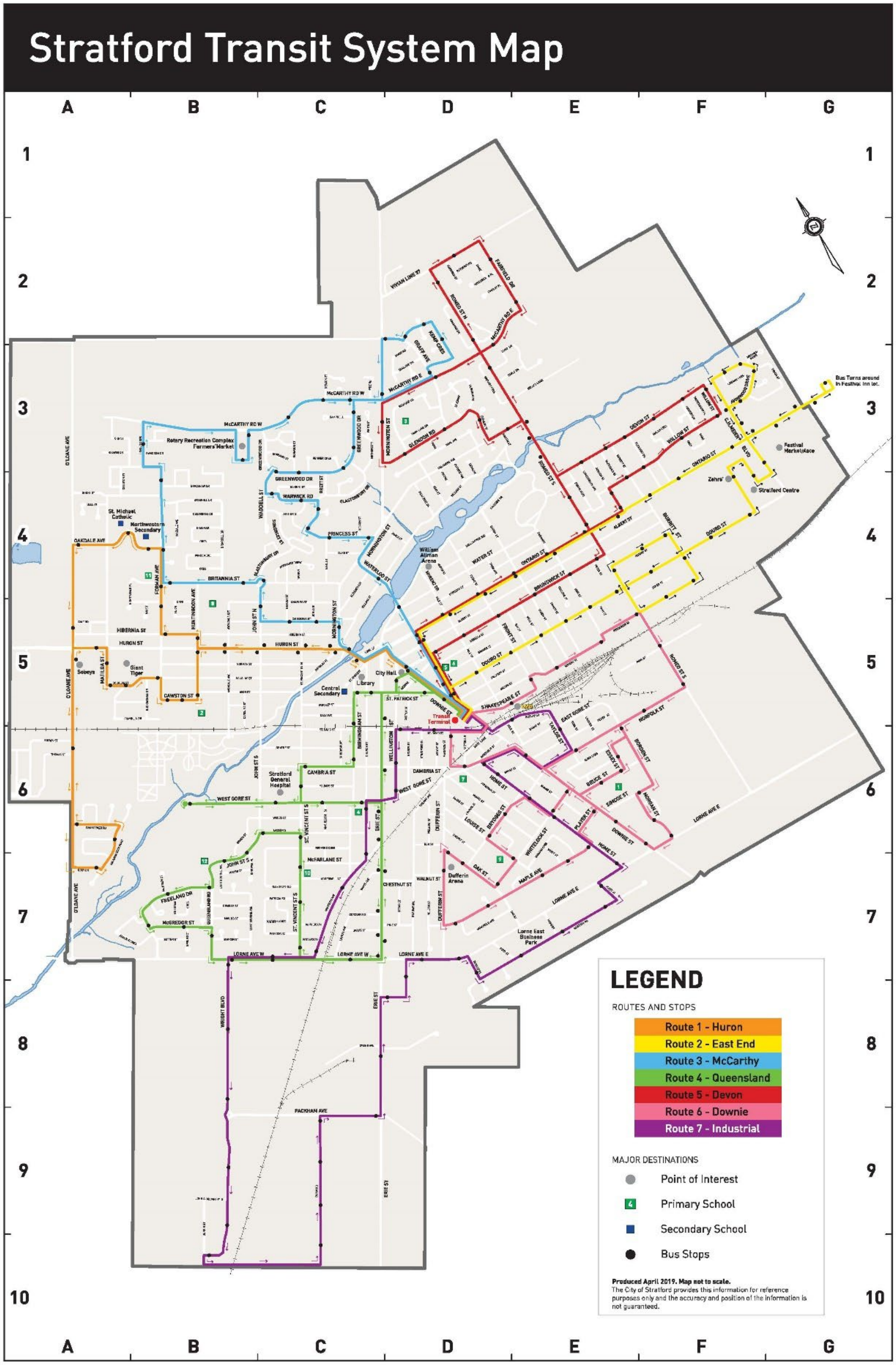
Stratford Fixed Route Transit (Weekday Only)

Stratford Transit has 7 bus routes that operate and start and end at the Transit Terminal at the centre of the City, as shown in **Figure 3**. Most routes are about half an hour end-to-end and average approximately 14km in length. There are 32 trips a day. One bus has the same route for the whole day and buses are out from 6am to 10pm.[2]

A piece of work for a transit bus is typically called a block which has information on the start/end time, routes on which it will operate and timetable of when it will be at various stops on the route. All of Stratford's blocks operate at approximately a distance of 300-400km.

[2] https://www.stratford.ca/en/live-here/transit.aspx#August-10-2022-Stratford-Transit-School-Specials-for-20222023

Figure 3: Stratford Transit System



The operation of longer blocks (over 200kms) makes it challenging to accommodate battery electric vehicles because their operation is contingent on their battery capacities. Based on GTFS data from Fall 2022, the current diesel and hybrid fleet's blocks typically last 15 hours and run for 300-400 kms for a typical weekday

By comparison, BEBs can only continuously run for about 200 km, with less running time capacity in cold winter weather. This limits block times to approximately 10 hours, which in turn requires significant adjustments to route planning and scheduling.

Weekend On-Demand Service

Stratford Transit runs on-demand services on Saturday and Sunday. Six buses run on Saturday and three are out on Sunday. All buses run for eight and a half hours and customers request the stops they want to go to at the time they need to be there. Hours of operation are 6am to 8pm on Saturdays and 10am to 5:30pm on Sundays.[3]

School Bus Service

Stratford Transit provides School Special buses on mornings and afternoons during the weekdays for Stratford Intermediate School, Stratford District Secondary School, and Street Michael Catholic Secondary School. The buses leave the Terminal and travel to the schools at 7:25am until 8:45am. The times the buses arrive at the schools in the afternoon vary between 2:40pm and 3:05pm.[4]

Parallel Transit

Parallel Transit is Stratford's paratransit service. It is a door-to-door paratransit service for people with disabilities and/or who are unable to use the fixed route transit service. Parallel Transit service is available on a first come, first served basis between 6:20am and 9:40pm Monday through Friday, from 6:20am to 7:40pm on Saturday, and between 9:00am and 4:00pm on Sunday.

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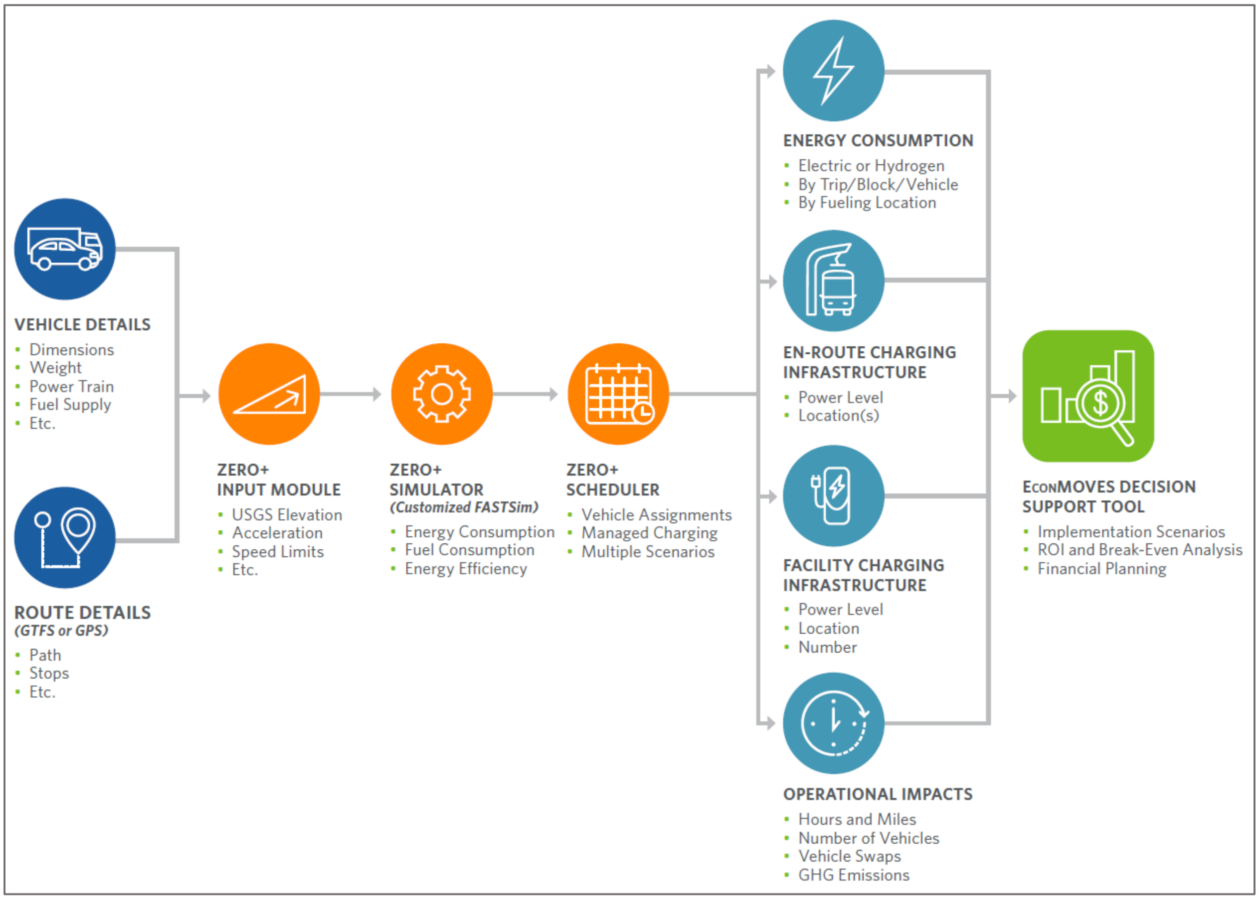
[3] https://www.stratford.ca/en/live-here/transit.aspx#August-10-2022-Stratford-Transit-School-Specials-for-20222023

[4] https://www.stratford.ca/en/live-here/transit.aspx#August-10-2022-Stratford-Transit-School-Specials-for-20222023

ENERGY CONSUMPTION ANALYSIS

The energy consumption analysis for Stratford's fixed route fleet was done using Zero+, HDR's proprietary energy consumption modelling tool to provide a comprehensive understanding of the potential impacts BEB technology may have on Stratford's existing service. Energy consumption is impacted by several factors; including slope and grade of the bus routes, number of vehicle stops, anticipated roadway traffic, terrain, and ambient temperature. Zero+ also analyzes variables known to affect lifetime vehicle performance like energy density, battery degradation, operating environment, auxiliary loads like heating and air conditioning, and lifecycle of bus batteries.

Figure 4: Zero+ Fleet Optimization Tool



The service data used was based on the service schedule on Stratford Transit's website as of October 2022[5], which notes reduced service due to COVID. Energy modelling for paratransit vehicles was conducted using a high-level mathematical modelling analysis due to less available data and the less structured nature of the services. Three BEB scenarios were modelled:

[5] https://www.stratford.ca/en/live-here/transit.aspx, October 2022

- **Baseline:** Bus reuse only with depot charging allowed all day (no modifications to the existing schedule)
- **Block Split:** Bus reuse and mid-block swaps allowed with depot charging allowed all day
- **Enroute Charging:** Bus reuse and mid-block swaps allowed with depot AND enroute charging allowed all day

During the schedule optimization process, larger battery (675 kWh) scenarios for the en-route charging option were added for sensitivity. The scenario outcomes are detailed below following discussion of key assumptions.

KEY ASSUMPTIONS

To develop a model relevant for Stratford's fleet and operations, a set of assumptions and variables was identified (**Table 2**). It is noted that the assumptions regarding vehicle Original Equipment Manufacturer (OEM) attributes represent a typical, commercially-available BEB model. Subsequent procurement of BEBs following this analysis may result in vehicle OEM specifications which differ from these assumptions, which may impact the results of this analysis. Additional energy consumption modelling based on the selected OEM should be conducted to confirm energy and infrastructure requirements.

Table 2: BEB Simulation Assumptions

Variable	Input
Service Data	October 2022
Battery Capacity	525 kWh (Larger assumed to be 675 kWh)
End-of-Life Battery State of Health	80% (max battery degradation)
Energy Reserve	20% state of charge (SOC)
Heating	Electric Heat, Diesel Heat
Ambient Temperature	-18C (Cold weather, 10^{th} percentile)
Passenger Capacity	100%
Depot Charger Power	150 kW @ 95% Efficiency
En-route Charger Power	450 kW (Vehicle Limited) @ 95% Efficiency

As shown in the table above, this model assumes a bus with a 525 kWh nameplate battery capacity, which is typical for longer-range BEBs available on the market today. While some bus manufacturers offer BEBs with greater battery capacities, modelling service with a standard vehicle provides flexibility when selecting a vehicle manufacturer.

The depot charging scenario is modelled with 150 kW chargers with a 95% efficiency and the en-route charging scenario is modelled with 450 kW chargers with a 95% efficiency. The main vehicle modelled in the Zero+ modelling tool are the 40' New Flyer Xcelsior Charge with a 525-kWh battery. For comparison purposes in some of the scenarios, the Proterra ZX5MAX is modelled as it currently has the largest battery capacity among manufacturers in North America with a nameplate capacity of 675 kWh.

A 20% reduction of battery capacity was applied to reflect end-of-life conditions. This is consistent with bus original equipment manufacturer (OEM) warranties which typically guarantee 80% of battery capacity for 12 years.

In addition to battery degradation, the model swaps out any vehicle that goes below the 20% state of charge (SOC) energy reserve. This is to account for both the fact that vehicles typically cannot use the last 10% SOC of a battery pack without performance reductions as well simulating the factor of safety most agencies use to reduce range anxiety for operators.

Energy consumption was modelled for the 10th percentile lowest temperature in Stratford in February (-18 °C)[6]. The initial modelling scenario assumed the use of an electric heater (which requires a loading of about 24 kW). This is a relatively conservative assumption as a heater would likely not need to be run the full day. A modelling scenario was also created that assumed a diesel auxiliary heater would be used to reduce the power requirement and increase the range of vehicles during cold weather.

It should be noted that while en-route chargers are capable of outputting 450 kW of power, the vehicle must be able to accept that level of power. In other words, as -is the case with the majority of transit buses today that can accept fast charging, the actual charge rate of a bus using a 450 kW charger is typically lower. The rate of output of the charger is determined by the vehicle and is based on a variety of factors that change based on the state of charge (SOC). The modelling factors in the charge curves (rate of charge vs SOC) are provided by manufacturers for each vehicle type. The achieved charging power in the Zero+ model is limited by both the charging curve for the vehicle and the maximum power of the charger.

BASELINE SCENARIO

The first modelled scenario assumes depot charging is allowed all day with no modifications to block schedules. Buses are reused if a vehicle has a minimum state-of-charge (SOC) of 60% or higher. In this scenario, if a short block is completed and the bus has at least 60% SOC, then the vehicle is used again to start another block that it can complete. This gives an indication of how feasible the blocks will be based on how Stratford currently operates. The main takeaway of the baseline scenario was that the vehicles were not able to complete the majority of the blocks so this option was discounted as there would be a significant increase in non-revenue hours, kilometres, and fleet

[6] https://weatherspark.com/s/19225/3/Average-Winter-Weather-in-Stratford-Canada#Figures-Temperature

DEPOT CHARGING ONLY SCENARIO

To develop a feasible alternative for Stratford, this scenario assumes that buses will be swapped out partway through the block with a fully-charged vehicle when the first vehicle reaches 20% SOC. From a scheduling perspective, this was done by swapping buses so they could run in shorter blocks that could be accommodated by BEB running time capacity.

The model assumes that when swaps occur, a bus that would normally stay in service would return to the depot, and another bus and bus operator would drive from the depot to take its place. This has impacts both on fleet size required (peak vehicle requirement) as well as operational costs due to the increased amount of deadhead (non-revenue hours and kilometres between the depot and the first/last stop).

The scheduled blocks have had swaps inserted once a vehicle falls below the parameters set in the model assumptions. This gives an idea of what a schedule would look like that is able to be completed by a full fleet of BEBs and how it impacts fleet size and operational costs.

In reality, schedulers will use their judgment when cutting blocks where it makes the most sense to do so. The 20% reserve is meant only as a guideline, but gives schedulers operational flexibility (unforeseen events, traffic, detours), improves battery life, and reduces driver range anxiety.

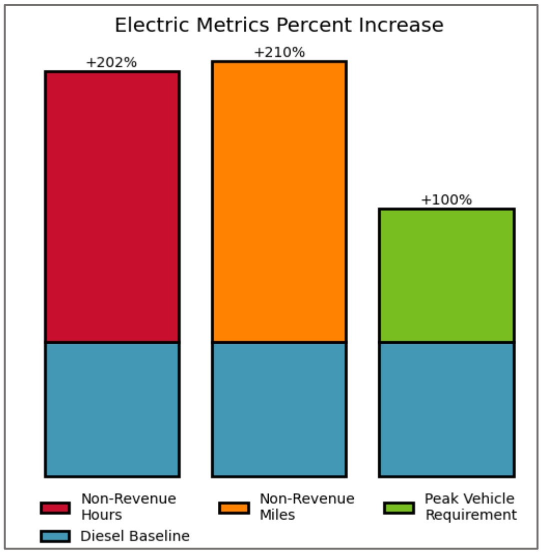
DEPOT CHARGING ONLY WITH ELECTRIC HEATERS

Model Results

Below is a review of the main components of the transit service and operations that are likely to change and should be considered when transitioning to a BEB fleet. **Figure 5** shows an estimate of the increase in non-revenue hours and kilometres as well as the estimated number of vehicles required to continue the current transit service.

Figure 5: Depot-Only Charging, Bus Swap - Electric Heating Outputs

- Revenue Hours & Kilometres remain the same
- Non-Revenue Hours: 202% increase
- Non-Revenue Kilometres: 210% increase
- Peak Vehicle Requirement: 100% increase
  Increase Fleet from 7 to 14 buses (does not include school service)
- At least 3 Depot Chargers will be required

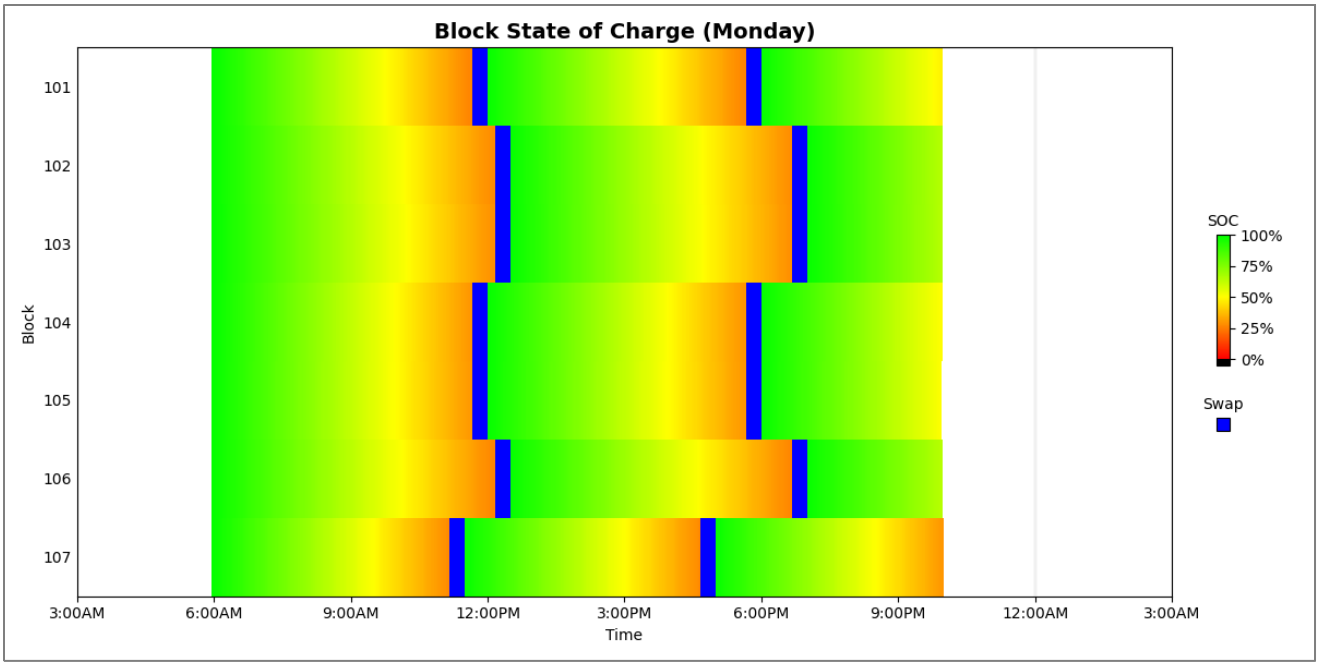


The vehicle battery state of charge on each block of typical weekday service are shown in **Figure 6**. Fleet and charging requirements are driven by weekday service.

Each block is represented by a line on the chart with the color of the line corresponding to the state of charge of the vehicle. The color changes from green to yellow to red to black as the state of charge drops from 100 to 0 percent. Bus swaps (shown in blue) are introduced only between trips to minimize service impacts.

All blocks require two swaps when we assume the buses are using electric heaters, which will be operationally challenging. Operating this service as defined would require a sizable increase in non-revenue hours, kilometres, and peak vehicles.

Figure 6: State of Charge with Electric Heating, Bus Swaps



Power Requirements

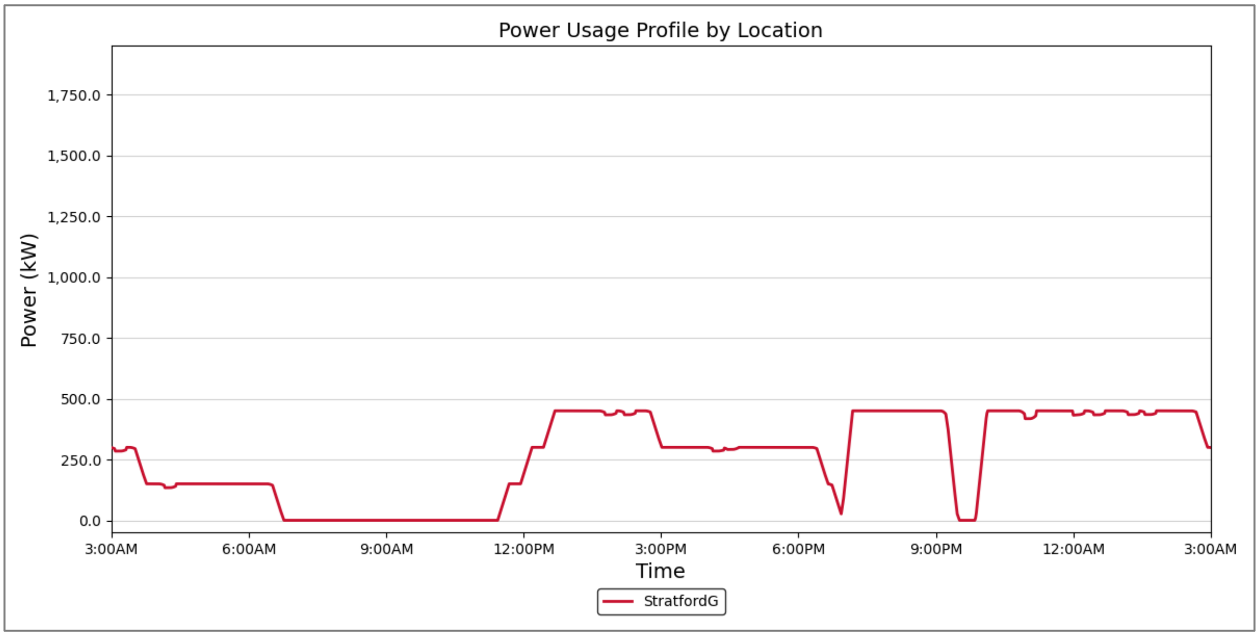
The modelling results provide estimates for both power demand and energy consumption at the Stratford Transit depot. Using these results, a preliminary assessment of the required infrastructure can be made. The baseline scenario is not shown here as it was not determined to be viable.

Below is the worst-case daily power demand, meaning the maximum load that would be required during weekday service with cold weather (10th percentile temperatures). Depending on the utility provider, the cost of energy depends not only on the peak power demand but also on the time of day when that peak demand occurs.

Electricity cost is typically billed based on two factors: peak power demand (kW) and amount of energy consumed (kWh). While consumption is the actual amount of energy consumed over the billing period, peak power demand is typically the maximum level seen over the billing period. Both of these factors can be impacted by the Time-of-Use (TOU) rates where costs fluctuate throughout the day.

The simulation results provide a power profile that can be used to understand when in the day the peak load occurs and how it is affected by any TOU charges. **Figure 7** shows the managed load profile, meaning the model attempts to use the fewest chargers to have vehicles ready for service the next day. The peak power demand for the Stratford Transit garage for a BEB fleet with electric heating and block swapping is around 0.45 MW assuming. three (3) 150 kW chargers would be required.

Figure 7: Charging Profile for Electric Heating, Block Swaps

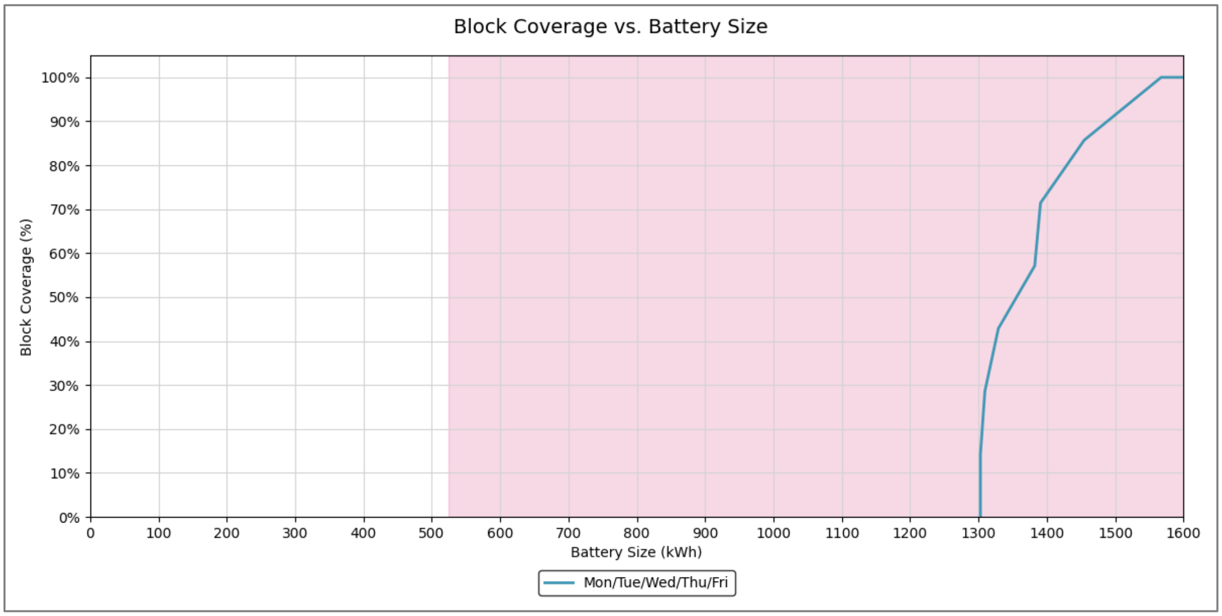


Vehicle Battery Sizes

With technological advances expected in the coming years, it may be possible to improve the performance of some scenarios by purchasing buses with larger battery sizes. There are vehicles with a battery size of (~600 kWh+) that offer more range than the 525 kWh battery that was modelled.

For the electric heating with bus swaps and depot charging only scenario, **Figure 8** illustrates that there is relatively little gain in performance when comparing a 525 kWh battery with a slightly larger batter (~600 kWh). A minimum 1,300 kWh battery would be needed to complete an entire block under present operating conditions and power usage rates. Batteries of this capacity do not yet exist.

Figure 8: Battery Size Requirement, Electric Heating, Bus Swaps



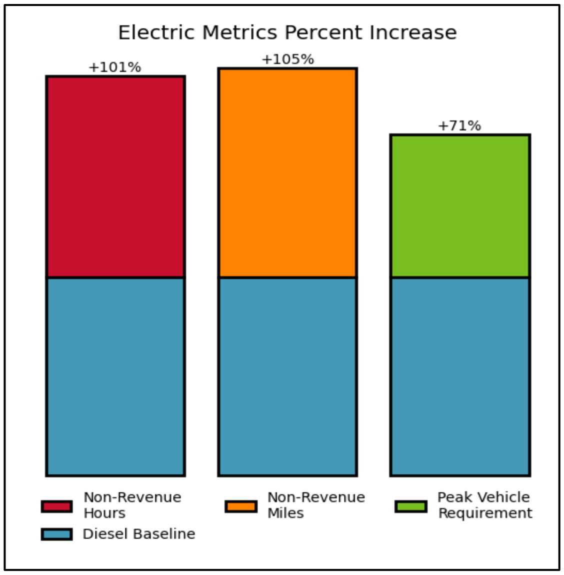
DEPOT CHARGING ONLY WITH DIESEL HEATERS

Model Results

Below is a review of the main components of the transit service and operations that are likely to change and should be considered when transitioning to a BEB fleet, particularly if onboard heaters are diesel powered. **Figure 9** shows an estimate of the increase in non-revenue hours and kilometres as well as the estimated number of vehicles required to continue the current transit service.

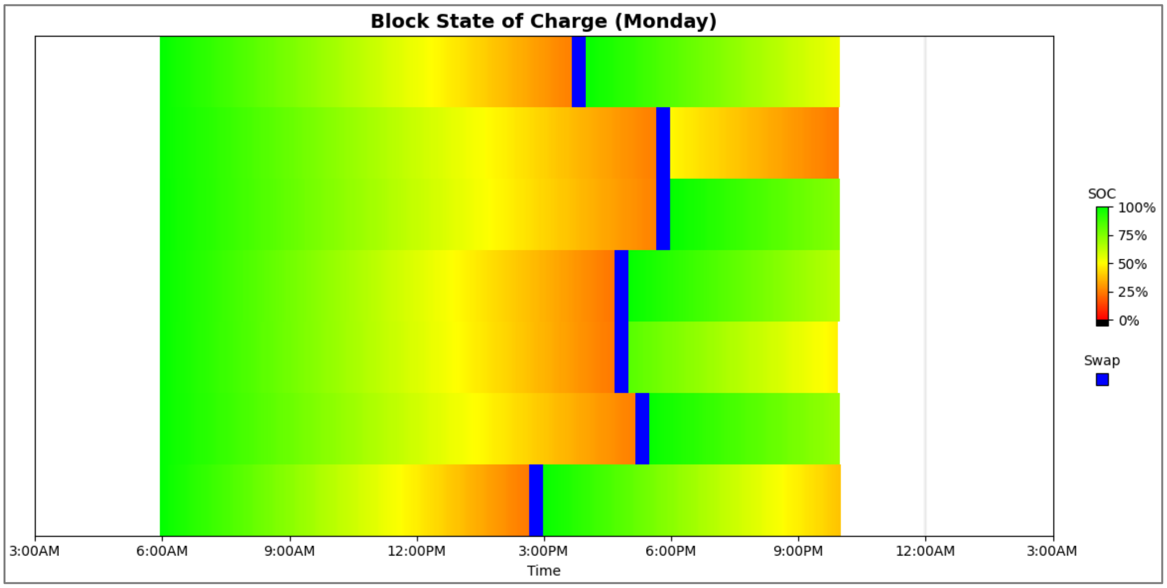
Figure 9: Depot-Only Charging, Bus Swap -- Diesel Heating Outputs

- Revenue Hours & Kilometres remain the same
- Non-Revenue Hours: 101% increase
- Non-Revenue Kilometres: 105% increase
- Peak Vehicle Requirement: 71% increase
  Increase Fleet from 7 to 12 buses (does not include school service, which would be an additional 3 buses [15 total])
- At least 2 Depot Chargers will be required



Including diesel heaters on the BEBs does offer significant operational improvements for Stratford service as all blocks are feasible with only one swap. SOC is shown in **Figure 10**. The increase in non-revenue hours, kilometres, and peak vehicle requirement is still high, although this option has lower non-revenue costs compared to electric hearing on board.

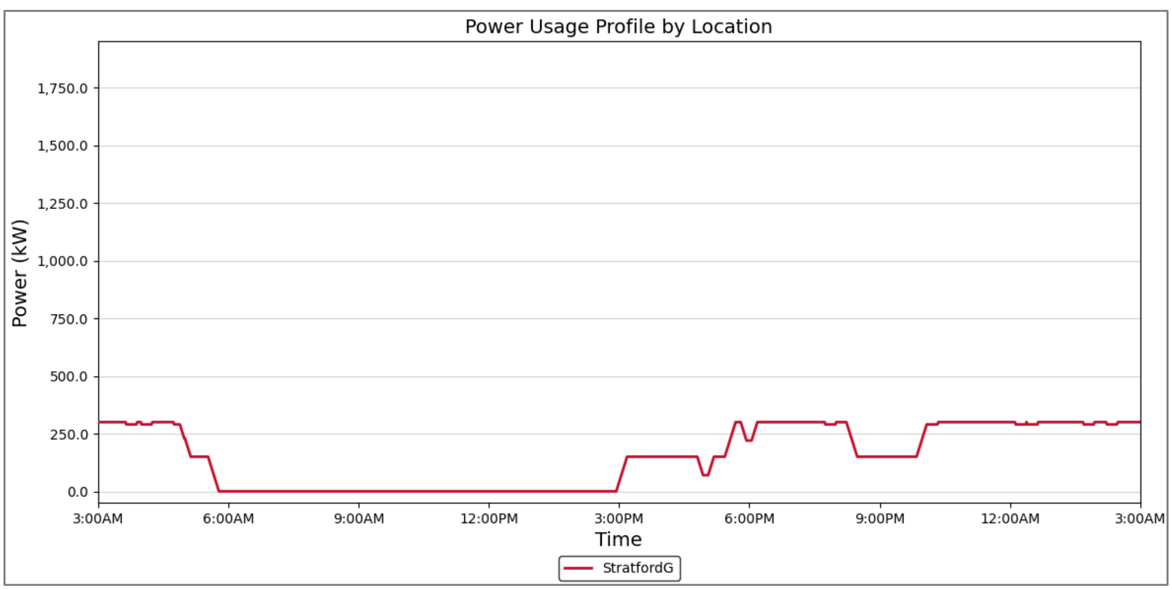
Figure 10: State of Charge with Diesel Heating, Bus Swaps



Power Requirements

The power profile for the Stratford Transit garage is shown in **Figure 11** for buses with diesel heaters. Diesel heaters bring the power requirement down to about 0.3 MW at the depot. In this scenario, only two, 150 kW chargers would be required.

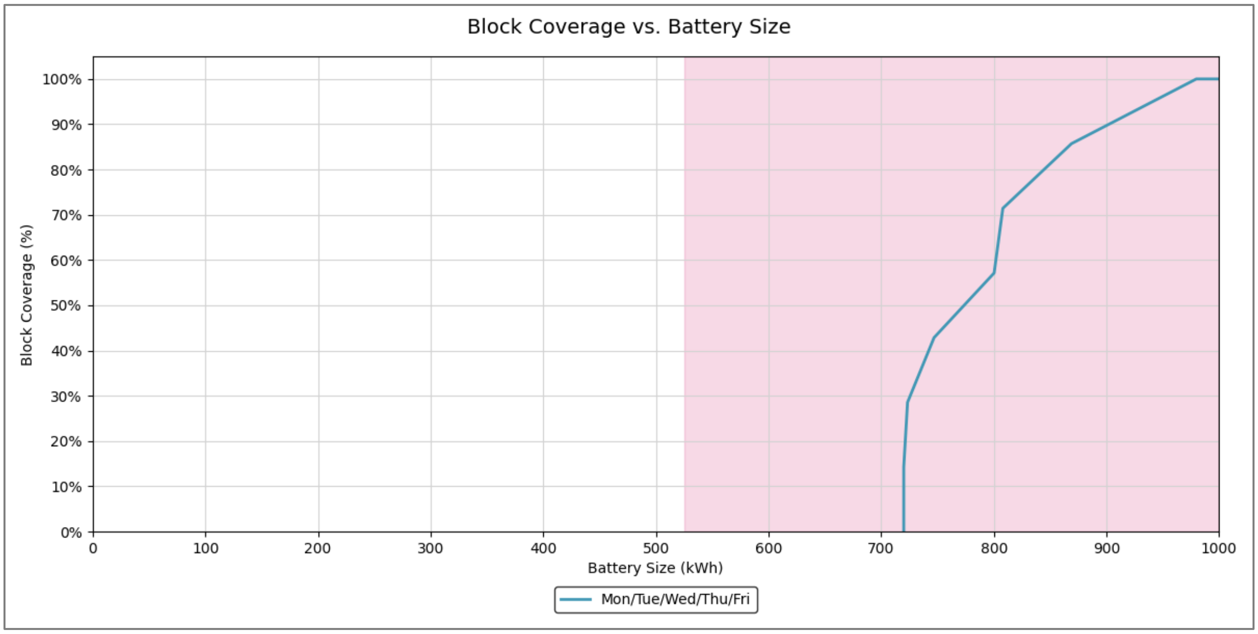
Figure 11: Charging Profile for Diesel Heating, Bus Swaps



Vehicle Battery Sizes

There is slightly more block feasibility (around 30%) for the diesel heating depot charging scenario when purchasing buses with larger battery sizes. **Figure 12** shows that no blocks can be fully covered with a 525 kWh battery.

Figure 12: Battery Size Requirement, Diesel Heating, Bus Swaps



DEPOT AND EN-ROUTE CHARGING SCENARIO

En-route (opportunity) charging is an enhancement that can greatly improve the feasibility of BEBs in many situations. This is particularly helpful with circulatory routes where the same en-route charger can be used by a vehicle multiple times throughout the day. En-route charging involves allowing a bus to charge for a short period of time using a high-powered charger (450 kW or greater) while stopped along its route while laying over. The mixture of en-route charging and charging in the bus depot greatly extends the range of a BEB and facilitates one-to-one replacement of a larger number of diesel vehicles when the routes are conducive to this charging strategy.

EN-ROUTE CHARGER LOCATION – COOPER TRANSIT TERMINAL

En-route charging infrastructure is ideally located at places such as transit centers where buses operating on multiple routes have scheduled layover time. When identifying potential en-route charging locations, property ownership and available grid capacity determine feasibility while average layover times and number of buses and riders passing through each site influence preference over other potential locations. Based on discussions with City staff on site feasibility and reviews of the current schedule for sites that have existing layover time, the Cooper Transit Terminal was identified as the primary location for en-route chargers as all routes start and end at the location and it is the only place on the transit network with scheduled layovers. The Terminal is off Downie Street as is shown in **Figure 13.**

Figure 13: Cooper Transit Terminal Location

The modelling is meant to evaluate if opportunity charging would have significant operational and range benefits for BEBs. No modifications were made in the model to existing vehicle schedules toutilize these chargers. A more detailed evaluation of site suitability for the location would need to be conducted before implementing any infrastructure.

Chargers capable of outputting up to 450 kW using an overhead pantograph were assumed at the en-route charging location. The scenario is reviewed with electric and diesel heaters below. There are two options explored for diesel heaters with a 525 kWh battery size and a larger 675 kWh battery size. The 675 kWh battery option is used to examine the extent to which a larger battery can impact the number of blocks completed with no swaps, the number of vehicles, and non-revenue hours and kilometres.

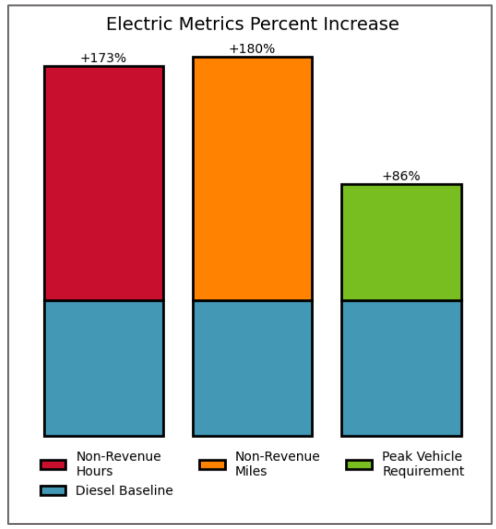
DEPOT CHARGING AND ONE EN-ROUTE CHARGER WITH ELECTRIC HEATERS

Model Results

Below is a review of the main components of the transit service and operations that are likely to change and should be considered when transitioning to a BEB fleet. **Figure 14** shows an estimate of the increase in non-revenue hours and kilometres as well as the estimated number of vehicles required to continue the current transit service.

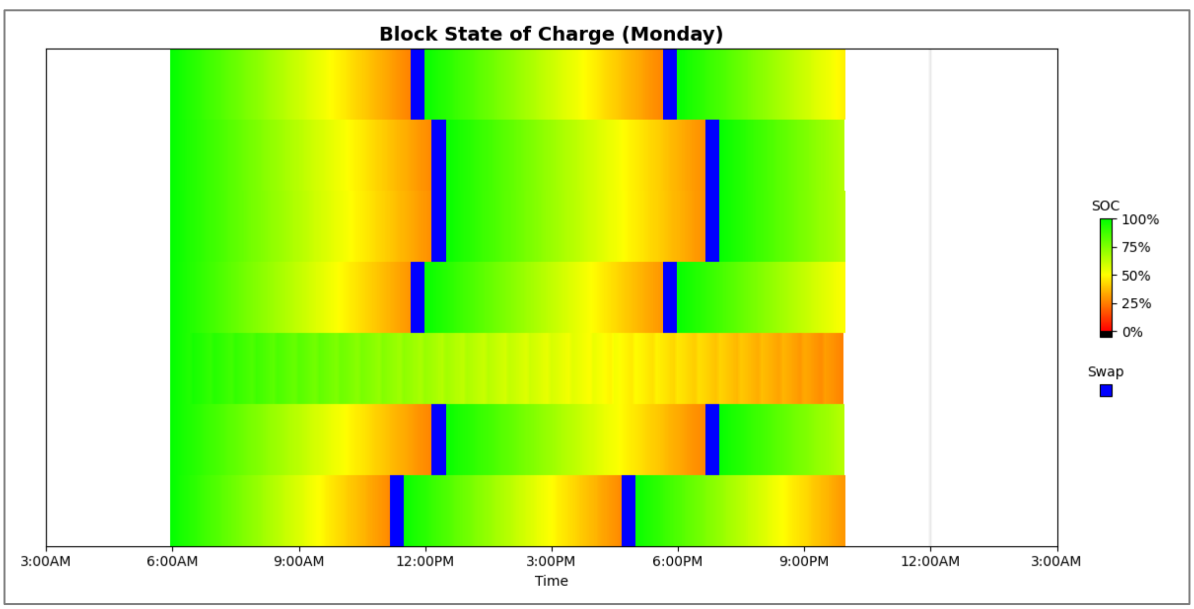
Figure 14: Electric Heating, En-Route and Depot Charging Outputs

- Revenue Hours & Kilometres remain the same
- Non-Revenue Hours: 173% increase
- Non-Revenue Kilometres: 180% increase
- Peak Vehicle Requirement: 86% increase
  Increase Fleet from 7 to 13 buses
- At least 2 Depot Chargers will be required
- 1 En-route Charger required



With an electric heater on-board, opportunity charging would not make a significant difference as all except one block still require two bus swaps, as shown in **Figure 15**.

Figure 15: State of Charge, Electric Heating, Bus Swaps, En-Route Charging

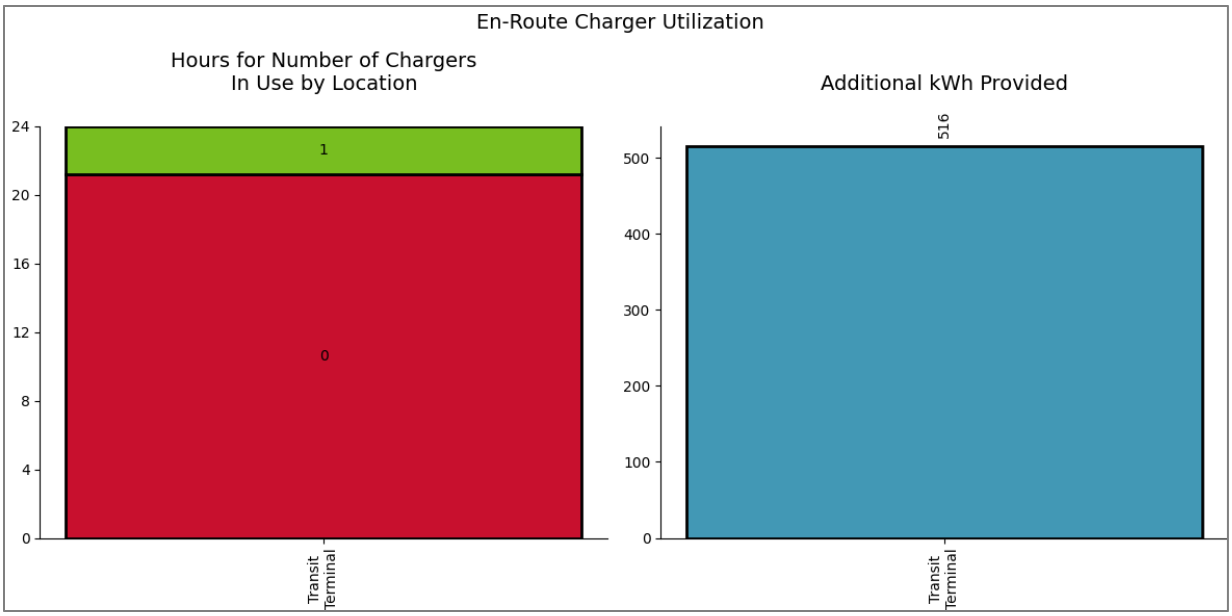


En-Route Charger Utilization

The en-route charger utilization is shown in **Figure 16**. Nine percent (9%) of total energy could be provided by en-route chargers, with the rest being supplied in depot.

In general, this gives a good indication of the quantity of equipment required at the Cooper Transit Terminal. There are operational benefits to having more than one charger at any location as it provides additional redundancy in case one charger goes out of service (or is down for maintenance), then there is at least one functioning charger at that location.

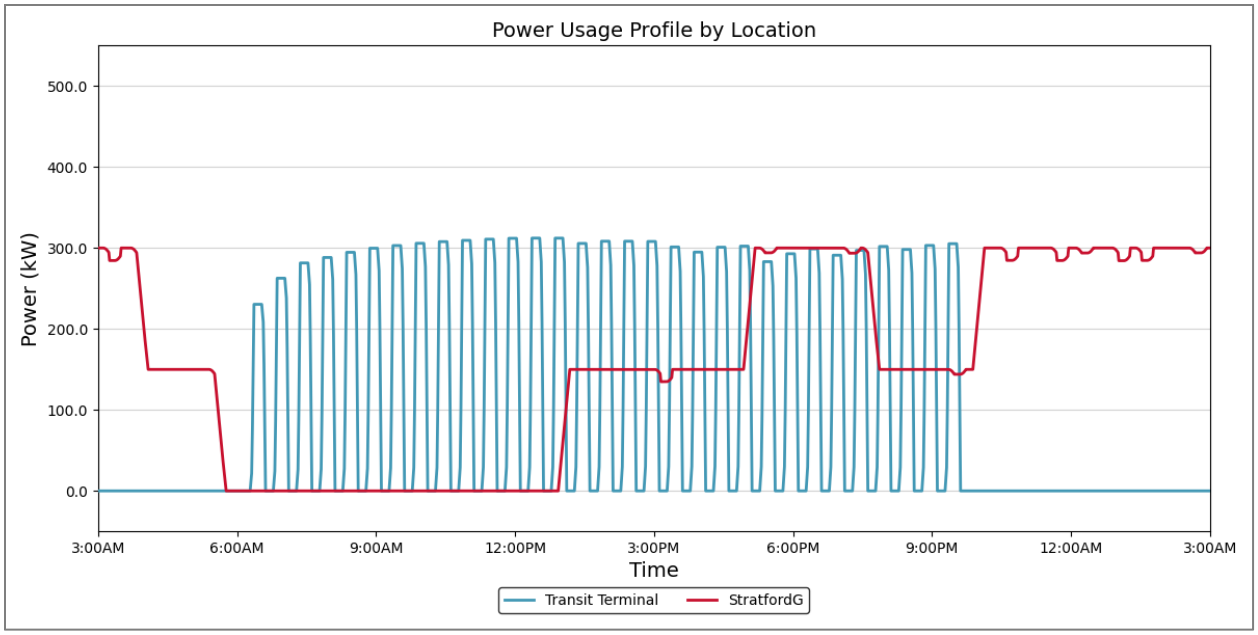
Figure 16: En-Route Charger Utilization, Electric Heating, Bus Swaps, En-Route Charging



Power Requirements

Adding en-route charging to the electric heating option reduced the peak power requirement by 0.2MW at the depot. The peak power demand would be around 0.3 MW and two, 150 kW chargers would be required at the depot. There would be a similar peak power demand of 0.3 MW for the one en-route charger. The power usage profile for the en-route charger scenario is shown in **Figure 17.**

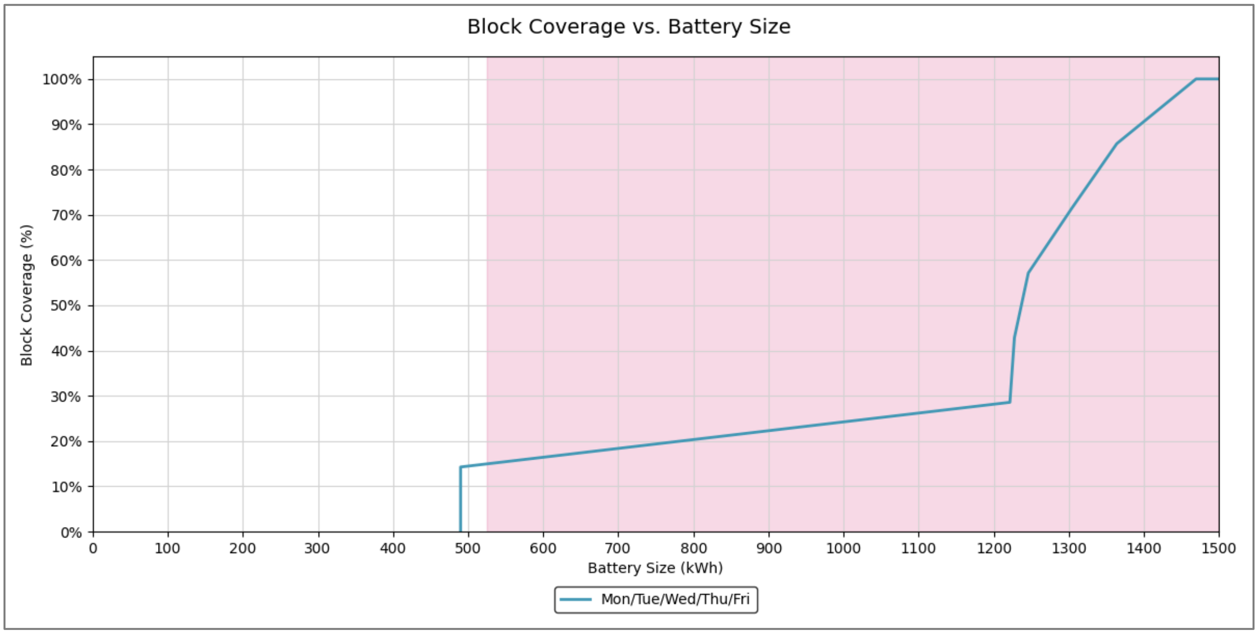
Figure 17: Charging Profile for Depot and En-Route Chargers, Electric Heating, Bus Swaps



Vehicle Battery Size

There is slight improvement in block feasibility for the electric heating, en-route charging scenario when purchasing buses with larger battery sizes. **Figure 18** shows block coverage with a 525 kWh battery is around 16% and a larger battery (~600 kWh+) kWh battery can only cover slightly more (~18%+).

Figure 18: Battery Size Requirement, Electric Heating, Bus Swaps, En-Route Charging



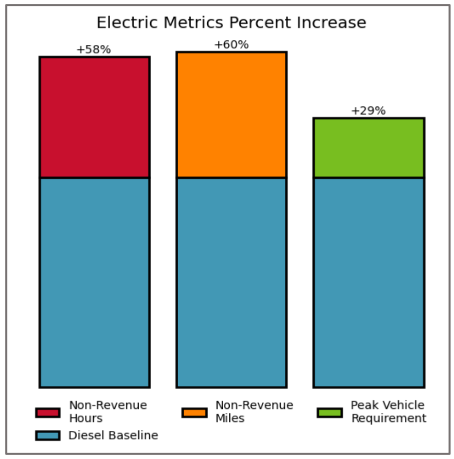
DEPOT CHARGING AND ONE EN-ROUTE CHARGER WITH DIESEL HEATERS (525 KWH BATTERY)

Model Results

Below is a review of the main components of the transit service and operations that are likely to change and should be considered when transitioning to a BEB fleet. **Figure 19** shows an estimate of the increase in non-revenue hours and kilometres as well as the estimated number of vehicles required to continue the current transit service.

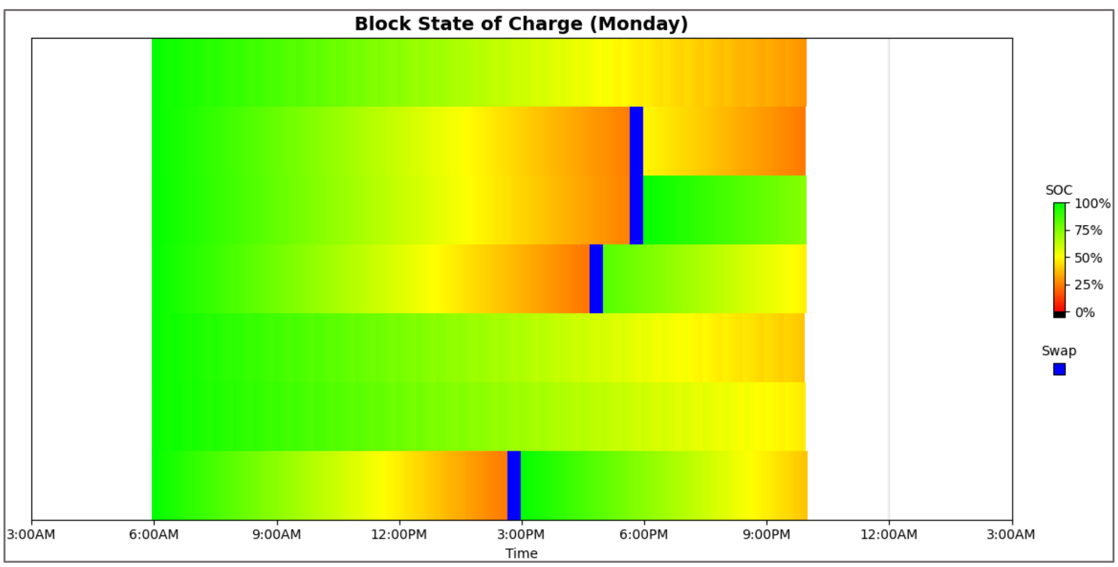
Figure 19: Diesel Heating, 525 kWh Battery, En-Route and Depot Charging Outputs

- Revenue Hours & Kilometres remain the same
- Non-Revenue Hours: 58% increase
- Non-Revenue Kilometres: 60% increase
- Peak Vehicle Requirement: 29% increase
  Increase Fleet from 7 to 9 buses
- At least 1 Depot Charger will be required
- 1 En-route Charger required



With a diesel heater onboard instead of electric heating, the number of feasible blocks without any bus swaps increases from 14% to 43%, as shown in **Figure 20**. The reduced energy requirement from the buses allows en-route charging to keep some of the buses at a relatively high level of charge for most of the day.

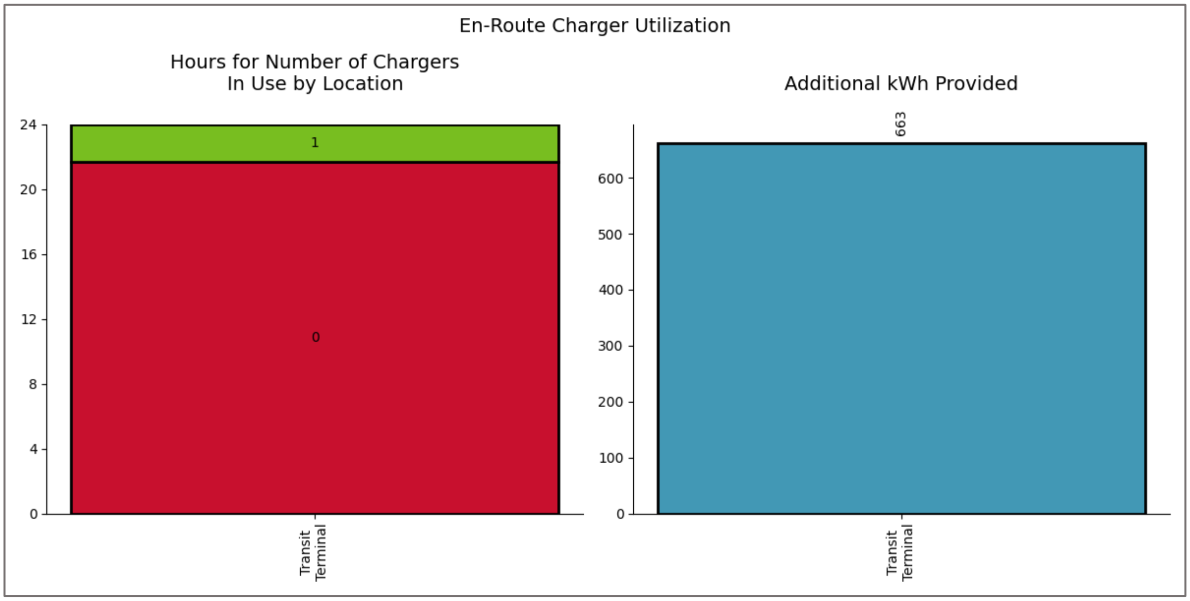
Figure 20: State of Charge with Diesel Heating, 525 kWh Battery, Bus Swaps, En-Route Charging



En-Route Charger Utilization

The en-route charger utilization is shown in **Figure 21**. 19% of total energy could be provided by the en-route charger, with the rest being supplied in depot.

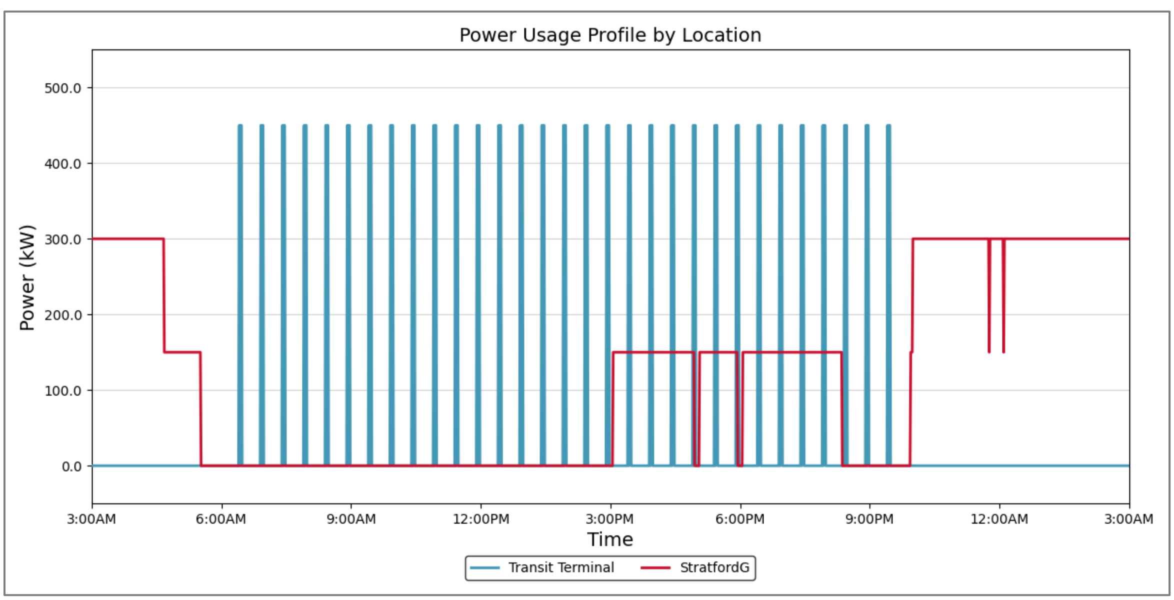
Figure 21: En-Route Charger Utilization, Diesel Heating, 525 kWh Battery



Power Requirements

With en-route charging and a diesel heater on-board, the peak power requirement in-depot is similar to the electric heating and en-route charging option, as shown in **Figure 22.** The peak power requirement would be just over 0.3 MW at the Stratford Transit garage. The charging profile for en-route chargers increases from a peak power requirement of 0.3 MW in the electric heating and en-route charging option to 0.45 MW.

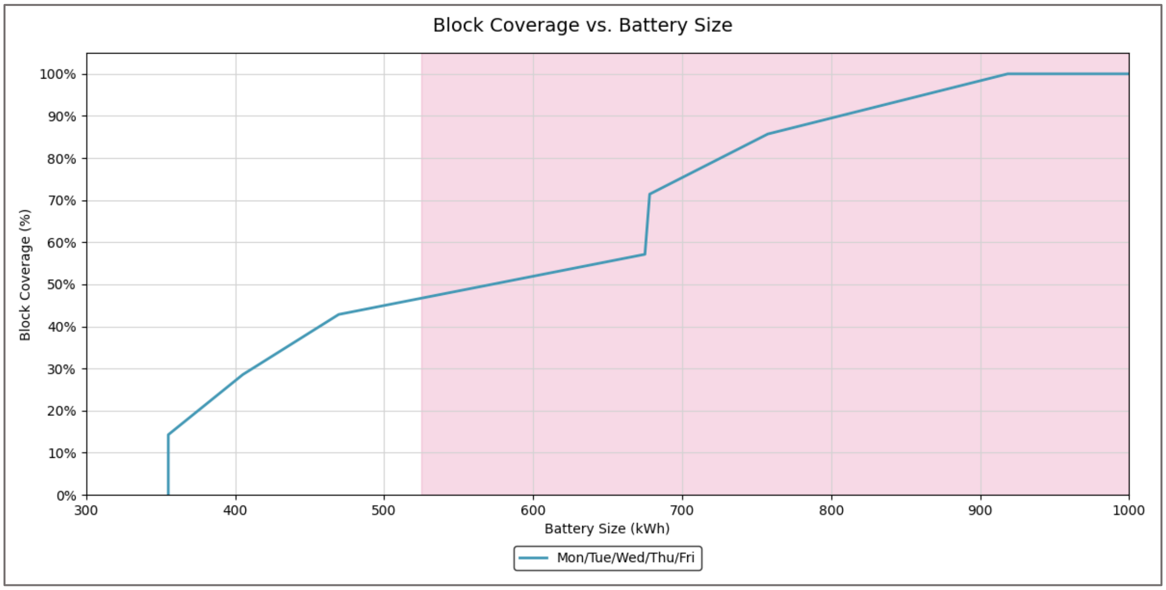
Figure 22: Charging Profile for En-Route Chargers and Depot, Diesel Heating, 525 kWh Battery



Vehicle Battery Size

The scenario with en-route charging and diesel heating has 48% block coverage at 525 kWh, as shown in **Figure 23**, and a larger battery size (~600 kWh+) would have slightly more coverage with at least 51% block coverage.

Figure 23: Battery Size Requirement, Diesel Heating, 525 kWh Battery, Bus Swaps, En-Route Charging



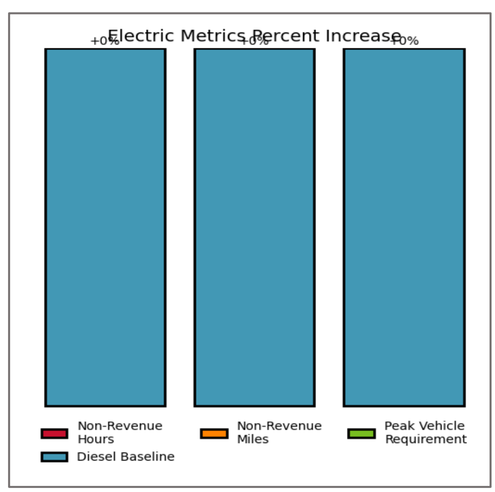
DEPOT CHARGING AND TWO EN-ROUTE CHARGERS WITH DIESEL HEATERS (675 KWH BATTERY)

Model Results

Below is a review of the main components of the transit service and operations that are likely to change and should be considered when transitioning to a BEB fleet. **Figure 24** shows an estimate of the increase in non-revenue hours and kilometres as well as the estimated number of vehicles required to continue the current transit service.

Figure 24: Diesel Heating, 675 kWh Battery, En-Route and Depot Charging Outputs

- Revenue Hours & Kilometres remain the same
- Non-Revenue Hours: 0% increase
- Non-Revenue Kilometres: 0% increase
- Peak Vehicle Requirement: 0% increase
- At least 3 Depot Charger will be required
- 2 En-route Charger required

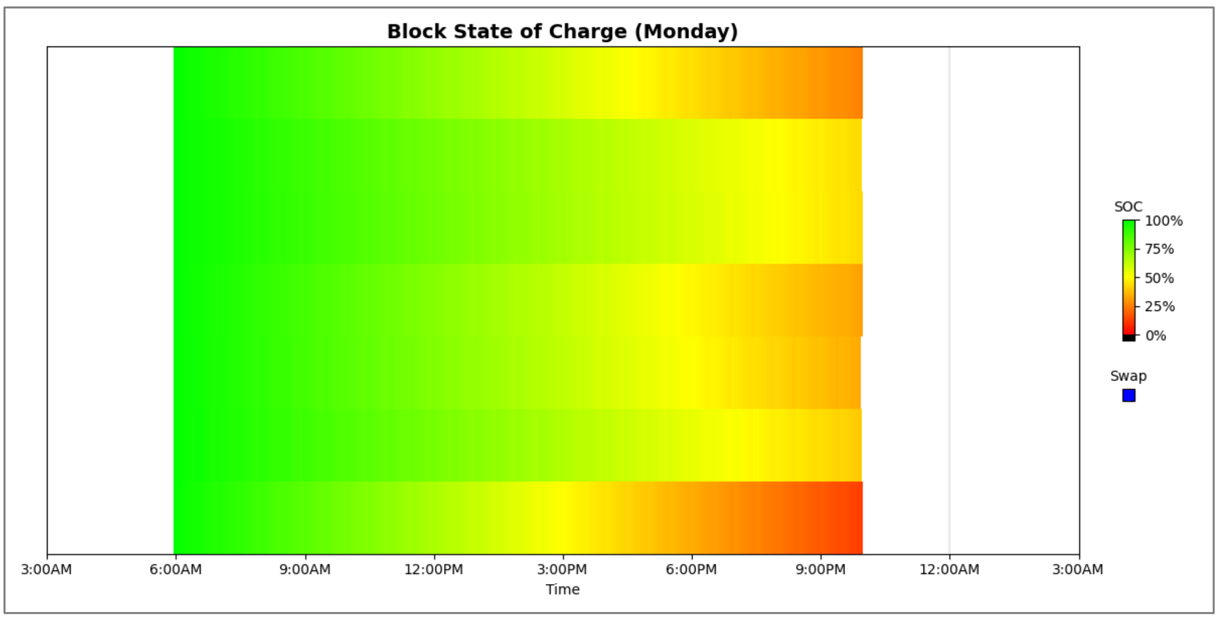


The results are not shown but increasing the battery size with one en-route charger was modeled but did not have a significant advantage. Increasing the number of en-route chargers without increasing battery size also modeled but again did not have a significant advantage in terms of operating hours or fleet size. When both battery size and number of en-route chargers we increased, there was a noticeable change which is presented here.

The diesel scenario with depot charging, two en-route chargers, and a 675 kWh battery was modelled to show the extent to which a larger battery size can decrease mid-block swaps and vehicle requirements. Although the 675 kWh battery was used in the Zero+ model, there are other battery sizes on the market so Stratford is not limited to one battery size and manufacturer. Using a larger battery size on top of including diesel heaters on the BEBs offers significant operational improvements for Stratford service. With larger batteries, 100% of blocks are feasible without swapping buses, as shown in **Figure 25**. There is no increase to fleet or non-revenue costs.

With this option, operators would get a charge every other time they arrive at the terminal; For example, buses 1-4 would be able to charge at the top of every hour and buses 5-7 would get to charge at the top of every half hour.

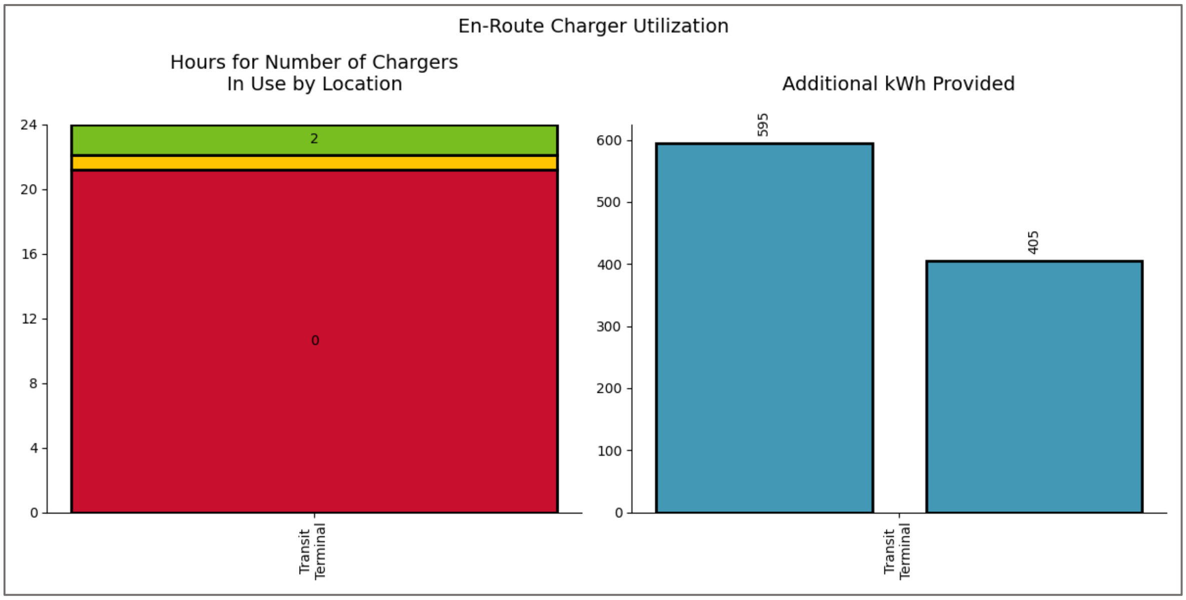
Figure 25: State of Charge with Diesel Heating, 675 kWh Battery, Bus Swaps, En-Route Charging



En-Route Charger Utilization

The en-route charger utilization is shown in **Figure 26**. 28% of total energy could be provided by the en-route charger, with the rest being supplied in depot.

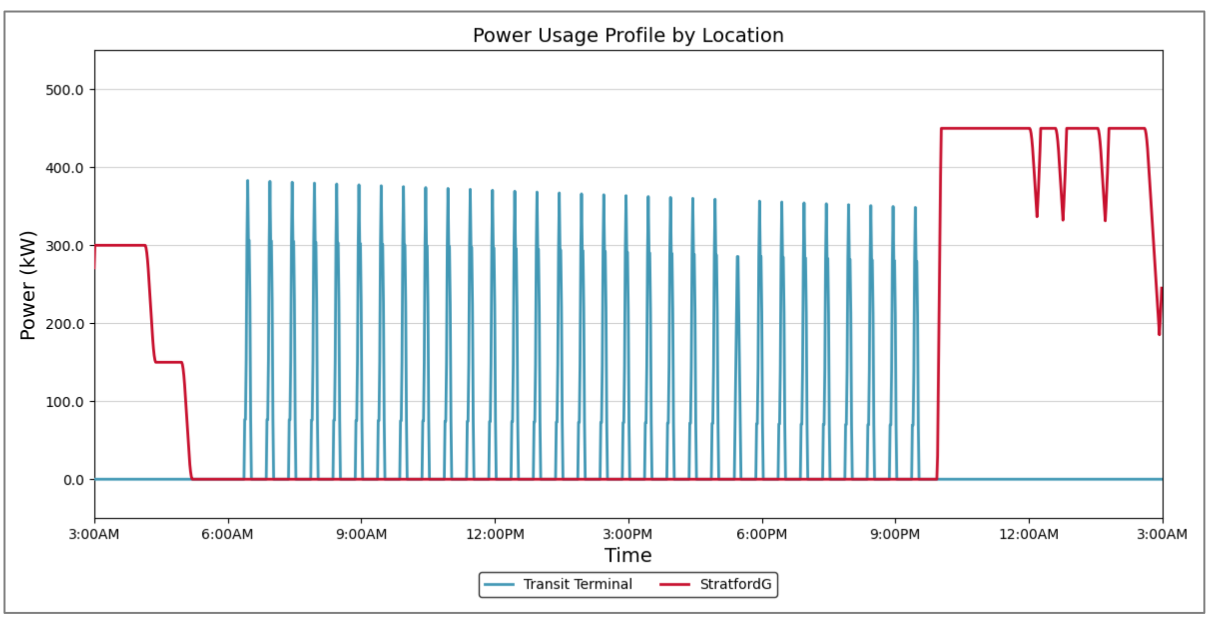
Figure 26: En-Route Charger Utilization, Diesel Heating, 675 kWh Battery, Bus Swaps, En-Route Charging



Power Requirements

With a larger battery and two chargers, the peak power requirement in-depot is higher than the other en-route charging options, as shown in **Figure 27.** The peak power requirement would be around 0.45 MW at the Stratford Transit garage. The charging profile for the two en-route chargers decreases slightly from the one en-route charger with diesel heaters (525 kWH Battery) option from 0.45 MW to just under 0.4 MW. For this option, there are no swaps which means that vehicles all go back to the garage at the end of service at similar times and complete a full charge for service back at the garage.

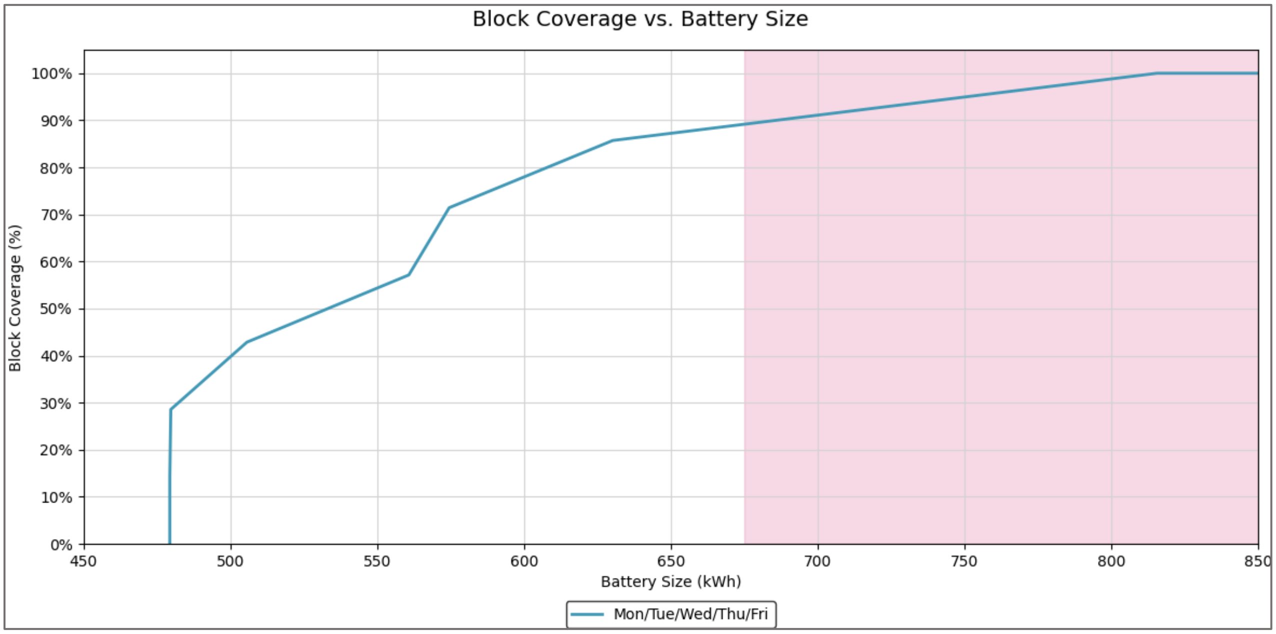
Figure 27: Charging Profile for En-Route Chargers and Depot, Diesel Heating, 675 kWh Battery



Vehicle Battery Size

En-route charging and diesel heating with a larger battery has approximately 90% block coverage at 675 kWh, as shown in **Figure 28**. With the two chargers at the Cooper Transit Terminal there is full block coverage.

Figure 28: Battery Size Requirement, Diesel Heating, 675 kWh Battery, Bus Swaps, En-Route Charging



FIXED-ROUTE TRANSIT MODELLING SUMMARY

The modelled fleet requirement column in **Table 3** is a summary of the modelling results discussed above. The table shows the peak number of buses without spares and the chargers columns show the minimum number of charges required. The block feasibility column notes the percentage of how feasible the blocks will be based on how Stratford currently operates.

The modelled fleet requirement considers feasibility for On Demand transit as the On Demand service information was an input within each of the energy modelling scenarios but does not factor in spares or AM/PM school service, which would add approximately three buses for each scenario.

Table 3: Fixed Route Modelling Summary

Scenario		Block Feasibility	Modelled Fleet Requirement	Depot Charger Quantity	En-Route Charger Quantity
Electric Heating	Depot Only	100%	14	3	0
	Depot and En-Route	100%	13	2	1
Diesel Heating	Depot Only	100%	12	2	0
	Depot and En-Route	100%	9	2	1
	En-Route (Larger Battery, 2 En-Route Chargers)	100%	7	3	2
Diesel		100%	7	-	-

PARALLEL TRANSIT MODELLING SUMMARY

An energy consumption analysis was also conducted for Parallel Transit fleet, as shown in **Table 4** and **Table 5** based on the range capabilities of the most similar EV equivalent vehicle. The range capabilities are shown as the average and maximum daily mileage based on an 8-hour shift assumption and 5% maximum mileage occurrence. The paratransit fleet can undergo a 1:1 replacement.

Table 4: Proposed Energy Consumption Plan for Paratransit

Service	Vehicle Type	Proposed EV Replacement Model	Average km	Maximum km
Non-Revenue Fleet	28' Mobility Bus	Lightning Electric E-450 129	105	115

Table 5: Chargers and Energy Demand Required for Paratransit Proposed Energy Consumption Plan

Total Charger Quantity	Total Power (kW)	Daily Energy Demand (kWh)	Required EV Fleet Size	Current Fleet Size
5	50	542	5	5

PATHWAY OPTIONS

To arrive at a final transition pathway, Stratford will select one or two scenarios that were discussed in the previous section. The number of BEBs required, costs, and GHG savings are detailed in this section based on the model outputs.

FIXED ROUTE TRANSIT

High level projections of fleet size requirements, charging equipment requirements, cost estimates, and emission reductions were produced for each option and compared to the baseline diesel "business as usual" (BAU) scenario.

The capital cost estimates include the purchase and installation cost for buses and fueling/charging infrastructure. The capital cost estimates are based on averages of best available quotes from the manufacturers or best available information from industry studies. It should be noted that the number of depot chargers is assumed to be the same for all scenarios to assure a 1:1 bus to dispenser ratio.

Operating costs includes energy and fuel cost, operating costs, and maintenance costs. These cost estimates are based on information provided by Stratford and best available information from industry studies.

Emissions reductions were estimated based on emission intensity data produced by Environmental and Climate Change Canada. **Table 6** summarizes these high-level projections.

In addition to the high-level quantitative estimates, each technology option was evaluated across a number of qualitative criteria:

- Route Flexibility – The routing and operational flexibility given the proposed fleet composition of each pathway
- Facility Constraints – The physical space requirements of supporting infrastructure and vehicle parking/storage
- Maintenance Complexity – The maintenance complexity of both the buses and the supporting equipment including chargers or hydrogen storage equipment
- Future Maintainability Risk – The expected availability of parts for maintenance in the future
- Technology Maturity – The maturity of both the technology and the supporting fuel and parts supply chain

Each pathway was graded on a scale of with the lowest number (1) being the best and highest number (3-5, depending on the category) being the worst. Some option rankings are combined, which means that they are tied. The grading of each pathway is presented in the **Table 6** below along with the quantitative estimate.

Table 6: Pathway Options High Level Summaries

Measure		Business as Usual (BAU)	Depot Only + Electric Heat (DE)	Depot Only + Diesel Heat (DH)	En-route + Electric Heat (EE)	En-route + Diesel Heat (EH)	
		Diesel	BEB Elec. Heat	BEB Hyb. Diesel Heat	BEB Elec. Heat	BEB (525 kWh) Hyb. Diesel Heat	BEB (675 kWh) Hyb. Diesel Heat
		N/A	Depot Only	Depot Only	En-Route + Depot	En-Route + Depot	En-Route + Depot
Peak Vehicle Requirement	BEB		14	12	13	9	7
	Alternative	7					
Garage Chargers			5	5	5	5	5
En-Route Chargers					1	1	2
Transformers			1	1	1	1	1
Capital Cost (Cumulative)[1]		$4,200,000	$19,400,000	$17,000,000	$19,400,000	$14,600,000	$13,400,000
Annual Operating Cost[2]		$1,545,177	$1,127,855	$1,023,016	$1,120,102	$1,018,738	$1,023,438
Annual GHGs Emissions (tCO2eq)		1,343	50	97	50	29	98
Annual GHGs Savings (%)[3]		0%	96%	93%	96%	98%	93%
Route Flexibility		1	3	2	5	4	
Facility Constraint		1	5	4	3	2	
Maintenance Complexity		1	3	2	5	4	
Future Maintainability Risk		1	2		3		
Technology Maturity		1	2		3		

[1]Total raw conversion costs. Capital Costs: Fleet, Depot Charger, En-route Charger, Transformer

[2]Operating Cost (based on current costs): Electricity Demand & Regulatory Cost, Electricity Consumption Cost, Fuel Cost, Maintenance Cost

[3]Relative to service level under diesel baseline. Includes upstream emissions and emissions from auxiliary heater.

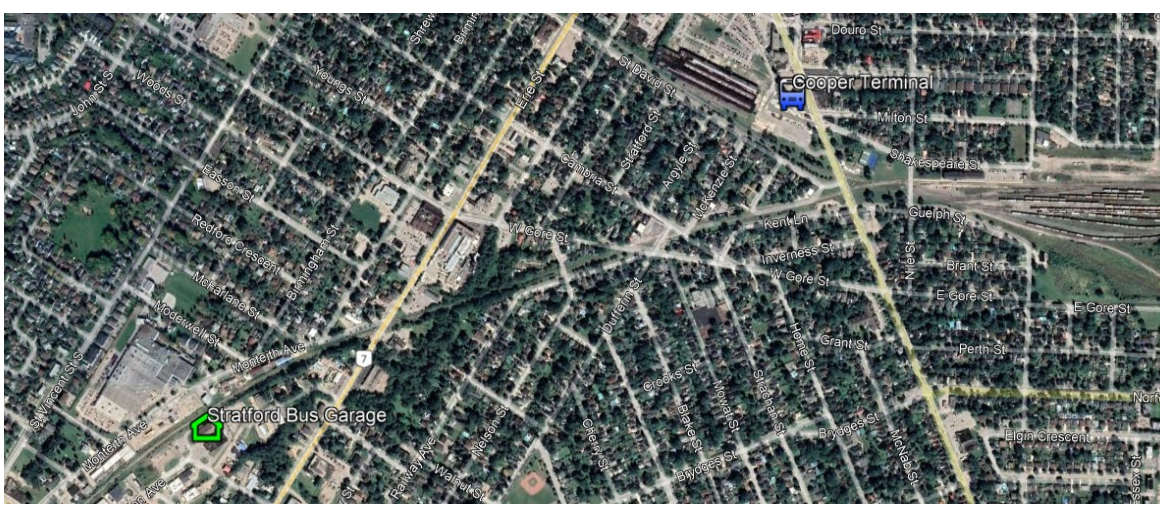
When considering options, it is important to consider both the initial capital costs of purchasing the vehicles as well as the operating costs. Typically, when transit fleets transition to BEBs, there is a significant shift from operating costs to capital costs. While the vehicles are more expensive to purchase, they are typically more cost effective to operate and maintain. One reason for this efficiency is due to electricity being typically a cheaper way to power vehicles than diesel, with more stable prices.

As can be seen in **Table 6**, all options require significant capital investment compared to the BAU scenario. However, there are savings in annual operating costs for the BEB scenarios compared to the BAU scenario. Capital and operating costs are comparable across each of the BEB options with the en-route and diesel heating scenario holding a slight advantage in both capital investment and operational cost. Although there are advantages for the en-route and diesel heating scenario, the en-route charging technology is not as mature as depot charging so there is a larger maintainability risk in the future.

It should be noted that the costs shown in **Table 6** assume that the entire fleet and facilities were converted in 2022 dollars with 2022 costs for vehicles and infrastructure. Recognizing the actual transition will occur over 10+ years, actual costs will be impacted by inflation and other factors. This will be evaluated in more detail in later phases of this study. It is also not necessary to commit to a single strategy now and a flexible plan that can adapt to technology improvements is recommended.

Cooper Terminal is where all of Stratford's transit service currently terminates and only 2.2 kms from Stratford's bus garage (see Figure 29). With the proximity of the garage being so close, the cost to swap buses is minimized. Furthermore, there is precedent with maintenance and operations for this type, as Stratford already does this type of swap when there are issues with vehicles that are in service.

Figure 29: Aerial photo of Cooper Terminal and Stratford Bus Garage which are 2.2 km apart



The vehicles that are used for school bus service also present an opportunity for service efficiencies. They use the same 40' transit buses as the fixed route service.

Based on the above evaluation and recognizing the uncertainty in future technological development for BEB technology, it is proposed that a phased approach be taken. This strategy will allow existing technology in the short term while leaving the door open for emerging technology in the future.

Recommendation:

- Implement BEBs with hybrid-diesel fired auxiliary heaters that are capable of both plug-in & en-route charging and operate them as depot charged buses prior to 2035. The vehicles procured should be longer range BEBs (~600 kWh+) that can at least complete more than a half day of service to avoid multiple bus swaps throughout the day.
- The technological maturity of plug-in charging and proximity of the bus garage make this a good low-cost strategy for Stratford that will still allow implementation of en-route charging in the future to limit increasing fleet size due to electrification. Stratford should explore a bus swapping strategy that utilizes the buses typically reserved for school bus service for transit service in the afternoon to avoid having to increase fleet size in the near term.
- Investigate adding en-route charging at Cooper Transit Terminal over the next 10 years. Become familiar with en-route charging technology risk by learning from other transit agencies and/or testing the technology. Installing a pilot pantograph charging dispenser at Stratford Bus Garage or Cooper Terminal to validate the vehicle overhead charging capability and future operating performance metrics.
- Conduct a follow-up evaluation in 3-5 years to confirm the number of buses and chargers required at each location based on actual performance in-service of the fleet selected. Increases in battery capacity or vehicle charging capabilities may reduce the number of vehicles or infrastructure required.

PARATRANSIT FLEET

The transition of the paratransit vehicle fleet is based on the analysis of the range capabilities of a similar EV equivalent. The project procurement timelines are established based on the retirement schedule provided by Stratford where vehicles are typically replaced eight years from their production.

The composition forecast also considers Stratford's plans for purchase of hybrid models between 2025 and 2028 and plans to start transitioning to battery electric paratransit buses in 2028. The recommended yearly fleet composition of the paratransit fleet is shown in **Figure 30**.

The Lightning Electric E-450 129 is currently the only similar style mini-bus that has been Altoona tested and is avialable on the market. This model is recommended because it is the most similar in passenger capacity, physical dimensions, and range capability to the 4500 GMC, 3500 Ford CTV, and the Chevrolet 4500 and ETV. Although this model is currently the best option, other models might become available in the coming years.

Currently a one-to-one replacement is possible for current distances but fleet size increases will be necessary to support longer distances. Purchase of the first five vehicles would occur in 2026 and their arrival would be in 2028.

Figure 30: Paratransit Fleet Composition Forecast