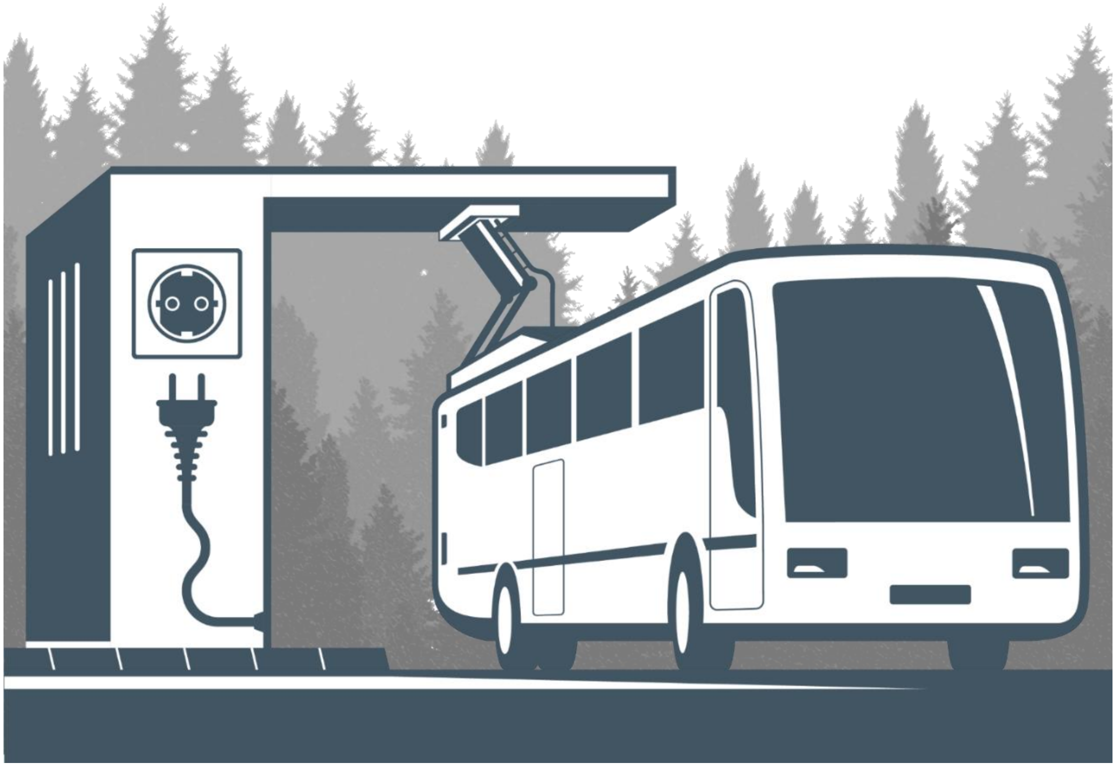

Bus Electrification Transition Plan for Greater Portland Metro

GREATER PORTLAND metro

Prepared by:

HATCH

Version: 1.1

2/10/2023

Table of Contents

1. Executive Summary

Greater Portland Metro, the bus agency serving the Portland area in Maine, is currently in the early stages of transitioning its diesel and CNG bus fleet to battery electric vehicles. To effectively plan the remaining stages of this transition a thorough analysis was conducted to develop a feasible strategy for the agency. This report summarizes the results of the analysis for asset configuration, emissions, and the costs associated with the transition.

Through this analytical process, Metro has expressed a preference for fleet and infrastructure asset configurations that will provide a feasible transition to battery electric drivetrain technologies while supporting the agency's operational requirements and financial constraints. The selected configuration maintains the agency's existing fleet size of 44 buses while ensuring viable operation for Metro's range of services. To support the battery electric buses, the agency also plans to procure, install, and commission nine additional charging systems that, together with additional dispensers on the existing chargers, will have the capacity to support overnight charging of up to 33 buses simultaneously.

One of the primary motivations behind Metro's continued transition to battery electric drivetrain technologies is to achieve emissions reductions compared to their existing mostly diesel operations. As part of this analysis, an emissions projection was generated for the proposed future battery electric fleet. The results of this emissions projection estimate that the new fleet will provide up to an 87% reduction in emissions compared to Metro's pre-electrification operations.

A life cycle cost estimate was also developed as part of the analysis to assess the financial implications of the transition. The cost estimate includes the capital costs to procure the new vehicles, charging systems, and supporting infrastructure, as well as the operational and maintenance expenditures. The costing analysis indicates that Metro can anticipate a 37% increase in capital expenditures due to the transition. It is estimated, however, that there will be a 10% annual reduction in operational and maintenance costs due to the improved reliability and efficiency of battery electric drivetrain technologies. In summation, the cost estimate predicts that Metro will see roughly 3% life cycle cost savings by transitioning to an entirely battery electric bus fleet.

The conclusion of the analysis is that battery electric buses can feasibly support Metro's operations. Furthermore, these buses offer the potential for the agency to greatly reduce emissions and to slightly reduce the life cycle costs required to operate its buses. Therefore, Metro is encouraged to proceed with the strategy as described in this transition plan.

2. Introduction

As part of its efforts to reduce emissions to slow the effects of climate change, the State of Maine has developed a "Clean Transportation Roadmap", which encourages Maine's transit agencies to transition their bus fleets to hybrid and battery electric vehicle technologies.

Additionally, the Federal Transit Administration (FTA) currently requires that all agencies seeking federal funding for "Zero-Emissions" bus projects under the grants for Buses and Bus Facilities Competitive Program (49 U.S.C. § 5339(b)) and the Low or No Emission Program (49 U.S.C. § 5339(c)) have completed a transition plan for their fleet. Specifically, the FTA requires that each transition plan address the following:

+ Demonstrate a long-term fleet management plan with a strategy for how the applicant intends to use the current request for resources and future acquisitions.
+ Address the availability of current and future resources to meet costs for the transition and implementation.
+ Consider policy and legislation impacting relevant technologies.
+ Include an evaluation of existing and future facilities and their relationship to the technology transition.
+ Describe the partnership of the applicant with the utility or alternative fuel provider.
+ Examine the impact of the transition on the applicant's current workforce by identifying skill gaps, training needs, and retraining needs of the existing workers of the applicant to operate and maintain zero-emissions vehicles and related infrastructure and avoid displacement of the existing workforce.

In response to the Governor's Roadmap and the FTA requirements, Metro, in association with the Maine Department of Transportation (Maine DOT) and its consultant Hatch, have developed this fleet transition plan. In addition to the FTA requirements, this transition plan also addresses details on Metro's future route plans, vehicle technology options, building electrical capacity, emissions impacts, resiliency, and financial implications.

3. Existing Conditions

Metro is a small transit agency providing service to the Greater Portland area of Maine. The agency currently owns and operates a revenue fleet of 32 diesel vehicles, 10 compressed natural gas (CNG) vehicles, and two battery-electric buses. These vehicles include standard low-floor transit buses (either 35' or 40' in length) and cutaway minibuses. The agency maintains an up-to-date fleet, procuring new buses on a rolling basis to replace old vehicles approaching the end of their useful life (7 years for cutaways and 14 years for transit buses).

Section Summary

- Metro operates ten routes with a 44-bus fleet, two of which are battery-electric buses

Table 1 Current Vehicle Roster

Bus Type/Roster Number	Fuel Type	Number of Buses	Procurement Date
Gillig Phantom Transit Bus (1101-1107)	Diesel	7	2011
Gillig Phantom Transit Bus (1401-1405)	CNG	5	2014
Arboc Cutaway (1606-1608)	Diesel	3	2015
Arboc Cutaway (1709)	Diesel	1	2016
New Flyer Transit Bus (1810-1814)	CNG	5	2018
New Flyer Transit Bus (1815-1820)	Diesel	6	2018
New Flyer Transit Bus (1921-1926)	Diesel	6	2019
New Flyer Transit Bus (2027-2033)	Diesel	7	2020
New Flyer Transit Bus (2134-2135)	Diesel	2	2021
Proterra 35' Transit Bus (2236-2237)	Electric	2	2022

Metro has ten fixed routes that operate on mostly 30-minute to 1-hour headways, including the BREEZ, a longer express route that provides service from Portland to Brunswick, ME. Most routes operate the same service pattern throughout the day. Nearly all routes serve the downtown Portland area, where connections are also available to other transit agencies, as shown in Figure 1 below.

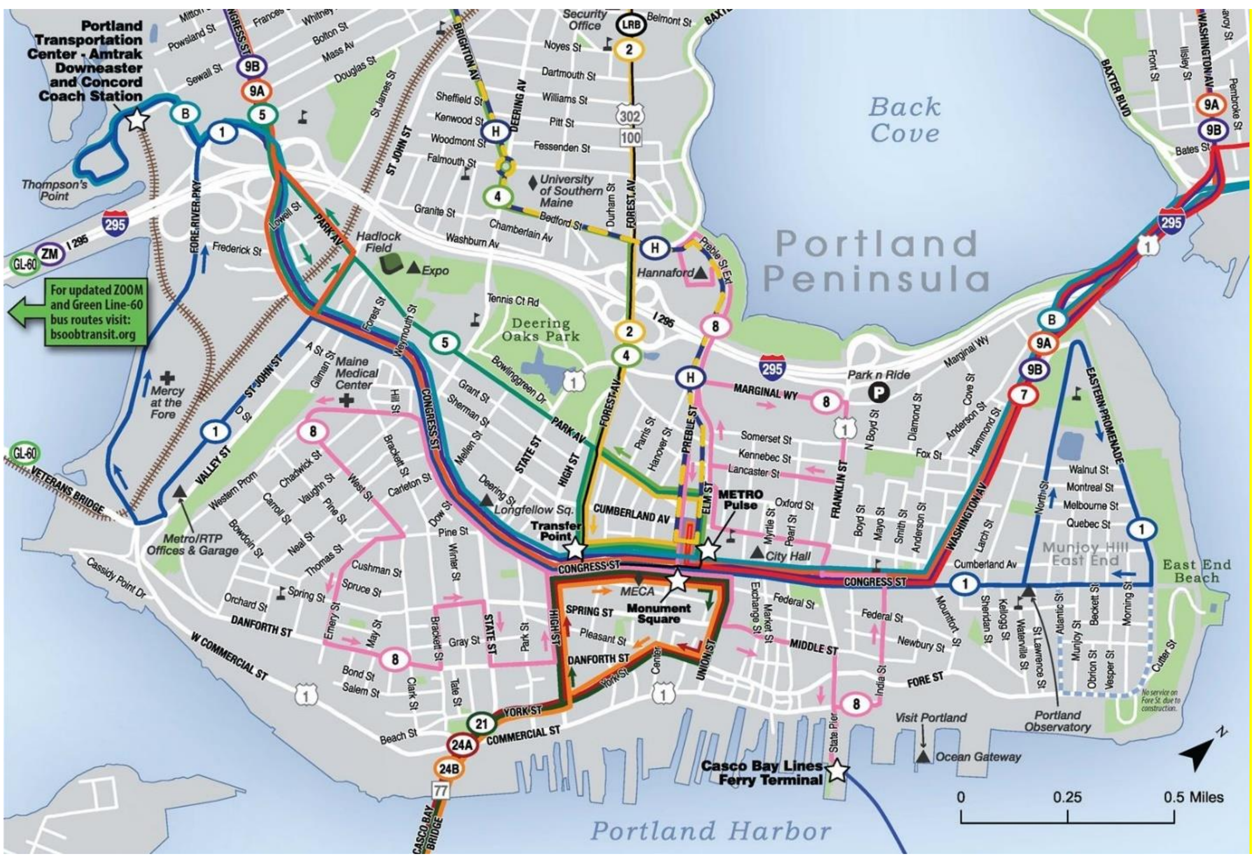

Figure 1 Map of Metro and Other Regional Transit Services in Downtown Portland

- **Route 1 – Congress Street**
  Serves Thompson’s Point/Portland Transportation Center and Munjoy Hill/Eastern Prom, via Congress Street and Fore River Parkway.
  Operates mostly every 30 minutes on Mondays-Saturdays, from 5:00 AM to 11:00 PM.
  Operates every hour on Sundays from 8:00 AM to 6:00 PM.
- **Route 2 – Forest Avenue**
  Serves downtown Portland and Prides Corner, Westbrook via Forest Avenue.
  Operates mostly every 30 minutes on Mondays-Fridays, from 5:00 AM to 11:00 PM.
  Operates every hour on Saturdays from 6:30 AM to 10:00 PM.
  Operates every hour on Sundays from 8:30 AM to 3:30 PM.
- **Route 3 – Portland, Westbrook, South Portland**
  Serves Portland / Riverside, Westbrook, and South Portland / Maine Mall area.
  Most trips continue with connection to Route 5 service.
  Operates every 45-60 minutes on Mondays-Fridays, from 5:30 AM to 10:30 PM.
  Operates every hour on Saturdays from 8:00 AM to 10:00 PM.
  Operates every hour and a half on Sundays from 10:00 AM to 5:30 PM.
- **Route 4 – Westbrook**
  Serves Portland and Westbrook, via USM (Portland) and Brighton Avenue.
  Operates mostly every 30 minutes on Mondays-Fridays, from 6:00 AM to 11:00 PM.
  Operates mostly every 45-50 minutes on Saturdays from 6:00 AM to 10:30 PM.
  Operates every 45 minutes on Sundays from 8:00 AM to 7:00 PM.
- **Route 5 – Maine Mall**
  Serves downtown Portland and Maine Mall area.
  Operates mostly every 30 minutes on Mondays-Fridays, from 5:30 AM to 10:00 PM.
  Operates mostly every 45-50 minutes on Saturdays from 6:00 AM to 10:00 PM.
  Operates every 45 minutes on Sundays from 8:00 AM to 6:00 PM.
- **Route 7 – Falmouth**
  Serves downtown Portland and Falmouth.
  Operates every hour on Mondays-Saturdays, from 6:30 AM to 6:30 PM.
  Operates every hour on Sundays from 8:30 AM to 4:00 PM.
- **Route 8 – Peninsula Loop**
  Serves Portland Peninsula.
  Operates mostly every 30 minutes on Mondays-Fridays, from 7:00 AM to 6:00 PM.
  Operates every hour on Saturdays from 8:00 AM to 6:00 PM.
  Operates every hour on Sundays from 9:00 AM to 3:30 PM.
- **Route 9A / 9B – Deering / West Falmouth**
  Serves downtown Portland and North Deering in clockwise (9A) and counterclockwise (9B) directions, including all three Portland Public High Schools.
  Operates every 30-60 minutes on Mondays-Fridays from 5:30 AM to 10:00 PM.
  Operates every hour on Saturdays, from 7:30 AM to 10:00 PM.
  Operates every hour on Sundays from 8:30 AM to 3:30 PM.
- **Husky Line**
  Serves Portland, Westbrook, Gorham, and the two USM campuses.
  Operates mostly every 45 minutes on Mondays-Fridays, from 6:30 AM to 10:00 PM.

Operates mostly every 45 minutes on Saturdays from 8:00 AM to 10:00 PM.
Operates mostly every 45 minutes on Sundays from 8:00 AM to 6:30 PM.

+ **Metro BREEZ** (Express)
  Serves Portland, Yarmouth, Freeport, and Brunswick.
  Operates every 45-90 minutes on Mondays-Fridays, from 6:30 AM to 10:00 PM.
  Operates every 2-3 hours on Saturdays from 8:00 AM to 8:30 PM.
  Operates every 2-3 hours on Sundays from 9:00 AM to 7:30 PM.

4. Vehicle Technology Options

Section Summary

- Buses will need diesel heaters for winter operation
- Manufacturers' advertised battery capacities do not reflect actual achievable operating range

As discussed in Section 3, Metro's revenue service fleet is composed primarily of 35'-40' transit buses, as well as several cutaways which are being replaced with transit buses. A summary of hybrid and battery electric vehicle models that are commercially available (provided in Appendix A) demonstrates that there is a variety of possible vehicles for Metro to utilize. For battery electric buses, battery capacity can be varied on many commercially available bus platforms to provide varying driving range.

For this study, battery electric transit-style buses were assumed to have either a 'short-range' 225kWh or 'long-range' 450kWh battery capacity, which are representative values for the range of batteries offered by the industry. The buses were assumed to have diesel heaters, which minimize electrical energy spent on interior heating during the winter months. Two types of safety margins were also subtracted from the nominal battery capacities of the buses. First, the battery was assumed to be six years old (i.e. shortly before its expected replacement at the midlife of the bus). As batteries degrade over time, their capacity decreases. To account for this, the battery capacity was reduced by 20%. Second, the bus was assumed to need to return to the garage before its level of charge falls below 20%. This is both a manufacturer's recommendation – batteries have a longer life if they are not discharged to 0% – and an operational safety buffer to prevent dead buses from becoming stranded on the road. Combining these two margins yields a usable battery capacity of 64% of the nominal value. Finally, as the industry is advancing quickly and technology continues to improve, a 3% yearly improvement in battery capacity was assumed.

5. Infrastructure Technology Options

Transit and other commercial buses typically require DC fast chargers. Transit buses are typically not equipped with an on-board transformer that would allow them to be charged with level 2 AC chargers.

The DC fast chargers typically come in two types of configurations:

1. Centralized
2. De-centralized

A decentralized charger is a self-contained unit that allows for the charging of one vehicle per charger. The charging dispenser is typically built into the charging cabinet. In contrast, in a centralized configuration, a single high-power charger can charge multiple vehicles through separate dispensers. The power is assigned to the dispensers dynamically based on the number of vehicles that are charging at the same time. Similarly, centralized systems can support high-powered pantograph chargers. Examples of both configurations are shown in Figure 2.

Figure 2 Example Charging Systems (Source: ABB):

Left – Charging Cabinet (System) and Three Dispensers (Charge Boxes)

Right – Overhead Pantograph Charger and Centralized Cabinets

Like the vehicles, charging infrastructure to support battery electric buses is available in numerous configurations. One of the primary metrics that can be customized is the charging power. For this study, it was assumed that Metro's future plug style charging systems would match the ones already procured – which have 150 kW of power that can be divided among three dispensers – while any future pantograph chargers would have up to 450 kW of power. These charging system power values have become standard to the transit bus industry. Appendix A shows additional commercially available charging system options and configurations.

Metro's electrification plan (discussed below) anticipates installing one pantograph-style charger at the Elm St Pulse, which is the hub of the network. These chargers are only compatible with transit-style buses, which have conductive bars on the roof. If Metro plans to share the charger with other transit agencies that operate different vehicle types – for example, RTP's Lakes Region Explorer, which runs a cutaway vehicle, or BSOOB's Zoom service, which operates a commuter coach – then the charger would need to be adapted to include a plug-in receptacle. With an appropriately configured charge management system, designed to provide power to either a pantograph or plug-in dispenser but not both at the same time, this would not require any additional charging cabinets or an increase in the utility feed size. Though the comparatively simple additional hardware would make a retrofit economical, the most effective option would be to install the plug dispenser during initial construction. To allow maximum futureproofing and regional coordination, Hatch recommends that Metro consider adding this to the Elm St Pulse charger specification as a priced option.

6. Route Planning and Operations

Section Summary

- Electric buses are typically sold in two battery capacity configurations – short and long range
- Neither electric bus configuration offers comparable operating range to diesel buses – so detailed operations modeling is needed
- To avoid wasteful deadheading, on-route charging is required for Elm St routes

Metro's current operating model (for its diesel and CNG vehicles) is similar to that of many transit agencies across the country. Except for buses operating school trips or supplemental peak-hour service, most vehicles leave the garage at the appropriate time in the morning, operate (on the same route or pair of routes) for the entire day, and then return to the garage once service has concluded in the evening. Although Metro's schedulers must account for driver-related constraints such as maximum shift lengths and breaks, the vehicles are assumed to operate for as long as they are needed. This assumption will remain true for hybrid buses, which have comparable range to diesel and CNG vehicles, but may not always be valid for electric vehicles, which have reduced range in comparison. Metro has operated its new electric buses accordingly, with a vehicle typically operating for as long as it is able and then being replaced with a diesel once its state of charge reaches 30-40%. Metro noted that the buses have not been able to operate for a full day, even given the comparatively mild weather experienced since their introduction in May 2022. Performance during the winter months is expected to be worse; even when diesel heaters are installed, as was assumed in this study, icy road conditions and cold temperatures degrade electric bus performance. Although practices like pre-conditioning the bus before leaving the garage are recommended to extend range, winter conditions will present challenges in electric bus operation.

6a. Operational Simulation

To assess how battery electric buses' range limitations may affect Metro's operations a simulation was conducted. A simulation is necessary because vehicle range and performance metrics advertised by manufacturers are maximum values that ignore the effects of gradients, road congestion, stop frequency, driver performance, severe weather, and other factors specific to Metro's operations. As mentioned above, it was not necessary to simulate hybrid operations because the vehicles offer comparable range to diesel and CNG buses.

Hatch conducted a route-specific electric bus analysis by generating "drive cycles" for several routes that represented the typical modes of Metro's operations, ranging from slower-speed in-city routes to higher-speed routes through the suburbs. For each representative route, the full geography (horizontal and vertical alignment), transit infrastructure (location of key stops), and road conditions (vehicle congestion, as well as traffic lights, stop signs, crosswalks, etc.) were modeled, and the performance of the vehicle was simulated in worst-case weather conditions (cold winter) to create a drive cycle. These Metro-specific drive cycles were used to calculate energy consumption per mile and therefore total energy consumed by a vehicle on each route.

As discussed in the previous section, all fixed-route services were evaluated against two common electric bus configurations: 'short-range' 225 kWh or 'long-range' 450 kWh battery capacity. As technology advances, Hatch assumed that these battery capacities will increase at a rate of 3% per year, allowing for additional range. In accordance with Metro's plans for fleet acquisition and depot reconstruction, battery capacity values as of 2032 were taken for analysis. (Buses procured before 2032 can be assigned to less energy-intensive blocks). Combined with the safety margins discussed in Section 4, this yielded usable battery energy of 194 kWh for short-range transit buses and 388 kWh for long-range transit buses. Clearly, if battery electric bus technology advances faster than anticipated, or if the existing fleet proves reliable and can outlast its 14-year lifespan, there will be a higher operating margin in bus electrification, allowing more service expansion and increased competition during procurements. Conversely, if technology develops more slowly or the existing fleet requires replacement sooner, less service expansion will be possible, and potentially additional on-route chargers or buses may be required.

Table 2 below presents the mileage and energy requirement for each block, with green shading denoting those blocks that can be operated by the specified bus by the first vehicle acquisition date and red shading denoting those that cannot. It should be noted that the energy requirements are slightly higher for long-range buses because of their higher weight due to the increased number of battery cells.

Table 2 Energy Requirements by Block

Block	Mileage	'Short-Range' Bus		'Long-Range' Bus	
		kWh Required	Mileage Shortage/Excess	kWh Required	Mileage Shortage/Excess
Route 1	164.7	447.6	-93.1	472.3	-29.1
	130.1	353.3	-58.4	372.8	5.6
Route 2	174.5	407.1	-91.3	429.8	-16.7
	225.7	526.0	-142.3	555.3	-67.7
Route 3/5	250.9	551.6	-160.9	583.8	-83.0
	197.5	438.5	-110.0	464.0	-32.0
	220.9	491.4	-133.8	519.5	-55.6
	173.9	385.8	-86.2	407.7	-8.0
Route 4	177.2	418.5	-95.0	445.0	-22.4
	159.8	377.4	-77.5	401.3	-5.0
	243.1	574.1	-160.9	610.4	-88.3
Route 7	200.4	406.2	-104.9	430.3	-19.4
Route 8	89.7	243.5	-18.1	257.0	45.9

Block	Mileage	'Short-Range' Bus kWh Required	'Short-Range' Bus Mileage Shortage/Excess	'Long-Range' Bus kWh Required	'Long-Range' Bus Mileage Shortage/Excess
	88.1	239.6	-16.6	252.8	47.4
Route 9A / 9B	173.8	383.0	-85.7	410.8	-9.3
	108.2	238.7	-20.1	256.0	56.3
	147.5	325.3	-59.5	348.9	16.9
	186.9	411.9	-98.9	441.8	-22.5
Route 9 (Schools)	30.0	66.0	58.4	70.9	134.7
	36.5	80.4	51.8	86.2	128.2
	30.3	66.7	58.0	71.6	134.4
	40.8	89.8	47.5	96.4	123.9
Husky Line	230.2	424.5	-125.1	454.5	-33.4
	254.7	470.5	-150.1	503.6	-58.3
Metro BREEZ	362.8	631.2	-251.0	663.9	-150.3
	243.5	425.0	-132.5	447.0	-31.8
	305.7	534.3	-195.3	562.0	-94.6

6b. Operational Alternatives

As shown in Table 2, short-range buses can only accommodate the four school-trip blocks, and even long-range buses are insufficient for the majority of blocks. To address the operational shortcomings of the battery electric buses a few options were considered. To maintain study focus, changes to passenger-facing schedules were not considered; optimization of schedules for electric bus operation is recommended only after an operating model is chosen to avoid over-committing to one particular schedule. More information about the tradeoffs between the operating strategies below is presented in Appendix B.

The operationally easiest option is to maintain existing operations, with electric vehicles operating on blocks where they can complete the entire day's service and hybrid vehicles covering all other blocks. This would allow Metro to continue operations without being impacted by vehicle range constraints. This is feasible for the school trip services, which have a lengthy midday layover period that can be used for charging. For the other services, however, adopting hybrids would not correspond with Metro's existing and planned electric vehicle procurements, would not lower emissions as much as adopting electric vehicles, and would introduce complications with operating and maintaining a split fleet. Therefore, hybrid vehicles were not considered further in this study.

Another possibility is to operate using "depot swapping," with electric buses operating as long as they are able to and then returning to the depot to charge while a fresh bus takes over their block. By cycling buses in and out of service throughout the day, Metro would be able to mitigate the range limitations of battery electric buses without requiring field infrastructure. However, this option requires additional deadheading, leading to wasted mileage and operator time. In addition, this option would require a substantial increase in fleet size because depot chargers are traditionally lower-power (slower) than on-route chargers, and additional time would be needed for vehicles to deadhead to and from the depot. For these reasons, Metro is currently considering this option only for blocks with lengthy midday scheduled layovers (such as some Breez and Route 9 blocks) and for routes terminating at Thompson's Point (where no on-route charger is planned) but not for the bulk of its routes.

An alternative possibility is to recharge buses during layovers over the course of the day. This could be achieved with either "short-range" or "long-range" buses. Short-range buses, though they are less expensive to purchase, operate a shorter distance between charges and recharge less quickly than long-range buses. Operationally, this has an impact on infrastructure and fleet size requirements. As short-range buses require more charging time per hour of operation, a greater number of buses must be charging at any given time, requiring a larger number of chargers and buses. This is compounded by the need to avoid charging during system-peak times to reduce electricity costs (discussed below), which increases the need for charging in the hours leading up to the beginning of the system peak. Therefore, three additional buses would be required for peak service, as well as two chargers at the Elm St Pulse; the extra charging time would also require more driver hours and operating cost. Operation with long-range buses, on the other hand, would allow Metro to continue operations with its existing fleet size and only one charger; a bus currently unused during the midday (for example, a Breez bus or school trip vehicle) would operate in place of the vehicle being charged. These fleet and infrastructure cost savings exceed the additional upfront expense of purchasing more expensive long-range buses. For this reason, Metro stakeholders have chosen to proceed with the latter option of purchasing long-range buses and recharging them throughout the day.

For layover charging to be most efficient, the schedule (and perhaps even the route structure) would need to be optimized for the needs of the buses. For example, coordination of driver meal breaks with bus charging times can ensure that drivers are not waiting unproductively while the bus charges (and can even simplify scheduling, as a driver and a bus would stay together throughout the driver's shift, with meal and charging breaks happening at the same time). Careful selection of route interlines can help balance layover durations with the time required for charging. For example, the schedule for Route 7 does not provide any layover time, with buses arriving at Elm St on the half-hour and departing immediately thereafter. However, Route 7 operates on a 60-minute frequency, and one hour is too long of a charge window for a single bus to allow all buses access to the charger throughout the day. Therefore, interlining vehicles between Route 7 and another route would be prudent to give all vehicles adequate charging time. A final option is to revise a route to start and end near the depot, to allow buses low on charge to be swapped out for fresh buses without requiring deadheading. A bus low on battery would operate the outbound trip and be replaced with a fresh bus, which would operate the inbound trip before resuming service on another route. In the meantime, another bus low on battery would operate the next outbound trip. This would reduce reliance on the on-route charger and may (assuming sufficient frequency on that route) eliminate the need for the charger entirely. As Metro continues to gain experience operating electric vehicles, Hatch recommends continual tweaks to the schedules and blocks, ensuring that vehicles have adequate charging time independent of weather, seasonal traffic, and other factors.

7. Charging Schedule and Utility Rates

Section Summary

- The local utility has proposed a new rate structure for charging EVs which will include cost penalties for charging during peak demand periods
- As a result, a charging schedule was developed to help Metro charge its buses economically

Developing a charging schedule is recommended practice while developing a transition plan as charging logistics can have significant effects on bus operations and costs incurred by the agency. From an operational perspective, charging buses during regular service hours introduces operational complexity by requiring a minimum duration for certain layovers. The operational configuration and fleet composition selected by Metro, and described in the previous section of this report, assumes that buses will be charged during both the overnight period and during layovers throughout the day.

Metro's current electricity rates are determined by Central Maine Power's 'MGS-S' rate. However, this rate structure is only applicable for services with peak load of 400kW or less. As discussed further down in this section, the peak load for Metro's depot charging location will exceed 1000 kW, requiring Metro to adopt the 'LGS-S-TOU' rate structure. Hence, the 'LGS-S-TOU' rate structure, as shown in Table 3, is assumed to estimate the utility cost under the "current" rate structure. Under this 'LGS-S-TOU' rate structure, Metro will pay a flat "customer charge" monthly, regardless of usage. Metro will also pay a distribution charge per kW for their single highest power draw (kW) that occurs during each month. The distribution charge is dependent on the time of the day and calculated based on the rate schedule outlined in Table 3 below. This peak charge is not related to Central Maine Power's grid peak and is local to Metro's usage. Finally, Metro is charged an 'energy delivery charge' of $0.001654 per kWh, and an 'energy cost' at a statewide average rate of $0.12954 per kWh. These costs are recurring and are dependent on the amount of energy used by Metro throughout the month.

The on-route charging load is under 400 kW so the on-route charging location will be eligible for the current 'MGS-S' rate structure, under which Metro pays a flat "customer charge" monthly, regardless of usage. As shown in Table 4, Metro also pays a single distribution charge of $16.64 per kW for their single highest power draw (kW) that occurs during each month. This peak charge is not related to Central Maine Power's grid peak and is local to Metro's usage. Finally, Metro is charged an 'energy delivery charge' of $0.001745 per kWh, and an 'energy cost' at a statewide average rate of $0.12954 per kWh. These costs are recurring and are dependent on the amount of energy used by Metro throughout the month.

To encourage the adoption of electric vehicles (EV), Maine's Public Utilities Commission (PUC) requested that utilities, including Central Maine Power, propose new rate structures for vehicle charging. In response to this request, Central Maine Power proposed a 'B-DCFC' utility schedule filed under Docket No. 2021-00325. The new proposed rate structure was approved effective July 1st, 2022. To qualify for this rate, Central Maine Power requires that the customers like Metro install a new meter and dedicated service for their charging equipment to accurately account for the power draw associated with charging.

The new rate structures would provide Metro with a lower monthly 'distribution charge' but introduces a transmission charge that is calculated based on Central Maine Power's grid peak, termed the 'coincidental peak'. The agency can avoid this transmission service charge, that is calculated on monthly basis, by not charging vehicles during periods when Central Maine Power's grid load is peaking. The historic data indicates that the daily system peak for Central Maine Power happens between 3 PM and 7 PM. Therefore, it is advisable for Metro to develop a charging plan which avoids charging buses during these hours.

Table 3 Utility Rates Structure Comparison (depot)

	Current Rates (LGS-S-TOU)	Future Rates (B-DCFC)
Customer Charge	$734.28 per month	$147.19 per month
Peak Demand Charge	$17.73 per non-coincidental peak kW (calculated monthly)	$2.60 per non-coincidental peak kW (calculated monthly)
Shoulder Demand Charge	$3.34 per non-coincidental peak kW (calculated monthly)	$2.60 per non-coincidental peak kW (calculated monthly)
Off-peak Demand Charge	$0.00 per non-coincidental peak kW (calculated monthly)	$0.00 per non-coincidental peak kW (calculated monthly)
Transmission Charge	$0.00 per non-coincidental peak kW (calculated monthly)	$19.35 per coincidental peak kW (calculated monthly)
Energy Delivery Charge	$0.001654 per kWh	$0.003747 per kWh
Energy Cost	$0.12954 per kWh	$0.12954 per kWh

Table 4 Utility Rates Structure Comparison (on-route)

	Current MGS-S Rates	B-DCFC Rates
Customer Charge	$50.01 per month	$50.01 per month
Distribution Charge	$16.64 per non-coincidental peak kW (calculated monthly)	$4.39 per non-coincidental peak kW (calculated monthly)
Transmission Charge	$0.00 per non-coincidental peak kW (calculated monthly)	$19.35 per coincidental peak kW (calculated monthly)
Energy Delivery Charge	$0.001745 per kWh	$0.001745 per kWh
Energy Cost	$0.12954 per kWh	$0.12954 per kWh

Accordingly, a charging schedule was optimized around the operational plan developed in the previous section of the report and the above listed utility schedules. The results of this optimization are shown in Figure 3 for the depot charging at 114 Valley Street facility and Figure 4 for on-route charging at the Elm St Pulse. It can be seen in the figures that the optimized charging schedule assumes buses will be charged overnight (between 7 PM and 5 AM) as well as during the day at the depot using the plug-in chargers. The optimized charging schedule also includes midday charging using the overhead fast charger at Elm St between 9 AM and 3 PM and again between 7 PM and 8 PM. (Although the overhead fast charger is capable of power levels up to 450 kW, as discussed previously, this analysis assumes a maximum power level of 300 kW plus a safety margin; this helps reduce power costs and provides operational resilience by allowing charging speed to be increased where needed in case of traffic delays). This charging schedule avoids charging during the Central Maine Power grid's 'coincidental peak' (between 3 PM and 7 PM), which would allow Metro to avoid a monthly 'transmission charge', should the agency decide to adopt the Central Maine Power's special optional 'B-DCFC' rate schedule for its charging operation.

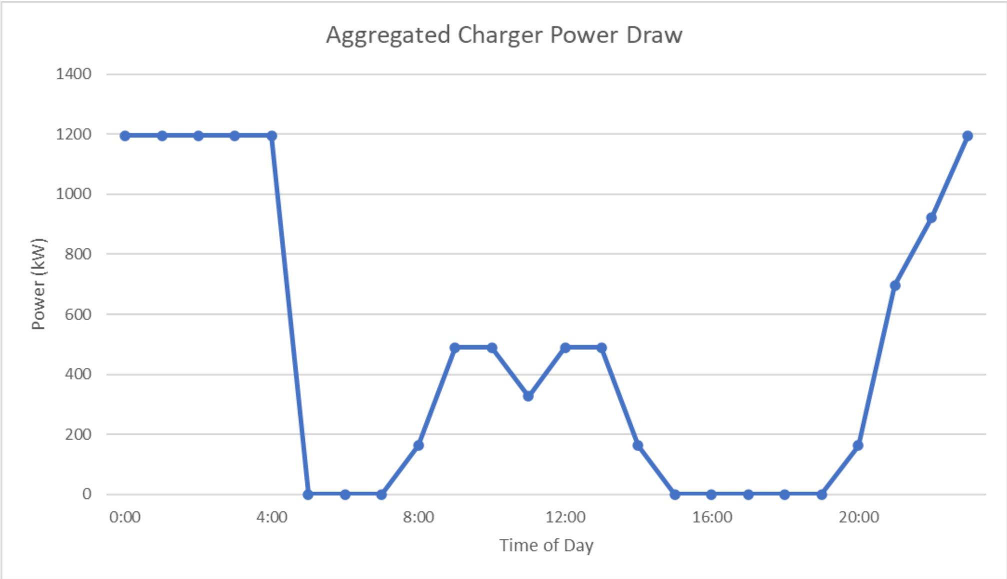

Figure 3 Proposed Depot Charging Schedule for Metro's Future Fleet

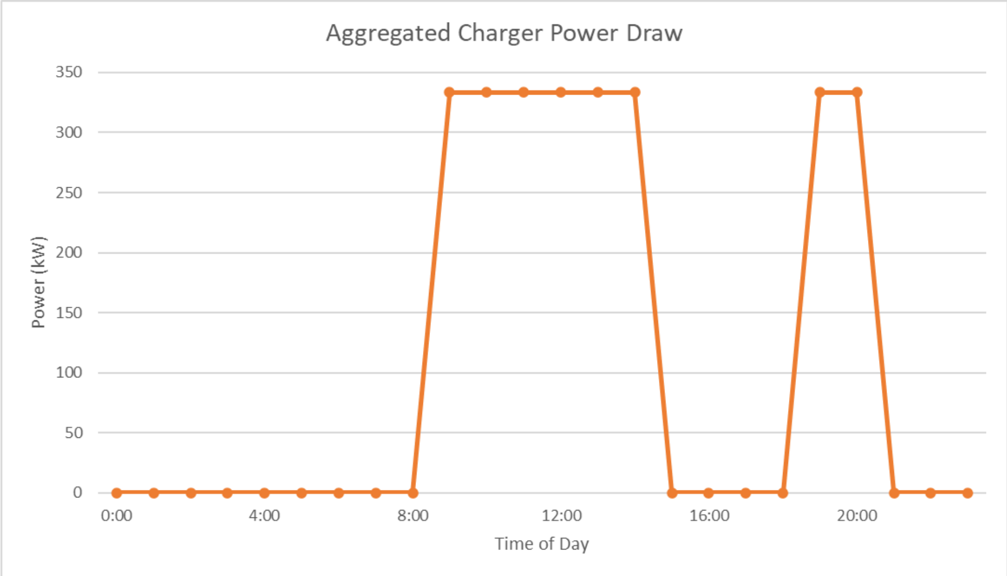

Figure 4 Proposed On-route Charging Schedule for Metro's Future Fleet

Below is an estimate of expected operational costs associated with the proposed charging schedule, based on both the existing and the new optional 'B-DCFC' rates.

Depot - 114 Valley St Facility

Daily kWh consumption = 9,807 kWh
Monthly Non-coincidental peak = 1196 kW
Monthly coincidental peak = 0 kW

Under Current LGS-S-TOU Rate Structure:

$$\begin{aligned}
&Daily\ Charge = \\
&\qquad Daily\ kWh\ consumption\ \times (Energy\ Delivery\ Charge + Energy\ Cost) \\
&= 9{,}807\ kWh\ \times (\$0.001654 + \$0.12954) \\
&= \$1286.61
\end{aligned}$$

$$\begin{aligned}
&Monthly\ Charge \\
&\qquad = Max\ ((Highest\ Power\ during\ Peak\ Period \\
&\qquad \times Peak\ Demand\ Charge), (Highest\ Power\ during\ Shoulder\ Period \\
&\qquad \times Shoulder\ Demand\ Charge), (Highest\ Power\ during\ Off \\
&\qquad - Peak\ Period\ \times Off - Peak\ Demand\ Charge)) \\
&= Max\ \big((490\ kW \times 17.73), (490\ kW \times \$3.34), (1{,}196\ kW \times \$0)\big) \\
&= Max\ (\$8{,}687.70, \$1636.60, \$0) \\
&= \$8{,}687.70
\end{aligned}$$

Under New B-DCFC Rate Structure:

$$\begin{aligned}
&Daily\ Charge = \\
&\qquad Daily\ kWh\ consumption\ \times (Energy\ Delivery\ Charge + Energy\ Cost) \\
&= 9{,}807\ kWh\ \times (\$0.001654 + \$0.12954) \\
&= \$1286.61
\end{aligned}$$

$$\begin{aligned}
&Monthly\ Charge \\
&\qquad = Max\ ((Highest\ Power\ during\ Peak\ Period \\
&\qquad \times Peak\ Demand\ Charge), (Highest\ Power\ during\ Shoulder\ Period \\
&\qquad \times Shoulder\ Demand\ Charge), (Highest\ Power\ during\ Off \\
&\qquad - Peak\ Period\ \times Off - Peak\ Demand\ Charge)) \\
&\qquad + (Monthly\ coincidental\ Peak\ \times Transmission\ Charge) \\
&= Max\ \big((490\ kW \times 3.34), (490\ kW \times \$3.34), (1196 \times \$0)\big) + (0\ kW\ \$19.35) \\
&= Max\ (\$1{,}636.60, \$1{,}636.60, \$0)) + (\$0) \\
&= \$1{,}636.60
\end{aligned}$$

On-Route – Elm St Pulse

Daily kWh consumption = 2,613 kWh
Monthly Non-coincidental peak = 315 kW
Monthly coincidental peak = 0 kW

Under Current MGS-S Rate Structure:

$$Daily\ Charge = Daily\ kWh\ consumption\ \times (Energy\ Delivery\ Charge + Energy\ Cost)$$
$$= 1{,}222\ kWh\ \times (\$0.001745 + \$0.12954)$$
$$= \$160.43$$

$$Monthly\ Charge = (Monthly\ Non - coincidental\ Peak\ \times Distribution\ Charge) + (Monthly\ Non - coincidental\ Peak\ \times Transmission\ Charge)$$
$$= 333\ kW\ \times \$16.64$$
$$= \$5{,}546.67$$

Under New B-DCFC Rate Structure:

$$Daily\ Charge = Daily\ kWh\ consumption\ \times (Energy\ Delivery\ Charge + Energy\ Cost)$$
$$= 1{,}222\ kWh\ \times (\$0.001745 + \$0.06580)$$
$$= \$160.43$$

$$Monthly\ Charge = (Monthly\ Non - coincidental\ Peak\ \times Distribution\ Charge) + (Monthly\ Coincidental\ Peak\ \times Transmission\ Charge)$$
$$= (333\ kW\ \times \$4.39) + (0\ kW \times \$19.35)$$
$$= \$1{,}463.33$$

As this estimate shows, the optional ‘B-DCFC’ rate structure would save Metro $7,051.10 per month at the depot location and $4,083.34 per month at the on-route charging location. These savings are, again, achieved by avoiding charging during the coincidental peak between 3 PM and 7 PM, and the reduced monthly ‘distribution’ charges under the “B-DCFC” rate structure. If the charging schedule were adjusted to charge during the coincidental peak, it could lead to an increase of up to $19,554.60 per month at the depot location and $6,443.55 at the on-route charging location from a ‘transmission charge’. Therefore, it is critical that Metro only charges the buses, whether using plug-in or overhead pantograph, outside the coincidental peak window between 3 PM and 7 PM or procures a smart charging management system which is programmed to avoid charging during the coincidental peak. Furthermore, it is also important that Metro monitors changes in Central Maine Power’s coincidental peak window and adjusts its charging schedule accordingly.

It should also be noted that the above charges are calculated based on a typical weekday load. Weekend and holiday calculation would follow a similar calculation for daily charges. The typical weekday and weekend/holiday charges are combined with monthly charges to calculate the annual utility cost for Metro's operation.

8. Asset Selection, Fleet Management and Transition Timeline

Section Summary

- Hatch recommends consolidating smaller orders into larger procurements to gain economies of scale
- Hatch recommends purchasing, rather than leasing, BEB batteries
- Hatch recommends installing a centralized charger at Elm St Pulse
- Hatch agrees with Metro's plan to coordinate fleet electrification with depot reconstruction

With operational and charging plans established, it was then possible to develop procurement timelines for infrastructure and vehicles to support those plans. Metro, like almost all transit agencies, acquires buses on a rolling schedule. This helps lower average fleet age, maintain stakeholder competency with procurements and new vehicles, and minimize scheduling risks. However, this also yields a high number of small orders. For any bus procurement – and especially for a newer technology like electric buses – there are advantages to larger orders, such as lower cost and more efficient vendor support. Metro is encouraged to seek opportunities to consolidate its fleet replacement into larger orders, either by merging orders in adjacent years or by teaming with other agencies in Maine that are ordering similar buses.

Another key decision to consider when developing a transition plan is battery ownership. Some BEB vendors, such as Proterra, offer bus battery leasing programs, where the agency can lease the battery for a twelve-year bus lifecycle instead of purchasing it. These programs allow the agency to lower up-front capital cost (as the batteries are a large portion of a BEB's purchase price). Proterra, for example, markets its leasing program as bringing the purchase cost of a BEB (roughly $1,000,000) down to be comparable with that of a diesel bus (approximately $550,000). Also, under the terms of the lease the vendor typically guarantees battery performance; if the battery degrades beyond a specified minimum level the vendor will replace it at no expense to the agency. This is particularly advantageous for especially demanding duty cycles, which are most likely to accelerate battery degradation and warrant midlife battery replacement.

These programs, however, have several disadvantages for agencies as well. First, in exchange for reduced capital cost a lease will require annual payments, increasing an agency's operating cost. The illustrative financial model Proterra provides, for instance, indicates a lease payment of $35,000 annually. As federal grants are typically easier to obtain for one-time capital spending than for yearly operating funds, this may increase agency funding needs in the long term, particularly if electricity or maintenance costs are higher than expected. Second, the terms of such leases usually require the agency to return the battery at the end of the 12-year lease. This means that Metro will be unable to operate the bus for the typical 14-year period, and will not be able to reuse the battery in any second-life applications. (Although second-life technology is in the early stages, given the large number of batteries being produced it is very likely that options for battery recycling or reuse for wayside storage capacity will soon become available.) Finally, the pricing models for most battery leases generally assume midlife replacement. Although the cost calculations in this report also assumed midlife replacement, with optimized battery usage it may be possible to use the initially provided battery for the full 14-year life. Some agencies have reported nearly no battery degradation after years of operation; as the electric bus market expands more data will become available on transit bus battery performance. In summary, battery leasing is an innovative funding strategy that gives agencies financial flexibility and lowers their exposure to risk. However, considering the operations cost implications and benefits of battery ownership, Hatch recommends that Metro avoid leases, instead purchasing its batteries outright.

With respect to infrastructure procurements, the maintenance facility will eventually need to have enough chargers to accommodate all of Metro's electric buses. Although the cost of one charger itself is more or less constant regardless of how many are being purchased, the additional costs such as utility feed upgrades, duct installation, structural modifications, and civil work make it economical to install all the support infrastructure at once. Metro's next order of electric buses can be accommodated by installing additional dispensers on the existing chargers; subsequent orders will arrive after Metro's depot is expected to be rebuilt. Hatch recommends that the depot be designed for a fully electric fleet, with dedicated space and power provision for all required chargers, with any support infrastructure for the remaining diesel/CNG fleet constructed in a temporary configuration for eventual removal.

To serve the charging requirements described in the previous section for the proposed electric fleet, expanding the already-installed centralized charging architecture is recommended for the maintenance facility. Centralized chargers will give Metro the most flexibility in its charging operation by providing a minimum of 50kW per vehicle but allowing for charging power of up to 150 kW when other dispensers on the same charger are not in use. Because each charger typically has three dispensers, Metro will require a minimum of nine additional chargers, plus four additional dispensers on the existing chargers (for a total of 33 dispensers) to ensure there is a dedicated dispenser for each of the 27 electric buses needed for peak service. A dedicated dispenser per vehicle allows overnight charging without requiring a staff member to move buses or plug in chargers overnight. This will also provide the recommended allowance of spare dispensers to accommodate dispenser cable failures, "hot standby" buses, vehicle maintenance, and possible future expansion. Table 5 provides a summary of the proposed vehicle and infrastructure procurement schedule. This schedule excludes the expected diesel vehicle procurement in 2025; those vehicles are accounted for during their following replacement cycle in 2039, when the fleet will become fully electrified.

Table 5 Proposed Fleet and Charging System Transition Schedule

Year	Buses Procured	Infrastructure Procured	Buses Replaced
2028	5 (5 450 kWh 35’)	4 additional dispensers on existing chargers	1401-5
2029			
2030			
2031		New depot; 9 new chargers with 27 dispensers, including transformers, switchgear, and utility feed Relocate existing transformer, chargers, dispensers	
2032	11 (11 450 kWh 40’)		1810-20
2033	6 (6 450 kWh 35’)		1921-6
2034	7 (7 450 kWh 35’)		2027-33
2035	2 (2 450 kWh 35’)		2134-5
2036	6 (6 450 kWh 35’)		2236-7, replacements for 1606-8, 1709
2037			
2038			
2039	7 (7 450 kWh 35’)		Replacements for 1101-7

Hatch recommends that Metro continue to operate its electric buses across all the routes, as it is doing now. This will help Metro continue to gain experience with electric bus operations and make any scheduling or routing adjustments that may be needed. Also, spreading electric buses out across the network will ensure that the benefits of electric vehicles (elimination of tailpipe emissions, reduced noise, etc.) are distributed equitably across the city. This may also prove valuable from a Title VI perspective, particularly as city demographics continue to change over the coming years. Rotating the electric vehicles across the routes will ensure that no area is disproportionately negatively impacted by Metro operations.

9. Building Spatial Capacity

Metro’s main storage and maintenance facility is located at 114 Valley Street in Portland, Maine. The current depot has space for 48 buses, with most vehicles housed in the storage area shown in Figure 5. The garage is currently equipped with two 150kW DCFC charging cabinets for the agency’s new Proterra buses. As shown in Figure 5, these are located along the eastern wall of the storage area. Though the present chargers ensure that the existing electric fleet can be properly charged and maintained, additional dispensers will need to be installed with upcoming bus orders. In addition, a dedicated back-shop area will need to be identified to maintain components related to electric drivetrains. If Metro’s plans change and the

Section Summary

- The 114 Valley St facility has sufficient space for required infrastructure and may undergo a proposed expansion.
- The Elm St Pulse is a feasible location for on-route charging.

existing facility needs to be retained for the long-term future, there should be sufficient space to accommodate these needs. The open, unobstructed design of the vehicle storage facility makes installation of overhead charging equipment comparatively simple (though a structural upgrade will likely be required), and shop space formerly used by RTP (which moved to its own facility in 2019) could be repurposed for BEB component storage and repair.

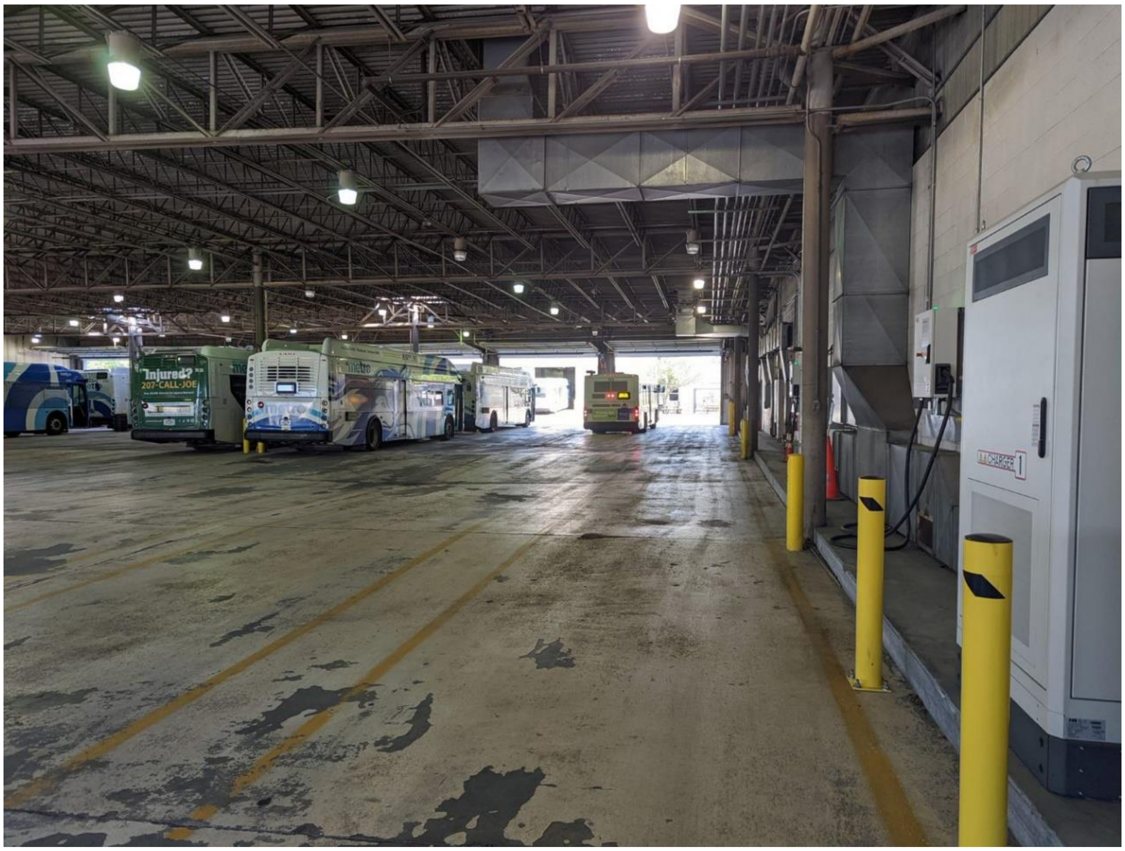

Figure 5 Existing DC Fast Chargers at 114 Valley St Facility

Metro is, however, in the process of designing a new facility that will replace the existing one. It is expected to occupy the same footprint as the existing facility, as well as the nearby parcel at 151 St John Street, and have space for up to 100 buses. Though this plan is in the very early stages, Metro expects to design the new facility specifically to serve BEBs, with diesel and CNG infrastructure provided on a temporary basis until the fleet is fully electrified. As a BEB-specific facility, it is expected to have sufficient space for all required chargers, dispensers, transformers, fire protection measures, and other items. Figure 6 shows the extents of the existing (in solid) and expanded (in dashed) property.

Figure 6 Existing and Proposed Footprint of Maintenance and Storage Facility

The Elm St Pulse, located at 21 Elm St in central Portland, is served by nearly all of Metro's routes. Downtown Portland is a regional transit hub, with service from Metro, BSOOB, RTP, and SPBS all converging at its center. As the primary transit hub and terminal for the greatest number of routes, the Elm St Pulse makes intuitive sense as a charging location. However, it has limited sidewalk space, as shown in Figure 7; discussions with other transit agencies and city and state governments would be needed to find land for, build, and operate a charging station. In addition, it may not remain the primary hub in the long term, as Metro is in discussions through the Transit Together study to potentially through-route more services across downtown Portland, or potentially have multiple new hubs. As shown in Figure 8, there is ample city-owned land available in downtown Portland, with other land owned by state or federal entities. As the city, state, and federal governments strongly support vehicle electrification, Metro is encouraged to consider partnering with government entities to find an optimal location for a future transit hub and potential on-route charging facility. As any such discussions are in the very early stages, this study assumed a charger at Elm St; spatial constraints at that site are discussed in Section 12.

Figure 7 Elm St Pulse (21 Elm St)

Figure 8 City-Owned Land near the Elm St Pulse in Downtown Portland (Source: City of Portland GIS)

10. Electrical, Infrastructure, and Utility Capacity

Section Summary

- The existing service at the garage can accommodate Metro’s next BEB order, but not subsequent orders
- Separately metered service at Elm St Pulse will let Metro take advantage of the DCFC specific utility rate structure in the future

Central Maine Power is the utility provider for Metro’s primary charging location at 114 Valley St. As part of its electrification efforts, Metro has been partnering with Central Maine Power to install the required electrical infrastructure.

As part of Metro’s initial deployment of electric vehicles, CMP installed a dedicated service to supply power to the new chargers. This is provided via a 12.47 kV high-voltage service that is stepped down to 480V through a 500 kVA on-site transformer, shown in Figure 9. This transformer can support one additional charger which, together with additional dispensers on the existing chargers, will be sufficient to support nine buses. However, the entire electric fleet will require a peak charging rate of 1.2 MW. As a result, when Metro procures its next set of new chargers in 2031, Hatch recommends that the transformer be upgraded as a part of the installation. This will allow the infrastructure to be fully installed and configured at one time without requiring expensive piecemeal upgrades as electrification advances. In addition, Metro plans to design its new depot for an eventual fleet size of 100 buses; Hatch recommends including provisions (such as spare conduits and transformer pads) to reduce the cost of future electrical infrastructure once the fleet expands beyond its current size.

Figure 9 Dedicated Transformer for BEB Chargers at 114 Valley St

The Elm St Pulse, on the other hand, does not yet have dedicated electrical infrastructure for vehicle charging, so installation of a separately metered service will likely be required. If the current location adjacent to the Elm St Parking Garage is maintained, this service could also potentially be used to install publicly accessible EV chargers in the garage. Coordination with city government, the utility, local stakeholders, and other transit agencies is recommended before determining a final location for the charger.

11. Risk Mitigation and Resiliency

Section Summary

- As with any new technology, electric bus introduction carries the potential for risks that must be managed
- Power outages have occurred rarely, but resiliency options must be considered
- Solar in conjunction with on-site energy storage system can be a viable option for resiliency, reducing GHG and offsetting electricity cost

Every new vehicle procurement brings about a certain degree of operational risk to the agency. Even when the existing fleet is being replaced 'in-kind' with new diesel and CNG buses, there are new technologies to contend with, potential build quality issues that must be uncovered, and maintenance best practices that can only be learned through experience with a particular vehicle. Bus electrification makes some failure modes impossible – for example by eliminating the diesel engine – but introduces others. For example, the ability to provide service becomes dependent on the continuous supply of electricity to the charging location. Although Metro has taken the key step of starting to operate electric vehicles, allowing the agency to get accustomed to BEB operation firsthand, as electrification continues in the coming years it will remain important to understand these risks and the best ways to mitigate them.

11a. Technological and Operational Risk

The vehicle and wayside technology required for electric bus operation is in its early stages; few operators have operated their electric fleets or charging assets through a complete lifecycle of procurement, operation, maintenance, and eventual replacement. As detailed in the earlier Transit Vehicle Electrification Best Practices Report, this exposes electric bus purchasers to several areas of uncertainty:

- Technological robustness: By their nature as newer technology, many electric vehicles and chargers have not had the chance to stand the test of time. Although many industry vendors have extensive experience with diesel and CNG buses, and new vehicles are required to undergo Altoona testing, some of the new designs will inevitably have shortcomings in reliability.
- Battery performance: The battery duty cycle required for electric buses – intensive, cyclical use in all weather conditions – is demanding, and its long-term implications on battery performance are still being studied. Though manufacturers have recommended general principles like battery conditioning, diesel heater installation, and preferring lower power charging to short bursts of high power, best practices in bus charging and battery maintenance will become clearer in coming years.
- Supply availability: Compared with other types of vehicles, electric buses are particularly vulnerable to supply disruptions due to the small number of vendors and worldwide competition for battery raw materials such as lithium. As society increasingly shifts to electricity for an ever-broader range of needs, from heating to transportation, both the demand and the supply will need to expand and adapt.
- Lack of industry standards: Although the market has begun moving toward standardization in recent years – for example through the adoption of a uniform bus charging interface – there are many areas (e.g. battery and depot fire safety) in which best practices have not yet been developed. This may mean that infrastructure installed early may need to be upgraded later to remain compliant.
- Reliance on wayside infrastructure: Unlike diesel buses, which can refuel at any publicly accessible fueling station, electric buses require DC fast chargers for overnight charging and specialized pantograph chargers for midday fast charging. Particularly early on, when there is not a widespread network of public fast chargers, this may pose an operating constraint in case of charger failure.
- Fire risk: The batteries on electric buses require special consideration from a fire risk perspective (see Section 12b).

All these risks are likely to be resolved as electric bus technology develops. Metro is in a good position in this regard, as it has already begun operating electric vehicles and can draw upon lessons learned as the electric fleet grows. Nevertheless, given Metro's leadership position in bus electrification it will be prudent for the agency to continue its transition to electric vehicles with an eye toward operating robustness in case of unexpected issues. Hatch recommends several strategies to continue maximizing robustness:

- With further BEB orders, continue requiring the electric bus vendor to have a technician on site or nearby in case of problems. This is most economical when the technician is shared with several nearby agencies.
- Reach a "mutual aid" agreement with another urban transit agency in Maine that would let Metro borrow spare buses in case of difficulties with its fleet.
- Retain a small diesel or CNG backup fleet to ensure they can substitute for electric buses if any incidents or weather conditions require it.
- Develop contingency plans in case the on-route charger fails and midday depot swapping is required.

11b. Electrical Resiliency

Electricity supply and energy resilience are important considerations for Metro when transitioning from diesel/CNG to electric bus fleets. As the revenue fleet continues to be electrified, the ability to provide service is dependent on access to reliable power. In the event of a power outage, there are three main options for providing resiliency:

- Battery storage
- Generators (diesel or CNG generators)
- Solar Arrays

Table 6 summarizes the advantages and disadvantages of on-site storage and on-site generation systems. The most ideal solution for Metro will need to be determined based on a cost benefit analysis.

Table 6 Comparison of the resiliency options

Resiliency Option	Pros	Cons
Battery Storage	Can serve as intermittent buffer for renewables. Cut utility cost through peak-shaving.	Short power supply in case of outages. Batteries degrade over time yielding less available storage as the system ages. Can get expensive for high storage capacity.
Generators	Can provide power for prolonged periods. Lower upfront cost.	GHG emitter. Maintenance and upkeep are required and can be costly.
Solar Arrays	Can provide power generation in the event of prolonged outages. Cut utility costs.	Cannot provide instantaneous power sufficient to support all operations. Constrained due to real-estate space and support structures. Requires Battery Storage for resiliency usage.

11.b.1. Existing Conditions

The 114 Valley St facility currently does not have resilient systems in place that would be able to support battery electric bus operations should there be an electrical service interruption. Metro has a generator that can accommodate low-power building loads (e.g. lighting) during an outage but is not suited for high-power bus charging. Similarly, the Elm St Pulse does not have any high-power generation capacity or other backup systems. This means that a prolonged power outage at both locations would deprive Metro of the ability to operate service as it continues transitioning to electric bus operations.

11.b.2. Outage Data and Resiliency Options

After noting no viable resiliency systems in place, Hatch assessed potential resiliency options. The first step in that assessment was to analyze the power outage data for the utility feeds that supply power to Metro's two main facilities to determine the requirements for backup power. Following is a summary of the outages at each of the locations in the last five years. Appendix C shows the outage data provided by Central Maine Power for reference.

+ 114 Valley St Bus Storage/Maintenance Facility – This facility has seen one outage in the last 5 years, which lasted for about 2 hours. Metro noted that because this facility is near two major medical complexes, power outages are rare and usually resolved quickly.
+ Elm St Pulse – This location had no recorded outages over the time period analyzed.

The resiliency system requirements are determined below based on the worst outage instance outlined above and the charging needs for the full fleet during this type of outage scenario. The on-site energy storage requirement to charge the fleet during that outage period would be 2.4 MWh. Assuming a 20% safety factor on top of the required energy, the size of the on-site energy storage system would need to be approximately 3 MWh. The power requirement for a generator was determined by the power draw of the number of chargers required to charge the peak service fleet. Assuming Metro purchases the centralized chargers with three dispensers each, as recommended in this report, 9 chargers would be required to charge the fleet. Assuming that all chargers Metro would purchase would be rated at a minimum 150kW, would have an efficiency of 90%, and a 20% spare capacity, the resulting on-site generation capacity required would be approximately 1.8 MVA.

Hatch next generated cost estimates associated with the two resiliency system options for the 114 Valley St facility. Table 7 summarizes the approximate project cost for implementing each option. Note that as these are conceptual proposals on which no decision has been made, these costs are not included in the life cycle costs in Section 14.

Table 7 Resiliency Options for Worst Case Outage Scenarios

	Size	Capital Cost
Option 1 On-site Battery Storage	3 MWh	$1.9 M
Option 2 On-site Diesel Generation	1.8 MVA	$1.1 M

The above analysis and corresponding options are based on the historic outage data, and an assumption that service is not reduced as a result of the outage. This assumption is targeted towards short-term, localized outages of the type that would cut off electricity from the 114 Valley St facility but leave the remainder of the city unaffected. These outages are typically too short to implement robust contingency plans, such as extended vehicle charging at Elm St, use of a public fast charger, or implementation of service changes. For long-term localized outages, preparing a contingency plan that incorporates one or more of these measures is recommended. For larger-scale outages that affect a broader swathe of the city, both the available resiliency options and the expected agency performance differ; a greater emphasis will be placed on providing limited service along key corridors, with remaining resources used for emergency transportation, providing buses as warming shelters during winter months, etc. In some cases, Metro's electric buses may also be requested for use as portable batteries to provide power to key buildings.

Since outages like these occur very rarely, the above resiliency options may be oversized for most use cases resulting in a poor return on the capital investments. As the utility industry evolves over the course of Metro's electrification transition, the agency will have to choose an appropriate level of resiliency investment based on historical and anticipated needs.

11.b.3. Solar Power

In addition to the above two options for backup power, on-site solar generation should also be considered to add resiliency, offset the energy cost, and further reduce Metro's GHG impact by utilizing clean energy produced on-site. As mentioned previously, however, solar does not reliably provide enough instantaneous power to provide full operational resilience. The on-site solar production can provide backup power in some specific scenarios, but a battery storage system is necessary for solar to be considered part of a resiliency system. The function of a solar arrays would primarily be to offset energy from the grid and reduce utility costs.

An on-site solar system was evaluated for the 114 Valley St facility because the roof of the future facility is expected to provide a large surface area that could be utilized for a solar array. Although a layout for the new facility has not yet been determined, Metro's current plans call for a building with an approximate roof area of 128,000 square feet. The solar array would likely be installed on racks mounted directly to the facility roof. Given the large available roof footprint, expansion of the solar panels onto an elevated structure above outdoor parking and maneuvering areas is likely uneconomical and is not recommended. Table 8 outlines parameters for the solar power system that could be installed on the future facility roof, as well as the expected annual energy production and resulting cost savings from offsetting energy consumed from the grid.

Table 8 114 Valley St Facility Future Available Roof

Solar System Design Parameters	
Solar System Sizing Method:	Available Area
Solar Array Area Width	357 ft
Solar Array Area Length	358 ft
Solar Array Area	127,806 ft^2
Maximum Number of Panels	5,751 panels
Maximum System Power	2,444 kW
Annual Production Coefficient	1,338 hours
Sunny Days Per Year	200 days
Annual Solar Energy Production	3,270,460 kWh
Annual Electric Usage	2,987,086 kWh
Maximum Percent of Electrical Usage Offset	109%
Electricity Rate	$0.12954 / kwh
System Cost	**$6,732,592**
Utility Bill Savings Per Year	**$423,655**
Simple Payback Period Without Grants	**15.9 years**
Payback Period with 80% Federal Grants	**3.2 years**

Based on the above parameters, the maximum daily production for sunny days is estimated to be approximately 16.3 MWh. Since the energy requirement for charging during the 2-hour outage scenario is estimated to be 2.4 MWh, solar has the potential to provide enough energy to support the operation in the event of an outages on a sunny day. The solar system can harvest enough energy for Portland Metro's needs throughout a full year, though this is likely an oversimplification because power outages tend to be most frequent, and bus energy consumption tends to be highest, during winter months when less sunlight is available. Therefore, solar power generation is not recommended as a primary resiliency system.

An on-site battery storage system could complement solar as it would allow for storing of energy produced during the daytime for use during overnight charging. This would not only result in cost savings from the grid energy offset, but it would also result in savings due to a smaller utility feed requirement and lower non-coincidental peak for the site. In addition, having on-site solar energy production can help further reduce Metro's GHG contribution by reducing the grid energy that is partially produced using the GHG emitting conventional energy sources.

If solar is considered for the site, the on-site storage system should be sized according to the full solar production rather than to only support outage scenarios. A more detailed study should be conducted to determine the battery energy requirements, which are likely to be more than 2.4 MWh based on the above solar estimates.

12. Conceptual Infrastructure Design

12a. Conceptual Layouts

To assist Metro with visualizing the required infrastructure transition, conceptual plans were next developed based on the previous information established in this report. As outlined previously, Hatch recommends that further overnight charging infrastructure be installed be installed in the 114 Valley St facility, and on-route charging should be installed at the Elm St Pulse. As this is the property of the city of Portland rather than Metro, municipal approval would be required.

Section Summary

- Hatch recommends installing centralized chargers with roof-mounted dispensers in the 114 Valley St facility, and one layover charger at the Elm St Pulse transit hub
- The new depot at 114 Valley St should be designed from the ground up for BEB operation

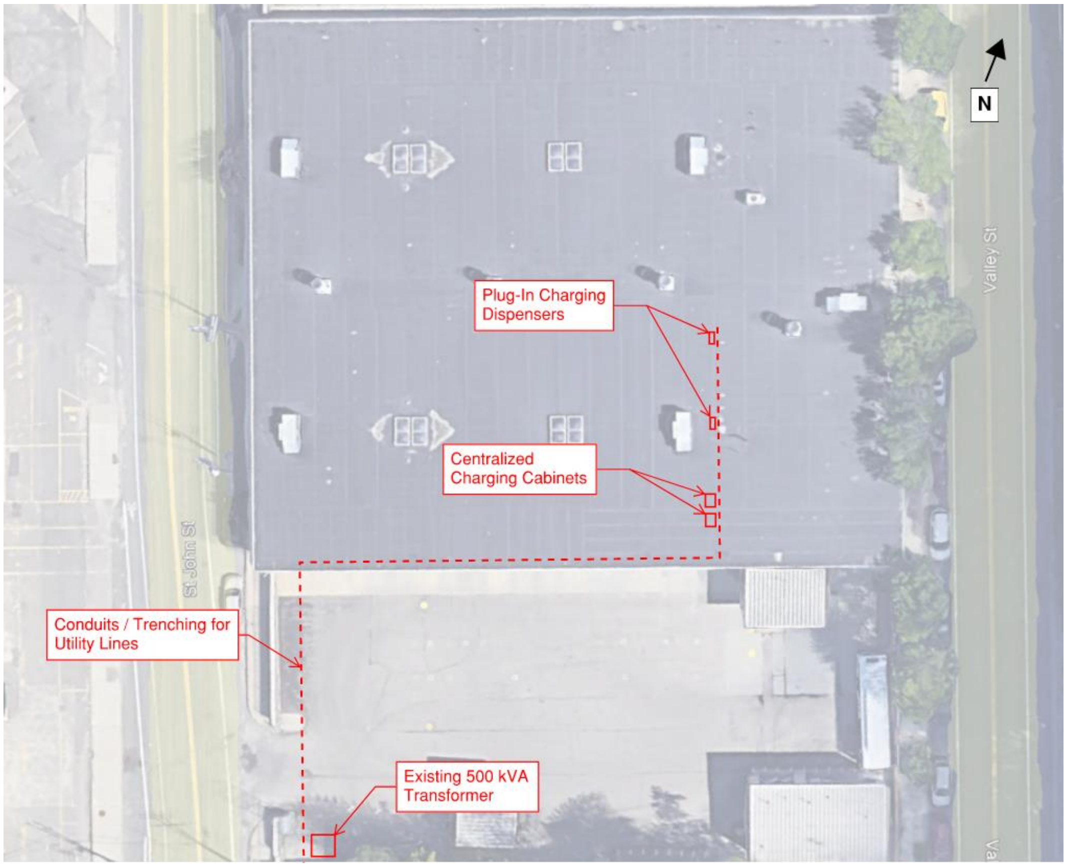

Figure 10 Existing Charging Infrastructure at 114 Valley St

As previously mentioned, at 114 Valley St there are already two existing centralized charging cabinets with one dispenser each; the dispensers are mounted on a wall inside the facility as shown in Figure 10. There is sufficient space to install two additional dispensers along the same wall; to avoid draping charging cables across bus movement paths a fifth and sixth dispenser (to fully utilize the capacity of the existing chargers) would likely need to be suspended from the ceiling. For future charger installations, either at the existing or a new building, there are two primary installation options for the dispensers:

+ Roof-mounted
+ Island-mounted

Each approach has advantages and disadvantages. Roof-mounted dispensers are best for saving space in the depot, as buses can operate around the storage area unencumbered. If pantograph-style dispensers are selected, then the storage capacity of the depot is expected to remain unchanged; the only loss of capacity will result from berths where consistently precise bus positioning is difficult, such as in depot corners or behind building columns. Roof-mounted plug-in dispensers are similarly efficient; although they allow more flexibility for slightly mis-aligned buses, they require marginally wider aisles between buses to provide clearance for the charging cables to hang between buses. The primary disadvantage of roof-mounted dispensers is maintenance, as they are only accessible via a portable lift unless dedicated catwalks are provided. They may also increase building structure cost by increasing the weight of equipment suspended from the roof. Island-mounted dispensers are simpler in both of these regards – they do not require any roof reinforcement and can be readily maintained from ground level. However, their presence on the depot floor reduces space available for bus operation, sometimes by as much as 25%, and introduces “lanes” that make it difficult to maneuver around a stalled bus.

At the Elm St Pulse, the most intuitive location for a pantograph charger is curbside, at the current area used for bus layover and boarding. This is a constrained site, with a sidewalk width of approximately 10 feet, but if aligned roughly parallel to the existing streetlights the pantograph should be able to fit. The road is also sloped gently downward from Congress St to Cumberland Ave; during detailed engineering the slope should be confirmed to not exceed 5 degrees, which is the recommended maximum for typical pantograph chargers. There are also limited spaces nearby for the pantograph charger’s associated cabinets, which are recommended to be no further than 500 feet from the pantograph. In addition to simple geometric compatibility there are several other constraints to consider when placing the pantograph charger; these include bus maneuverability, nearby underground utilities, sight lines around parked buses, snow clearance, and security. Figure 11 below shows a charger location that would probably best accommodate these constraints.

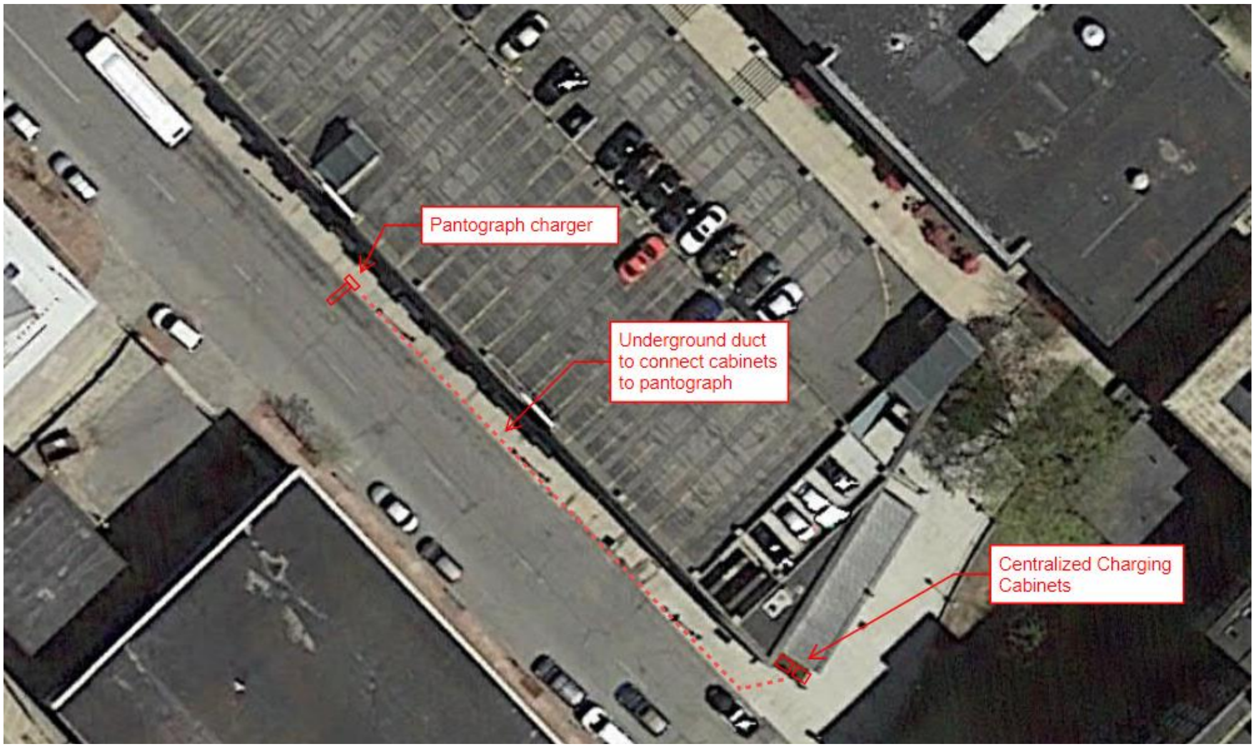

Figure 11 Elm St Pulse On-Route Charger Layout Option

12b. Fire Mitigation

An electric bus's battery is a dense assembly of chemical energy. If this large supply of energy begins reacting outside of its intended circuitry, for example due to faulty wiring or defective or damaged components, the battery can start rapidly expelling heat and flammable gas, causing a "thermal runaway" fire. Given their abundant fuel supply, battery fires are notoriously difficult to put out and can even reignite after they are extinguished. Furthermore, without prompt fire mitigation the dispersed heat and gas will likely spread to whatever is located near the bus. If this is another electric bus then a chain reaction can occur, with the heat emanating from one bus overheating (and likely igniting) the batteries of another bus. This can endanger all the buses in the overnight storage area.

For the aforementioned risks that battery electric vehicle operations introduce, mitigations are recommended. On the vehicles themselves, increasingly sophisticated battery management systems are being developed, ensuring that warning signs of battery fires – such as high temperature, swelling, and impact and vibration damage – are quickly caught and addressed. Though research is ongoing, most battery producers believe that with proper manufacturing quality assurance and operational monitoring the risk of a battery fire can be minimized.

The infrastructure best practices for preventing fire spread with electric vehicles are still being developed. Because Metro has a comparatively large fleet and plans to charge it entirely indoors, it is critical that Metro monitor any development of standards for fire suppression and mitigation of facilities housing battery electric vehicles (which currently do not exist). There are partially relevant standards for the storage of high-capacity batteries indoors for backup power systems, such as UL9540, NFPA 70, and NFPA 230, and the primary components of any fire mitigation strategy are well understood. These include detectors for immediate discovery of a fire, sprinklers to extinguish it as much as possible, and barriers to prevent it from spreading to other buses or the building structure. In terms of staffing, it is recommended that staff be located nearby to respond in case of a fire and move unaffected buses out of harm's way. Each of these requires specific consideration with respect to Metro's operations. Hatch recommends that Metro commission a fire safety study as part of detailed design work for the new depot to consider these factors.

13. Policy Considerations and Resource Analysis

Section Summary

- A wide range of funding sources is available to Metro to help fund electrification
- State and local support will be required as well

In 2021, Metro's operating budget was roughly $12.8 million per year. The agency's funding sources are summarized in Figure 12. As can be seen in the figure, Metro's largest source of funding comes from federal assistance. For bus, facility, and infrastructure costs the agency's primary federal funding comes from the Urbanized Area Formula Funding program (49 U.S.C. 5307), and the Buses and Bus Facilities Competitive Program (49 U.S.C. 5339(b)) through the FTA.

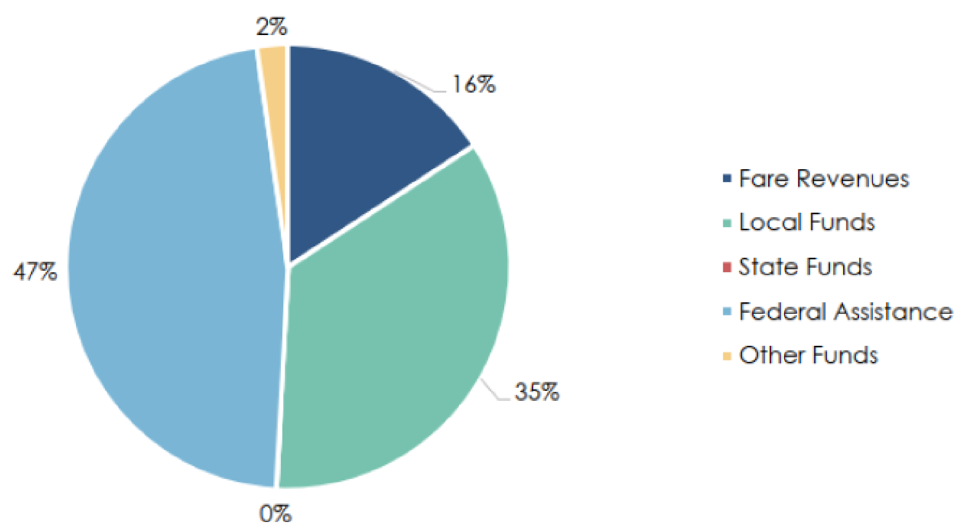

Figure 12 Current Agency Funding Summary (Source: Maine DOT)

As the agency transitions to battery electric technology, additional policies and resources will become applicable to Metro. Table 9 provides a summary of current policies, resources and legislation that are relevant to Metro's fleet electrification transition.

Despite the large number of potential funding opportunities available to transit agencies seeking to transition to battery electric technologies, these programs are competitive and do not provide Metro with guaranteed funding sources. Therefore, this analysis assumes that Metro will only receive funding through the largest grant programs that provide the highest likelihood of issuance to the agency. Specifically, this analysis assumed that Metro will receive 80% of the capital required to complete the bus, charging system, and supporting infrastructure procurements outlined in this transition plan through the following major grant programs:

- Urbanized Area Formula Funding (49 U.S.C. 5307),
- Low or No Emission Grant Program (FTA 5339 (c)
- Buses and Bus Facilities Competitive Program (49 U.S.C. 5339(b))

It is assumed that all other funding required to complete this transition will need to be provided through state or local funds.

Table 9 Policy and Resources Available to Metro

Policy	Details	Relevance to Agency Transition
The U.S. Department of Transportation's Public Transportation Innovation Program	Financial assistance is available to local, state, and federal government entities; public transportation providers; private and non-profit organizations; and higher education institutions for research, demonstration, and deployment projects involving low or zero emission public transportation vehicles. Eligible vehicles must be designated for public transportation use and significantly reduce energy consumption or harmful emissions compared to a comparable standard or low emission vehicle.	Can be used to fund electric bus deployments and research projects. (*Competitive funding)
The U.S. Department of Transportation's Low or No Emission Grant Program	Financial assistance is available to local and state government entities for the purchase or lease of low-emission or zero-emission transit buses, in addition to the acquisition, construction, or lease of supporting facilities. Eligible vehicles must be designated for public transportation use and significantly reduce energy consumption or harmful emissions compared to a comparable standard or low emission vehicle.	Can be used for the procurement of electric buses and infrastructure (*Competitive funding)
The U.S. Department of Transportation's Urbanized Area Formula Grants - 5307	The Urbanized Area Formula Funding program (49 U.S.C. 5307) makes federal resources available to urbanized areas and to governors for transit capital and operating assistance in urbanized areas and for transportation-related planning. An urbanized area is an incorporated area with a population of 50,000 or more that is designated as such by the U.S. Department of Commerce, Bureau of the Census.	This is one of the primary grant sources currently used by transit agencies to procure buses and to build/renovate facilities. (*Competitive funding)
The U.S. Department of Transportation's Grants for Buses and Bus Facilities Competitive Program (49 U.S.C. 5339(b))	This grant makes federal resources available to states and direct recipients to replace, rehabilitate and purchase buses and related equipment and to construct bus-related facilities, including technological changes or innovations to modify low or no emission vehicles or facilities. Funding is provided through formula allocations and competitive grants.	This is one of the primary grant sources currently used by transit agencies to procure buses and to build/renovate facilities. (*Competitive funding)

Policy	Details	Relevance to Agency Transition
The U.S. Department of Energy (DOE) Title Battery Recycling and Second-Life Applications Grant Program	DOE will issue grants for research, development, and demonstration of electric vehicle (EV) battery recycling and second use application projects in the United States. Eligible activities will include second-life applications for EV batteries, and technologies and processes for final recycling and disposal of EV batteries.	Could be used to fund the conversion of electric bus batteries at end of life as on-site energy storage. (*Competitive funding)
Maine Renewable Energy Development Program	The Renewable Energy Development Program must remove obstacles to and promote development of renewable energy resources, including the development of battery energy storage systems. Programs also available to provide kWh credits for solar and storage systems.	Can be used to offset costs of solar and battery storage systems. (*Non-Competitive funding)
Energy Storage System Research, Development, and Deployment Program	The U.S. Department of Energy (DOE) must establish an Energy Storage System Research, Development, and Deployment Program. The initial program focus is to further the research, development, and deployment of short- and long-duration large-scale energy storage systems, including, but not limited to, distributed energy storage technologies and transportation energy storage technologies.	Can be used to fund energy storage systems for the agency. (*Competitive funding)
The U.S. Economic Development Administration's Innovative Workforce Development Grant	The U.S. Economic Development Administration's (EDA) STEM Talent Challenge aims to build science, technology, engineering and mathematics (STEM) talent training systems to strengthen regional innovation economies through projects that use work-based learning models to expand regional STEM-capable workforce capacity and build the workforce of tomorrow. This program offers competitive grants to organizations that create and implement STEM talent development strategies to support opportunities in high-growth potential sectors in the United States.	Can be used to fund EV training programs. (*Competitive funding)
Congestion Mitigation and Air Quality Improvement (CMAQ) Program	The U.S. Department of Transportation Federal Highway Administration’s CMAQ Program provides funding to state departments of transportation, local governments, and transit agencies for projects and programs that help meet the requirements of the Clean Air Act by reducing mobile source emissions and regional congestion on transportation networks. Eligible activities for alternative fuel infrastructure and research include battery technologies for vehicles.	Can be used to fund capital requirements for the transition. (*Competitive funding)

Policy	Details	Relevance to Agency Transition
Hazardous Materials Regulations	The U.S. Department of Transportation (DOT) regulates safe handling, transportation, and packaging of hazardous materials, including lithium batteries and cells. DOT may impose fines for violations, including air or ground transportation of lithium batteries that have not been tested or protected against short circuit; offering lithium or lead-acid batteries in unauthorized or misclassified packages; or failing to prepare batteries to prevent damage in transit. Lithium-metal cells and batteries are forbidden for transport aboard passenger-carrying aircraft.	Should be cited as a requirement in procurement specifications.
Maine Clean Energy and Sustainability Accelerator	Efficiency Maine administers the Maine Clean Energy and Sustainability Accelerator to provide loans for qualified alternative fuel vehicle (AFV) projects, including the purchase of plug-in electric vehicles, fuel cell electric vehicles, zero emission vehicles (ZEVs), and associated vehicle charging and fueling infrastructure.	Can be used to fund vehicle and infrastructure procurements. (*Competitive funding)
Maine DOT VW Environmental Mitigation Trust	The Maine Department of Transportation (Maine DOT) is accepting applications for funding of heavy-duty on-road new diesel or alternative fuel repowers and replacements, as well as off-road all-electric repowers and replacements. Both government and non-government entities are eligible for funding.	Can be used to fund vehicle procurements (*Competitive funding)
Efficiency Maine Electric Vehicle Initiatives	Efficiency Maine offers a rebate of $350 to government and non-profit entities for the purchase of Level 2 EVSE. Applicants are awarded one rebate per port and may receive a maximum of two rebates. EVSE along specific roads and at locations that will likely experience frequent use will be prioritized.	Can be used to subsidize charger purchases. (*Formula funding)
Efficiency Maine Electric Vehicle Accelerator	Efficiency Maine's Electric Vehicle Accelerator provides rebates to Maine residents, businesses, government entities, and tribal governments for the purchase or lease of a new PEV or plug-in hybrid electric vehicle (PHEV) at participating Maine dealerships.	Can be used to subsidize vehicle procurements. (*Formula funding)

14. Cost Analysis

Hatch calculated the life cycle cost (LCC) of the proposed transition strategy and compared it to maintaining Metro's current diesel and CNG operations as a baseline, using a net present value (NPV) model. This allows all costs incurred throughout the fleet transition to be considered in terms of today's dollars. The costs, which are based on the weekday service levels analyzed above and scaled to account for weekends and holidays, include initial capital as well as operations and maintenance costs of the vehicles and supporting infrastructure for diesel/CNG and battery electric buses. Table 10 outlines the LCC model components, organized by basic cost elements, for diesel/CNG and battery electric bus technologies.

Section Summary

- Bus electrification will save Metro money over the long term, as electric vehicles cost less to maintain and fuel
- Upfront capital costs increase by approximately 37% and annual operating cost will decrease by approximately 10%, yielding a net 3% savings in total cost of ownership

Table 10: Life Cycle Cost Model Components

Category	Diesel/CNG (Base case)	Battery-Electric Buses
Capital	Purchase of the vehicles	Purchase of the vehicles
	Mid-life overhaul	Mid-life overhaul
		Battery replacement (or lease payments, if battery leasing is selected)
		EV charging Infrastructure
		Electrical infrastructure upgrades
		Utility feed upgrades
Operations	Diesel/CNG Fuel	Electricity
	Operator's Cost	Operator's Cost
		Demand charges for electricity
		Diesel Fuel for Auxiliary Heaters
Maintenance	Vehicle maintenance costs	Vehicle maintenance costs
		Charging infrastructure maintenance costs
Financial Incentives	Grants	Grants

Like any complex system, Metro has a range of ways it can fund, procure, operate, maintain, and dispose of its assets. In coordination with agency stakeholders, Hatch developed the following assumptions to ensure that the cost model reflected real-world practices:

Capital Investment

- The lifespan of a bus is 14 years, in accordance with Metro practice.
- Buses are overhauled at midlife. This is recommended for electric buses as the lifespan of a battery is approximately 6-7 years.

- Buses are replaced with buses of the same length, at their expected retirement year.
- Metro purchases the batteries on its electric buses, rather than leasing them.
- The cost of the depot construction is not included as it is independent of electrification.

Funding

- Federal grants cover 80% of the procurement cost for buses (of all types) as well as charging infrastructure.

Costs

- The proposed DCFC utility rate is implemented
- Discount rate (hurdle rate) of 7%
- Inflation rate of 3%

Table 11 lists the operating and capital costs that Hatch assumed for this study. These are based on Metro's figures and general industry trends and have been escalated to 2022 dollars where necessary.

Table 11 Cost Assumptions

Asset	Estimated Cost Per Unit (2022 $'s)
35' Diesel Transit Bus	$546,000
35' CNG Transit Bus	$595,000
35' Battery Electric Transit Bus (450 kWh)	$1,009,000
40' Diesel Transit Bus	$551,000
40' CNG Transit Bus	$600,000
40' Battery Electric Transit Bus (450 kWh)	$1,050,000
DC Fast Charger – Plug-in Garage (de-centralized unit and 3 dispensers)	$270,000
DC Fast Charger – Pantograph Overhead	$630,000

Expense	Estimated Cost (2022 $'s)
Diesel/CNG bus maintenance	$1.53 / mile
Electric bus maintenance	$1.15 / mile
Operator salary, benefits, overhead	$36.46 / hour
Diesel fuel	$3.00 / gallon
CNG	$2.04 / gallon

Because the electrification transition process will be gradual, life cycle cost calculations would necessarily overlap multiple bus procurement periods. Hatch addressed this issue by setting the start of the analysis period to be the year when the last diesel/CNG bus is proposed to be retired (2039), with the analysis period stretching for a full 14-year bus lifespan. For buses at midlife at the end of the analysis period, a remaining value was calculated and applied at the end of the time window.

The LCC analysis determines the relative cost difference between the baseline (diesel/CNG) case and the proposed case. Therefore, it only includes costs which are expected to be different between the two options. Costs common to both alternatives, such as bus stop maintenance, are not included as they do not have a net effect on the LCC comparison. Thus, the model indicates the most economical option but does not represent the full or true cost for either technology. Table 12 and Figure 13 summarize the NPV for both technologies by cost category.

Table 12: Net Present Value Summary

Category	Diesel/CNG Baseline	Future Fleet	Cost Differential (Future Fleet vs. Baseline)
Vehicle Capital Costs	$6,678,290	$8,686,047	+37%
Infrastructure Capital Costs	$0	$465,768	
Vehicle Maintenance Costs	$12,532,630	$9,441,949	-10%
Infrastructure Maintenance Costs	$0	$107,791	
Operational Cost	$26,293,288	$25,578,408	
Total Life Cycle Cost	**$45,504,207**	**$44,279,962**	-3%

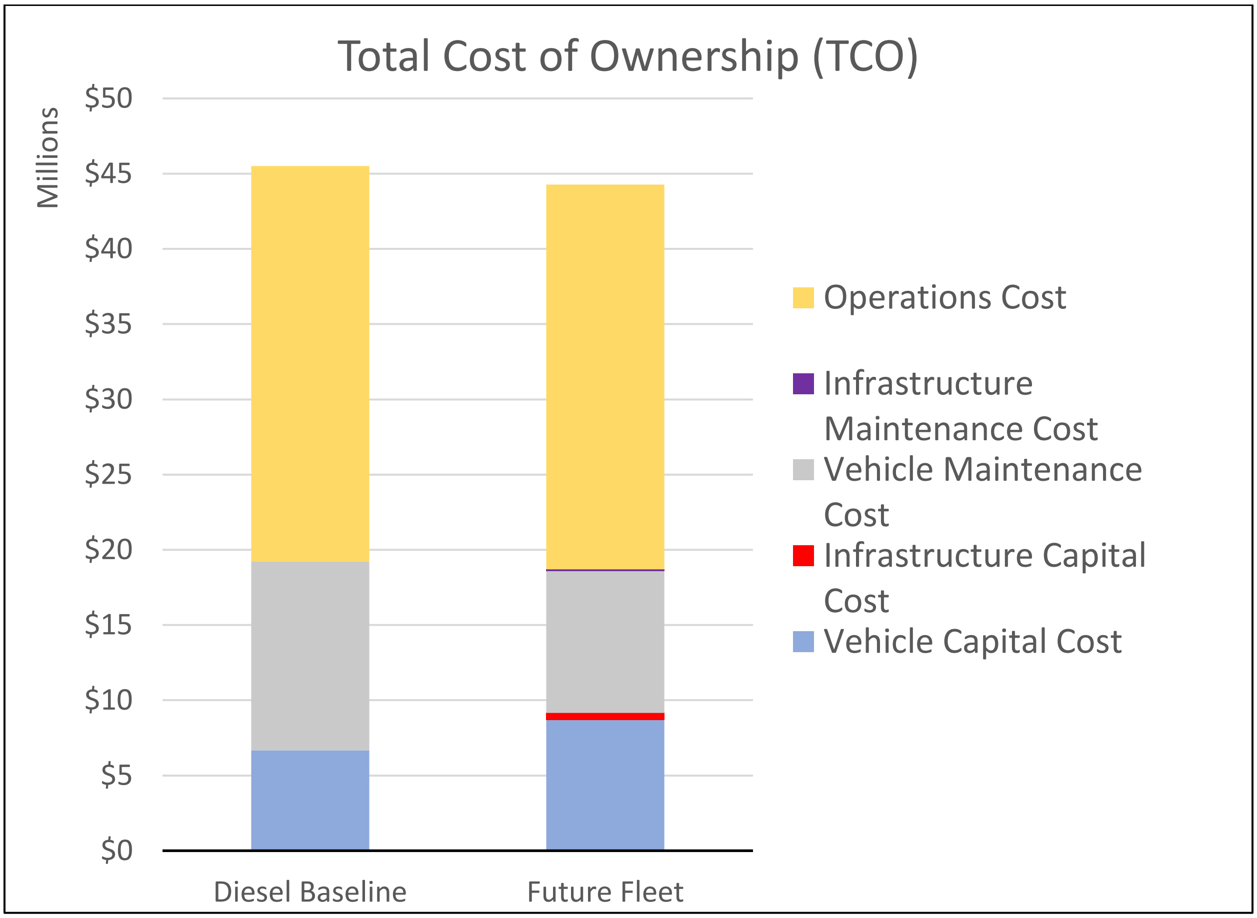

Figure 13 Life Cycle Cost Comparison

As shown in Figure 13, bus electrification reduces total system cost at the expense of increasing initial capital cost. Although there is some expense related to the charging equipment at the 114 Valley St facility and Elm St Pulse, the bulk of the extra capital spending is on the vehicles themselves, as electric buses are much simpler mechanically than diesel or CNG buses but command a cost premium due to their large battery systems. This yields a 37% increase in capital costs over the diesel/CNG baseline. This initial, non-recurring cost is balanced out by the maintenance and operating savings over the lifetime of the vehicles. Because electric vehicles have fewer components to maintain and are cheaper to refuel than diesels and CNG vehicles, the maintenance and operating costs of the proposed fleet are 10% lower than of the diesel/CNG baseline. However, these costs recur daily – worn parts must be replaced and empty fuel tanks must be refilled throughout the lifetime of the vehicle. This means that over the long term the operations and maintenance savings outweigh the initial extra capital spending, yielding a net-present-value savings of approximately 3%.

The proposed fleet transition requires initial capital spending to reduce life cycle cost and achieve other strategic goals. This finding is common to many transit projects and is representative of the transit industry as a whole, with nearly all bus and rail systems requiring capital investments up front to save money in other areas (traffic congestion, air pollution, etc.) and achieve broader societal benefits over the long term. By extension, just as with the transit industry at large, policy and financial commitment will be required from government leaders to achieve the desired benefits. The federal government's contribution to these goals via FTA and Low-No grants is already accounted for, leaving state and local leaders to cover the remaining 37% increase in upfront capital cost.

The electric bus market is a fairly new and developing space, with rapid advancements in technology. Although Hatch has used the best information available to date to analyze the alternatives and recommend a path forward, it will be important in the coming years for Metro to review the assumptions underlying this report to ensure that they have not changed significantly. Major changes in capital costs, fuel costs, labor costs, routes, schedules, or other operating practices may make it prudent for Metro to modify vehicle procurement schedules or quantities, tweak operating schedules, or otherwise revise this report's assumed end state.

Full details on the LCC model are provided as Appendix D.

14a. Joint Procurements

The cost figures presented above assume that Metro independently procures its vehicles and infrastructure, instead of coordinating with other agencies and the state DOT to form a joint procurement. Shifting to a joint procurement strategy, in particular through the adoption of a state purchasing contract, has the potential to save money for Metro.

State purchasing contracts offer financial savings for several reasons. First, the overhead expenses associated with an order – specification development, vendor negotiation, training, and post-acceptance technical support – can be divided across several agencies. Second, the number of orders required by each agency can also be reduced. State purchasing contracts typically have a duration of five years, allowing a large portion of the agency's fleet to be replaced in one lifecycle. For example, in accordance with the procurement schedule in Table 5, Metro expects to place seven vehicle orders over the next 16 years. With five-year purchasing contracts, this number can be reduced to three, saving on many of the same per-order expenses outlined previously. These two factors are estimated to reduce Metro's cost per bus by approximately 4%, or $40,000, for a typical BEB. Third, the increase in total order size is likely to reduce cost per vehicle as well. Like agencies, BEB vendors incur some of their costs (business development, contract negotiation, customization setup) on a per-order basis; therefore, they typically decrease the price of each bus as order size grows. Furthermore, a larger order is likely to attract additional vendors (who would be unwilling to participate in a small procurement); this is expected to drive down cost as well. In addition, technical support for the new vehicles will be more economical if it can be divided among several vehicles, or even several nearby agencies, as the expense of having an on-site vendor technician is roughly constant regardless of the size of the BEB fleet. Recent BEB orders across the US show that, on average, for each additional bus in an order the per-bus cost decreases by 0.63%. In other words, combining five two-bus orders into one ten-bus order would reduce purchase cost by 5%, or $500,000, due to order size alone.

Metro plans to order 44 buses over the next 16 years and these orders can easily be allocated to purchasing contracts. The 2028 order for 35' buses can be part of a 23-vehicle order purchased together with Bangor CC, BSOOB, and South Portland Bus Service (SPBS); the 2032 and 2033 order for 35' and 40' buses can be part of a 33-vehicle order purchased together with Bangor CC and Citylink; and the 2034, 2035, 2036, and 2038 order for 35' buses can be part of a 49-vehicle order purchased together with Bangor CC, BSOOB, Citylink, and SPBS.

In summary, although this analysis assumed that Metro acts independently in placing its orders, the agency is encouraged to explore opportunities for joint procurements with other agencies. This will potentially save the agency money through reduced administrative expenses, increased vendor competition, and efficiencies with post-procurement technical support. Overall, this strategy will produce a 25% cost saving for the agency.

15. Emissions Impacts

One of the motivations behind Metro's transition towards battery electric buses is the State of Maine's goals to reduce emissions. While specific targets for public transportation have not been established, the state goal to achieve a 45% overall emissions reduction by 2030 was considered as a target by Metro.

Hatch calculated the anticipated emissions reductions from Metro's transition plan to quantify the plan's contribution toward meeting the state's emissions reduction goals. To provide a complete view of the reduction in emissions offered by the transition plan, the effects were analyzed based on three criteria:

Section Summary

- Bus electrification will be critical to helping meet State emission goals
- Forecasted grid conversion to clean energy will maximize the benefit of bus electrification
- The transition is expected to reduce emissions by 78-87%

- Tank-to-wheel
- Well-to-tank
- Grid

The tank-to-wheel emissions impact considers the emissions reduction in the communities, where the buses are operated. As a tank-to-wheel baseline, the ‘tailpipe’ emissions associated with Metro’s existing diesel and CNG fleet were calculated. These calculations used Metro emissions averages for diesel and CNG buses and assumed an average fuel economy of 5.3 miles per gallon of diesel and 4.4 miles per gallon of CNG.

Battery electric bus propulsion systems do not create emissions, and therefore there are no ‘tailpipe’ emissions. As explained in Section 6, this transition plan does, however, assume that diesel heaters will be used on the battery electric buses during the winter months. Therefore, the emissions associated with diesel heaters are included in the tank-to-wheel estimates for battery electric buses.

Well-to-tank emissions are those associated with energy production. For diesel and CNG vehicles well-to-tank emissions are due to fuel production, processing, and delivery. This emissions estimate used industry averages for the well-to-wheel emissions associated with the delivery of diesel/CNG fuel to Metro. For battery electric vehicles, well-to-tank emissions are due to the production, processing, and delivery of diesel fuel for the heaters.

Battery electric vehicles have a third emissions source: grid electricity generation. The local utility, Central Maine Power, was not able to provide specific details on the emissions associated with its electricity production as part of this project. Therefore, the emissions calculations assumed an EPA and EIA average grid mix for Maine. Similar to the state’s overall goals to reduce emissions, the state has also set the goal of reducing grid emissions by roughly 67% by 2030 by transitioning to more renewable energy production. To account for these future grid emissions reduction goals, calculations were completed based on the most recent actual data available (2020), as well as projections that assume that the 2030 targets are met. Table 13 and Figure 14 summarize the results of the emissions calculations. These results demonstrate that the transition plan will achieve 78% emissions reduction assuming the grid mix that existed in 2020, or 87% emissions reduction assuming that Central Maine Power is able to meet the state’s goals to reduce grid emissions by the year 2030. In either case, Metro’s transition plan will achieve a reduction in emissions in excess of the 45% goal established by the State of Maine.

Table 13 CO_2 Emissions Estimate Results

Scenario	Well-to-Tank (kg)	Tank-to-Wheel (kg)	Grid (kg)	Total (kg)	Reduction over Baseline
Diesel/CNG Baseline	1,604,926	2,591,298	---	4,196,224	----------
Future Fleet (Assuming 2020 grid mix)	119,276	205,290	611,034	935,600	78%
Future Fleet (Assuming 2030 grid mix)	119,276	205,290	201,641	526,207	87%

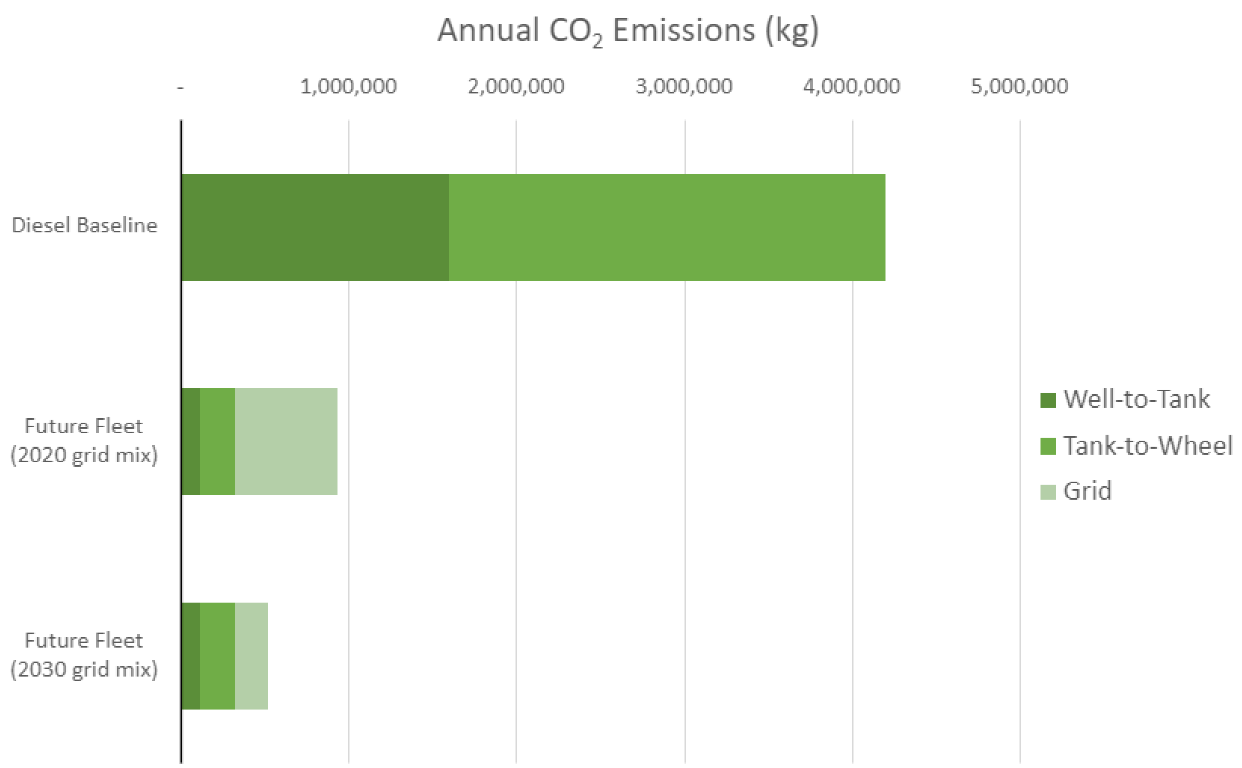

Figure 14 Graph of CO_2 Emissions Estimate Results

Should Metro seek to achieve greater emissions reductions than those calculated here, the agency may consider the following options:

+ Purchase green energy agreements through energy retailers to reduce or eliminate the emissions associated with grid production.
+ Install solar panels on the roof of the new facility as detailed in Section 11b.
+ Use spare buses as mobile peak-shaving batteries (allowing them to feed the grid during periods of high demand) to reduce grid emissions and potentially generate revenue

16. Workforce Assessment

Section Summary

- Once the initial training is completed and staff turnover occurs over time, maintaining employees' skills in BEB operations and maintenance will be critical to BEB success
- Hatch recommends partnering with local colleges and other transit agencies to share skills

As part of its first procurement of electric buses, Metro staff received training and special tools for operating, charging, and maintaining BEBs. Ensuring that this knowledge remains with the agency despite future staff turnover will be key to successful fleet electrification. Because electric vehicle maintenance is currently a relatively niche market, the agency cannot solely rely on hiring pre-trained personnel. Agency leaders will have to continuously monitor the skillset of their employees and improve training as needed. To ensure that both existing and future staff members can operate Metro's future system a workforce assessment was conducted. Table 14 details the key skills that Metro's workforce groups will need to maintain for safe and effective electric bus operation.

Table 14 Workforce Skill Gaps and Required Training

Workforce Group	Key Skills and Required Ongoing Training
Maintenance Staff	High voltage systems, vehicle diagnostics, electric propulsion, charging systems, and battery systems
Electricians	Charging system functionality and maintenance
Agency Safety/Training Officer/First Responders	High Voltage operations and safety, fire safety
Operators	Electric vehicle operating procedures, charging system usage
General Agency Staff and Management	Understanding of vehicle and charging system technology, electric vehicle operating practices

To address these training requirements Hatch recommends that Metro consider the following training strategies:

+ Add requirements to future vehicle procurement contracts for staff refresher training on the safe operation and maintenance of electric vehicles.
+ Coordinate with other peer transit agencies, especially within the state of Maine, to transfer 'lessons learned' both to and from Metro. Send staff to transit agency properties – both those that already operate BEBs and those that are just procuring them – to stay up to date on agencies' experiences and the newest BEB technology.
+ Coordinate with local vocational and community colleges to learn about education programs applicable to battery electric technologies, similar to the one Southern Maine Community College recently introduced.

As electric vehicles become increasingly widespread, Metro should take note of any potential differences between skills that incoming employees may already have – such as operating their personal electric cars – and the knowledge needed for operation and maintenance of electric transit buses. Transit buses pose special challenges that must be considered when training new staff members. Hatch recommends that Metro participate in industry conferences and workshops with other agencies around the US to understand the best way to keep its employees fully trained and up to date.

17. Alternative Transition Scenarios

> ***Section Summary***
>
> - Hatch recommends reviewing this report annually for comparison with technology development and Metro operations

As part of this study, Metro was presented with alternative fleet and infrastructure transition scenarios that would also satisfy the agency's operational requirements. These alternatives considered other vehicle battery configurations, different fleet sizes, other charging locations, and different operational plans. Through discussions, however, Metro currently favors the transition plan presented in this report. Details on the alternative plans are presented in Appendix B and D. Should Metro's plans or circumstances change in the future, it is possible that one of the alternative transition plans presented may become more advantageous. Hatch recommends that Metro review this transition plan on an annual basis to reevaluate the assumptions and decisions made at the time this report was authored.

18. Recommendations and Next Steps

The urban transit industry is currently at the beginning stages of a wholesale transition. As electric vehicle technology matures, climate concerns become more pressing, and fossil fuels increase in cost, many transit agencies will transition their fleets away from diesel/CNG-powered vehicles in favor of battery-electric. By beginning operation of electric buses Metro has taken the first step toward fleet electrification, and the agency stands well-positioned to continue this process in the coming years. In partnership with Maine DOT, other transit agencies in Maine, as well as other key stakeholders, Metro will be able to reduce emissions, noise, operating cost, and other negative factors associated with diesel/CNG operations, while complying with the Clean Transportation Roadmap and operating sustainably for years to come.

For Metro to achieve sustainable and economical fleet electrification, Hatch recommends the following steps:

- Proceed with transitioning the agency's buses and infrastructure in the manner described in this report.
- For the vehicles:
  - Consider ordering buses as part of larger orders or partnering with other agencies or the DOT to form large joint procurements. In particular, consider combining the four procurements in 2033 – 2036.

  - Purchase bus batteries outright, rather than leasing them.
  - With further BEB orders, continue requiring the electric bus vendor to have a technician on site or nearby in case of problems. This is most economical when the technician is shared with several nearby agencies.
  - Reach a "mutual aid" agreement with another transit agency in Maine that would let Metro borrow spare buses in case of difficulties with its fleet.
  - Retain diesel/CNG buses for at least two years after they are retired to ensure they can substitute for electric buses if any incidents or weather conditions require it.
- For the proposed reconstruction of the 114 Valley St facility:
  - Design the roof to support the weight of solar panels.
  - Conduct a fire safety analysis in accordance with Section 12b and standards UL9540, NFPA 70 and 230.
  - Include structural and electrical provisions for a future 100-bus electric fleet.
- For the infrastructure at the Elm St Pulse:
  - Coordinate with the city of Portland on the best location for the Elm St Pulse itself, and on the best positioning of electrical infrastructure at that location
  - Consider adding a plug-in dispenser to the future pantograph charger, for use by RTP's Lakes Region Explorer, BSOOB's Zoom service, or other transit providers
  - Work with the city of Portland to develop contingency plans in case the layover charger fails and midday depot swapping is required.
- For other components of the transition:
  - Tweak operating schedules as required for optimal BEB operation.
  - Add requirements to future procurements for staff refresher training.
  - Participate in industry conferences and coordination with other Maine transit agencies to share best practices for staff training programs, as described in Section 16.
  - Coordinate transition efforts with peer transit agencies, CMP, and Maine DOT.
  - Continually monitor utility structures and peak charge rates and adjust charging schedules accordingly.
  - Develop a funding strategy to account for the 37% increase in capital expenditure.
  - Review this transition plan annually to update based on current assumptions, plans, and conditions.

Appendices

A. Vehicle and Infrastructure Technology Options
B. Alternative Transition Strategy Presentation
C. Utility Outage Data
D. Life Cycle Costing Models