Metro Transit

Zero-Emission Bus Transition Plan

February 2025

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List of Acronyms

ABRT	arterial bus rapid transit
ACS	American Community Survey
AFLEET	Alternative Fuel Life-Cycle Environmental and Economic Transportation
APTA	American Public Transportation Association
ATU	Amalgamated Transit Union
BEB	battery electric bus
BESS	Battery Energy Storage Systems
BIPOC	Black, Indigenous, People of Color
BRT	bus rapid transit
CAWP	Climate Action Work Plan
CDL	commercial driver's license
CDPH	Chicago Department of Public Health
CEJST	Climate and Economic Justice Screening Tool
CEQ	Council on Environmental Quality
CIP	Capital Improvement Plan
CNG	compressed natural gas
CO_2e	CO2-equivalent
CTA	Chicago Transit Authority
DCOO	deputy chief operating officer
E&F	engineering and facilities
EEJ	equity and environmental justice
EJ	environmental justice
ESS	Energy Storage System
FCEB	fuel cell electric bus
FHA	Fire Hazard Assessment
FTA	Federal Transit Administration

GHG	greenhouse gas
HH2H	Heartland Hydrogen Hub
HVAC	heating, ventilation, and air conditioning
IIJA	Infrastructure Investment and Jobs Act
Kg	kilogram
KPI	Key Performance Indicator
kV	kilovolt
kVa	kilovolt-ampere
KW	kilowatt
kWh	kilowatt-hour
Low-No	Low Emissions-No Emissions
LRT	light rail transit
MAC	Metropolitan Airports Commission
MBRC	miles between road calls
MnDOT	Minnesota Department of Transportation
MPCA	Minnesota Pollution Control Agency
MTS	Metropolitan Transportation Services
MTT	Metro Transit technician
MUNI	San Francisco Municipal Railway
O&M	operations and maintenance
OEM	original equipment manufacturer
OHB	Overhaul Base
PUC	Public Utilities Commission
SAE	Society of Automotive Engineers
SBTF	South Base Test Facility
SFSP	Support Facilities Strategic Plan
SMR	steam methane reformation

SOC	state of charge
SOP	Standard Operating Procedure
STA	Suburban Transit Authority
TCC	Transit Control Center
TTC	Toronto Transit Commission
TPP	Transportation Policy Plan
VMT	vehicle miles traveled
ZEB	zero-emission bus
ZEBTP	Zero-Emission Bus Transition Plan

Executive Summary

Under state statute, the Metropolitan Council is responsible for developing a Zero-Emission and Electric Transit Vehicle Transition Plan and revising the plan every 3 years (Minn. Stat. 473.3927). The initial plan was submitted to the Legislature in February 2022; this is the first revision. After evaluating the available Zero-Emission Bus (ZEB) technology, Metro Transit has selected battery electric buses (BEBs) as the short-term ZEB propulsion technology for implementation and deployment.

The influx of Infrastructure Investment Jobs Act (IIJA) federal funding is enabling increased investment in ZEB projects nationwide; however, only 29 percent of requested funds were awarded in federal fiscal year 2023,[1] demonstrating a continued need for investment. Metro Transit was fortunate to receive a $17.5 million award in 2023 to advance their transition, in addition to a nearly $4.2 million award in 2021. Yet, in order to fully transition to ZEBs, Metro Transit will require a ***significant financial investment***.

Zero-Emission Bus Progress to Date

In addition to over two decades of pursuing various sustainability measures spanning both operations and facility-related initiatives, Metro Transit has integrated BEBs into its fleet and daily operations. In 2018, Metro Transit started their ZEB journey by establishing a BEB pilot program for their C Line bus rapid transit (BRT) with 8 60-foot BEBs. Since then, and in total, Metro Transit has invested in the following BEB technologies:

- 13 60-foot New Flyer BEBs (8 C Line (start 2019) + 5 Gold Line (anticipated 2025))
- 20 40-foot BEBs (anticipated 2026)
- 30 150-kilowatt plug-in chargers (the first 8 were replaced under warranty in 2021)
- 4 mobile chargers to be used for maintenance
- 2 on-route overhead conductive chargers at Brooklyn Center Transit Center (BCTC) (decommissioned in 2023 due to safety and reliability concerns)

Moving Forward

To plan for additional ZEB adoption, Metro Transit has already programmed out seven programs of projects to gain experience with different BEBs and infrastructure manufacturers in different aspects of its service to inform future decision-making. Metro Transit has also drafted out future packages that will be informed by what it learns from the programmed packages. The programmed packages plus future packages include Metro Transit's ZEB planned progress from now until 2030. Estimated capital costs are outlined in **Table 1** below.

[1] Source: *FY 2024 Competitive Funding Opportunity: Low or No Emission Grant Program and the Grants for Buses and Bus Facilities Competitive Program*. U.S. Department of Transportation. February 2024.

Table 1: First 60 BEB transition costs by package

Package	Predicted Cost
A: C Line BRT 60-foot pilot	$14.7 M
B: BRT Dedicated Guideway	$13.5 M
C: 40-Foot Local Service Pilot and Distributed Energy Resources Pilot	$44.6 M
D: Implementation of HASTUS scheduling software update	$1.7M
E: 40-foot BEB Replacement Transition	$76.6 M
F: Replacement of Heywood Garage Chargers	$4.0 M
G. Fire Hazard Assessment & Electric Bus Fire Protection	$15.5 M
Future Packages up to 2030	$32.0 M
ZEB Program Funding	$202.6 M

Metro Transit has already ***programed more than $200 million towards transitioning its fleet to ZEB through 2030***. Additionally, Metro Transit has identified the need for a series of future studies to evaluate and consider the preferred approach to ZEB transition beyond 2030.

One of the early studies will consider different vehicle propulsions, different rates of ZEB, and potential fleet distributions (e.g., 100% BEB, 75% BEB/25% fuel cell electric bus [FCEB], 50% BEB/50% FCEB, 25% BEB/75% FCEB, 100% FCEB). The findings from this early study, which Metro Transit is referring to as *Propulsion Type Performance and Alternatives Analysis*, will help inform Metro Transit's decisions regarding the composition of its future ZEB fleet and the rate of ZEB adoption. Another foundational study that will impact future decisions will be the *Service Evaluation*, which will consider the implications for both current and projected future service under the "Network Now" and 2025 ABRT Plan update. Further ZEB expansion could impact Metro Transit's ability to expand service as the ***prioritization between adding transit routes and deploying ZEBs creates new conflicts***. This evaluation will weigh the environmental benefits of ZEBs against the potential opportunity costs of reduced service expansions, ***balancing expanded service priorities with carbon reduction goals***. The ***nine subsequent necessary studies*** currently identified that would take place following these analyses, would each evaluate the impacts to Metro Transit for the same five (or so) fleet distributions identified as well as the ability to expand service.

Then the findings of these studies would each need to be implemented. The costs of implementation remain unknown at this time, as there are too many variables to consider calculating an amount. Examples of implementation following these studies include electrical grid upgrades. Following an electrical grid capacity study, which would evaluate power demand and utility grid readiness for supporting ZEB transition and on-site generation opportunities, the findings may call for large investments from Metro Transit to support energy needs for a full ZEB fleet.

Garage Storage Capacity

Of Metro Transit's five garages, four are not designed to accommodate BEB charging infrastructure. Because of this, the installation of charging infrastructure will require forfeiting current vehicle parking spaces. If all five existing garages were to be fully electrified, it is estimated that 47 parking spaces would be lost compared with existing storage capacity (**Table 2**).

Table 2: Metro Transit garage storage capacity

Fully Electrified Fleet: Bus Storage Capacity Impacts Across all Metro Transit Garages	Current Storage Capacity
Current storage capacity	813
Storage capacity if all garages retrofitted to accommodate BEB Charging infrastructure	766
Difference from current storage capacity	-47 (-6%)
# of vehicles stored as of September 2024	603
Available capacity	163

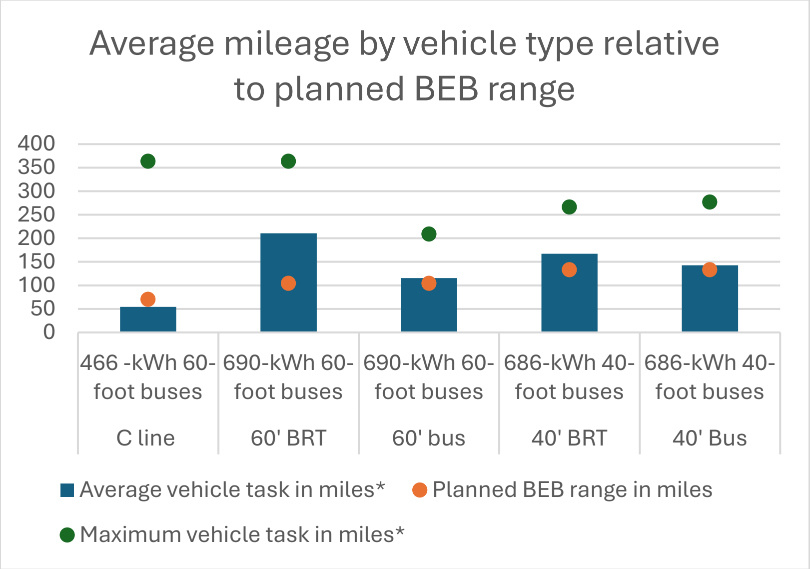
Note: South Garage was included in this analysis but is not recommended for electrical upgrades at this time. See South Garage section for more details

These numbers do not account for any service expansion; however, Metro Transit's Network Now concept plan calls to expand transit service by more than 35 percent through 2027, improving frequency on 60+ routes. Service expansion of this magnitude will require a massive increase in Metro Transit's bus fleet, regardless of the propulsion type (ZEB or diesel). BEBs simply cannot replace all diesel buses 1 to 1, due to range limitations (**Figure 1**), and so merely transitioning Metro Transit's fleet and current level of service today will require more vehicles. Combining the factors of BEB transition *and* service expansion will quickly reduce and possibly eliminate this available storage capacity in Metro Transit's garages.

Changes in Service Needs

In the past 3 years since Metro Transit published their first zero-emission bus transition plan (ZEBTP), Metro Transit has seen a more level, less peaked, demand for service, which it anticipates will continue as it expands and improves service. The reduction of peak-only service levels results in fewer short blocks/vehicle tasks that naturally fall within current BEB range, meaning there are ***limited opportunities for BEBs to replace diesel buses at a 1 to 1 ratio***. Metro Transit needs to better understand how many more BEBs will be required to operate the same service levels it offers today and how that will vary by service operation, vehicle type, and block length. The range limitations of BEBs require more and shorter vehicle tasks (as seen in **Figure 1**), which in turn requires ***more vehicles*** and ***more operators***.

Figure 1: Average mileage by vehicle type relative to planned BEB range



When contemplating the future financial burden of fully transitioning to a ZEB fleet, the costs beyond transitioning the current fleet need to be considered. Facility upgrades, electrical grid upgrades, fleet storage lost to charging infrastructure (possibly requiring an entirely new garage): these are some additional, and largely unknown costs that will come hand in hand with future transitions to a fully ZEB fleet.

Zero-Emission Bus Valuable Experiences

Metro Transit has compiled lessons learned from five North American transit agencies that have implemented or piloted a variety of ZEB types and systems, including their own experience with ZEBs. Although each of the transit agencies included in the case studies have had unique ZEB experiences, several key themes and lessons learned were shared across the agencies, including:

- ***Expect the unexpected***;
- Start the ZEB process early as implementation ***takes much longer*** than for a diesel bus;
- Plan for ***longer*** ZEB and supporting infrastructure ***repair times***;
- ***Incorporate flexibility*** into ZEB planning and implementation efforts where possible to accommodate technological advancements;
- ***Meet early and often*** with your electric utility;
- Elements of ***redundancy*** and contingency planning will alleviate potential challenges;
- Consistent range allows for reliable operation through all seasons. ***Plan for bad weather days***;
- ***Predictable and reliable range*** is often more important than achieving the lowest energy consumption;
- Develop ***strong contractual language*** including performance metrics;
- Clearly define successful ZEB implementation and deployment using ***comprehensible KPIs***;
- When conducting an equity analysis, ***consider impacts to service reliability*** with emerging technologies; and
- Transparently set and ***manage expectations*** using a broad communication strategy with frequent stakeholder communication.

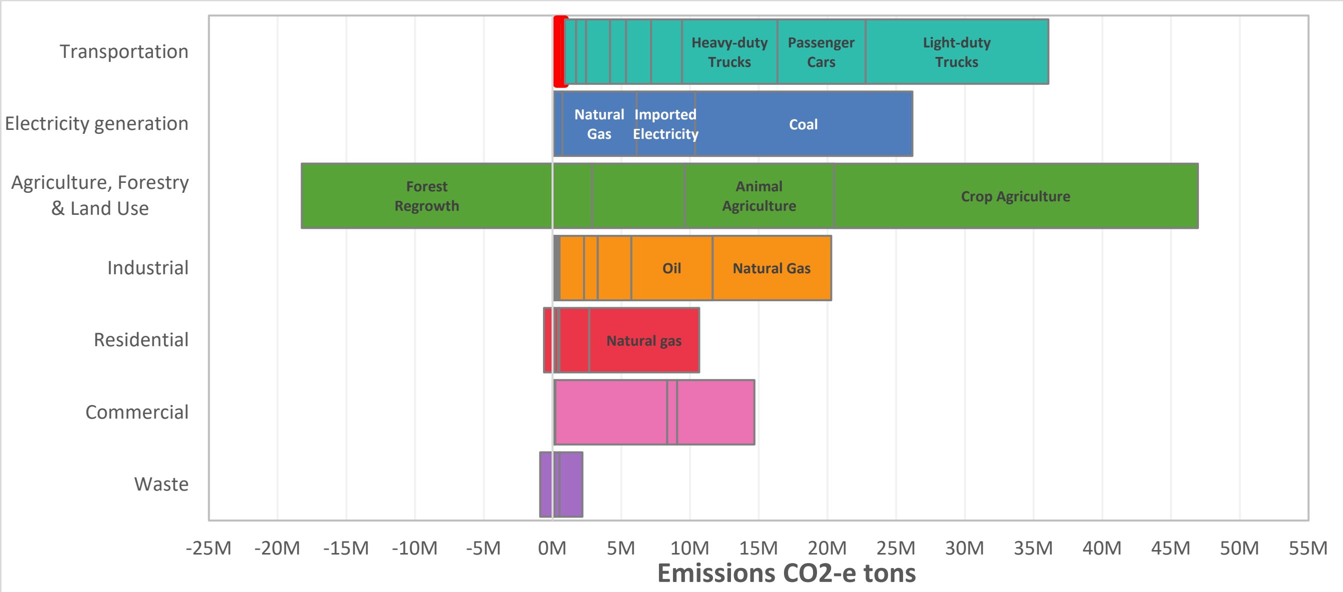
1 Transition Plan Purpose and Context

This section outlines the purpose and motivation for Metro Transit's ZEBTP and places the Transition Plan in a broader political and environmental context. Specifically, this section highlights the impact the transportation and public transit sectors have on the environment, the global trend towards zero-emission buses (ZEBs), Metro Transit's continued commitment to sustainability, and existing studies and initiatives with zero-emissions implications.

1.1 Transportation and the Environment

According to 2020 data from the Minnesota Pollution Control Agency (MPCA), the transportation sector is the largest source of greenhouse gas (GHG) emissions in Minnesota, accounting for about one quarter of all statewide GHG emissions (**Figure 2**).[2] Figures from both 2019 and 2020 MPCA data were analyzed due to potential COVID-19 pandemic impacts; however, trends in the transportation sector's emissions were similar, with the only distinction being a lower magnitude of emissions in 2020 compared to 2019 (36.1 vs. 43.1 million tons of CO2-equivalent [CO_2e] emissions, respectively). The majority (74 percent) of 2020 transportation-related GHG emissions in Minnesota came from light-duty trucks (including SUVs), passenger vehicles, and heavy-duty trucks.

Figure 2*: Sector Sources of GHG Emissions and Storage in Minnesota (2020)*



Source: MPCA Data Services GHG Emissions Data, MPCA, 2020[2]

Note: The thin red bar in the transportation sector indicates the share of Minnesota Transportation GHG emissions attributable to all "buses" including school buses, transit buses, and intercity buses, which accounts for 2 percent (595,500 CO_2e tons).

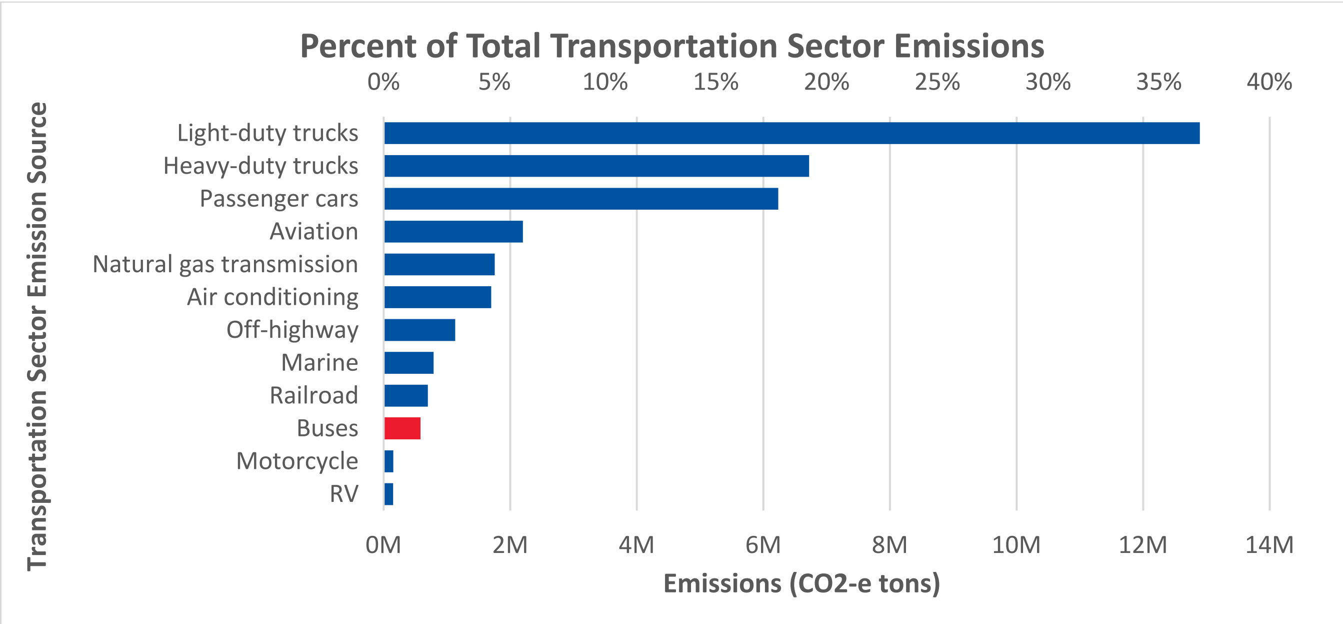
[2] Source: *MPCA Data Services Greenhouse Gas Emissions Data*, MPCA, 2020.

1.2 Role of Public Transit and Emissions

Although the transportation sector accounts for about a quarter of all Minnesota GHG emissions, buses (including school buses, transit buses, and intercity buses) made up only 2 percent (595,500 CO_2e tons) of these transportation GHG emissions in 2020 (**Figure 3**). It is estimated that about 9 percent of all bus emissions statewide are emitted by Metro Transit's heavy-duty buses[3]—the equivalent of 51,490 CO_2e tons of GHG. This equates to 0.04 percent of the state's overall GHG emissions.

Buses only contribute 2 percent of transportation GHG emissions in Minnesota

Figure 3: Minnesota Transportation Sector GHG Emissions by Source (2020)



Source: MPCA Data Services GHG Emissions Data, MPCA, 2020.[2]

With this 0.04 percent of statewide GHG emissions, **Metro Transit provided over 30 million rides on buses in 2023.**[4] Metro Transit's transition to ZEBs is only one of many strategies the agency intends to implement to make meaningful impact on tackling climate change. Another example includes Metro Transit's planned investments in the bus rapid transit (BRT) network to provide fast, frequent, all-day service, which has proven to increase ridership. As detailed in their Network Now plan, Metro Transit has created a roadmap to expand and improve Metro Transit's service by 2027, which will reduce GHG emissions by encouraging transit use.[5] While it is imperative that Metro Transit plans for and strives to reduce the agency's GHG emissions, Metro Transit believes that providing accessible, reliable, fast, and frequent transit service to more people will have the greatest role in reducing Minnesota's GHG emissions

Metro Transit's 45 million rides in 2023 only produced 0.04 percent of total state GHG emissions.

[3] Source: Metro Transit submittal to the MN Office of Enterprise's Sustainability Climate Registry, 2021.
[4] Source: *Metro Transit Factbook*, Metro Transit, 2023.
[5] Source: *Network Now Draft Concept Plan*, page 5, Metro Transit, September 2024.

by attracting people to transit instead of driving their personal vehicles (which account for up to 56 percent of all statewide transportation emissions in 2020).[6]

1.3 Metro Transit Fleet History and Sustainability Trends

Over the past two decades, Metro Transit has been continuously pursuing different initiatives to aid in sustainable transit operations, including different bus propulsion methods as well as modifications to existing exhaust systems and conservation-focused facility improvements.

Metro Transit is committed to providing transportation options that reduce energy use as well as harmful criteria pollutants and GHG emissions to the environment. Over the past two decades, Metro Transit's fleet and facilities have both become increasingly sustainable. For example, the East Metro Garage, constructed in 2001, is four times more energy-efficient than older garages and was the basis of design for next generation facilities, such as the North Loop Garage, which opened in 2023.[7] In 2012, Metro Transit also began investing in solar and other renewable energy sources to help meet the energy needs of its buildings and customer facilities. The Metropolitan Council and Xcel Energy entered into the Green Energy Partnership in 2018, which established goals to have the Metropolitan Council's electrical load, including Metro Transit, increasingly renewable over time and created a framework for continued partnership on demonstration projects including the METRO C Line electric bus pilot.

In addition to facility-related sustainability initiatives, Metro Transit has also made significant strides in reducing bus emissions. Since 1995, older buses have been replaced by new models with cleaner and more efficient engine technology. In addition, particulate matter trap filters were added to buses beginning in 2007, resulting in a more than 96 percent reduction of particulate matter emissions. Diesel exhaust fluid was added to buses beginning in 2010, resulting in a 94 percent reduction in nitrous oxide emissions.[8]

Metro Transit was an early adopter of hybrid electric buses and introduced the first hybrid electric buses into the fleet in 2002. As Metro Transit worked through implementation of hybrid electric buses, the agency made additional purchases of hybrid electric buses in 2012 and 2015. Many years of hybrid electric bus experience has shown Metro Transit that they consistently provide a fuel efficiency improvement over diesel buses. While the efficiency improvement can vary, typical hybrid electric buses approach or exceed a 20 percent improvement over diesel buses.[9] Metro Transit also began piloting electric engine cooling fans in 2011, which became standard in 2013, and began using advanced acceleration management transmission controls in 2012 with incremental improvements in the following years. Electric engine cooling fans and the acceleration management transmission controls resulted in efficiency improvements of nearly 10 percent for diesel bus miles per gallon (4.4 to 4.8) from 2012 to 2023. On average, this resulted in savings of nearly 450,000 gallons of fuel per year, further demonstrating a commitment to emissions reductions and efficiency. Metro Transit has been working to reduce emissions from buses through the use of alternative fuels since 2009, when the agency first used a 5 percent soy-based biodiesel blend.[10] In 2013, the agency began to use up to a 20 percent blend, which

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[6] Note: Personal vehicle emissions include emissions from the 'Passenger Cars' category as well as the "Light-Duty Trucks" category, which includes SUVs.
[7] Source*:* *Our Facilities*, Metro Transit.
[8] Source: M. Porter, Metro Transit Statement, December 8, 2017.
[9] Source: Metro Transit's Bus Maintenance Fleet Performance reports from 2021 to 2023. Information relayed by Metro Transit staff.
[10] Source: Buses going big on biodiesel, Rider's Almanac Blog, 2013.

benefitted the environment and saved money. Biodiesel produces fewer carbon emissions and comes from soy crops grown locally in Minnesota.[11] Metro Transit typically uses an 11.4 percent soy-based biodiesel blend when averaged annually. Additionally, Metro Transit is also investigating the use of renewable diesel as an emerging technology. Renewable diesel, produced from organic sources such as animal fats and cooking oils, performs much like petroleum diesel and can be used in the engines of Metro Transit's existing diesel vehicles without any modifications to the vehicles.[12]

The next step in Metro Transit's continued efforts to increase sustainability and reduce emissions is to continue planning for a transition to a ZEB fleet.

1.4 Infrastructure Investment and Jobs Act

Signed into law by President Biden on November 15, 2021, the Infrastructure Investment and Jobs Act (IIJA), also known as the "Bipartisan Infrastructure Law," includes provisions to continue the grants for the Buses and Bus Facilities Program with increased funding levels compared to that of previous authorizations. The IIJA includes funding appropriation for the Low Emissions-No Emissions (Low-No) Grant Program at around 1.1 billion dollars annually from 2022 through 2026, which is a program within the Federal Transit Administration's (FTA) Buses and Bus Facilities Program. This discretionary grant program requires agencies to have a zero-emission fleet transition plan. It also requires that 5 percent of Low-No Grants related to zero-emission vehicles and related infrastructure must be used for workforce development activities, unless the applicant certifies that less is needed to carry out their zero-emission fleet transition plan. While the influx of IIJA funding is enabling increased investment in ZEB projects with more than 1,800 ZEBs funded from 2022 to 2024,[13] only 29 percent of requested funds were awarded in federal Fiscal Year 2023,[14] demonstrating a continued need for investment. Metro Transit was fortunate to receive a $17.5 million award in 2023 to advance the transition program. However, Metro Transit's 2024 application for Low-No funding was unsuccessful through the competitive process. Metro Transit applied for $74.5 million to fund the purchase of 35 40-foot BEBs, accompanying charging equipment, workforce development activities, and facility improvements at the East Metro Garage to ensure service continuity in the transition to a zero-emission fleet, It should be noted that federal transit funding focuses on capital needs, not addressing the costs associated with operation and maintenance (O&M) of ZEBs or other transit services.[15,16]

1.5 State Statute Requirements

The following sections describe applicable Minnesota state legislation that have ZEB planning and implementation requirements and implications.

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[11] Source: Buses going big on biodiesel, Rider's Almanac Blog, 2013.

[12] Source: Renewable Diesel vs. Biodiesel: What's the Difference?, Fuel Logic Blog, 2024.

[13] Source: *Biden-Harris Administration Announces Availability of $1.5 Billion in Federal Funding to Modernize Bus Fleets and Deploy Clean Transit Buses Across America | FTA*, Federal Transit Administration, February 8, 2024.

[14] Source: *FY 2024 Competitive Funding Opportunity: Low or No Emission Grant Program and the Grants for Buses and Bus Facilities Competitive Program*, U.S. Department of Transportation, February 2024.

[15] Note: COVID-19 Relief laws Coronavirus Aid, Relief, and Economic Security (CARES) Act, Coronavirus Response and Relief Supplemental Appropriations Act (CRRSAA), and American Rescue Plan allowed federal funds to be used for O&M costs. However, funds provided for transit to large urban areas outside of COVID relief bills have been restricted to capital projects.

[16] State of Minnesota Statute 473.3927, Minnesota Legislature Office of the Revisor of Statutes.

1.5.1 Minnesota State Statute Zero-Emission Bus Transition Plan Requirements

Minnesota State Statute (2022) Section 473.3927 states that the Metropolitan Council is responsible for developing a ZEB and electric transit vehicle transition plan and revising the plan every 5 years. This statute was amended by Chapter 127, H.F. 5247, Article 3, Section 106 during the 2024 Regular Session,[17] which established new minimum requirements for plan development and required that the ZEB plan be updated every 3 years, rather than every 5 years (**Figure 4**).

Figure 4*: Text of Minnesota Statute Update in Chapter 127, Article 3, Sec. 106*

EFFECTIVE DATE; APPLICATION. This section is effective the day following final enactment and applies in the counties of Anoka, Carver, Dakota Hennepin, Ramsey. Scott. and Washington.

Sec. 106. Minnesota Statutes 2022, section 473-3927, is amended to read:

473.3927 ZERO-EMISSION AND ELECTRIC TRANSIT VEHICLES.

Subdivision 1. **Transition plan required.**

(a) The council must develop and maintain a zero-emission and electric transit vehicle transition plan.

(b) The council must ~~complete the initial~~ revise the plan by February 15, ~~2022~~ 2025, and revise the plan at least once every ~~five~~ three years following each prior revision.

Subd. la. **Definitions.**

(a) For purposes of this section, the following terms have the meanings given.

(b) “"Greenhouse gas emissions” includes those emissions described in section 216H.01, subdivision 2.

(c) “Qualified transit bus” means a motor vehicle that meets the requirements under paragraph (d), clauses (1) and

(d) “Zero-emission transit bus” means a motor vehicle that:

   (1) is designed for public transit service;

   (2) has a capacity of more than 15 passengers. including the driver: and

   (3) Q)_produces no exhaust-based greenhouse gas emissions from the on board source of motive power of the vehicle under all operating conditions.

Subd. 2. **Plan development.**

At a minimum, the plan must

(1) establish ~~implementation~~ policies ~~and~~, guidance, and recommendations to implement the transition to a transit service fleet of exclusively zero-emission and electric transit vehicles. including for recipients of financial assistance under section 473.388;

(2) establish a bus procurement transition strategy. so that beginning on January 1, 2035, any qualified transit bus purchased for regular route transit service or Special transportation service under section 473.386 by the council is a zero-emission transit bus;

[17] Source: *State of Minnesota Chapter 127, H.F. 5247, Article 3, Section 106*. Minnesota Legislature Office of the Revisor of Statutes. 2024.

(3) consider methods for transit providers to maximize greenhouse gas reduction in addition to zero-emission transit bus procurement, including but not limited to service expansion, reliability, improvements, and other transit service improvements;

(4) analyze greenhouse gas emission reduction from transit improvements identified under clause (3) in comparison to the zero-emission transit bus procurement strategy under clause (2);

(5) set transition milestones or performance measures, or both, which may include vehicle procurement goals over the transition period in conjunction with the strategy. under clause (2);

~~(3)~~ (6) identify barriers, constraints, and risks, and determine objectives and strategies to address the issues identified;

~~(4)~~ (7) consider findings and best practices from other transit agencies;

~~(5)~~ (8) analyze zero-emission and electric transit vehicle technology impacts, including cold ·weather operation and emerging technologies;

(9) prioritize deployment of zero-emission trans it buses based on the extent to which service is provided to environmental justice areas, as defined in section 116.065, subdivision 1;

~~(6)~~ (10) consider opportunities to prioritize the deployment of zero-emissions vehicles in areas with poor air quality;

(11) consider opportunities to prioritize deployment of zero-emission trans it buses along arterial and highway bus rapid transit routes, including methods to maximize cost effectiveness with bus rapid transit construction projects;

~~(7)~~ (12) provide detailed estimates of implementation costs to implement the plan and achieve the transition under clause (2), which, to the extent feasible, must include a forecast of annual expenditures, identification of potential sources of funding, and a summary of any anticipated or planned activity to seek additional funds; ~~and~~

~~(8)~~ (13) examine capacity., constraints, and potential investments in the electric transmission and distribution grid, in consultation with appropriate public utilities;

(14) identify methods to coordinate necessary facility upgrades in a manner that maximizes cost effectiveness and overall system reliability;

(15) examine workforce impacts under the transition plan, including but not limited to changes in staffing complement; personnel skill gaps, and needs; and employee training, retraining, or role transitions; and

(16) summarize updates to the plan from the most recent version.

Subd. 3. **Copy** to **legislature.**

Upon completion or revision of the plan, the council must provide a copy to the chairs, ranking minority members, and staff of the legislative committees with jurisdiction over transportation policy and finance.

1.5.2 Minnesota State Statute Definition of Environmental Justice

As shown in **Figure 5** (Item 9), the amended transition plan requirements specify that ZEB deployment must be prioritized based on the extent to which service is provided to environmental justice (EJ) areas. **Figure 6** depicts the definition of EJ areas adopted by the Minnesota Legislature in 2023.[18]

Section 8 of this ZEBTP provides additional detail on how Metro Transit developed a methodology for prioritizing ZEB deployments taking in consideration equity and EJ environmental justice (EEJ). Section 8 also explains how this methodology serves state defined EJ areas.

Figure 5: Text of Minnesota State Statute 116.065

116.065 CUMULATIVE IMPACTS ANALYSIS; PERMIT DECISIONS IN ENVIRONMENTAL JUSTICE AREAS.

Subdivision 1. **Definitions.** (a) For the purposes of this section, the following terms have the meanings given.

(b) "Commissioner" means the commissioner of the Minnesota Pollution Control Agency.

(c) "Cumulative impacts" means the impacts of aggregated levels of past and current air, water, and land pollution in a defined geographic area to which current residents are exposed.

(d) "Environmental justice" means:

(1) the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies; and

(2) in all decisions that have the potential to affect the environment of fill environmental justice area or the public health of its resident due consideration is given to the history of the area's and its residents' cumulative exposure to pollutants and to any current socioeconomic conditions that could increase harm to those residents from additional exposure to pollutants.

(e) "Environmental justice area" means one **or** more census tracts in Minnesota:

(1) in which based on the most recent decennial census data published by the United States Census Bureau:

(i) 40 percent or more of the population is nonwhite;

(ii) 35 percent or more of the households have an income at or below 200 percent of the federal poverty level; or

(iii) 40 percent or more of the population over the age of five has limited English proficiency.

(2) located within Indian Country.

(f) "Environmental stressors" means factors that may make residents of an environmental justice area susceptible to harm from exposure to pollutants Environmental stressors include:

[18] Source: *State of Minnesota Statute 116.065*, Minnesota Legislature Office of the Revisor of Statutes, 2023.

(1) environmental effects on health from exposure to past and current pollutants in the environmental justice area, including any biomonitoring data from residents reported through the Centers for Disease Control the Department of Health or peer-reviewed scientific or medical articles; and

(2) social and environmental factors, including but not limited to poverty substandard housing, food, insecurity, elevated rates of disease, and poor access to health insurance and medical care.

(g) "Indian Country" has the meaning given in United States Code title 18, section 1151.

(h) "Permit" means a major source air permit as defined in Minnesota Rules, part 7007.0200, or a state air permit required under Minnesota Rules part 7007.0250 subpart *5* or 6. Permit includes a permit required for new construction or facility expansion or the reissuance of an existing permit.

1.5.3 Minnesota State Statute Regional Sales Tax and Uses

Under state statute,[19] the Metropolitan Council must impose a 0.75 percent regional transportation sales tax on retail sales and uses in the metropolitan area to use for transportation activities (**Figure 6**). This sales tax provides funding to the Metropolitan Council[20] to implement and maintain transportation networks. Associated state statute notes that the Metropolitan Council must expend a portion of this revenue on ZEB procurement and associated costs (**Figure 6**).[21]

Figure 6*: Text of Minnesota Statute 297A.9915*

1 MINNESOTA STATUTES 2023 297A.991.5

297.99 1:5 REGIONAL TRANSPORTATION SALE AND USE TAX.

Subdivision 1. **Definitions.** (a) For purposes of this section, the following terms have the meanings given.

(b) "Metropolitan area" means the counties of Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington.

(c) "Metropolitan Council" or "council" means the Metropolitan Council established by section 473.1.23.

(d) "Regional transportation sales tax" means the regional transportation sales and use tax imposed under this section.

Subd. 2. **Sales tax imposition; rate.** Notwithstanding section 4 73.123, subdivision 1, the Metropolitan Council must impose a regional transportation sales and use tax at a rate of three-quarters of one percent on retail sales and uses taxable under this chapter made in the metropolitan area or to a destination in the metropolitan area.

Subd. 3. **Administration; collection; enforcement.** Except as otherwise provided in this section, the provisions of section 297A.99, subdivisions 4, and 6 to 12a, govern the administration, collection, and enforcement of the regional transportation sales tax.

Subd. 4. **Deposit.** Proceeds of the regional transportation sales tax must be allocated as follows:

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[19] Source: *State of Minnesota Statute 297A.9915*. Minnesota Legislature Office of the Revisor of Statutes. 2023.
[20] Source: *State of Minnesota Statute 473.4465*. Minnesota Legislature Office of the Revisor of Statutes. 2023.
[21] Source: *State of Minnesota Statute 297A.9915*. Minnesota Legislature Office of the Revisor of Statutes. 2023.

(1), 83 percent to the Metropolitan Council for the purposes specified under section 473.4465; and

(2) 17 percent to metropolitan counties, as defined in section 174.49, subdivision 1, in the manner provided under section 174.49, subdivision *5.*

473.4465 REGIONAL TRANSPORTATION SALES AND USE TAX USES.

Subdivision J. **Definition.** For purposes of this section, "sales tax revenue" means the portion of revenue from the regional transportation ales and use tax under section 297A.991.5 that is allocated to the council for the purposes of this section.

Subd. 2. **Use of funds; Metropolitan Council. (a)** Sales tax revenue is available as follows:

(1) five percent for active transportation as determined by the Transportation Advisory Board under subdivision 3; and

(2) 95 percent for transit system purposes under section 473.371 to 473.452, including but not limited to operations, maintenance, and capital projects.

(b) The council must expend a portion of sales tax revenue in each of the following categories:

(1) improvement to regular route bus service levels;

(2) improvements related to transit safety including additional transit officials, as defined under section 473.4075;

(3) maintenance and improvements to bus accessibility at transit stop and transit centers;

(4) transit shelter replacement and improvement under section 473.41;

(5) planning and project development for expansion of arterial bus rapid transit lines;

(6) operations and capital maintenance of arterial bus rapid transit;

(7) planning and project development for expansion of highway bus rapid transit and bus guideway lines;

(8) operations and capital maintenance of highway bus rapid transit and bus guideways;

(9) zero-emission bus procurement and associated costs in conformance with the zero-emission and electric transit vehicle transition plan under section 473.3927;

(10) demand response microtransit service provided by the council;

(11) financial assistance to replacement service providers under section 473.388, to provide for service, vehicle purchases, and capital investment related to demand response microtransit service;

(12) financial assistance to political subdivisions and tax-exempt organization under section 501 (c)(3) of the Internal Revenue Code for active transportation; and

(13) wage adjustments for Metro Transit hourly operations employees.

1.6 Existing Studies and Initiatives

This section provides a review of Metro Transit and Metropolitan Council studies and initiatives with zero-emissions implications. By aligning key regional plans, sustainability initiatives, and infrastructure studies, these studies highlight how the ZEBTP supports the agency's goals of enhancing sustainability, equity, and developing a plan to understand the impacts of shifting towards 100 percent ZEB purchases by 2035.

1.6.1 Regional Long-Range Transportation and Strategic Plans

Efforts in the plans discussed below prioritize regional transit planning and equity considerations across various plans, supporting the ZEBTP.

1.6.2 Thrive MSP 2040 (2020)

Adopted by the Metropolitan Council in May 2014, Thrive MSP 2040 is a comprehensive plan that outlines regional goals, including sustainability.[22] It sets the policy foundations for systems and policy plans, including the 2040 Transportation Policy Plan (TPP), which describes how the transportation system will be developed and operated in a way that is consistent with the regional vision and goals described in the regional vision. The plan lists five outcomes, including sustainability and equity, that define its shared regional vision, aiming to provide leadership to support climate change mitigation, adaptation, and resilience. This framework aligns with the ZEBTP, helping to advance shared goals of reducing emissions and enhancing equity through the transition towards purchasing only ZEBs by 2035.

1.6.3 Imagine 2050 (2025)

Imagine 2050 is the successor regional comprehensive long-range plan to Thrive MSP 2040. The plan aims to set the framework for creating an equitable, inclusive, healthy, safe, dynamic, and resilient region that leads to climate change considerations and protects natural systems.[23] Imagine 2050 will set policy foundations for various subject areas, including transportation, which may then be folded into updated policy plans.

The climate change objectives within the plan emphasize the need to minimize GHG emissions for the region's transportation system and to expand access to reliable zero-emissions infrastructure. Another key goal is to reduce vehicle miles traveled (VMT) by 20 percent per capita from 2019 levels by 2050—an effort that directly aligns with the Network Now plan (described below).

Imagine 2050 is expected to be adopted in 2025, with implementation beginning the same year, further advancing the region's shift toward sustainable transportation systems in line with the ZEBTP.

1.6.4 Forward: Metro Transit Strategic Plan (2024)

Metro Transit's strategic framework, Metro Transit Forward, outlines the long-term vision for the region's transportation network, with a focus on sustainable growth.[24] The plan guides these efforts by prioritizing

[22] Source: Thrive MSP 2040, Metropolitan Council, 2020.
[23] Source: Imagine 2050, Metropolitan Council.
[24] Source: Metro Transit Forward, Metro Transit, 2024.

employees, rider experience, and service. As part of the service priority, the framework emphasizes achieving the goals of the ZEBTP and driving down Metro Transit's rate of GHG emissions. Metro Transit Forward provides a larger framework that supports broader sustainability goals for future transit investments that align with state and federal sustainability goals.

1.6.5 Everyday Equity Initiative

Metro Transit's Everyday Equity Initiative is an organizational assessment of equity aligned with Thrive MSP 2040 that aims to proactively address barriers to opportunity.[25] Through its Everyday Equity Initiative, Metro Transit is committed to proactively addressing barriers to opportunity. The mission of the 15-member Everyday Equity team is to identify and remove barriers that community members, customers, and employees face. The Everyday Equity team regularly recommends solutions to Metro Transit leadership that will lead to more equitable outcomes.

1.7 Transit Network Service Planning

The planning efforts below are focused on expanding and improving bus service through a combination of expansion of local, and express, bus service and additional BRT lines that align with the ZEBTP and related legislative initiatives on prioritizing mass transit and reducing VMT.

1.7.1 Network Now (2024)

Network Now is Metro Transit's plan for bus and rail service improvements through 2027.[26] The plan builds on new sources of funding for Metro Transit and responds to changes in ridership and travel behavior due to the COVID-19 pandemic. Among the plan's key values are providing access to opportunities and services with a focus on advancing equity and reducing regional disparities. Overall, the Network Now concept plan expands transit service by more than 35 percent to grow ridership.

1.7.2 Gold Line Bus Rapid Transit

The METRO Gold Line is a 10-mile dedicated BRT line that is planned to open in 2025, running between Saint Paul and Woodbury near Interstate 94.[27] The project will introduce five 60-foot 690 kilowatt-hour (kWh) BEBs, four bus storage chargers, one mobile maintenance charger, and smart charging software based in the East Metro Garage. The Gold Line will be Metro Transit's first experience running electric buses in the highway-based BRT service format.

Following the opening of the Gold Line, the Gold Line Extension Project is anticipated to open in 2027. The Extension will provide service from downtown Minneapolis to downtown St. Paul, including Interstate 94 and Snelling Avenue and some of the region's top destinations[28]. This extension will likely introduce service changes that will impact BEB blocking and scheduling.

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[25] Source: Everyday Equity, Metro Transit, 2024.
[26] Source: Network Now, Metro Transit, 2024
[27] Source: Gold Line Transit, Metro Transit, 2024.
[28] Source: METRO Gold Line Extension, Metro Transit, 2024.

1.7.3 Purple Line Bus Rapid Transit

The METRO Purple Line BRT was initially envisioned as a 15-mile line between Union Depot in Downtown Saint Paul and Downtown White Bear Lake generally along Robert Street, Jackson Street, Phalen Boulevard, Ramsey County rail right-of-way collocated with the Bruce Vento Regional Trail and Highway 61. In spring 2022, a Route Modification Study began to evaluate a new northern terminus north of Beam Avenue to either end the line at Maplewood Mall Transit Center, Vadnais Heights City Center, or Century College. In spring 2023, a second phase of the Route Modification Study began to evaluate the White Bear Avenue Corridor as an alternative to collocating with the Bruce Vento Regional Trail north of Maryland Avenue. Since fall 2024, project partners have been working to identify a clear path forward for the project that could be brought forward for consideration by funding partners in spring 2025. The Purple Line plans to operate electric buses in exclusive or semi-exclusive bus lanes for a majority of the route. As an East Metro serving line, the Purple Line bus fleet is anticipated to be based out of the East Metro Garage. Project scope and budget will be set upon re-entry into the FTA's Capital Investment Grants Program (entry into the New Starts engineering phase), anticipated to occur in early 2027.

1.7.4 Arterial Bus Rapid Transit Plan (2025 anticipated)

Metro Transit's efforts to explore arterial bus rapid transit (ABRT), which can provide faster, more frequent, and reliable service, began in 2011. Following the exploration of more than a dozen potential arterial BRT lines between 2011 and 2012, Metro Transit implemented the METRO A Line in 2016 and the METRO C Line in 2019; both of which have been "highly successful posting significant ridership increases and earning customer's satisfaction."[29] In 2020, Network Next, a 20-year plan that aimed to establish Metro Transit's vision for the bus network of 2040, charted the course for new ABRT lines.[30] As of 2024, the current ABRT network consists of the A, C, and D lines in operation, with the B and E lines under construction, and the F, G, and H lines identified for implementation between 2026 and 2030.[30]

The 2025 update will identify the next programmed arterial BRT lines to be implemented between 2030 and 2035 and identify additional ABRT candidate corridors for implementation before 2050.[31] Once the ABRT Plan is completed, future lines can be evaluated for ZEB technical viability, ensuring that the deployment of electric buses fits within both sustainability goals and the BRT prioritization outlined in legislation.

1.8 Infrastructure Readiness and Facility Upgrades

The planning initiatives below focus on ensuring that the physical and operational infrastructure is prepared to support the transition to ZEBs.

1.8.1 North Loop Garage Battery Electric Bus Feasibility Study (2019)

In tandem with the C Line BEB pilot program, Metro Transit conducted a BEB Feasibility Study to inform implementation strategies and considerations for adding electric buses to the North Loop Garage in the

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[29] Source: *Network Next Arterial BRT Final Report*, Metro Transit, February 2021.
[30] Source: *Arterial Bus Rapid Transit - 2024 Regional Solicitation*, Metro Transit, March 2024.
[31]Source: Introduction to the 2025 Arterial Bus Rapid Transit Plan Update, Metro Transit, 2024.

future.[32] Based on the findings of the Feasibility Study, the North Loop Garage design was modified to accommodate the future possibility for fleet electrification.[33] The garage opened in 2023 and has the capacity to house approximately 216 buses.

The BEB Feasibility Study included planning for both 40-foot standard buses and 60-foot articulated buses for BEB consideration. Two 13.8 kilovolt services totaling 8MW have been installed to serve the North Loop Garage: 2MW of power serves the main facility, and 6MW serves bus charging needs. The three 2MW substations dedicated to serving electric bus charger bases were included as part of the initial garage build and are estimated to serve approximately 70 BEBs.

Although not part of initial construction, Metro Transit received funding from the FTA's Low-No Grant Program in 2019, 2021, and 2023 to construct renewable energy resources, create charging infrastructure, purchase twenty 40-foot BEBs, and pilot charge management software. The first BEBs at the North Loop Garage are anticipated to enter revenue service in 2026.

1.8.2 Support Facilities Strategic Plan (2022)

The Support Facilities Strategic Plan (SFSP) is a long-range planning process that identified support facility expansion options potentially needed by Metro Transit through 2040. The plan considers both lower-growth and higher-growth futures, identifying possible facility needs gaps over time.[34]

The SFSP identified three substantial findings with capital planning consequences. The first is uncertainty regarding Metro Transit's ability to renew its South Garage facility lease with the Metropolitan Airports Commission (MAC) after its expiration in 2035. The second is the removal of Ruter Garage from active revenue service use in 2023. The third is the coming decision regarding whether or not to continue operating South Garage. These findings highlight the fluidity of Metro Transit's decision-making and planning regarding the continued reliance on these facilities. Metro Transit's support facility needs will be routinely monitored and evaluated as Metro Transit studies how to purchase only ZEBs beginning in 2035 in accordance with Minnesota Statute Chapter 127, Article 3, Sec. 106.

1.8.3 East Metro Garage Battery Electric Bus Space Planning Study (2022)

In tandem with Gold Line BEB infrastructure planning, Metro Transit studied how to expand power service, power resiliency, and space planning for future deployments of BEBs out of the East Metro Garage. This planning study developed space plans for new infrastructure for up to 5MW of power or approximately 60 BEBs. As of fall 2024, the first substation is under construction, which includes a 2.5MW switchgear. These plans and construction are in addition to the five BEBs and five chargers set to be introduced through the Gold Line BRT. The space-planning efforts of this plan also identified the locations for future chargers. Metro Transit collaborated with Xcel to install an automatic throwover switch, allowing for added resiliency in the event of a localized power outage.

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[32] The North Loop Garage is referred to as the Minneapolis Bus Garage (MGB) in the Metro Transit Battery Electric Bus Feasibility Report.
[33] Source: Metro Transit Battery Electric Bus Feasibility Report, 2020.
[34] Source: SFSP, Metro Transit, 2022.

1.9 Climate Action and Sustainability

The plans and partnerships below are shaping Metro Transit's transition to ZEBs and represent the broader strategy to reduce emissions and promote sustainability, in line with climate-focused legislation.

1.9.1 Metropolitan Council Climate Action Work Plan (2023 to 2028)

The Metropolitan Council's Climate Action Work Plan (CAWP) is a 5-year plan beginning in 2023 that aims to unify efforts across Metropolitan Council divisions, including Metro Transit, to reduce GHG emissions, adapt to climate impacts, and build resilience to potential changes. This work plan integrates climate resilience into regional transportation and complements the ZEBTP's targets and strategies.

The CAWP defines six core commitments, 20 accompanying strategies, and 73 actions that will strengthen the Metropolitan Council's ability to plan and deliver services to the region through leadership, collaboration, and stewardship.[35] One of the ongoing strategies identified in the CAWP is to "transition Met Council fleets to electric and alternative fuel vehicles" with a supporting action to "continue to implement and follow the Metro Transit Zero-Emission Bus Transition Plan."[36]

1.9.2 Metro Transit Sustainability Plan (2025)

The Metro Transit Sustainability Plan, to be released in 2025, will build upon the CAWP and create a broad and holistic approach to managing Metro Transit's operational impacts on the region's natural systems, as well as prioritizing its commitment to EJ. The plan will focus on energy conservation, reduction of GHG emissions, and reducing operational impacts on the region's natural systems, with the goal of becoming more adaptive, less intrusive, and a more resilient region. Both the CAWP and Sustainability Plan emphasize the reduction of environmental burdens on vulnerable communities and ensuring equitable outcome, which is aligned with the ZEBTP. Reducing emissions and enhancing energy efficiency advances both climate and resiliency goals identified in these plans.

1.9.3 Xcel Energy Green Energy Partnership (2018)

In June 2018, Xcel Energy and the Metropolitan Council announced the creation of a green partnership focused on working together to produce and purchase clean, renewable energy.[37] This partnership supports the transition to ZEBs by establishing the shared goal of providing renewable energy for charging infrastructure. The agreement establishes a formal partnership between Xcel Energy and the council for the purposes of creating electric bus pilot programs, pursuing funding, and sharing data with the goal of further advancing electric bus technology. As of conversations with Xcel Energy in fall 2024, Metro Transit is requesting to power charging infrastructure with electricity from 60 percent renewable energy sources by 2030 and 100 percent renewable energy sources by 2040.[38]

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[35] Source: *Climate Action Work Plan Update*, Metropolitan Council.
[36] Source: Climate Action Work Plan Annual Report, Metropolitan Council, April 2024.
[37] Source: *Met Council, Xcel Energy Work to Get Council to 100% Renewable Energy By 2040*, June 8, 2018.
[38] Source: *Xcel Energy – Green Energy Partnership Update*, Presentation to the Metropolitan Council, September 16, 2020.

1.10 Metropolitan Council Fleet Electrification Shifts

The plans below coordinate with Metro Transit's transition to ZEBs by providing for knowledge-sharing among peers and opportunities to achieve regional consistency regarding fleet electrification.

1.10.1 Metropolitan Transportation Services and Suburban Transit Authority Zero-Emission Bus Transition Plan (2023)

Developed in accordance with Minnesota Statute 473.3927,[39] the Metropolitan Transportation Services (MTS) and Suburban Transit Authority (STA) ZEBTP lays out a roadmap for how five public transit providers in the Minneapolis-Saint Paul region—MTS, Maple Grove Transit, Minnesota Valley Transit Authority, Plymouth Metrolink, and SouthWest Transit (collectively, the Suburban Transit Authorities)—could facilitate the shift from conventional gas- or diesel-powered vehicles to zero-emission vehicles. The plan covers the entire MTS fleet including over 1,100 council-owned transit vehicles, over 300 of which are operated by the suburban providers. Coordination and communication regarding lessons learned from the Metro Transit ZEBTP and the MTS and STA ZEBTP enable improved planning efforts council wide. These plans were designed to provide regional consistency in infrastructure upgrades and operational strategies, creating synergies that streamline the zero-emission transition. Additionally, they align with state and federal requirements for ZEBTPs.

1.10.2 Metropolitan Council Electric Vehicle Study (2022)

The Metropolitan Council's Electric Vehicle Planning Study resulted in three reports that include a summary of the electric vehicle landscape, an analysis of equity in electrification strategies, and a set of recommendations that the Metropolitan Council can carry out to accelerate adoption of the benefits of electric vehicles.[40] This study explored the feasibility of electric vehicles within the context of the broader transportation network and supports ZEBTP by offering insights on electrification while aligning with legislative priorities to reduce emissions through advanced vehicle technologies.

Several of the recommendations from the Electric Vehicles Study support Metro Transit's ZEBTP, most notably:[41]

- Align Metro Transit electric bus routes with the ZEBTP;
- Assess internal fleet for electrification opportunities; and
- Invest in projects identified in Metro Transit ZEBTP.

[39] *Adoption of the MTS & STA Zero-Emission Bus Transition Plan Committee Report*, Metropolitan Council, May 2023.
[40] Source: Electric Vehicle Planning Study, Metropolitan Council, 2021 and 2022.
[41] Source: Metropolitan Council Electric Vehicles Planning Study: Analyses & Recommendations, Metropolitan Council, May 2022.

2 Transition Plan Guiding Principles

Having provided the motivation and broader context within which this Transition Plan exists, this section establishes guiding principles that will be used to define a successful transition to ZEBs. In addition, these guiding principles will be used to inform the development of program policies, milestones, and a framework and methodology to prioritize the transition to ZEBs in the short- and long term. Time horizons are defined as follows:

- Short term: 2025 to 2030
- Long term: 2030 and beyond

2.1 Guiding Principles Framework

Metro Transit has developed three guiding principles and six supporting actions to guide the development and implementation of the ZEBTP. The development and creation of these guiding principles and supporting actions in 2021 was primarily informed by three elements:

- Twin Cities Region Long-Range Plan
- Metro Transit Strategic Framework
- Cross-disciplinary workshop of Metro Transit staff

2.1.1 Twin Cities Region Long-Range Plan

In recognition of the broader role the ZEBTP will have in addressing the future needs of the region and our responsibility to future generations, the guiding principles and supporting actions were developed in alignment with the policy foundation and outcomes outlined in the region's comprehensive development guide and long-range plan, Thrive MSP 2040 (**Table 3**).[42]

Table 3: ZEBTP alignment with Thrive MSP 2040 regional outcomes

Thrive MSP 2040	ZEBTP
Stewardship	
Responsibly managing our region's finite resources	Yes
Leveraging transit investments	Yes
Prosperity	
Fostering the conditions for shared economic vitality by balancing major investments across the region	Yes
Protecting natural resources that are the foundation of prosperity	Yes
Equity	
Using our influence and investments to build a more equitable region	Yes
Creating real choices in how we travel for all residents, across race, ethnicity, economic means, and ability	Yes
Engaging a full cross-section of the community in decision-making	Yes

[42] Source: *Thrive MSP Introduction*, 2014.

Thrive MSP 2040	ZEBTP
Livability	
Promoting healthy communities and active living	Yes
Sustainability	
Providing leadership, information, consideration of climate change mitigation, adaption, and resilience	Yes
Operating the region's wastewater treatment and transit systems sustainability	Yes

Imagine 2050, successor regional comprehensive long-range plan to Thrive MSP 2040 as described in Section 2.6.3, is an under-development strategic regional development guide that will aim to guide developments in the metro region towards a more connected, equitable, and sustainable future by the year 2050, setting policy foundations for land use, housing, transportation, water resources, and regional parks.[43] This initiative builds on the comprehensive planning work undertaken by the Metropolitan Council in previous decennial cycles, most recently Thrive MSP 2040. It will be informed by values and goals articulated in these past plans and in the comprehensive plans of the communities in the region. Imagine 2050 is expected to begin adoption and implementation in early 2025. Any related updates to the ZEBTP guiding principles will be evaluated after publication.

2.1.2 Metro Transit Strategic Framework

In addition to aligning with Thrive MSP 2040, the guiding principles and supporting actions defined in this plan also align with the strategic priorities, Employees, Experience, and Service, defined in Metro Transit's Strategic Framework, which supports and supplements the Metropolitan Council's long-range plan, *Thrive MSP 2040*, and *Metro Transit's TPP*.

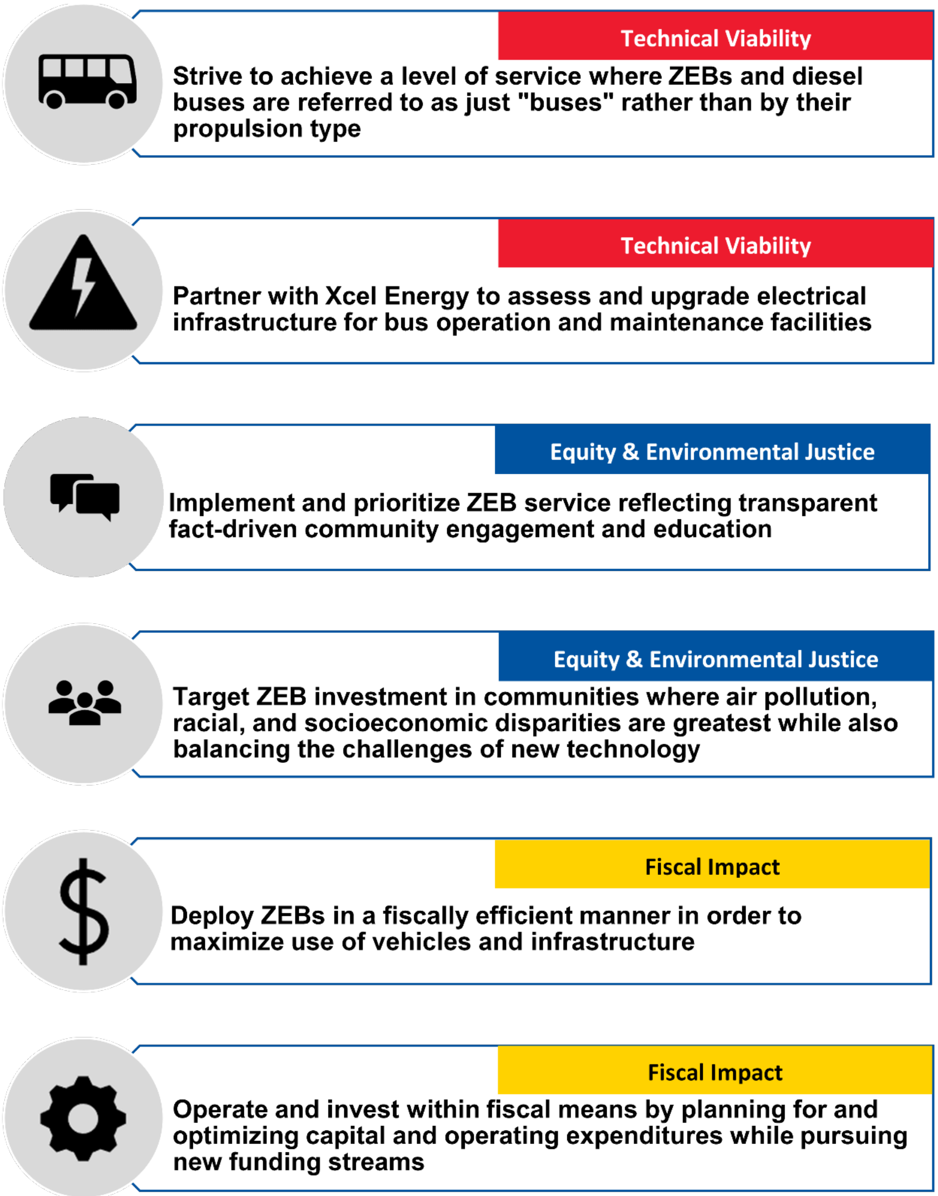
2.1.3 Cross-Disciplinary Internal Workshop

To assist in the creation of these guiding principles and the ZEBTP, Metro Transit assembled a cross-disciplinary team. This cross-disciplinary team held a workshop to discuss and establish the supporting actions and guiding principles for Metro Transit's transition to ZEB service. The workshop included an overview of the purpose of the ZEBTP, Metro Transit's experience with ZEBs to date, as well as information on the state of practice in North America for ZEB implementation.

Through this discussion and in alignment with the region's long-range plan, Thrive MSP 2040, and the Metro Transit Strategic Plan, the cross-disciplinary team established three guiding principles and six supporting actions that will guide the implementation of the ZEBTP (**Figure 7**).

[43] Source: Planning for 2050.

Figure 7: ZEBTP guiding principles and supporting actions summary



2.2 Principle 1: Technical Viability

To transition to a strong and reliable ZEB transit system, buses, facilities, and service must all be technically viable. To attain technical viability, we will strive to achieve a level of service where ZEBs and diesel buses are simply referred to as buses rather than by their propulsion type. This means that ZEBs must be able to provide an excellent, safe, and reliable service to transit customers similar to vehicles with any other propulsion type. We will also partner with Xcel Energy to assess and upgrade electrical infrastructure and bus facilities to ensure that these facilities have the necessary infrastructure needed to house and support the efficient and reliable operation of a technically viable bus service.

2.2.1 Supporting Action: Strive to achieve a level of service where ZEBs and diesel buses are referred to as just "buses" rather than by their propulsion type

Metro Transit currently has a ZEB pilot program for the C Line BRT service using a type of ZEB, BEBs. The pilot program has been established to help Metro Transit better understand the implications of transitioning its fleet to ZEB. From this experience, Metro Transit has learned that ZEBs have different characteristics than the diesel and hybrid (diesel-electric) buses the agency has been operating for decades. These differences include the equipment needed to maintain the vehicles and charging/fueling infrastructure, standard operating procedures (SOPs) regarding the recharging/refueling of the buses, how an operator accelerates and decelerates, the reduced range the buses can operate between recharging/refueling, as well as many other characteristics. Based on these differences, Metro Transit is examining how these propulsion types can be utilized to best deliver bus service to the region.

Metro Transit established a vehicle reliability target that 90 percent of buses should be available and ready for service daily

A successful transition to ZEBs would be one in which Metro Transit is not required to operate distinct sub-fleets based on limitations of various propulsion types. While this is a long-term goal to be incrementally achieved over an extended period of time, Metro Transit will aim for a point where the agency will no longer need separate use cases for buses of different propulsion types. In alignment with this aim, Metro Transit established a vehicle reliability target for its bus fleet that 90 percent of buses should be available and ready for service daily.

Workforce development will be part of every ZEB project

Reaching this long-term goal where buses are equally utilized regardless of propulsion will require changes to how Metro Transit operates its bus service. It will also require additional staff training so that Metro Transit's existing workforce can continue to operate and maintain the system. As a result, workforce development will be a part of every ZEB project. This training and development will include operators, Maintenance, Service Development, Dispatch, Customer Service, Communications, Engineering and Facilities (E&F), and other staff with the goal of increasing the share of Metro Transit staff that are well versed in the intricacies of the rapidly evolving ZEB technology.

While Metro Transit has established a long-term vision of a fully integrated bus fleet, the agency recognizes that in the short term, operating requirements and procedures will need to be tailored to take advantage of the unique operating characteristics associated with ZEBs to maximize the benefit to the region. For example, based on current technology and battery sizes, ZEBs will need to be assigned to shorter blocks, which limits their utility (blocks are the service a bus provides between refueling or charging).

2.2.2 Supporting Action: Partner with Xcel to assess and upgrade electrical infrastructure for bus operation and maintenance facilities

ZEBs require unique supporting infrastructure due to the different mechanisms and energy sources required to power and operate these buses compared with conventional diesel buses. For example, whereas diesel buses require fuel storage tanks and pumps to refuel, electric buses require extensive electrical infrastructure and additional power delivered to bus O&M facilities in order to recharge. To ensure that future ZEBs will have the support infrastructure necessary to operate consistently and reliably, Metro Transit will build upon our existing partnership with Xcel Energy to assess the existing electrical infrastructure and capacity limitations at our bus O&M facilities and perform upgrades as necessary. This collaboration will include the confirmation of available electrical transmission capacity, transformer specifications, and current peak power demands at each facility.

As part of the ZEBTP's technical analysis, Metro Transit and Xcel Energy collaborated on long-range planning to forecast future power needs at bus O&M facilities. This collaboration will inform Xcel Energy capital planning to help ensure necessary power feeds can be designed and constructed in accordance with Metro Transit needs. In accordance with the Green Energy Partnership, Metro Transit and Xcel Energy will continue to identify joint pilot projects. Projects will also be considered for designation as a demonstration project as applicable. Demonstration projects are projects of statewide significance that advance mutual areas of technological innovation and often require approval by and reporting to the Minnesota Public Utilities Commission (PUC).

In addition to capital projects, Metro Transit and Xcel Energy intend to study operational challenges to fleet electrification including collaboration on smart charging software to minimize Metro Transit's peak energy demand. By shifting as much of the charging loads as operationally feasible to non-peak times, Metro Transit can be part of the solution of optimizing how much grid infrastructure is needed and help Xcel Energy use the grid more efficiently while minimizing the need for costly upgrades. The two organizations also intend to work together to study existing tariffs to identify any opportunities to better align electricity rates with the unique needs of heavy-duty fleet charging.

2.3 Principle 2: Equity and Environmental Justice

The principle of EEJ is based on the Metropolitan Council's and Environmental Protection Agency's definitions of EEJ and EJ, respectively. As defined in the Metropolitan Council's long-range vision for the region, equity...

> *Connects all residents to opportunity and creates viable housing, transportation, and recreation options for people of all races, ethnicities, incomes, and abilities so that all communities share the opportunities and challenges of growth and change.*[44]

Complementing this definition of equity, in 2023 the Minnesota Legislature formally defined "environmental justice" as...

> *(1) the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies; and*
> *(2) in all decisions that have the potential to affect the environment of an environmental justice area or the public health of its residents, due consideration is given to the history of the area's and its residents' cumulative exposure to pollutants and to any current socioeconomic conditions that could increase harm to those residents from additional exposure to pollutants.*[45]

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[44] Source: Thrive MSP 2040.
[45] Source: 2023 Minnesota Statutes 116.065 Cumulative Impacts Analysis; Permit Decisions In Environmental Justice Areas.

In that same statute, the Minnesota Legislature provided a definition of an “environmental justice area” as a census tract…

> *(1) in which, based on the most recent decennial census data published by the United States Census Bureau:*
> - *(i) 40 percent or more of the population is non-white.*
> - *(ii) 35 percent or more of the households have an income at or below 200 percent of the federal poverty level; or*
> - *(iii) 40 percent or more of the population over the age of 5 has limited English proficiency; or*
>
> *(2) located within Indian Country.*[46]

In addition, the principles of EEJ and EJ relate to the following regional core values of Imagine 2050[47]:

- **Equity:** We value the people and communities of our region. Our region is economically and culturally vibrant. However, we also recognize the harm and disparities that injustices, including racism, have created. We are dedicated to creating systems, policies, and programs that repair and heal past harm, foster an equitable future, and eliminate disparities. Communities that have been marginalized in the past will be at the center of this work in leadership roles.
- **Leadership:** We value those in our region who inspire and motivate others for positive change. Our region is known for its civic engagement. We need broad and inclusive leadership to help confront the significant challenges we face around equity, climate change, safety, and other pressing issues. To maximize the potential of our region and its communities, we turn to leadership that is diverse, collaborative, culturally competent, and innovative. We encourage this kind of leadership across all sectors including business, government, non-profit, and education.
- **Accountability:** We value being effective in our work and achieving measurable outcomes. Our region is known for its research, initiatives, and collaborations. We must be open to criticism and clearly understand when we are not achieving results or have harmed communities. We recognize that we can maximize our effectiveness by being in partnership with others. We will also be transparent and flexible so that we can change course when needed.

In 2022, Metro Transit adopted a Transit Equity Statement.

> *Metro Transit acknowledges that providing safe, affordable, and reliable transportation increases opportunity. Transit services and programs should be built to equitably benefit all, especially underserved communities, including BIPOC, low-wealth, women, people with disabilities, LGBTQ, youth and older adults. Transit equity requires identifying and addressing injustices and building actionable pathways to create a fair and more just future.*
>
> *Metro Transit understands that transit decisions can impact the ability of underserved communities to find and keep jobs, reach medical care, access educational opportunities and affordable housing, and develop and maintain social connections, among other impacts. Transit services and investments can reduce spatial inequalities that contribute to racial, environmental, and economic disparities.*

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[46] Source: 2023 Minnesota Statutes 116.065 Cumulative Impacts Analysis; Permit Decisions In Environmental Justice Areas.
[47] Source: *Imagine 2050*, Metropolitan Council, accessed August 1, 2024.

Metro Transit has an essential role and responsibility to examine all decisions impacting our region's access to quality transit, reduce existing disparities, and prevent further inequities by:

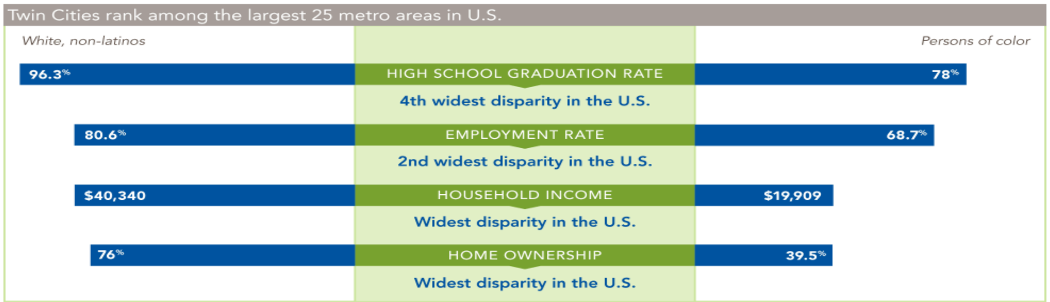
- *Reviewing and revising policies*
- *Seeking partnerships with other responsible institutions; and*
- *Improving planning and operational practices*

In alignment with the above definitions and to maximize EEJ, ZEB implementation and prioritization will reflect transparent, fact-driven community engagement and education through public meetings, seminars, surveys, and staff engagement. This means that community members will be able to make informed contributions so that ZEB investments align with the communities' needs and wants. These communities include members of the Metro Transit workforce whose backgrounds and perspectives reflect the diverse interests of the many communities served by the agency. Based on this engagement and education, Metro Transit will target ZEB investments to make the greatest difference in areas where poor air quality, racial, and socioeconomic disparities are greatest while also balancing the challenges associated with new technology.

2.3.1 Supporting Action: Implement and prioritize ZEB service reflecting transparent, fact-driven community engagement and education

In the Twin Cities region, underserved and underrepresented communities have borne a disproportionate share of negative environmental consequences. For example, low- and moderate-income communities, communities of color, and indigenous communities all experience significantly higher levels of air pollution when compared with white and wealthy communities.[48] As shown in **Figure 8**, the Twin Cities region has some of the largest disparities between white communities and communities of color. Given the ingoing disparities, Metro Transit is focused on ensuring that its ZEBTP, along with any updates, considers the social, political, economic, and environmental impacts on corridors or neighborhoods. The aim is to equitably distribute the benefits of ZEB service without placing disproportionate risk on the same underserved communities. To guide this focus on EEJ and to ensure that the ZEBTP aligns with communities' needs and wants, Metro Transit has prioritized transparent, fact-driven community engagement and education to ensure that the ZEBTP aligns with the needs and wants of the communities it serves.

Figure 8***:*** **Inequities in the Twin Cities Region**



Source: metrotransit.org

[48] Source: Environmental justice and air, MPCA.

To best align with the many competing interests and priorities within communities, Metro Transit engaged in a public outreach effort as part of the initial development of the ZEBTP in fall 2021 to understand the needs and priorities of communities where ZEB service may be deployed in the next several years. To guide this conversation and allow community members to make informed contributions, Metro Transit placed a strong emphasis on transparently educating the community on the many decision drivers that impact ZEB deployment.

Throughout the initial development of the ZEBTP in fall 2021, internal and external engagement events were held to educate and inform interested stakeholders about the plan. These engagement opportunities included an online survey, pop-up events with frontline Metro Transit staff including bus operators and mechanics, two virtual summit workshops, and targeted outreach to Minneapolis and Saint Paul neighborhood organizations. Overall, more than 800 participants attended one of these events and over 300 people completed the online survey, with nearly 90 percent of respondents rating Metro Transit's transition to ZEBs as either important or very important.

Metro Transit is and will continue engagement efforts on an annual basis, both internally and externally, to update progress and gather valuable feedback in an effort to maintain alignment with community needs and to keep stakeholders informed.

2.3.2 Supporting Action: Target ZEB investments to make a difference in communities where air pollution, racial, and socioeconomic disparities are greatest while also balancing the challenges of new technology

Air quality and noise reduction benefits associated with ZEBs increase as the number of in-service ZEBs integrated into a community increases. Therefore, to deliver the greatest possible benefits to the communities where air pollution, racial, and socioeconomic disparities are greatest, Metro Transit will focus their ZEB investments that have and continue to face significant historical disinvestment and/or poor air quality. Metro Transit developed a methodology for prioritizing ZEB deployments, as detailed in Section 8.5.2. Metro Transit has recently evaluated this methodology in light of Minnesota's new EJ definition and federal Justice 40, Executive Order 14008[49]. As part of this focus, Metro Transit will work to mitigate the many risks of deploying emerging technologies so as to minimize adverse impacts to these same communities.

The investment priority in EJ areas was determined with communities through the community education and outreach process. At each engagement event, and as part of the online survey, participants were asked to evaluate and rank the relative importance seven unique population and environmental variables should have in identifying equitable and environmentally just areas within which to prioritize ZEB deployment. Overall, engagement participants identified lifetime cancer risk from the inhalation of air toxics as the most important consideration followed by population density and the portion of a census tract's residents that identify as Black, Indigenous, or a person of color (BIPOC).[50] Reflecting this feedback, Metro Transit has identified priority areas for ZEB service based on the relative percentage of

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[49] Source: Justice 40, The White House.

[50] Note: The seven census-tract level variables participants were asked to rank were lifetime cancer risk from inhalation of air toxics, population density, portion of residents who identify as BIPOC, portion of households lacking a vehicle, the number of years in which the census tract was designated as an area of concentrated poverty, the portion of households that are housing cost-burdened (housing costs are 30 percent of household income), and the average land surface temperature on a hot summer day (proxy for urban heat island effect).

first choice votes engagement participants assigned to each of the aforementioned EEJ variables. These priority areas have then been aligned with the EJ areas as defined in Minnesota law, as documented in Section 8.5.2.

While Metro Transit's methods for prioritizing ZEB investments were established prior to the Justice 40 initiative, it is consistent with both federal and state guidance on EEJ. The methodology for prioritizing ZEB investments is detailed in Chapter 8. Additionally, Metro Transit's approach complies with relevant state and federal laws, ensuring alignment with current EJ standards.

2.4 Principle 3: Fiscal Impact

Metro Transit Forward emphasizes the need for measuring and reporting the agency's progress towards offering service that is convenient, reliable, and environmentally sustainable. Key indicators and metrics, including those related to fiscal impact, will inform Metro Transit's budget decisions beginning in 2024, enabling the agency to communicate progress annually.

Metro Transit will continuously evaluate the agency's fiscal performance to identify areas of improvement as we strive to operate and invest within our fiscal means while deploying ZEBs in a fiscally efficient manner.

2.4.1 Supporting Action: Deploy ZEBs in a fiscally efficient manner in order to maximize use of vehicles and infrastructure

The purchase cost[51] of a ZEB for Metro Transit is currently more than 2.25 times that of a diesel bus.[52] Given the significant financial investment required for ZEBs, Metro Transit is focused on extracting the most benefit and usage from these vehicles. To maximize the return on investment these ZEBs can provide, Metro Transit will deploy ZEBs in a fiscally efficient and sustainable manner focused on maximizing the technically viable amount of time ZEBs are on the road serving customers.

2.4.2 Supporting Action: Operate and invest within fiscal means by planning for and optimizing capital and operating expenditures while pursuing new funding streams

As an increasing emphasis is placed on environmentally sustainable solutions, it is anticipated that funding opportunities for ZEB systems will need to grow to remain fiscally sustainable. Beyond the capital costs associated with ZEBs, Metro Transit will also need to ensure that it can fund ongoing O&M. This is particularly important given that the current purchase cost of a ZEB is more than 2.25 times as expensive as a diesel bus. Additionally, on-route chargers, which are often used during peak hours when buses are in service, can further increase operating costs due to high electricity demand charges during these times. This makes the cost of charging during the day more expensive compared to off-peak hours, adding to the overall operational expenses.

With three of the five application cycles for federal IIJA funding now completed, Metro Transit's potential capital funding options for ZEB systems are becoming increasingly challenging. The IIJA allocated $1.1 billion annually to the FTA Low-No program for federal Fiscal Years 2022 to 2026.The FTA's Low-No

[51] Purchase cost here is for both the vehicle and charging equipment.
[52] Source: Metro Transit Statement, D. Hass, September 2024.

Program is a discretionary grant program which historically has been awarded to less than 40 percent of the applicants through 2024.[53,54,55] Metro Transit applied for all three cycles and was successful in 2023 (Metro Transit was previously successful and secured grant funding in 2019 and 2021). Despite receiving a high rating for technical merit in all applications, the program's competitive nature means that not all applications were awarded. The program was significantly burdened, with 477 applications totaling $9 billion in demand, while only 117 were awarded for a total of $1.5 billion in available funding. This is also coupled with the Grants for Buses and Bus Facilities Program, which awards upwards of $390 million annually to purchase, replace, rehabilitate, or lease buses and bus facilities.[56] Xcel Energy had proposed a $30 million Electric Bus Rebate Program, but after review from the Minnesota PUC, this program was not approved and does not exist as of 2024.[57] As a result, Metro Transit will need to continue to identify capital funding from a variety of sources to help to cover the costs of transitioning to a zero-emission fleet.

The recently approved regional sales tax provides Transportation with approximately $400 million annually, offering a stable source of funds to address system needs now and in the future. This new revenue stream supplements other funding sources such as Motor Vehicle Sales Tax, federal grants, fares, and local partnerships. However, the transition to a zero-emission fleet faces logistical challenges. Currently, it can take up to 2 years from the time a contract is awarded for an electric bus to be delivered, and more than a year for the supporting infrastructure to be ready from the time it is ordered. Moreover, there is still shortage of workers across every sector of transportation, which continues to impact the pace of project delivery. Despite these challenges, Metro Transit shares the public's urgency to advance these projects and is committed to growing to meet the expectations associated with these new funds.

Beyond the capital costs associated with ZEBs, Metro Transit will also need to ensure that it can fund ongoing O&M costs. These costs may initially be higher than the O&M costs associated with conventional diesel buses for several reasons. One key factor is the increased energy cost per mile compared to traditional diesel buses. These factors include charger inefficiency (heat generated while charging and during low output idle charge periods) as well as additional expenses added onto the electricity bill (such as demand charges and fuel fees) that drive a higher overall dollar per kWh. Apart from regular O&M costs, ZEBs will also require midlife assessments of their ESS to evaluate performance to date, larger overhaul maintenance needs, and plans for future necessary replacements and/or upgrades. Additionally, maintaining ZEBs requires specialized safety protocols, such as working in pairs during high-voltage maintenance, further driving up labor costs. Another contributing factor includes the challenges of working with emerging technology, resulting in excess costs attributed to less reliable chargers and vehicles.

The limited range capacity of ZEBs also contribute to less efficient vehicle assignments, which can create additional operational inefficiencies. Lower availability and range capacity may require Metro Transit to place additional mileage on newer diesel buses, and older buses that are scheduled for retirement may even need to be brought back into service to ensure that service commitments are met. This further introduces indirect but significant costs, as both the maintenance of newer diesels and the extension of

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[53] Source: *INVESTING IN AMERICA: Biden-Harris Administration Strengthens Transit Manufacturing Industry with $1.5 Billion from Bipartisan Infrastructure Law to Put More American-Made Buses on the Road*, Federal Transit Administration.
[54] Source: Top 10 Takeaways for the FTA Low or No Emissions and Grant for Buses and Bus Facilities Competitive Program, Electrification Coalition.
[55] *Federal Fiscal Year 2016 to 2021 Low or No Emission Grant Program Projects Selections*. (Representative link for FY2020), FTA.
[56] Source: https://www.transit.dot.gov/bus-program.
[57] Docket Number: E,G-999/CI-20-492, Minnesota PUC.

service for older buses add to the overall financial burden of the transition to ZEBs. As Metro Transit gains additional ZEB experience and develops a more complete understanding of the practical O&M costs associated with ZEBs, Metro Transit will collaborate with its partners to continue to study and identify actions to control and reduce these costs.

Specific steps to manage the O&M costs of the ZEB system will include implementing smart charging at garages to optimize electricity costs and working with Xcel Energy and the Minnesota PUC on electricity rate design. Metro Transit has signed 2-year licenses with smart charging systems from the Mobility House and ChargePoint to test these programs and build knowledge about smart charging capabilities. Procedures have been implemented for maintenance staff to charge buses at more advantageous times, especially overnight during off-peak hours for revenue service. However, maintenance needs still require limited charging at the garage during the day while completing repairs. Additionally, while this is achievable with a small quantity of buses, as the fleet continues to grow, more time will be needed to charge the fleet beyond the overnight off-peak period. The current approach, focused on general cost-management strategies, may not fully address the needs of a larger ZEB fleet. Establishing a new rate structure is critical to the long-term financial implications of supporting a fully scaled ZEB fleet.

Metro Transit is actively trying to build a case for a dedicated transit rate that better reflects the unique requirements of electric bus operations, in contrast to the standardized commercial and industrial rates that are currently in use. Metro Transit has also enrolled in a time-of-use rate pilot program with Xcel Energy for the Heywood Garage. Participation in the pilot will provide real-world transit data to the Minnesota PUC and Xcel Energy, demonstrating the operational requirements to charge battery electric transit buses. The results of these efforts, including the outcomes of the time-of-use rate pilot program, will be studied and reported in the coming years.

Additionally, where financially possible and available, extended warranties should be pursued and exercised to ensure that manufacturers are a committed partner in repairs and to ensure equipment reliability. Extended warranties can also be leveraged to better manage some of the unknowns with battery life expectancy. Extended warranties can potentially be purchased up front for battery systems as an added capital cost at a reduced rate when compared to a mid-life operational expense at full cost. Extended warranties are also evaluated with charger purchases. Recent vendor quotes have ranged from a 15 percent to 40 percent added cost to extend the standard 1- to 2-year charger warranty to 5 years.

As Metro Transit implements items to control and reduce O&M costs, the agency will gain increased budget predictability. In the longer term, improved budget predictability may result in operational cost stability as unexpected costs and investments are reduced, which could otherwise result in cost overruns. Currently, Metro Transit's diesel fleet is dependent on diesel rates that are subject to market volatility despite a purchasing strategy to lock in rates at levels advantageous for the Metropolitan Council. Utility rates, conversely, are typically locked in and often require a multi-year process to adjust. Therefore, a stable usage of electricity improved by smart charging systems, in tandem with stable utility rates, is anticipated to result in the greatest budget predictability, thereby helping Metro Transit operate within its fiscal means. Even with systems in place to optimize electricity usage and costs, Metro Transit anticipates electricity will cost more per mile than diesel, which would increase overall energy operations costs. **From the opening of the C Line in June 2019 through 2023, the average energy cost per mile for the BEB fleet was $1.24 compared with $0.69 for the diesel C Line bus fleet**.[58]

[58] Source: *Metro Transit ZEB Transition 2023 Annual Report*, Metro Transit.

3 Zero-Emission Bus Technologies

3.1 Electric Trolleybuses

The first zero-emission transit vehicle that did not operate on rail tracks was the electric trolleybus. An electric trolleybus, also referred as “trackless trolley” in some regions, is a rubber-tired bus vehicle with an electric motor that draws power from overhead catenary wires. While electric trolleybuses have been in use for nearly a century, there are currently only five transit agencies across the country that are operating this type of ZEB as a part of their regular service offerings.[59]

3.1.1 Vehicle and Infrastructure

Trolleybuses require overhead catenary wires to be installed throughout the operating corridor. Unlike streetcars or other electrified rail vehicles that run on metal rail tracks that act as the electrical return, trolleybuses have rubber tires and must therefore use two trolley poles and dual overhead wires, one for the positive current and the other for the negative or neutral return. Where two or more routes join in or diverge to branches, trolleybus wire switches are installed on the overhead wires. The switches are triggered by a pair of shoe contacts that power a pair of electromagnets on the switches.

Figure 9: Trolleybus in Operation with Two Trolley Poles in Seattle, Washington

In modern operations, there are two trolley poles on the top rear of a trolleybus with contact shoes or wheels at the end of the trolley poles (**Figure 9**). Operators usually raise and lower the trolley poles manually using a rope from the back of the trolleybus vehicles. The trolley poles must be pulled behind the bus and not pushed. The poles are usually longer than those used on streetcars to allow the trolleybus vehicle to maneuver the street with flexibility by giving a degree of lateral steerability.

3.1.2 Operating Characteristics

As trolleybuses require physical overhead infrastructure throughout their operating corridors to deliver electricity to the vehicles, there are certain limitations to trolleybuses as a modern ZEB mode, including:

- Trolleybuses require overhead catenary wires to be installed throughout the corridors and in garages to which trolleybuses are assigned, which requires extensive initial capital investments for new systems;
- Garages need overhead clearance and to be retrofitted with overhead wires to accommodate trolleybuses for storage and maintenance needs;

[59] Source: *The National Transit Database (NTD)*.

- Trolleybuses have limited flexibility for off-wire operation;
- Trolleybuses may not be suitable for high-speed operations, as faster speeds increase the likelihood that a trolleybus will detach and come uncoupled from the overhead wires, particularly around curves and corners;
- In multi-lane operations, it is difficult for a trolleybus to overtake a preceding trolleybus without coordinated crossover points;
- Overhead catenary wires may have visual impacts on surroundings, which may make implementation in neighborhoods protected by historic preservation laws difficult; and
- Placement of catenary poles can impact accessibility of sidewalk, underground utilities, and/or underground vaults.

3.1.3 Current Applications

Most of current application of trolleybus technology in the U.S. are legacy streetcar lines that have been converted to trolleybuses where conventional diesel operations were difficult due to compatibility with existing tunnel infrastructure due to diesel fumes, or the inability of diesel buses to climb steep inclines. The last major trolleybus network expansion in the country was in 2004 on the Massachusetts Bay Transit Authority (MBTA) Silver Line in Boston, for the portion of the alignment under Boston Harbor; however, the MBTA retired its final trolleybuses in 2022.[60] See **Table 4**, below, for a summary status of electric trolleybus usage in the U.S.

Table 4: Applications of electric trolleybuses in the U.S.

Agency	Fleet Size	Routes Served	Notes
San Francisco Municipal Transportation Agency *(SFMTA)*	**284** 185 (40-foot New Flyer) 99 (60-foot New Flyer)	**15**	Steep incline in the system necessitated trolleybus.
King County Metro	**174** 110 (40-foot New Flyer) 64 (60-foot New Flyer)	**15**	Steep incline in the system necessitated trolleybus. King County Metro plans to acquire 30 additional trolleybuses by 2037.
Greater Dayton Regional Transit Authority *(GDRTA)*	**45** (40-foot Gillig)	**7**	--
Southeastern Pennsylvania Transportation Authority *(SEPTA)*	**38** (40-foot New Flyer)	**3**	--

[60] Source: Cambridge Trackless Trolleys to Retire this Weekend as the Technology Nears Extinction, WGBH, 2022.

Several agencies recently underwent their procurement cycles to replace their aging trolleybus fleets; with the development of new propulsion technologies, all agencies opted to procure trolleybuses with additional auxiliary power units (e.g., diesel or battery electric) to enable limited off-wire operations of around 15 to 20 miles as needed.

King County Metro, with the support of Seattle Department of Transportation is planning to add overhead wires on 23rd Avenue and on Jackson Street in Seattle to electrify Route 48 and future RapidRide routes. King County Metro is also planning to acquire 30 additional trolleybuses by 2037.[61] While originally planned to be implemented with trolleybuses, RapidRide G Line (formerly known as "Madison Corridor BRT") will be implemented with hybrid electric buses instead, as King County Metro experienced challenges with procuring articulated trolleybuses with left-loading doors that can climb steep hills.[62]

3.2 Hydrogen Fuel Cell Electric Buses

As the name suggests, a hydrogen fuel cell electric bus (FCEB) uses onboard hydrogen gas to create energy. The fuel cell is an electrochemical device that combines this gas with ambient oxygen to produce electricity to power the vehicle. While less common than other forms of zero-emission vehicles, the application of fuel cells as a power source for transit vehicles has been considered and studied by several researchers and early adopter transit agencies such as AC Transit in California and Stark Area Regional Transportation Authority in Ohio for well over a decade.

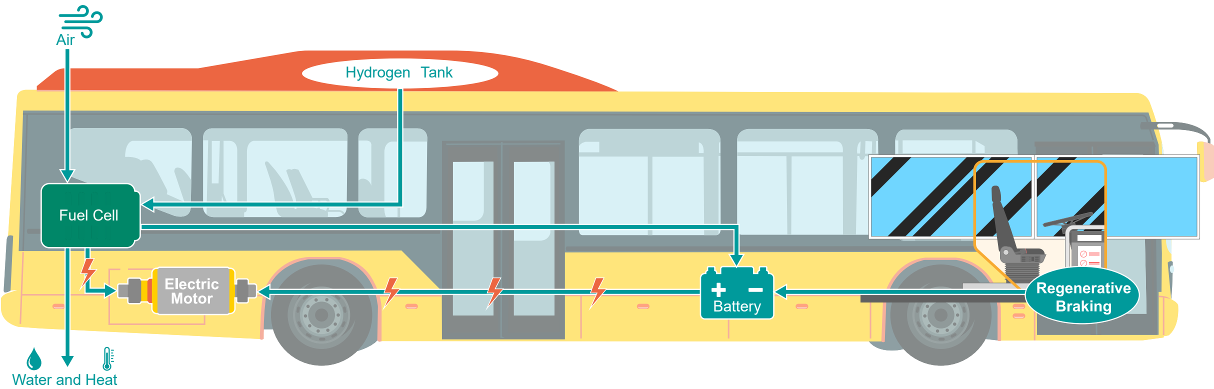
3.2.1 Operating Characteristics

An FCEB functions similarly to a BEB and shares many of the same components. The key difference between the two vehicles is that instead of an extensive bank of batteries, which a BEB solely relies on for energy storage, an FCEB has onboard gaseous hydrogen that creates electricity through a fuel cell to charge the small battery pack that powers the vehicle. The byproduct of the fuel cell process is heat, which can be recirculated to heat the vehicle during colder days, and water, both of which can be discharged from the vehicle with no harmful effects to the surrounding environment. **Figure 10** illustrates how this bus's energy system functions. It is anticipated that, similar to diesel buses and BEBs, an auxiliary heater would be needed for operations in Minnesota winters.

The key benefit of hydrogen gas is that it can store more energy than today's BEBs at a much lower weight. This means the FCEB can have a much more significant range than a BEB, potentially running 200 or more miles on a tank of fuel. The onboard hydrogen gas tank can also be refilled in 6 to 10 minutes[63], a similar time frame to a diesel bus, instead of the hours a BEB requires to charge its batteries.

[61] Source: Interview and email with King County Metro staff, October 2021.
[62] Source: *Madison BRT nearing 90-percent design*, Madison Park Times, January 2019.
[63] Source: Xcelsior CHARGE FC Brochure, New Flyer, April 2024.

Figure 10: FCEB Energy Diagram



3.2.2 Current Applications

As of September 2023, around 6 percent of all ZEBs nationwide were FCEBs with a total of 211 FCEB either funded, ordered, or delivered. California has been an early adopter state regarding FCEBs, as nearly 75 percent of all FCEBs operated by U.S. transit agencies were in California while the remainder were spread over 13 other states.[64] FCEBs operated over 7 percent of all the ZEB revenue miles in the U.S. in 2022.[65]

Due to the high cost of hydrogen fueling infrastructure and challenges with sourcing the fuel, applications of FCEBs are mostly limited to small pilot programs by a few transit agencies. However, the quick fueling times and comparatively longer ranges than other ZEB technology have led many agencies to invest heavily in FCEB, including them as a significant part of their future zero-emission fleets. California alone aims to put more than 2,000 FCEBs on the road in the near future.[66]

3.2.3 Hydrogen Fueling Infrastructure

The majority of industrially generated hydrogen gas is produced from natural gas through steam methane reformation (SMR). SMR involves heating the gas with steam and a catalyst to extract hydrogen from the fuel source and release carbon monoxide as a byproduct. The hydrogen can then be delivered in either a gaseous or liquid form.[67] Hydrogen gas is compressed and stored in storage tanks when delivered. In contrast, hydrogen liquid is vaporized first before being compressed and stored. Hydrogen is typically transported and stored in liquid form for transit bus usage, as it allows for higher storage capacity.

When hydrogen's environmental impact is discussed, it is typically associated with a color that symbolizes its feedstock and production method (**Figure 11**). This may be known as the hydrogen color spectrum or hydrogen color wheel. The most common colors are green, blue, and gray, as they are the most popular production methods; **Figure 11** below provides insights into the ways in which hydrogen is produced.

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[64] Source: *Zeroing In On ZEBS*, CALSTART, February 2024.
[65] Source: *Fuel and Energy by Mode and TOS*, National Transit Database, 2023.
[66] Source: *Why fuel cell buses are becoming operators' vehicle of choice for public transport*, Sustainable Bus, March 2024.
[67] Source: *Hydrogen Costs and Financing*, California Fuel Cell Partnership.

Figure 11: Color classifications of hydrogen[68]

	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind | Solar | Hydro Geothermal | Tidal	Minimal
	Purple/Pink Hydrogen		Nuclear	
	Yellow Hydrogen		Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS Gasification + CCUS	Natural gas | coal	Low
	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
	Grey Hydrogen	Natural gas reforming		Medium
	Brown Hydrogen	Gasification	Brown coal (lignite)	High
	Black Hydrogen		Black coal	

*GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

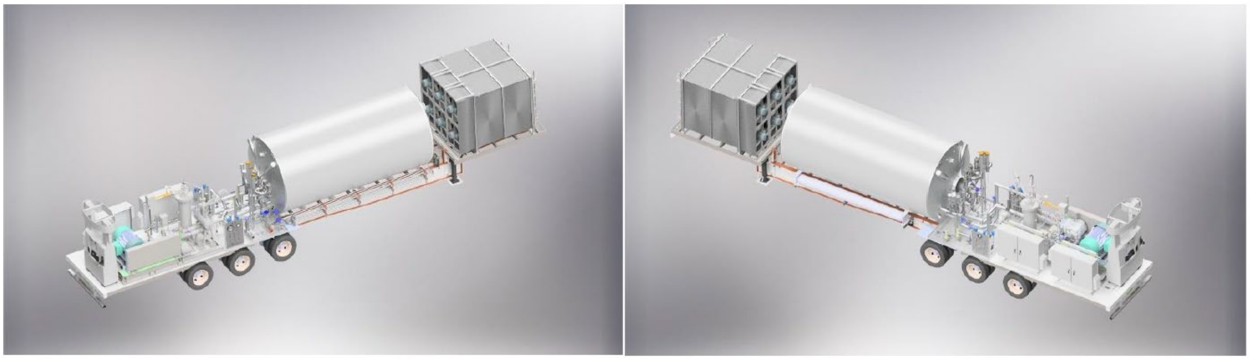
Hydrogen fueling infrastructure and associated fueling stations operate similarly to compressed natural gas (CNG) fueling infrastructure. Unlike CNG, hydrogen is typically sourced from a supplier, and its storage footprint for the equipment is similar to that of diesel fueling infrastructure.

While most FCEBs in North America are fueled outdoors, these vehicles can also be fueled indoors, which is currently happening in Santa Ana, California, at the Orange County Transit Authority. This was safely achieved through minor modifications to the existing safety equipment it already had in place to operate its CNG buses. Metro Transit's existing garages are not designed for light-than-air gases like hydrogen and CNG and would need to undergo significant renovations to meet the safety requirements of this fuel.

To help reduce the costs of hydrogen fueling infrastructure, particularly for agencies with smaller FCEB fleets, some agencies turn to mobile dispensing as a temporary solution before building permanent station infrastructure. Relying on a mobile (or temporary) fueling device reduces the capital costs of building permanent storage facilities on-site. The cost savings are magnified for transit facilities that require multiple storage facilities due to their fleet's refueling requirements. One company, Plug Power, offers a portable refueler to dispense and store liquid hydrogen, acting as both a supply source and pump for compressed hydrogen gas. The 53-foot-long trailer has a cryogenic tank, pump, and vaporizer all in one piece of infrastructure (**Figure 12**).

[68] Source: Hydrogen – data telling a story, Global Energy Infrastructure, March 2021.

Figure 12: Plug's Mobile Refueler



The refueler provides 1,275 kilograms (kg) of usable fuel, dispensing at a rate of 3.6 kg per minute at 350 bar pressure. Assuming a fleet with FCEBs uses 25 kg of hydrogen daily per vehicle, 7 FCEBs could be fueled from this arrangement with one hydrogen fuel delivery a week. The refueler could support larger fleet sizes with more frequent deliveries or if less hydrogen fuel is needed for each vehicle's daily use. Plug's mobile dispenser can safely operate in temperatures as low as -20 degrees Celsius (-4 Fahrenheit).

3.2.4 Hydrogen Fuel

While it is possible to produce hydrogen on-site, reliable access to fuel production sources and fueling stations is a significant challenge associated with FCEB. Only two transit agencies, Sunline Transit in California and Champaign-Urbana Mass Transit District in Illinois, currently can self-produce the fuel. However, Sunline Transit has experienced production challenges that have led to resiliency issues.[69] As a result, transit agencies must either drive the FCEBs to local hydrogen fuel retail stations to refuel or purchase hydrogen created off-site and trucked to the transit facility. As of July 2024, however, there are only 60 retail hydrogen fueling stations nationwide, all in California except for one in Hawaii.[70] Therefore, although FCEBs are most feasible in California due to a higher prevalence of hydrogen fuel production sources and retail stations, these sources still need to be expanded in number, and currently, none exist in Minnesota.

In 2023, the U.S. Department of Energy selected seven regional clean hydrogen hubs to receive a portion of $7 billion in federal funding.[71] Funded by the IIJA, these hubs are a part of the federal government's efforts to jump-start the market for low-cost clean hydrogen, which it sees as key to achieving climate goals. One of the seven hubs to receive funding was the Heartland Hydrogen Hub (HH2H), a partnership between Minnesota, North Dakota, and South Dakota. HH2H can receive up to $925 million in federal aid to increase hydrogen production in the region.[72]

While this is a positive sign of clean hydrogen availability in the region, this funding has some challenges. The HH2H project is expected to begin hydrogen production in 2029 at the earliest, while conservative estimates have it starting in 2035. It is also important to mention that hydrogen as a vehicle fuel is only

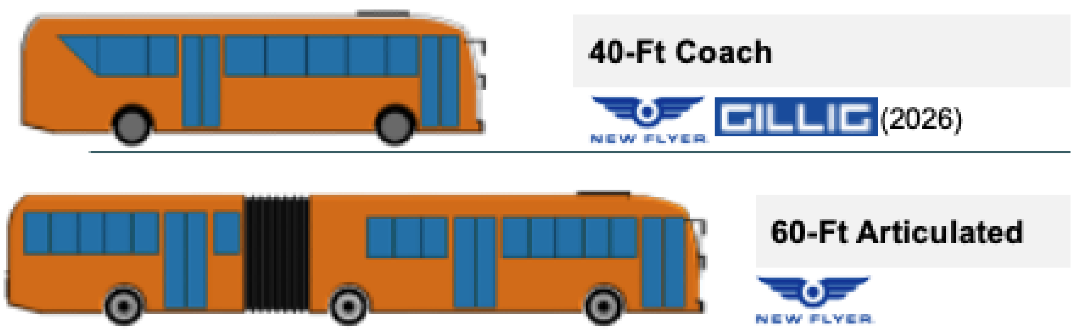
[69] Source: SunLine Transit Agency shares struggles with hydrogen fueling station, Mass Transit Magazine, November 2023.
[70] Source: *Alternative Fueling Station Counts by State*, U.S. Department of Energy, July 2024
[71] Source: Regional Clean Hydrogen Hubs, US Department of Energy, accessed August 2024
[72] Source: Regional Clean Hydrogen Hubs Selections for Award Negotiations, accessed August 2024

one of the uses identified for the hydrogen hubs[73]. The HH2H application focused on using its clean hydrogen to reduce the carbon footprint of its industrial energy generation and fertilizers for agriculture.[74]

3.2.5 FCEB Availability

There is currently only one bus original equipment manufacturer (OEM) producing heavy-duty FCEBs (New Flyer); however, Gillig plans to start production of its own FCEB in 2026 with availability soon after. **Figure 13** shows the current FCEB transit bus availability and its cost multiplier relative to a diesel bus.

Figure 13*:* FCEB Availability[75]



3.3 Battery Electric Buses

BEBs use onboard battery packs to propel and power the vehicle. BEBs are charged either at garages or on-route during operation. Transit agencies located in colder climates typically include an auxiliary diesel heater on their BEBs for supplemental heat to increase bus range.

3.3.1 Vehicles

BEBs have traditionally been categorized into two types: (1) extended-range BEBs and (2) fast-charge BEBs. However, as technology has evolved, the distinction between both vehicle types has blurred, with agencies purchasing buses with larger battery packs and utilizing on-route chargers less than in previous generations.

Extended-range BEBs have larger battery packs (345 to 738 kWh) to maximize their operating range between charges; operationally, they are typically charged once or twice per day (overnight and/or midday). Depending on the size of the battery and charger output, a complete charge cycle can take up to 6 hours or more. While their advertised range may be longer, the reliable range in transit service for currently available BEB models can be as little as 79 miles per charge in Minnesota winters. With the presently available BEB models, it is challenging to perform 1 to 1 replacements of conventional buses with extended-range BEBs due to their limited range and extended charging downtime when compared to diesel buses, which can travel more than 300 miles per tank and take less than 10 minutes to refill.

[73] Source: *Xcel Energy, Heartland Hydrogen Hub selected for up to $925 million federal award, Xcel Energy, October 2023.*
[74] Source: *Heartland Regional H2Hub Community Briefing*, U.S. Department of Energy, November 2023.
[75] Source: Transit Bus Contract- New Flyer Bid Pricing, State of Washington, September 2024.

Fast-charge BEBs are an early version of the technology with smaller battery packs (50 to 250 kWh) and depend on high-powered charges to extend their range. These buses typically charge several times per day, from 5 to 20 minutes at higher power, typically on-route. When implemented effectively, fast-charge BEBs can have an indefinite range of daily operation.

While some fast-charge BEBs are still in service, bus OEMs no longer make buses with their small battery capacities. Instead, extended-range BEBs can be produced with the overhead charge rails necessary for fast charging on an overhead conductive charger on-route or at a bus garage. If an agency plans to utilize on-route charging to extend the bus range, they may elect to purchase a smaller battery size. Many agencies choose the larger battery capacities to avoid the operational risks and increased layover times associated with the on-route fast-charging strategy.

3.3.2 Battery Capacity and Energy Usage

The distance range that a BEB can travel is a function of two primary characteristics: (1) battery capacity and (2) energy usage.

Larger **battery capacity** translates to increased energy (fuel) storage and thus, increased range. As of 2024, BEB manufacturers offer onboard BEB batteries with capacities typically ranging from 345 kWh to 738 kWh.[76,77] These advertised capacities, also referred to as nameplate or nominal battery capacities, indicate the theoretical capacity of a new battery pack. Unfortunately, however, not all the nominal battery capacity can be used for BEB operation. Instead, batteries wear down and become less efficient over time as they are constantly charged and discharged. Also, charging a BEB to full capacity or charging it from a zero state of charge (SOC) increases the rate at which the batteries degrade as this process puts additional strain on the physical and chemical components of the battery. Additionally, just as operators avoid driving a conventional vehicle until the fuel tank is empty, a portion of a BEB's battery capacity is typically preserved for operational flexibility. By preserving this capacity, transit agencies are more likely to be able to plan so that BEBs will have sufficient range to return to the garage in the event of an unforeseen delay or other unexpected event requiring a BEB to remain in service longer than originally planned. These factors translate to usable battery capacities between approximately 170 kWh and 501 kWh.

The amount of **energy usage** by the bus (kWh/mile) also impacts BEB range. When the energy used to heat and cool the bus cabin is the same energy that would be used for the propulsion of the bus, bus range can be substantially reduced in cold weather as increased energy must be devoted to maintaining a comfortable temperature in the passenger cabin. The speed at which a BEB operates also influences energy usage and therefore BEB range. Busy or congested environments typically lead to slower travel speeds and decreased mileage. Buses also often see greater energy usage in busy environments from the doors being open more often and for longer periods of time, increasing energy consumption for temperature control in the bus cabin.

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[76] Source: *Electrifying Transit: A Guidebook for Implementing Battery Electric Buses*, National Renewable Energy Laboratory, April 2021.
[77] Source: *GILLIG's next-generation battery to provide 32 percent increase in onboard energy*, Gillig, November 2021.

3.3.3 Manufacturers

Available BEBs on the market, as of 2024, are listed in **Table 5**. It should be noted that the table only contains publicly available information from the manufacturer for models compliant with Buy America regulations. Compliance with Buy America regulations is required if federal funding is used to purchase buses. Since the publication of the 2022 Transition Plan, bus manufacturers such as Green Power and Nova are no longer producing BEBs for sale to public transit agencies in the United States. BYD, now known as RYDE Mobility, is producing BEBs for transit agencies, however they have been banned from entering new, federally funded bus contracts through the National Defense Authorization Act for Fiscal Year 2020.[78] Proterra Transit declared bankruptcy and was purchased by Phoenix EV in 2023. As of this report, Phoenix is currently evaluating Proterra's existing contracts and is expected to resume selling BEBs within the year. New Flyer is the only Buy America compliant manufacturer of 60-foot BEBs.

Table 5: Currently available BEB manufacturers as of 2024

Manufacturer	Bus Length (feet)	Battery Capacity	Advertised (Nominal) Range	Usable Range in Minnesota Winter*
GILLIG[79]	35 and 40	490 to 686 kWh	170 to 239 miles	96 to 133 miles
New Flyer[80]	35, 40, and 60	345 to 690 kWh	182 to 254 miles	68 to 104 miles
PhoenixEV (Proterra)[81]	35 and 40	492 to 738 kWh	240 to 340 miles	96 to 143 miles

*Usable range assumed to be 68 percent of usable winter battery capacity. See Section 8.3.2 for detail on the motivation and rationale used in developing this conversion rate.

3.4 Charging Infrastructure

Currently, in the North American electric bus industry, available BEB charging infrastructure is primarily categorized into three types: (1) plug-in chargers, (2) overhead conductive chargers, and (3) wireless inductive chargers (**Figure 14**), which are primarily characterized by their dispenser type. Plug-in chargers are more commonly used at garages, whereas overhead and inductive chargers are mostly used for on-route charging. BEB charging infrastructure typically includes transformers, switchgear, chargers (charger "bases" where the majority of equipment is housed), and dispensers (e.g., plugs, pantographs, or charging pads).

[78] Source: Federal Transit Administration Clarifies Limits on Sale of BYD Buses, BYD, August 2024.
[79] Source: FLORIDA ELECTRIC TRANSIT BUSES WITH CHARGING AND ASSOCIATED EQUIPMENT, Gillig, September 2021.
[80] Source: Xcelsior CHARGE NG, New Flyer, August 2024.
[81] Source: ZX5 Transit Bus, PhoenixEV, August 2024.

Figure 14*:* BEB charging infrastructure

Plug-In Charger

Overhead Conducive

Inductive Charger

3.4.1 Types of Chargers

Plug-in chargers typically have between one and four dispensers, allowing for scheduled charging of multiple buses. Charge power for individual plug-in chargers ranges from 60 to 200 kilowatts (kW). Buses frequently have plug-in ports on multiple sides of the vehicle to increase flexibility in parking positions. Per-unit capital costs for plug-in chargers are lower than for other types of charging infrastructure. The J1772 standard, published by the Society of Automotive Engineers (SAE), allows for interoperability of plug-in chargers with different types of buses from multiple manufacturers, analogous to the standardized pump size for gasoline vehicles across manufactures, which allows the gas tank to be filled at any gas station.

Overhead conductive chargers typically use a movable pantograph that lowers down from the charger to connect to the charge rails on the bus. Charge power for overhead conductive chargers ranges from 60 to 450kW. Overhead conductive chargers typically rely on a smaller ratio of chargers to buses due to their higher power output that reduces the footprint for the charging equipment. However, it also means that a malfunction of a charging station may have a larger impact on service if the charger is not available. Overhead conductive charging can be operationally challenging as proper alignment between a bus and pantograph is critical in achieving proper charging. Similar to the standard set for plug-in chargers, the J3105 standard for overhead conductive chargers allows transit agencies to operate different models of buses from multiple vehicle manufacturers with the same overhead conductive charger.

Inductive chargers utilize a wireless power pad embedded in the floor of a garage or roadway surface in addition to a power receiver installed under the bus. Inductive chargers eliminate concerns for overhead clearances, as they are built into the floor of a garage or roadway. However, there may be significant costs and operational disruptions to install, repair, or replace the charger and wireless pad since it would be embedded in the floor of the garage or roadway. Inductive charging can be operationally challenging, as proper alignment between a bus and inductive charger is critical in achieving proper charging. Inductive charging is still considered to be in its infancy, as only a small number of North American agencies have implemented inductive chargers. There have been even fewer deployments in cold weather climates, although Link Transit in Wenatchee, Washington, has demonstrated some early successes with the technology[82]. There is not yet a national standard for inductive charging. As a result, each bus manufacturer could approach this charging strategy differently, meaning that different charging

[82] Source: InductEV expands wireless charging success to Canada, InductEV, April 2024.

equipment may not work for different types of buses or even different bus models from the same manufacturer. These complexities are analogous to how some smartphone charging ports are incompatible with smartphones from other manufacturers or how smartphone companies can change the charging port between phone versions.

A summary of BEB charging infrastructure is shown in **Table 6**.

Table 6: Comparison of BEB charging infrastructure

Charging Infrastructure	Typical Installation	Advantages	Disadvantages
Plug-in Chargers	• Used to charge buses for several hours (usually overnight or between blocks) • One to four buses per charger	• Additional chargers can be added for redundancy • Lowest capital infrastructure cost • Lower cost of (overnight) off-peak electricity can result in lower operating costs	• Require staff to manually plug and unplug buses • Slower charging • Larger battery capacity requirement • Space requirement for equipment with large-scale deployments
Overhead Conductive Chargers	• Used to charge buses for 5 to 20+ minutes at higher power • One charger serves multiple buses	• Operators or maintenance staff can charge buses • No manual connections	• High capital and construction costs • High-power charging may result in higher peak demand, leading to higher electricity bills • Precise alignment required for proper use
Wireless Inductive Chargers	• One charger serves multiple buses	• No manual connections or moving parts • Could be used by multiple vehicle types • Operators or maintenance staff can charge buses	• High capital and construction costs • Charging efficiency varies based on bus alignment • No interoperability among different wireless charger providers/no published standard • Not all vehicle manufacturers offer inductive charging

Note: Adapted from Transit Cooperative Research Program (TCRP) *Research Report 219: Guidebook for Deploying Zero-Emission Transit Buses*[83]

[83] Source: *TCRP Research Report 219: Guidebook for Deploying Zero-Emission Transit Buses*, 2021.

3.4.2 Mega Chargers

As battery electric fleets have grown, the need for more powerful chargers has become more practical. Companies such as Hitachi and Power Electronics now offer chargers with over a megawatt (1000kW) of power. This charger contains multiple modules that can be wired to any of the three dispenser types. For example, a 1.4MW (1400kW) unit may contain 24 modules with ~60kW charging capability. Each module can be wired to one dispenser to charge 24 buses at once or multiple modules can be wired to a single dispenser to provide more charging power, depending on the end users' needs.[84] These units can be installed indoors or outdoors to support depot and on-route charging (**Figure 15**).

Figure 15: 1MW Charger at the Regional Transit Capital in Quebec City

3.4.3 Garage Charging and On-Route Charging

All types of chargers discussed above are capable of garage charging (often for more prolonged durations such as overnight charging). In comparison, on-route charging (also known as "opportunity charging") is typically performed by overhead conductive chargers and is used for shorter layovers. **Table 7** and **Table 8** summarize the key benefits and challenges associated with both charging scenarios.

[84] Source: NB Station, Power Electronics, September 2024.

Table 7: On-route charging benefits and challenges

Benefits	Challenges
Allows for longer blocks	Maintaining chargers throughout the region will be less cost-effective than at garages
Allows for closer to 1:1 replacement of buses	4x cost of garage chargers
Fewer changes to block configurations required	Challenging to maintain outdoors in Minnesota winters without targeted mitigations in equipment design
Provides greater flexibility in service design	More expensive to operate due to daytime electricity premium
Smaller batteries, greater efficiency	May require more operators and vehicles to allow for longer layovers if charging ability does not align with layover time
Increases bus productivity by remaining in service for extended times	Adds operational complexity, as proper alignment between the charger and bus side is critical for proper connection

Table 8: Depot charging benefits and challenges

Benefits	Challenges
Chargers are centrally located for easier maintenance	Reduced service delivery due to less opportunities to charge during the day
Charging during non-revenue service, therefore reduced service delivery risk if equipment malfunctions	As BEB fleet size increases, depot charging infrastructure may take up more indoor space
Chargers are stored safely within Metro Transit property and are protected from vandalism	Single charging location means any power loss will limit all vehicles' ability to charge

Benefits	Challenges
Centralized charging empowers more vehicles to charge, not just the vehicles serving an on-route location	Shared charging infrastructure at the depot may require additional vehicle movements throughout the night to ensure all vehicles have time to recharge
Allows buses to service different routes, not just ones with on-route chargers	Buses parked in one position while charging may prevent other vehicle movements during pullout

3.5 Comparison of Zero-Emission Bus Propulsion Technologies

Having introduced each of the three types of ZEBs as well as their operating characteristics and fueling/charging infrastructure above, **Table 9** presents a direct comparison of several critical aspects across each of the three ZEB technologies.

Table 9: Comparison of ZEB propulsion technologies

Consideration	Electric Trolleybus	BEB	Hydrogen FCEB
Range	• Unlimited range on overhead catenary wire • Limited auxiliary off-wire operations around 15 to 22 miles	• Potentially unlimited range with on-route charging • Garage-only charging has a limited range (likely less than 150 miles on a single charge) influenced by battery capacities, challenging climates, and topographies.	• Proven range of up to 250 to 300 miles per day
Fueling/Charging Technology	• Electricity sourced via overhead wires • Auxiliary batteries or fuel tanks can be added to augment flexibility in operations	• Can be charged at garage or on-route via: ○ Plug-in charging ○ Overhead conductive charging ○ Wireless inductive charging	• Hydrogen can be stored in gaseous or liquid states • Can produce hydrogen on-site • Mobile/temporary fueling solutions are available for smaller deployments[85]
Capital Costs	• High initial capital cost as overhead	• BEBs are more expensive than diesel buses	• Buses are more expensive than both diesel and BEBs.

[85] Source: Plug Delivers Several Portable Liquid Hydrogen Refuelers to Customers, Plug Power, 2024.

Consideration	Electric Trolleybus	BEB	Hydrogen FCEB
	wires are required throughout the corridor for power supply • Significant capital cost to retrofit garages with overhead wires	• Charging infrastructure costs are initially low, but increase with fleet size • Space requirements increase with fleet size as charging infrastructure expands	• Permanent fueling infrastructure has a high upfront cost for any size deployment but requires limited additional costs as fleet expands. • May require significant facilities upgrades to safely store hydrogen due to it being a lighter-than-air gas
Operating Cost Considerations	• Higher maintenance costs to maintain overhead wire system • Increased electricity usage during peak (more expensive) periods	• Longer layover times necessary for on-route charging requires more operators and vehicles • Garage charging provides opportunities to charge during off-peak (less expensive) periods • Allows budget predictability due to stable utility rates	• May require less operators and vehicles compared to BEBs due to greater vehicle range • Significant fuel costs ($10 to $16 per kg) • Fuel storage O&M costs can be expensive.
Recharging/ Refueling Considerations	• No recharging/ refueling required for operations • Regular maintenance of overhead wires required, analogous to rail tracks and systems maintenance	• Reduced upstream carbon emissions compared diesel and hydrogen • Charging times can last up to 8 hours, which may create risks for bus pullout • Major facility and operational changes are often required	• Significant upstream carbon emissions to extract and transport hydrogen • Refueling times of 5 to 10 minutes are much faster than for BEBs • No current hydrogen fueling stations or production facilities in Minnesota

Note: Adapted from TCRP *Research Report 219: Guidebook for Deploying Zero-Emission Transit Buses* and California Fuel Cell Partnership unless otherwise noted.

4 Zero-Emission Bus Case Studies

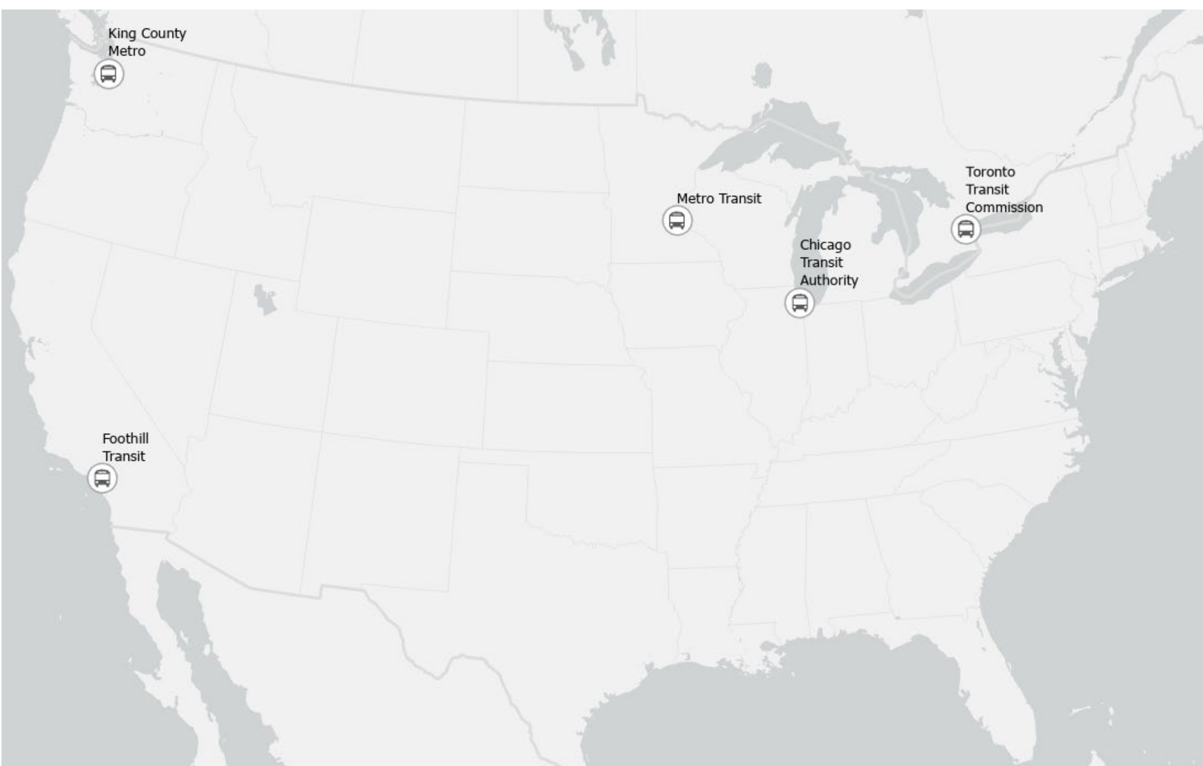
This section summarizes case studies of five transit agencies' experience implementing ZEB technology. Each case study documents the transit agencies' experiences with ZEBs, including key lessons learned, best practices, and challenges faced during their ZEB transition.

During the development of the 2022 ZEBTP, Metro Transit compiled lessons learned from five North American transit agencies that have implemented or piloted a variety of ZEB types and systems. These case studies focus on agencies with a long track record of operating ZEBs, with emphasis on northern agencies located between 40- and 50-degrees latitude, except for Foothills Transit (**Figure 16**). Since the ZEBTP's publication, Metro Transit has continued to engage with more than 40 peer agencies around the continent, taking stock of key takeaways from operators' ZEB experiences.

To provide insight from a wide range of ZEB implementation scenarios, the case studies were specifically selected to encompass a variety of different technologies (buses and supporting infrastructure), fleet sizes, climates, future goals, and operating characteristics (urban, suburban, local service, express service). The case studies summarized in this review include:

- Metro Transit – Minneapolis-Saint Paul, Minnesota
- Foothill Transit – Greater Los Angeles, California
- King County Metro– King County, Washington
- Chicago Transit Authority (CTA) – Chicago, Illinois
- Toronto Transit Commission (TTC) – Toronto, Ontario, Canada

Figure 16*: Geographic Distribution of Case Studies*



Metro Transit reviewed and refreshed each case study to ensure that the most current, readily available information available informed in the agency's ZEB transition effort. To this end, Metro Transit examined publicly available ZEBTPs, news articles and announcements of new technology and fleet additions, executive updates and reports, and all public information about fleet changes available on each agency's website.

In addition to the formal case studies presented below, Metro Transit staff regularly engage in peer discussions to exchange ZEB experiences, challenges, and successes two to three times per month (**Figure 17**). Since the plan's publication, Metro Transit participated in 60 peer exchange discussions and hosted the American Public Transportation Association (APTA) Mobility Conference, where Metro Transit staff led several sessions and tours focused on discussing ZEB technology and advancements.[86] Metro Transit has also been sought out for their ZEB expertise by the National Academy of Science and the National Renewable Energy Lab to aid in research on ZEBs. Metro Transit staff actively participate in the Minnesota Electric Transit Call and the North American eBus Experience Group, hosted by the TTC. The latter meets several times per year to share experiences and challenges with electric bus deployment and includes over 40 North American transit agencies. In addition, Metro Transit's manager for electric bus infrastructure is currently serving in her third term as an officer of APTA's Zero-Emission Fleet Committee, which compiled the *Battery Electric Bus Charging Infrastructure: Key Performance Indicators* document in 2023. The Zero-Emission Fleet Committee is an industry forum for the discussion and sharing of information and best practices around ZEBs and infrastructure. The Key Performance Indicators (KPI) document identifies a menu of BEB charging infrastructure KPIs that agencies can use to determine which metrics are best suited to their operations.[87]

Figure 17: ZEB Engagement since 2022 ZEBTP Publication

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[86] Source: [*Metro Transit's Presentation to the Metropolitan Council about ZEB advancements*](), Outreach and Engagement Information, Slide 37.
[87] Source: [BEB Charging Infrastructure KPIs](), APTA, 2023.

4.1 Metro Transit (Minneapolis-Saint Paul, Minnesota)

4.1.1 Zero-Emission Bus Program History

Metro Transit has a long-standing history of implementing projects, policies, and programs to move the agency towards greener operations. In 2018, Metro Transit established a BEB pilot program during the implementation of the METRO C Line (**Figure 18**), an arterial BRT route traveling from Downtown Minneapolis to Brooklyn Center. This pilot program included the purchase of eight New Flyer 60-foot Xcelsior Charge BEBs with 466 kWh batteries, two on-route overhead conductive chargers installed at the Brooklyn Center Transit Center (the route's northern terminus), and eight plug-in garage chargers installed at the Fred T. Heywood (Heywood) Garage. The METRO C Line was selected for the pilot program as the first route in the region to receive electric bus service. In part, the C Line was selected because it is a heavily utilized transit corridor serving historically underinvested communities with historically higher rates of asthma, in Downtown Minneapolis, North Minneapolis, and Brooklyn Center. Service on the METRO C Line BEB pilot began in June 2019.

Figure 18: Metro Transit C Line 60-foot Articulated BEB

When planning the C Line pilot, Metro Transit determined 60-foot buses would be necessary provide adequate capacity for the high levels of anticipated ridership along the route. At this time, BEBs of that size were a very new technology. Only one manufacturer, New Flyer, produced 60-foot BEBs that had passed Altoona quality and safety testing, a necessary requirement to be eligible to receive FTA funds. As a result, Metro Transit selected New Flyer as the manufacturer for the C Line pilot program. As of 2024, New Flyer continues to be the only manufacturer offering 60-foot BEBs that have passed Altoona Testing and are eligible for FTA funding.

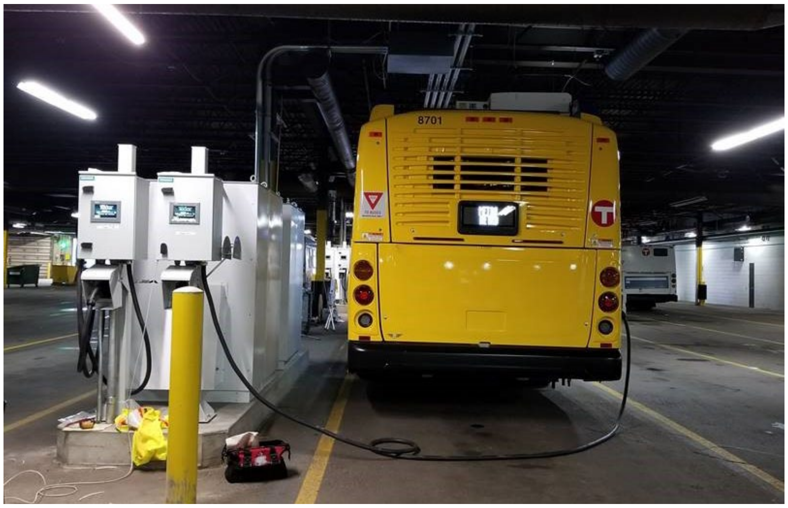
Because 60-foot buses were novel at the time of the pilot, much of the program's infrastructure incorporated new technology. Metro Transit was the first North American transit agency to utilize:

- 60-foot articulated BEBs produced at New Flyer's St. Cloud, Minnesota facility, eight total.
- Siemens HPC 1.0 300kW on-route overhead conductive chargers with serial numbers 1 and 2 (**Figure 19**).
- Buy America compliant Siemens RAVE 150 150kW plug-in chargers, eight total.

Notably, all eight plug-in chargers were replaced under warranty in 2021 with second-generation Siemens MaxxHP plug-in chargers while the two on-route overhead conductive chargers were retired in 2023 due to safety and reliability concerns.

Building upon the C Line pilot program experiences, and in alignment with the 2022 ZEBTP, Metro Transit plans to significantly increase and diversify its ZEB fleet in the coming years. Key project updates include:

Figure 19: Siemens RAVE 150 Plug-In Chargers at the Heywood Garage



- **East Metro Garage:** Purchase of five 690-kWh 60-foot articulated New Flyer BEBs and four ABB plug-in chargers at the East Metro Garage. These buses are planned to enter revenue service in 2025 on the METRO Gold Line. Project construction at East Metro Garage began in June 2024.
- **North Loop Garage:** Purchase of 20 686-kWh 40-foot GILLIG BEBs and 18 plug-in chargers from ABB, ChargePoint, and Heliox. These are planned to enter revenue service in 2026 on local service routes based out of the North Loop Garage.
- **Mobile Chargers:** Four Heliox 60KW mobile chargers will be used for maintenance beginning in 2026. One charger will be located each at the Overhaul Base (OHB), East Metro, Heywood and North Loop garages.

Following these deployments, Metro Transit's BEB fleet will include buses from two manufacturers and seven charger models from four manufacturers (**Figure 20**). This variety will allow Metro Transit to better understand and evaluate different product offerings and service models prior to proceeding with larger ZEB orders.

Figure 20: Metro Transit BEB and Charger Partners (2026)

4.1.2 Operational Experience

Based on the experiences from the first several years of the C Line Electric Bus Pilot Program, Metro Transit has identified elements of program success and improvement. Since the BEB pilot's kickoff in June 2019, Metro Transit has heard positive feedback from both bus operators and passengers who prefer the smoother and quieter ride compared with traditional diesel or hybrid electric buses. In general, when chargers are operational, the BEBs have met estimated range and energy expectations provided by New Flyer at the start of the pilot program. It is worth noting, however, that the pilot's initial on-route charging system was retired in 2023, leading to a change in charging and blocking strategy, discussed in *Charging Strategy Challenges* (Section 5.1.8).

Areas of success for Metro Transit's C Line BEB pilot program are described in greater detail below and include:

- Partnerships and relationship building;
- The dedication of staffing resources to ZEBTP implementation; and
- Contingency planning.

Metro Transit also faced several challenges throughout the C Line BEB pilot program, which are described in greater detail below and include:

- Climate and range;
- Early adoption; and
- Charging strategies.

4.1.3 Partnerships and Relationship Building

One of Metro Transit's key areas of success was in establishing and building interagency relationships with electrical specialists and Xcel Energy, the primary electrical utility provider for Metro Transit facilities.[88] Maintenance of these relationships has allowed Metro Transit to create partnerships instrumental to providing reliable BEB service in the future. For example, Xcel Energy has helped fund make-ready improvements to the Heywood Campus and Brooklyn Center Transit Center such as the purchase and installation of the electric switchgear, conduit, and AC power cables, which connect the transformer to the base of each charging cabinet. Metro Transit and Xcel are also working towards establishing a rate design pilot for the Heywood facility.

In addition to its partnership with Xcel Energy, Metro Transit has relied on electrical engineering consultants and contractors to provide technical expertise and additional staff, allowing Metro Transit to quickly respond to any electrical challenges despite a limited number of in-house Metro Transit staff with appropriate electrical experience.

Through the 60-foot BEB pilot program, Metro Transit developed a network of external stakeholders who are interested in Metro Transit's transition to ZEBs. Metro Transit continues to build upon this network to strengthen existing external partnerships. For example, Metro Transit engages with the PUC by participating in electric vehicle dockets and providing written comments and testimony regarding their experience with BEB adoption. Metro Transit also hosts a ZEBTP annual summit in which it provides

[88] Source: Interview and email with Metro Transit Staff. October 2021.

updates on the transition, including successes and lessons learned over the past year. Additionally, Metro Transit participates in the Minnesota Electric Transit Group, the University of Minnesota Electroposium, and Electrification Engineering Advisory Board. Continued regular involvement with each of these partners is a step towards Metro Transit's cultivation of a broader communication strategy that transparently sets timelines, manages expectations, and outlines the BEB transition goals that define a successful project.

Lesson Learned: Establish partnerships early in the ZEB adoption process to facilitate coordinated operations and knowledge sharing.

4.1.4 Zero-Emission Bus Transition Plan-Dedicated Staffing Resources

Over time, Metro Transit has successfully grown the volume of dedicated resources to ZEBTP implementation.

From 2018 to 2019, Metro Transit established two key efforts to aid in the implementation of the C Line pilot: a senior-level standing meeting between department heads to ensure coordination during the rollout of BEBs and an interdepartmental working group at the staff level. This working group ensured that frontline staff had the latest information regarding BEBs and were able to react to potential issues as they arose in real time. Over time, the compositions and function of these groups evolved to better suit Metro Transit's changing needs. While the working group was eventually retired in 2021, other groups formed to further Metro Transit's ZEB implementation efforts, such as the electric bus infrastructure engineering team and the ZEBTP implementation team. In 2021, Metro Transit established a dedicated electric bus infrastructure engineering team to support ZEB infrastructure engineering including the design, testing, and commissioning of BEB chargers. In 2022, the ZEBTP implementation team was created to focus on incrementally advancing the rollout of BEBs via monthly meetings, affording staff the opportunity to collaboratively talk through questions and resolve ongoing issues. In 2023, the monthly ZEBTP update meeting with senior department heads was revived in response to the need for additional high-level coordination as the implementation plan matured.

From the ZEBTP's publication in 2022 to 2024, Metro Transit has established six positions that focus at least half of their time on ZEBTP implementation. These staff, working groups, and additional shared resources throughout the agency have been instrumental to Metro Transit's ZEB transition.

4.1.5 Contingency Planning

While developing its first BEB pilot program, Metro Transit knew that things would not always go according to plan, especially because the pilot program involved new technology and equipment that had not been used in revenue service before. To proactively prepare for potential challenges associated with these new technologies, Metro Transit developed various contingency plans to help the agency quickly and flexibly respond in the event of any operational issues to ensure a reliable customer experience.

One such contingency plan developed by Metro Transit was branding five additional 60-foot diesel buses as C Line BRT buses.[89] In the event that a BEB could not make service, these C Line-branded diesel buses could be deployed to provide visually similar service along the route. This contingency plan is of particular importance, as the C Line BEBs had an average monthly availability of approximately 64 percent between

[89] Source: *C Line Electric and Diesel Bus Performance Comparison Memo,* February 2021.

June 2019 and December 2023, compared to an 81 percent availability for the C Line diesel buses.[90] These five branded diesel buses were used from the C Line's opening in 2019 until September 2021, when they were unwrapped and placed back into regular service because Metro Transit's BRT diesel subfleet grew in size, with the addition of Orange Line and D Line buses. From September 2021 onwards, a 60-foot diesel bus of similar color and door configuration has been deployed any time a BEB is not available for service.

A second contingency plan used by Metro Transit was the development of an alternative service plan/block configuration, which utilized shorter blocks that did not require the use of range-extending on-route overhead conductive chargers. Due to this planning, Metro Transit was able to provide BEB service on the C Line in the initial, temperate months of the pilot program while the installation of on-route overhead conductive chargers was finalized. Metro Transit discovered that although the alternative service plan/block configuration was successful during warmer months, it was ultimately insufficient for colder weather conditions that necessitated greater onboard fuel demands. As a result, Metro Transit reduced block lengths from approximately 90 miles to 70 miles to ensure reliable operations in all weather conditions. The alternate service plan/block configuration for BEBs has also allowed Metro Transit to continue to provide BEB service despite retiring the overhead conductive chargers in 2023 due to safety and reliability concerns, although the block length has subsequently been reduced to 55 miles, further discussed in Section 5.1.8.

Lesson Learned: Ensure reliable operations in <u>all</u> weather conditions.

Due to these contingency plans, Metro Transit has not missed service for the C Line due to vehicle unavailability or charger issues despite, at times, experiencing technical difficulties with various aspects of the charging equipment and BEBs. Prominent technical difficulties include battery pack failures, blown fuses, failed capacitors, blank charging interface screens, chargers not restarting in extreme cold, transformer failures, and longer than expected charging infrastructure installation and commissioning times. Despite the many lessons learned and successful use of contingency planning on the C Line, this would not be practical at a larger scale nor possible with FTA's spare factor limits. With an average monthly availability that is 17 percent less than diesel buses, BEB technology reliability will need to improve to reduce the need for contingency planning as Metro Transit continues to add more BEBs to the fleet. For further discussion of reliability challenges, see Section 5.1.7.

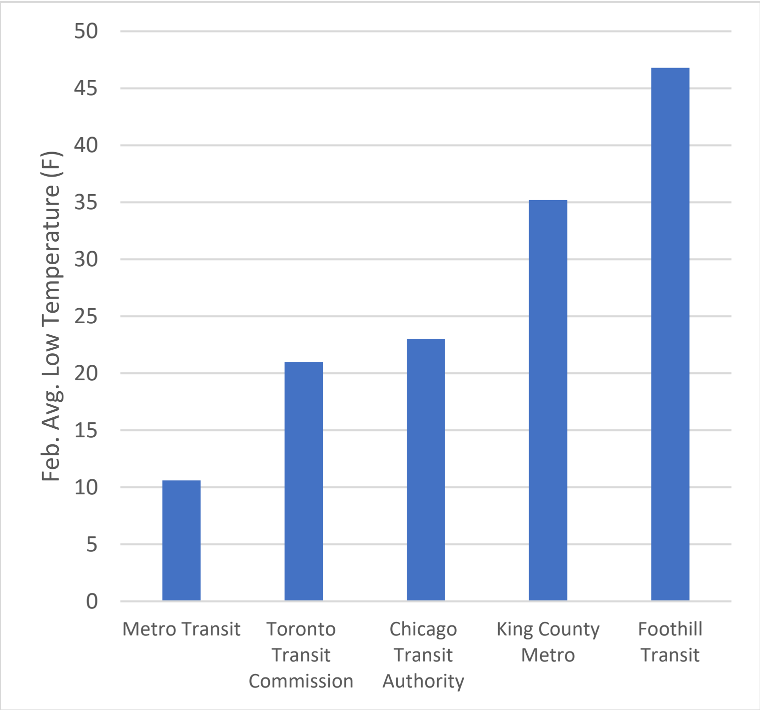
[90] Source: *C Line Electric and Diesel Bus Performance Comparison Data,* December 2024.

4.1.6 Climate and Range Challenges

In addition to the aforementioned areas of success, Metro Transit has been able to use the C Line pilot program to identify and learn from the operational challenges faced during the program. These lessons have led to increased operational knowledge and understanding of BEB intricacies, which contribute to the consistent provision of service for Metro Transit's riders.

In February 2021, the region experienced 13 days of below-zero temperatures down to -19 degrees Fahrenheit.

Figure 21: Average February Temperature, Case Study Cities



One of the biggest challenges that Metro Transit faces in implementing BEBs is the climate in Minnesota, which impacts both range and charging infrastructure. When the energy used to heat the bus cabin is the same energy that would be used for the propulsion of the bus, bus range can be substantially reduced in cold weather. The climate in the Twin Cities region poses challenges not experienced by many (if any) major metropolitan areas in the U.S. Based on 30-year average temperatures, Minneapolis averages the coldest winters of any major U.S. city.[91] Additionally, compared to other peer cities, Minneapolis has the coldest historical low temperature for the month of February (**Figure 21**).[92] Beyond these overall trends, the Twin Cities region also experiences periods of prolonged severe cold. For example, in February 2021 the region experienced 13 days of below-zero air temperature, including one day reaching -19 degrees Fahrenheit.[93]

Metro Transit anticipated 150-mile BEB ranges prior to the pilot's implementation, a number that has reduced over time due to challenges with charging infrastructure, weather, and charging strategies (discussed further in Section 5.1.8). At the onset of the pilot, the agency established 90-mile BEB blocks because on-route chargers were not available during the initial deployment of BEBs; this blocking distance was developed based on anticipated range limitations of the buses without on-route charging. As the pilot progressed and temperatures dropped, BEB blocks were shortened to 70 miles to accommodate increased energy requirements associated with vehicle heating. Metro Transit opted to

[91] Source: *America's 20 Coldest Major Cities*. NOAA. 2014.
[92] Source: *Weather Forecast and Temperature*. Weather.us. 2014.
[93] Source: *Twin Cities Weather – February 2021*, Weather.gov, 2021.

shorten BEB block lengths to 55 miles reduce the complexity associated with seasonal, or even daily, variations to operations.

To reduce the impact of cold weather on bus range, Metro Transit's BEBs are equipped with diesel auxiliary heaters, similar to the agency's diesel buses. These can be used in cold weather to heat the cabin, allowing the electricity from the battery to primarily be used to propel the bus.

Figure 22: Temporary Charger Structure

Extreme low temperatures also proved to be problematic for the operation of Metro Transit's outdoor on-route overhead conductive chargers. These chargers had a minimum operating temperature of -20 degrees Fahrenheit, which is a temperature the Twin Cities occasionally drops below. Chargers were unable to start when the temperature dropped below these levels. Metro Transit adapted to this challenge by building temporary structures around the chargers and blowing hot air into the sheltered environment (**Figure 22**). Only then could the agency warm charging equipment, returning functionality to these devices.

In 2023, as a result of safety and reliability concerns associated with on-route charging and discussed further in Section 5.1.8, on-route charging was retired.

4.1.7 Early Adopter Challenges

Metro Transit's BEB pilot program was one of the first programs to experience and operate 60-foot BEBs in cold weather transit service. The pilot program also utilized technology and equipment that had never been implemented before, including the first eight 60-foot articulated BEBs produced at New Flyer's St. Cloud, Minnesota facility, Siemens HPC 1.0 300kW on-route overhead conductive chargers with serial numbers 1 and 2, and the first eight Buy America-compliant Siemens RAVE 150 150kW plug-in chargers.

As an early adopter of these BEB technologies, Metro Transit experienced unique operational challenges related to both the climate and technological novelty of the C Line pilot program. Although being an early adopter meant that Metro Transit experienced additional challenges, operating in real transit service settings provided Metro Transit and partner vendors with the opportunity to identify and adapt to shortcomings as they continue to arise.

Following the delivery and acceptance of the BEBs, Metro Transit identified several lingering challenges with the BEBs and their associated charging infrastructure, including both software and mechanical issues. Several system software updates were necessary to correct the initial configuration of the heater controls and bus acceleration rates as well as to resolve wheel slippage issues in snow and icy conditions.[94] In addition to software updates related to these specific issues, general software updates are necessary to keep pace with the rapid advancements and improvements to BEB technology. For example, between March 2019 and December 2021, 25 updates, or nearly one update every month, were been made to the C Line's BEB software.[94] Although each update improves BEB operation, Metro Transit

[94] Source: Interview and email with Metro Transit staff, October 2021.

must learn new BEB software each time. In addition to these software setbacks and frequent updates, Metro Transit also experienced and corrected bus mechanical challenges including wire and cable connection issues and battery cell failures that led to lower output voltages and the need to replace individual batteries.

Lesson Learned: Battery reliability is inconsistent and can reduce operational capacity for extended periods of time.

Battery reliability has been one of the substantial challenges faced by Metro Transit throughout the C Line's operation. Because Metro Transit was an early adopter, real-world battery life data was not readily available during the pilot's planning phase. The agency began with the assumption that batteries would require mid-life overhaul, but this has not been Metro Transit's experience. Instead, batteries require replacement on a pack-by-pack basis. Early in the pilot, individual batteries needed to be replaced only occasionally, but this has become more prevalent over time. Because battery failure occurs sporadically, it is challenging to proactively address, and it serves as the primary cause for bus unavailability. Supply chain challenges exacerbate disruption, extending the timeline to obtain replacement batteries. While Metro Transit's extended warranties currently shield the agency from additional financial burden associated with battery replacement, BEB unavailability means that Metro Transit cannot operate at full capacity.

A greater number of battery pack replacements and shorter blocks result in a reduction in miles traveled per BEB, which has additional impacts on Metro Transit's operations (**Table 10**). Not being able to fully utilize BEBs shifts the burden to diesel buses, which increases wear on newer diesel buses and decreases the window of time when they can have maintenance and repair work performed. It can also cause older, non-BRT buses to be placed into service on BRT routes, which increases the maintenance needs of vehicles that would have otherwise belonged to "non-active fleet" status.

Historically, Metro Transit has not tracked bus availability, defined as the percent of buses available for use in service, as the ability of diesel buses to make revenue service has not been a concern. However, due to the early and continued challenges associated with operating BEBs, BEB availability is closely monitored. As of 2023, six BEBs are planned for use on a typical day while the remaining two BEBs are spares to allow for non-revenue needs such as maintenance and training. In 2023 as well as in 2024, an average of only four BEBs were available per day. Although BEB availability was at its lowest in 2023, annual BEB availability has averaged at or below the six bus (75 percent) delivery schedule since the pilot program began in 2019 and the 90 percent target established in the 2022 ZEBTP (**Figure 23**).[95]

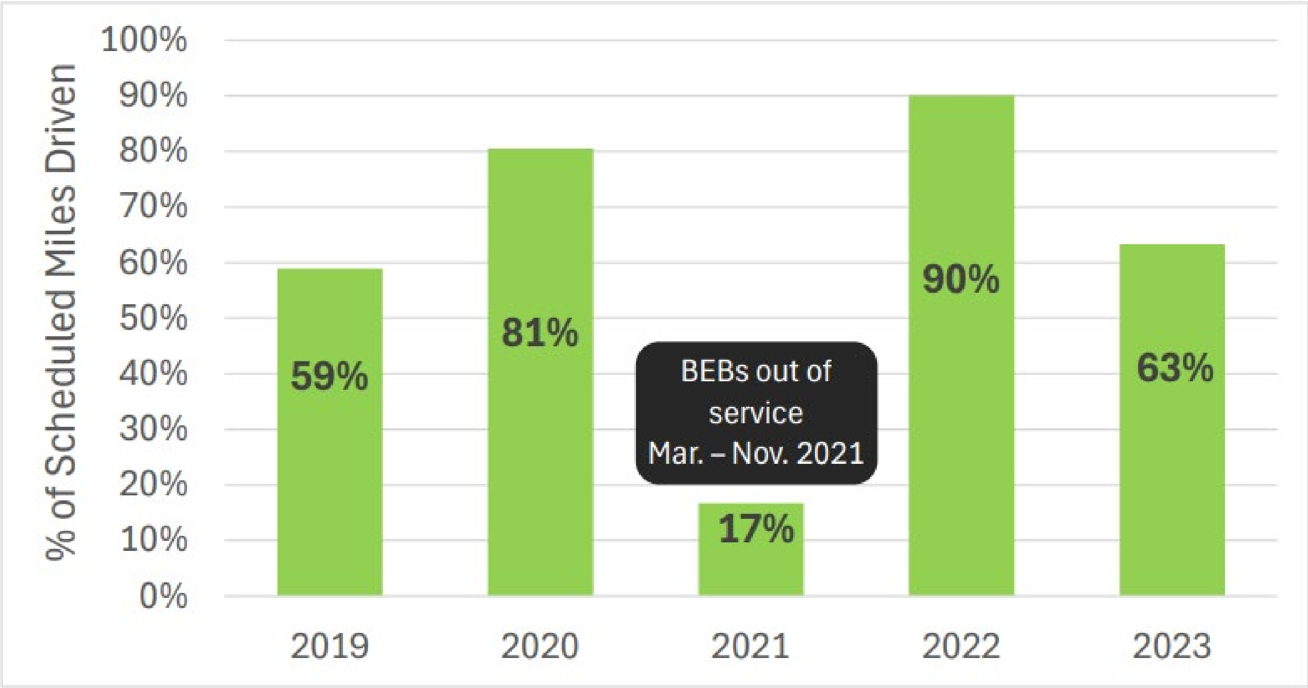
Table 10: Total annual C Line miles driven by propulsion type (2020 to 2023)

	2019	2020	2021	2022	2023
Annual C Line BEB Miles	66,400	162,700	37,800*	175,300	117,400
Annual C Line Diesel Miles	312,600	466,700	625,200	476,900	561,800

*2021 metrics measured for the 90 days BEBs were used in service, due to charges being replaced under warranty.

[95] Source: *Metro Transit ZEB Transition 2023 Annual Report*, Metro Transit, June 2024.

Figure 23: Percent of BEB Miles Driven vs. Scheduled (2019 to 2023)



As part of Metro Transit's efforts to monitor performance and resolve potential BEB-related challenges, Metro Transit also tracks the number and frequency of chargeable C Line road calls; road calls are defined as instances when a bus requires unplanned maintenance attention while in service. As road calls involve removing a bus from service, these issues have the potential to delay passengers until a replacement bus can be dispatched to continue and complete the trip. During the first 7 months of the pilot program (June 2019 to December 2019), C Line BEBs had poor reliability with an average chargeable road about every 1,300 miles, more than 6 times the frequency of chargeable road calls for comparable 60-foot diesel BRT buses (**Table 11**). Through working with the bus and charger manufacturers to perform incremental upgrades and improvements, Metro Transit was able to resolve and learn from these challenges, and in 2020, BEB reliability significantly improved with the average distance between chargeable road calls increasing to about 4,300 miles. From 2020 to 2022, however, BEBs were approximately half as reliable as comparable 60-foot diesel BRT buses. In 2023, BEB reliability declined driven by a significant number of battery pack replacements and reduced BEB fleet mileage due to the retirement of the Brooklyn Center Transit Center (BCTC) on-route chargers prior to schedule reductions in December 2023.

Table 11: Mean distance between chargeable road calls

Year	60-Foot BEB BRT Bus *Average Miles Between Chargeable Road Calls*	60-Foot Diesel BRT Bus *Average Miles Between Chargeable Road Calls*
2019 (June to December)	**1,270**	**8,247**
2020	**4,281**	**8,656**
2021* (January to March, November to December)	**2,763**	**5,201**
2022	**4,870**	**8,862**
2023	**2,668**	**7,700**

*2021 metrics measured for the 90 days BEBs were used in service
Source: Metro Transit ZEB Transition 2023 Annual Report[96]

Beyond bus-specific challenges, garage plug-in chargers required repairs at least once per month in 2020 and 2021 to resolve various incidents. As a result, all garage plug-in chargers were replaced under warranty in 2021; though the agency did not bear the financial burden of replacement, charger repair and replacement were nonetheless disruptive to typical operations. Since their replacement, plug-in chargers have met operational needs and have required repairs less than once per month.

On-route overhead conductive chargers used for the pilot program have also contributed to Metro Transit's early adopter challenges. From 2019 to 2023, these chargers have experienced dozens of blown fuses, as well as a premature transformer failure leading to the chargers being out of service for extended periods of time. In 2023, both of Metro Transit's on-route chargers were retired due to safety considerations, reliability concerns, and operational costs (see Section 5.1.8 for more information).

As a result of these challenges, the BEB pilot program was suspended three times between launch and November 2021, and C Line service has had to rely more heavily on diesel buses than originally planned.[97] These outages lasted approximately 1 week in July 2019, approximately 1 month in October 2019, and 9 months from March 2021 through November 2021. To minimize charger-related issues and reliance on contingency plans, moving forward Metro Transit intends to avoid widespread usage of the low serial number equipment while still striving to be an early adopter of a variety of BEB technology.

To address and resolve the challenges associated with being an early adopter of new technology and given the added software and technical complexity of BEBs compared to diesel buses, Metro Transit has learned the importance of allowing significant time to accept and test BEB equipment. Compared to diesel procurements where supporting infrastructure is already in place at Metro Transit garages, based on the C Line pilot program, Metro Transit has reaffirmed the importance of allowing increased lead

[96] Source: [Metro Transit ZEB Transition 2023 Annual Report](), Metro Transit, June 2024.
[97] Source: *C line Electric and Diesel Bus Performance Comparison Memo*, February 2021.

times and construction times to install the significant electrical infrastructure necessary to support successful BEB operation.

4.1.8 Charging Strategy Challenges

Metro Transit's C Line pilot program initially included an on-route charging strategy for BEBs, though this ultimately presented additional operational challenges and was eliminated in June 2023.

Lesson Learned: BEB operations are not interchangeable with diesel buses. Plan staffing considerations accordingly.

The C Line is Metro Transit's shortest BRT route, providing 10-minute headways at peak service, with a one-way run time of approximately 38 minutes per trip. During initial stages of the C Line pilot, BEB blocks operated at varied times of the day and were allocated the same recovery time as diesel blocks. However, operators noted on-time performance concerns with this scheduling. BEBs utilizing on-route charging require comparatively more recovery time than diesel vehicles because buses must make an additional loop around the terminal facility to the charging location. Additionally, operators must achieve precise alignment with the vehicle and charging equipment to engage the chargers and must walk additional distance to the break room. These actions must also be repeated in reverse before operators and vehicles can return to service. In contrast, diesel vehicles can begin recovery immediately after passengers alight. In response to these additional time constraints, Metro Transit implemented a new blocking scheme in August 2022, later refined in December 2023, that reduced block length by approximately 15 miles. Under the new schedule, all BEBs operate in peak, rather than at various times throughout the day, and blocks are 55 miles in length to address scheduling and labor operational efficiencies. To accommodate the additional time requirements of on-route charging, 6 minutes were added to the vehicles' existing layover time. These blocking changes required an additional BEB, operator, and footprint, resulting in additional capital and operational costs, as well as opportunity costs to service.

On-route charging also faced several other operating challenges related to weather conditions and communications. As previously mentioned, Metro Transit's on-route chargers were required to operate in weather conditions where temperatures dipped below the device's designed minimum. The agency was able to adapt to this challenge by constructing shelters surrounding the chargers and blowing hot air to raise the ambient air temperature and ensure charging capabilities. Metro Transit faced other weather-related challenges regarding snow blowing and the precision needed to achieve alignment between vehicles and chargers in snowy conditions. Additional operational challenges arose when charging problems occurred at unstaffed facilities, presenting communication and troubleshooting issues when trying to resolve these issues. Ultimately, on-route charging was taken offline in 2023 due to these challenges, as well as the additional capital and operational costs associated with operations.

4.1.9 Lessons Learned

Based on the C Line BEB pilot program, Metro Transit has learned several key lessons:

- Where possible, avoid BEB deployment based on schedules driven by launch of a new service to allow for enough time to accept and test BEB equipment.

- BEB projects require significantly greater lead and construction times due to the need for new infrastructure investments, unlike diesel bus procurements where such investments have been previously made.
- Establish a broader communication strategy with more frequent stakeholder communication to transparently set and manage expectations.
- Clearly define successful ZEB implementation and deployment.
- Establish an internal project team dedicated to working on ZEB projects rather than adding ZEB project work to daily staff responsibilities.
- Be an early adopter but not the first adopter; avoid low serial number equipment.

4.2 Foothill Transit (Greater Los Angeles, California)

4.2.1 Zero-Emission Bus Program History

Foothill Transit has long been an industry leader in sustainable transportation. In 2010, Foothill Transit was the first transit agency in the country to put fast-charge BEBs on the road. Based on their experience with early BEBs and to align with the California Air Resources Board's Innovative Clean Transit Program, in 2019, Foothill Transit set their transition goal to target a 100 percent zero-emissions fleet by 2040 (previously 2030).[98] As of 2024, Foothill Transit's ZEB fleet has grown to include a total of 52 ZEBs in revenue service (14.5 percent of the total bus fleet) including the first two double-decker BEBs purchased by a United States public transit agency (**Figure 24**) as well as 33 FCEBs (**Table 12**).[99, 100, 101]

Figure 24*:* Foothill Transit Enviro500EB Double-Decker BEB

[98] Source: *Foothill Transit Announces All Electric Bus Fleet By 2030*, Foothill Transit, May 2016.
[99] Source: Foothill Transit Sustainability, Foothill Transit.
[100] Source: *Foothill Transit Agency: Leveraging the Power of Fuel Cells*, Ballard Bus Blog, 2024.
[101] Due to Minnesota's climate, Metro Transit stores it buses indoors, as a result, double decker buses would require major renovation to a garage due to the fixed height of garage doors for vehicle entry and exit.

Table 12: Foothill Transit fleet composition[102]

Bus Type	Bus Quantity	Manufacturer and Model
FCEB	33	Xcelsior CHARGE H2 buses
CNG	307	Various ages and types of CNG buses
BEB	19	40-foot Proterra buses (fast-charge and extended-range)
BEB	2	45-foot ADL Enviro500EV Double-Decker buses
Total	359	--

Foothill Transit's initial experience with ZEBs was BEBs, but after gaining experience with BEBs and learning about their limitations, the agency began exploring other ZEB options. Limited range was the biggest challenge that Foothill Transit experienced with their BEB fleet. On average, the BEBs operated at approximately 60 percent of the expected range and required up to 4 hours to charge. "I would say that I was disappointed with a pure battery electric solution," said Roland Cordero, Foothill Transit's director of maintenance and vehicle technology. "It really does impose range limitations on the buses. I thought they would perform better—especially in our climate conditions." Cordero noted that, for a full transition to BEBs, the agency would have required 1.5 BEBs for every existing CNG bus to maintain all existing routes and service.[103]

As an alternative to BEBs and to address existing challenges, Foothill Transit began to explore the hydrogen fuel cell electric technology and found FCEBs to be a better fit for the service, frequency, and capacity the agency was aiming to provide. In the agency's experience, FCEBs operate the same way CNG buses do. On average they take about 8 minutes to refuel and stay at full charge for longer due to the holding capacity.[104] The battery in a FCEB is small and powered by the chemical reaction between hydrogen and oxygen.

While Foothill Transit has deemed a 100 percent BEB fleet impractical given the current state of the technology, the agency is still open to technology or design advancements that might result in better long-term BEB operations.

The following sections will discuss the most recent developments with Foothill Transit's ZEB fleet from FCEBs to BEBs.

4.2.2 Fuel Cell Electric Bus Program

As part of Foothill Transit's commitment to sustainability and the environment, the agency is continuously seeking new ways to advance zero-emission technology. In line with this commitment, in December 2021, Foothill Transit developed a plan to deploy 33 FCEBs and the associated fueling infrastructure on Line 486, a 20.5-mile route that provides service between El Monte and Pomona. The FCEBs began service in December 2022. Foothill Transit has plans to add an additional 19 FCEBs in fall 2024. In addition to Foothill Transit's FCEBs, the agency has also built a hydrogen refueling station to support their bus

[102] Source: *Foothill Transit Agency: Leveraging the Power of Fuel Cells*, Ballard Bus Blog, 2024.
[103] Source: *Foothill Transit Agency: Leveraging the Power of Fuel Cells*, Ballard Bus Blog, 2024.
[104] Source: *Foothill Transit Agency: Leveraging the Power of Fuel Cells*, Ballard Bus Blog, 2024.

services. The Pomona Hydrogen Fueling Station was built in 2022 and includes a 250,000-gallon tank, the largest fuel tank used for transit in North America. To support the 19 new FCEBs, Foothill Transit is planning on building another hydrogen fueling station in the Arcadia Bus Yard.

4.2.3 Fuel Cell Electric Bus Operational Experience

Foothill Transit operates FCEBs out of the Pomona Hydrogen Fueling Station and its BEBs out of the Arcadia Bus Yard and a transit center in Azusa (to supplement in-route charging). All the FCEBs are Xcelsior CHARGE H2 buses. Out of the current 33 FCEBs, 20 operate on Line 486, which runs from the Pomona Transit Center to El Monte Bus Station.[105] The other 13 buses now run on Line 291. Additional details of this service are available in Section 5.2.4.1.

4.2.4 Battery Electric Bus Operational Experience

All of Foothill Transit's current BEBs, excluding the two double-decker BEBs, are Proterra buses and utilize Proterra's lighter weight composite body (**Figure 25**). The agency operates two 40-foot fast-charge Proterra BEBs, 17 extended-range 40-foot Proterra BEBs, and two 45-foot ADL Enviro500EV Double-Decker buses. The following subsections summarize Foothill Transit's experience with these BEBs.

4.2.4.1 Fast-Charge Battery Electric Bus Experience

Line 291, a 16-mile round-trip local route running between the cities of La Verne and Pomona was Foothill Transit's first BEB experience with fast-charge BEBs. Not only was Line 291 the agency's first BEB route, but it was also the first all-electric fast-charge bus line in the nation.[106] The first BEB servicing this route was deployed in 2010 and, by 2014, the route was exclusively served by 15 total BEBs. Previously, 13 of the 15 fast-charge BEBs operating on this route were 35-feet long, while two were 40-feet long. Between 2023 and 2024, the 13 fast-charge 35-foot BEBs were replaced by 13 FCEBs, achieving a 9- to 13-year lifespan.[107] Currently, Foothill Transit primarily operates two fast-charge 40-foot BEBs and 13 FCEBs on this line.

Figure 25: Foothill Transit Overhead Charger and Proterra Electric Bus

Based on historical data collected between 2014 and 2020, Foothill Transit's 35-foot and 40-foot fast-charge BEBs had an average availability of 80.6 percent and 76.1 percent, respectively (**Table 13**).[108] As a result, BEBs of both lengths did not consistently achieve Foothill Transit's 85 percent availability target across the duration of the study period. They also fell short of the 94 percent availability achieved by the baseline CNG buses during the same timeframe.

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[105] Source: *FY2025 Adopted Business Plan and Budget*, Foothill Transit.
[106] Source: *FY2025 Adopted Business Plan and Budget*, Foothill Transit.
[107] Source: *FY2025 Adopted Business Plan and Budget*, Foothill Transit.
[108] Source: *Foothill Transit Battery Electric Bus Evaluation: Final Report*, NREL, June 2021.

Table 13: Summary of Foothill Transit fast-charge BEB 2014 to 2020 evaluation results

--	Fast-Charge 35-Foot BEBs	Fast-Charge 40-Foot BEBs	CNG 40-Foot Buses (Baseline)
Average Monthly Mileage per Bus	1,885	1,594	4,606
Availability (85% Target)	81%	76%	94%
Fuel Economy	2.15 kWh/mile	2.10 kWh/mile	3.74 mpgge*
Fuel Cost ($/mile)	$0.45	$0.45	$0.28
Miles between Road Calls (MBRC) – (4,000 Target)	5,680	8,050	25,100
MBRC – Propulsion System Only	13,400	17,000	37,900
Total Maintenance Cost ($/mile)	$0.50	$0.56	$0.32
Maintenance Cost - Propulsion System Only	$0.18	$0.23	$0.13

*Mpgge defined as the miles per gasoline gallon equivalent

Despite a fairly high average availability across the full duration of the evaluation period, analyzing this data on a year-by-year basis provides a more detailed analysis of the BEBs' performance over time. In the first few years of evaluation, from 2014 to 2017, when Proterra technicians were permanently on-site to handle warranty work, the BEBs consistently met Foothill Transit's 85 percent availability target, fluctuating between an average monthly availability of 80 to 100 percent. From 2017 to 2020, however, BEB availability steadily declined from approximately 85 percent to approximately 60 percent.[109]

In addition to monitoring general availability, Foothill Transit also measures the reliability of their buses. To measure bus reliability, Foothill Transit tracks the average MBRC. As shown in **Table 13**, both the 35-foot and 40-foot fast-charge BEBs met and exceeded the 4,000-mile target.

In 2023 and 2024, after between 9 to 13 years of operation, Foothill Transit's 35-foot fast-charge buses were retired. Over time, the electrical components and general body of these BEBs started to show signs of wear. Specific issues with the bus body included cracking, as well as the deformation of plastic interior panels, front wheel cabinets, and driver bulkheads due to the exposure to heat and sunlight.[110] Additionally, as the BEBs aged, their availability decreased. Since the BEB technology was still relatively new, Foothill Transit found it challenging to find replacement parts for the vehicles. For more discussion, see Section 5.1.7.

4.2.4.2 Extended-Range Battery Electric Bus Experience

In addition to short-range BEBs, Foothill Transit also operates 17 extended-range BEBs as of 2024.[111] These buses are based out of the Arcadia facility and primarily operate on Line 280, a 22-mile round trip

[109] Source: Foothill Transit Battery Electric Bus Evaluation: Final Report, NREL, June 2021.
[110] Source: Executive Board Meeting, Foothill Transit, July 23, 2021.
[111] Source: Adopted Business Plan and Budget FY2025, Foothill Transit, June 2024.

running between the city of Azusa and Puente Hills. Unlike the fast-charge buses, the extended-range BEBs are primarily charged by plugging into garage chargers overnight. They take advantage of the overhead fast-charger at the Azusa Intermodal Transit Center to extend the bus range since some of the route blocks go beyond the 150-mile range of these buses.[112]

To evaluate the performance of their extended-range BEBs, Foothill Transit compared several KPIs between 14 40-foot extended-range BEBs and 14 CNG buses (**Table 14**). The BEBs were operated primarily on Line 280 while the CNG buses were randomly dispatched on routes operating out of the Arcadia garage. Based on a year-long evaluation conducted in 2020, Foothill Transit found that the availability of the extended-range buses (82 percent) has not yet consistently achieved Foothill Transit's 85 percent availability target. However, whereas the availability of the fast-charge BEBs has declined in recent years, the availability of the extended-range BEBs remained fairly stable throughout 2020.

Lesson Learned: Choose ZEBs that are right for your agency.

Although these existing buses have not yet consistently achieved the availability target, the relative difference between the evaluation-period BEB and CNG availability was less for the extended-range BEBs (12 percent) than it was for the fast-charge BEBs (13 to 18 percent). Additionally, whereas the fast-charge BEBs had MBRC rates nearly three to four times smaller than the baseline CNG buses, the frequency of road calls for the extended-range BEBs was nearly comparable to that of the CNG buses.

Table 14: Summary of Foothill Transit extended-range BEB 2020 evaluation results

--	Extended-Range 40-Foot BEBs	CNG 40-Foot Buses (Baseline)
Average monthly mileage per bus	3,022	4,687
Availability (85% Target)	82%	94%
Fuel economy	1.90 kWh/mile	3.38 mpgge*
Fuel cost ($/mile)	$0.42	$0.37
MBRC – (4,000 Target)	23,100	24,600
MBRC – propulsion system only	33,800	31,500
Total maintenance cost ($/mile)	$0.36	$0.35
Maintenance cost - propulsion system only	$0.10	$0.12

*Mpgge defined as the miles per gasoline gallon equivalent

4.2.5 Express Service Battery Electric Bus Experience

In 2021, Foothill Transit began operating two 45-foot double-decker BEBs on the Silver Streak Line 707 commuter express route to Downtown Los Angeles. Foothill Transit has heard anecdotal evidence that the BEBs have attracted additional riders to the service and that passengers have enjoyed the overall experience and quality of the ride. For these reasons, among others, Foothill Transit is adding 24 double-decker buses to the fleet in upcoming years.

[112] Source: Foothill Transit Battery Electric Bus Evaluation: Final Report, NREL, June 2021.

4.2.6 Early Adopter Challenges

As an early adopter of BEBs, Foothill Transit has used their operational experience to help BEB and charger manufacturers identify and resolve issues necessary to make design improvements for future generation BEBs.

Foothill Transit has worked with manufacturers to improve reliability issues and the overall "fit-and-finish" quality of the buses. In particular, the fast-charge BEBs steadily degraded from 2019 to their retirement in 2023 and 2024. For example, since 2019, the BEBs have been out of service between 30 to 67 percent of the time. In July 2021, only 3 of the 15 fast-charge BEBs on Line 291 were available for service. As a result, CNG buses were deployed on Line 291 to compensate for the lack of BEBs available for service.[113] These availability challenges informed Foothill Transit's decision to ultimately retire the fast-charge BEBs and replace them with FCEBs.

Lesson Learned: Being an early adopter can cause challenges with sourcing replacement parts as time passes and technology evolves.

The BEBs' high out-of-service rates largely stem from general bus issues and the availability of replacement parts rather than the chargers and bus propulsion systems. The availability of replacement parts is particularly challenging for early adopters such as Foothill Transit who operate and utilize first-generation BEB technology. For example, Foothill Transit's fast-charge BEBs were among the very first produced by Proterra. Proterra and other manufactures now build to industry standards that were adopted long after Foothill Transit first deployed BEB technology, and as such, these buses rely on an overhead fast-charge solution that is obsolete. As manufactures continuously improve their BEBs, parts that failed in earlier generation models are regularly replaced and upgraded. Consequently, Foothill Transit has found that it is increasingly difficult to obtain replacement parts for early generation vehicles and chargers, which has in turn led to lower BEB availability due to the extended periods of time required to source replacement parts. Some of the original parts manufacturers no longer make those parts or are no longer in business. Additionally, due to the technical complexity of BEBs, when an issue does occur, repair times are typically longer for BEBs compared to diesel and CNG buses. This lengthened repair time is in large part due to the extensive quantity of software and programming onboard a BEB. As a result, when a bus fails, it is much harder to quickly diagnose and repair any potential issues.[114]

Overall, due to the relative youth and rapid advancement of BEB technology, there are many unique challenges that Foothill Transit and the BEB industry are still working to resolve.[115] Due to the range limitations and other technological and operational challenges associated with BEBs, Foothill Transit has found that BEBs require changes to the way in which transit service is operated. For example, based on the current state of BEB technology, BEBs cannot be used as a 1 to 1 replacement to deliver the same level of service that is currently provided by CNG buses. Instead, to deliver this same level of service, Foothill Transit would need a significantly larger fleet of BEBs based on the agency's calculations that BEBs are a 1.5-to-1 replacement of existing CNG buses.[116, 117] This increased fleet size would, in turn, lead

[113] Source: Executive Board Meeting, Foothill Transit, July 23, 2021.
[114] Source: Interview and email with Foothill Transit staff, October 2021.
[115] Source: Interview and email with Foothill Transit staff, October 2021.
[116] Source: Interview and email with Foothill Transit staff, October 2021
[117] Source: *In Depot Charging and Planning Study*, Burns & McDonnell, September 2019.

to further increases in capital and operating costs. Due to these fleet implications, in the short term, Foothill Transit is gaining experience with FCEBs as hydrogen fuel sources are available in California and because FCEBs, if reliable, would allow for a 1 to 1 replacement of CNG or diesel buses without significant operational changes.

4.2.7 Charging Configuration

Lesson Learned: When possible to plan for redundancy, do so.

Foothill Transit's existing BEB charging infrastructure consisted of one overhead charger at the Pomona garage, four on-route overhead chargers, 12 60kW plug-in garage chargers, and one 125kW plug-in garage charger.[118] For the fast-charge BEB fleet, overhead fast charging at the Pomona garage also allows for semi-automated charging as the bus progresses through the end-of-the-day cleaning and checkout cycles. The extended-range buses, on the other hand, are charged overnight with the plug-in chargers at the Arcadia garage. As a significant portion of BEB charging also occurs on-route at two transit centers (Pomona Transit Center and Azusa Intermodal Center), two chargers at each location were constructed to prevent potential availability issues. Moving forward, however, Foothill Transit does not plan to implement any additional on-route chargers, as the agency will instead focus on in-garage charging.[119] This decision to focus BEB charging at the garages was made in order to consolidate the number of locations with charging infrastructure investments, which will be easier and less expensive to maintain.

In addition to the FCEB fueling center in Pomona and the slated addition of Arcadia in-route FCEB charging, Foothill Transit also plans to replace the CNG fueling equipment in the future.

4.2.8 Cost Benefit Analysis

Based on over 6 years of data, Foothill Transit's fuel costs by distance across its entire fleet are approximately $0.45/mile for the BEBs and $0.28/mile for the CNG buses.[120] When comparing the life cycle costs between BEBs and CNG buses, Foothill Transit has estimated that pursuing a fully electric bus fleet of 368 buses will cost the agency an additional $15.4 million per year over the next 25 years.[121] This estimation is based on Foothill Transit's experience from 2010 to 2021. As of 2024, there have been 56 buses that have met or exceeded their useful life. In 2023, 13 of those BEBs were replaced with FCEBs, 19 CNGs will be replaced in fall 2024 with FCEBs, and 24 CNGs will be replaced with double-decker BEBs in the next 3 years.[122] However, no information on true life cycle costs of these buses is publicly available.

4.2.9 Prioritization Method

When selecting routes and blocks for ZEBs, Foothill Transit primarily focuses on three considerations. First, the agency has set a goal of prioritizing high ridership routes that serve disadvantaged communities. Second, Foothill Transit also initially focused on routes that serve transit hubs with connections to multiple additional routes in order to expose the greatest number of riders to BEB service while providing the agency with space for on-route charging hubs where future BEB service could charge. As Foothill

[118] Source: Foothill Transit Battery Electric Bus Evaluation: Final Report, NREL, June 2021.
[119] Source: Interview and email with Foothill Transit staff, October 2021
[120] Source: Foothill Transit Battery Electric Bus Evaluation: Final Report, NREL, June 2021.
[121] Source: In Depot Charging and Planning Study, Burns & McDonnell, September 2019
[122] Source: *FY2025 Adopted Business Plan and Budget*, Foothill Transit.

Transit transitions away from on-route charging, this focus on transit hubs will be driven by the connections to other routes rather than charging space available at the transit hub. Until BEB range improves, as a tertiary consideration, Foothill Transit has also focused on ensuring that the initial routes for BEB service operate in areas with level topography to minimize energy consumption and to ensure that routes are technically viable.[123]

4.2.10 Lessons Learned

Lessons learned from Foothill Transit's implementation of ZEBs include:

- Expect the unexpected;
- ZEBTPs should be flexible and dynamic to respond to technology advancements;
- Repair times for BEBs can be longer than traditional CNG and diesel buses due to software complexity;
- Install two charging systems for BEBs as a backup in case a charging station breaks down;
- Understand the different technologies and pros and cons of each transit solution and work with stakeholders to help them understand the technology as well; and
- Implement solutions that work for your transit agency.

4.3 King County Metro (King County, Washington)

4.3.1 Zero-Emission Bus Program History

King County Metro is a national leader and early adopter of alternative-fuel buses including diesel-electric hybrids, electric trolleybuses, and most recently, BEBs.[124] King County Metro operates the second largest electric trolleybus fleet in the country behind San Fransisco Municipal Railway (MUNI) and has for decades.[125,126] These trolleybuses draw power from overhead electrified wires, allowing the buses to efficiently operate on routes with steep hills due to the higher torque their electric motors provide.[127] Despite this benefit, electric trolleybuses require extensive supporting infrastructure, have limited flexibility for off-wire travel, and the overhead wires present maintenance challenges due to potential buildup of snow and ice in winter months. Currently, only four transit agencies across the country operate trolleybuses.[128] As a result, King County Metro operates more trolleybuses than the rest of the country combined, excluding MUNI.

In addition to their electric trolleybus experience, King County Metro was also an early adopter of BEBs, purchasing 11 short-range Proterra BEBs between 2016 and 2018.[129] In 2017, the agency committed to transitioning to a 100 percent ZEB fleet powered by renewable energy by no later than 2040.[130] From 2018 to 2019 King County Metro leased and piloted 10 BEB buses from three manufacturers (Proterra, New Flyer, and BYD) (see Section 5.3.2.2 below). Building upon these experiences and in recognition of the

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[123] Source: Interview and email with Foothill Transit staff, October 2021.
[124] Source: *Metro is Transitioning to a Zero-Emission Bus Fleet*, King County Metro, August 2019.
[125] Source: *National Transit Data Base (NTD)*
[126] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.
[127] Source: *King County Trolley Bus Evaluation*, King County Metro, May 2011.
[128] Source: *The National Transit Database (NTD)*
[129] Source: *Metro is Transitioning to a Zero-Emission Bus Fleet*, King County Metro, August 2019.
[130] Source: *Metro is Transitioning to a Zero-Emission Bus Fleet*, King County Metro, August 2019.

worsening climate crisis, the King County Council adopted an ordinance in February 2020 to shorten the previous transition timeline by 5 years to 2035.[131] To reach this ZEB transition goal, King County Metro plans to continue to utilize electric trolleybuses where they are currently operating while primarily implementing BEBs elsewhere.[132] As of 2024, approximately 16 percent of the agency's buses are ZEBs (174 electric trolleybuses and 51 BEBs[133]).

Going forward, King County Metro plans to primarily focus on expanding their BEB fleet to replace retiring diesel-electric hybrids, although they continue to consider opportunities for strategic expansion and enhancement of the trolleybus system. By 2028, the agency plans to order 360 new BEBs and 30 additional electric trolley buses.[134] Other notable plans include the exploration of adding up to four FCEBs as early as 2026 as part of a pilot project[135] and the plan to replace the trolleybus fleet in 2033, when the existing trolleybus fleet will reach retirement age.[136]

Following these procurements, King County Metro plans to purchase at least 15 BEBs per year between 2028 and 2035.[137] By spacing out their BEB procurements and selecting this timeline, King County Metro anticipates being able to learn from their past BEB procurements and gain valuable operational experience and knowledge based on 2 to 3 years of revenue service with large-scale BEB deployment before purchasing more BEBs. In addition, this lengthened timeline will provide King County Metro with sufficient time to work with their utility provider to make the necessary electrical infrastructure upgrades required to support BEB service.

4.3.2 Operational Experience

As of 2022, King County Metro's operational experience with BEBs is centered around two unique pilot programs: the fast-charge Bellevue Service and the extended-range BEB head-to-head analysis, both of which are described in the following subsections.

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[131] Source: *Council Approves Plan to Accelerate Conversion of Metro Fleet to All-Electric*, King County, February 4, 2020.
[132] Source: Interview and email with King County Metro staff, October 2021.
[133] Note: BEB count reflects 11 40-foot short-range Proterra BEBs, 30 30-foot extended-range New Flyer BEBs, and 20 60-foot extended range New Flyer BEBs.
[134] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.
[135] Source: *Metro Explores Hydrogen Fuel Cell Buses to Reduce Emissions*, King County Metro, June 11, 2024.
[136] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.
[137] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.

4.3.2.1 Bellevue Service

Figure 26*: King County Overhead Gantry Charging System*

As part of King County Metro's first exploration of BEBs, the agency purchased three first-generation rapid-charge 40-foot Proterra BEBs in 2016 followed by an additional eight second-generation 40-foot Proterra BEBs in 2018. These rapid-charge buses provide service on Routes 226 and 241 and have a range of approximately 25 miles.[138] The BEBs are supported by both layover (on-route) charging at the Eastgate Park-and-Ride and base charging (garage charging) at the Bellevue Base (garage). At Eastgate Park-and-Ride, King County Metro uses a unique charging setup with three on-route chargers affixed to a single overhead gantry with space for two additional chargers (**Figure 26**). King County Metro's single gantry charging setup was the first of its kind in North America and allows the agency to minimize the charging infrastructure located at ground level; however, this legacy pantograph system is a unique solution that is no longer available on the market. As the fast-charge BEBs have limited range, they are required to charge during every pass through the Eastgate Park-and-Ride, taking approximately 10 minutes to reach a full charge. During the first year of operations on this service, the cost of fueling the BEBs was nearly twice the cost of fueling diesel buses ($0.57/mi vs. $0.30/mi) in large part due to the higher relative cost of electricity and the demand charges incurred when rates exceeded 50kW.[139] To supplement this layover charging, King County Metro also uses a low-power plug-in maintenance charger and overhead charger located at the base (garage).[140]

From their experience on the Bellevue BEB service, King County Metro has realized the importance of understanding the impact BEBs' operational differences can have on route scheduling and training needs. For example, from a scheduling perspective, while operators on conventional buses can shorten a layover period to make up lost time and keep on schedule, the planned BEB layover times at the Eastgate Park-and-Ride include charging time. Thus, if operators shorten the layover period to get back on schedule, the BEBs may leave Eastgate Park-and-Ride without a full charge. To emphasize the heightened importance of BEB layover time and to highlight other operational differences between BEBs and conventional buses, King County Metro has focused on developing specific training programs for all operators and staff working on routes serviced by BEBs.

[138] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.
[139] Source: *Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses*, FTA, February 2018.
[140] Source: Interview and email with King County Metro staff, October 2021.

4.3.2.2 Head-to-Head Extended-Range Battery Electric Bus Analysis

Complementing their experience with short-range fast-charge BEBs on the Bellevue Service, King County Metro leased a mix of ten extended-range BEBs from three manufacturers (Proterra, New Flyer, and BYD) in 2019 and 2020. This head-to-head analysis pilot test was designed so that King County Metro could gain experience with extended-range BEBs and study the difference in bus performance and technology limitations across different manufacturers. This lease included 40-foot and 60-foot electric buses from New Flyer and BYD and 40-foot buses from Proterra, as Proterra, now Phoenix Motorcars, does not manufacture 60-foot BEBs[141] (**Table 15**). To ensure that the test BEBs would have sufficient range to cover the majority of the routes/blocks in the system, King County Metro required that the manufacturers provide buses with batteries that would support a range of 140 miles or more as part of the contractual language of this lease program.[142] To meet this requirement, all buses had battery packs with capacities of at least 500 kWh. At the end of this testing period, the ten buses and charging infrastructure were returned to their manufacturers.

Lesson Learned: Test different BEBs against each other to identify which best suits your unique transit agency's needs.

Table 15: King County Metro head-to-head BEB testing quantities

Manufacturer	40-foot BEBs	60-foot BEBs
New Flyer	2	2
Proterra	2	0
BYD	2	2

To assess BEB performance in a variety of conditions, King County Metro drove the buses in all types of weather and on all route types, ranging from freeway service to local service with hills.[143] For this lease period, the agency's service planners selected blocks with total distances of 100 miles or less to allow for potential fluctuations in BEB battery efficiency and range. Between September 2019 and June 2020, King County Metro found that although the New Flyer BEBs had the greatest distance between failures and a much higher availability than the Proterra buses, they also had the worst average energy efficiency (**Table 16**).[144]

Table 16: King County Metro BEB head-to-head manufacturer analysis metrics

--	Avg. Energy Efficiency (kWh/mile)	Avg. Availability	Mean Distance Between Failures (Miles)
New Flyer	2.43	54%	6,477
Proterra	1.81	39%	742
BYD	2.09	65%	2,068

Source: Zero-Emission Battery Bus Preliminary Implementation Plan, King County Metro, September 2020.[145]

[141] In November 2023, Proterra's bus manufacturing business line was acquired by Phoenix Motorcars.
[142] Source: Interview and email with King County Metro staff, October 2021.
[143] Source: Zero-Emission Battery Bus Preliminary Implementation Plan, King County Metro, September 30, 2020, accessed. 2021.
[144] Source: Zero-Emission Battery Bus Preliminary Implementation Plan, King County Metro, September 30, 2020, accessed. 2021.
[145] Source: Zero-Emission Battery Bus Preliminary Implementation Plan, King County Metro, September 30, 2020, accessed. 2021.

Despite this variation in energy efficiency, the Proterra and New Flyer 40-foot buses were found to meet or exceed range expectations in all weather and route types, while the 60-foot buses did not perform as well in cold weather, as their range was reduced by up to 50 percent. Additionally, the BYD buses were found to perform poorly in King County's hilly topography. King County Metro noted that a change in the traction power motor could improve BYD bus performance in hilly terrain but that the change may impact the BEBs' range.[146]

In addition to providing invaluable data to compare BEB performance across manufacturers, a key success of this head-to-head pilot program was that it allowed stakeholders, including operators, maintenance staff, and customers, to identify and provide feedback on the aspects of each bus type that they did or did not like. King County Metro provided this data and detailed feedback to each of the bus manufacturers. Overall, the head-to-head pilot program has provided the agency with a wealth of information that the agency can use to further improve their future procurement and operation of BEBs.

4.3.3 Key Performance Indicator Reporting

To monitor BEB performance and identify areas for future improvement, King County Metro tracks several KPIs. When initially presenting KPIs, the agency included multiple pages of graphics and numbers summarizing BEB performance. Over the course of their BEB pilot programs, however, King County Metro found that presenting such detailed information was unnecessary and at times could obscure the key takeaways, particularly for stakeholders that were not intimately familiar with the data. Therefore, to increase comprehension and usage of the KPIs, the agency has recently focused on limiting the information they present to just a select number of key items that can be easily understood by stakeholders from a wide range of backgrounds. King County Metro has found that the best way to provide both an overall summary on BEB performance as well as the interaction between performance indicators is to present four KPIs as a single package. These KPIs include:

Lesson Learned: Focus on a limited set of easy-to-understand KPIs.

- kWh/mile
- kWh/hour
- Ambient temperature
- Average speed

Together, these indicators capture and place the overall efficiency of the BEBs in the context of two readily understood characteristics: temperature and speed. To streamline the KPI reporting process and distill the vast amounts of performance data into the most useful and usable reports, moving forward, King County Metro plans to explore pursuing the inclusion of telematics packages with custom report templates on all vehicles. To improve KPI comprehension, the agency anticipates that this prewritten template would include both the KPIs as well as the rationale behind why each indicator is critical towards understanding and evaluating BEB performance.

4.3.4 Charging Configuration

Based on an analysis of their KPIs as well as the overall operational experience of the two BEB pilot programs, in the future, King County Metro has decided to rely primarily on extended-range buses

[146] Source: Zero-Emission Battery Bus Preliminary Implementation Plan, King County Metro, September 30, 2020, accessed. 2021.

charged with a combination of fast and slow chargers located at their bases (garages) as well as charging at select on-route locations.[147] This charging strategy was selected in order to both minimize electricity costs when transitioning to a larger BEB fleet and to gain the operational flexibility to provide BEB service on longer length routes and blocks. For buses with a low midday charge status or those that need to return to service quickly, King County Metro anticipates utilizing its fast chargers.[148] If the agency were to only utilize its garage-based lower-power chargers, King County Metro estimates that 70 percent of their existing service could be supported with no route structure changes assuming a BEB range of 140 miles.[149] King County Metro recognizes, however, that BEBs are different than diesel and diesel-electric hybrid buses and therefore, may require some changes in operating strategy to extract the maximum utility from these vehicles. In the short term, however, the agency does not intend to change route structures of their block buildup given that nearly three quarters of their existing service can be served with the current technology and the charging scheme outlined above.[150]

4.3.5 (Garage) Transition

To support the King County Metro's growing BEB fleet and provide the space necessary to install and operate BEB charging infrastructure, the agency is implementing significant facility renovations. As part of this effort, King County Metro is building a 12-charger installation located at its South Campus, known as the South Base Test Facility (SBTF).[151] The SBTF was designed to be large enough to provide charging infrastructure for the 40 extended-range BEBs that arrived in 2021 and is intended to allow the agency to demonstrate interoperability between various charger and bus manufacturers as well as serve as a facility for the development of training and maintenance practices.[152] The facility features a variety of charging types including overhead gantry systems (with both a pantograph and plug-in dispenser) and mast-style overhead pantograph chargers; a variety of charger OEMs including ABB, Heliox, and Siemens; and pantograph OEMs including Schunk and Stemmann-Technik, a Wabtec company.[153]

In addition to the SBTF, King County Metro is currently constructing its Interim Base (garage) at the South Campus, which is expected to be electrified in 2025.[154] The Interim Base (garage) is intended to be a prototype for future BEB deployment and electrification and will support 120 BEBs. Additionally, the South Annex Base at South Campus will be in operation as an electrified base in 2028 with capacity for 250 BEBs.

King County Metro plans to convert each of its bases sequentially, with conversion at each base expected to have an 18- to 24-month construction timeline depending on the size and complexity. Due to the installation of charging infrastructure within the yards, the agency estimates that there will be a systemwide permanent reduction in capacity of 10 to 15 percent.[155]

[147] Source: Interview and email with King County Metro staff, October 2021.
[148] Source: Zero-Emission Battery Bus Preliminary Implementation Plan, King County Metro, September 30, 2020, accessed. 2021.
[149] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.
[150] Source: Interview and email with King County Metro staff, October 2021.
[151] Source: Interview and email with King County Metro staff, October 2021
[152] Source: *King County Trolley Bus Evaluation*, King County Metro, May 2011.
[153] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.
[154] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.
[155] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.

4.3.6 Cost Benefit Analysis

As King County Metro begins their large-scale transition to ZEBs, a key consideration for the agency is the relative cost difference between operating a zero-emission fleet versus a diesel-hybrid fleet. To inform this consideration, in 2020, King County Metro conducted an updated cost benefit analysis of transitioning to a zero-emission fleet using BEBs. The analysis examined capital, operating, disposal, and societal costs. In this analysis, the agency ran two scenarios: the moderate/current case and a favorable BEB case that assumed that the costs for BEBs decreases over time as technology develops.[156] Although the capital and operating costs were found to be more expensive for BEBs than diesel-hybrid buses, King County Metro recognized that BEBs provide additional benefits to the community that diesel-hybrid buses do not, including reduced noise and reduced tailpipe emissions. When including societal benefits in their analysis, King County Metro found that overall, a BEB fleet would be 1 percent less expensive than a diesel-hybrid fleet for the favorable BEB case and 42 percent more expensive than a diesel-hybrid fleet for the moderate scenario.[157]

4.3.7 Prioritization Method

When planning and implementing ZEB service, King County Metro considers technical and physical viability criteria, in addition to equity considerations and community feedback. In particular, the agency strives to advance social equity by prioritizing the implementation of ZEB service in disadvantaged communities most vulnerable to air pollution. In consultation with public health and air quality experts, King County Metro developed a methodology to identify and prioritize bus route alignments and bus bases (garages) that serve areas with the highest priority for reducing air pollution. This methodology considers health and environmental conditions as well as social factors including income and race.[158] Based on this analysis, for the initial transition to ZEB service, King County Metro has prioritized service out of their South Campus, which includes the SBTF and Interim Base (garage). By prioritizing ZEB service from the South Campus, King County Metro is able to provide the greatest benefit to communities that have historically been disproportionately affected by air pollution.[159]

Lesson Learned: Prioritizing historically served areas means that these communities will feel both the benefits and operational risks associated with BEBs.

BEBs are a new and rapidly evolving technology. Given the challenges associated with implementing and operating new technology, in the short to medium term, BEBs may be less reliable than traditional diesel or hybrid buses while the industry works to resolve these challenges. Although King County Metro has made it a priority to implement BEB service in areas that have been disproportionately affected by air pollution, the agency also recognizes the importance of providing reliable bus service to these same areas. Therefore, until the industry advances to resolve the technological challenges associated with BEBs, the agency is balancing the equitable deployment of BEBs with the need to provide reliable service. To promote an understanding of this balance in advance of and during the implementation of BEB service, King County

[156] Source: Zero-Emission Battery Bus Preliminary Implementation Plan, King County Metro, September 30, 2020, accessed. 2021.
[157] Source: Zero-Emission Battery Bus Preliminary Implementation Plan, King County Metro, September 30, 2020, accessed. 2021.
[158] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.
[159] Source: *King County Metro Zero-Emission Fleet Transition Plan*, King County Metro, 2022.

Metro has transparently educated elected officials and other stakeholders about these efforts, so stakeholders are aware of and understand the rationale behind BEB deployment and prioritization.

4.3.8 Lessons Learned

Lessons learned from King County Metro's implementation of BEB include:

- For maximum KPI usage and utility, limit the amount of numbers and graphs that are presented and instead focus on presenting key information in a manner that is easily understood by stakeholders who are not familiar with the data;
- Stakeholders and politicians must be informed that although ZEBs and their associated benefits, including reduced emissions and quieter operation, are prioritized in historically underserved areas, this prioritization may also come with operational risks associated with new technology that may negatively impact service reliability until the industry advances the technology to resolve these challenges; and
- Implementing a pilot program with ZEBs from multiple manufacturers allows staff, customers, and other stakeholders the opportunity to identify positive and negative aspects of the different buses, which can be used to improve the procurement and operation of future ZEBs.

4.4 Chicago Transit Authority (Chicago, Illinois)

4.4.1 Zero-Emission Bus Program History

The CTA first implemented ZEBs over two decades ago with a pilot of three FCEBs between 1997 and 2000.[160] Following the pilot program, the vehicles were returned to the manufacturer. Twelve years later, the CTA unveiled the first BEBs to be added to their bus fleet with the purchase of two 40-foot New Flyer buses with a range of 80 to 120 miles. When these two BEBs entered service in 2014, the CTA became one of the first U.S. transit agencies to use BEBs as part of regular service.[161] Since their initial deployment, the CTA has retrofitted the two New Flyer BEBs with charge rails to the roofs of the buses for compatibility with overhead conductive chargers. Following this initial procurement of BEBs, 4 years later, in 2018, the CTA executed a contract for 20 Proterra 40-foot BEBs, which was later expanded to include a total of 23 (rather than 20) BEBs.[162] In 2019, the City of Chicago made a commitment for all of CTA's more than 1,850 buses to be electric by 2040.[163]

To ensure a successful BEB deployment and to mitigate any potential challenges associated with this new technology, the CTA gradually introduced the BEBs into their fleet. In April 2021, the first 6 of the 23 Proterra BEBs entered in-service testing on the #66 Chicago bus route that serves Chicago Avenue. Based on the success of these tests conducted over the course of several months, the CTA authorized the production of the additional 17 Proterra BEBs. All 17 additional buses arrived in Q4 2021 in preparation for entering service over the first half of 2022. As part of this procurement, the CTA installed five rapid-charge overhead charging stations spread between the Chicago Avenue Garage and the Navy Pier and Chicago/Austin bus turnarounds.[164] In May 2023, the #63 Route became the

[160] Source: *Chicago Transit Authority Concludes Fuel Cell Bus Demonstration Program*, CTA, March 2000.
[161] Source: *CTA Announces First Electric-Powered Buses Added to its Fleet*, CTA, October 2014.
[162] Source: *CTA Expands Electric Bus Fleet*, CTA, June 2018.
[163] Source: *Charging Forward: CTA Bus Electrification Planning Report*, CTA, 2022.
[164] Source: *CTA Unveils New Electric Buses as Part of City's Green Initiatives*. CTA. April 2021.

second bus route to feature BEBs and the first route with BEBs to operate out of the 74th Street Garage, which runs out of the South Side and targets high-pollution areas. As of 2024, the CTA operates 25 BEBs, representing approximately 1 percent of its total fleet of over 1,850 buses.[165] The CTA also purchased an additional 22 BEBs in 2023, slated to arrive in 2025.[166] Further in the future, the CTA has identified 5-year funding between 2022 to 2026 that will provide for a new procurement to purchase up to 70 BEBs, at which point approximately 5.4 percent of the CTA's fleet is anticipated to be composed of ZEBs.[167]

The State of Illinois' 2023 Transportation Omnibus Bill, HB1342,[168] signed into law on July 28, 2023, created a hard deadline for transit agencies in Illinois to stop purchasing diesel buses by July 1, 2026. Beyond this date, transit agencies will only be able to purchase ZEBs.[169] The three exemptions as written in HB1342 allow the transit agency to not be in violation of the law:

1. "The unavailability of zero-emission buses from a manufacturer or funding to purchase zero-emission buses;
2. The lack of necessary charging, fueling, or storage facilities or funding to procure charging, fueling storage facilities, or;
3. The inability of a third party to enter into a contractual or commercial relationship with a service board that is necessary to carry out the purposes of this Section."[170]

4.4.2 Battery Electric Bus Operational Experience

In 2021, the CTA completed the initial testing and pilot phase of revenue service for the first six Proterra BEBs (**Figure 27**). Results from the CTA's current test pilot have been positive, as the electric vehicles have generally met anticipated performance metrics.[171] Following the arrival and entry into service of all 23 new Proterra BEBs, the CTA plans to comprehensively evaluate and track BEB availability as a metric to compare BEB performance with the rest of their bus fleet.[172] BEBs require unique electrical infrastructure to support their O&M. While the infrastructure needed to support diesel buses is already installed at CTA garages, the CTA must newly install supporting electrical infrastructure as they introduce BEBs into their bus fleet. The installation of this equipment requires detailed utility coordination and infrastructure planning and design. Based on their pilot program experience, the CTA has found that due to this additional coordination and planning, including design and permitting, BEB projects require significantly longer lead times than those associated with traditional diesel bus procurements. As a result, going forward, the CTA intends to begin these processes even earlier than they did for their current BEB pilot program to allow for greater time to complete infrastructure upgrades. By allowing additional time for the charging infrastructure planning, design, procurement, and installation process, the CTA will minimize the

Lesson Learned: BEBs require longer lead times than diesel buses. Coordinate with utilities and plan infrastructure well in advance of ZEB rollout.

[165] Source: *Electric Buses*, CTA.
[166] Source: *CTA to Nearly Double Electric Bus Fleet*, CTA, 2023
[167] Source: *President's 2022 Budget Recommendations*, CTA, 2021.
[168] Source: *HB1342, Transportation Omnibus Bill*, Illinois General Assembly, 2023.
[169] Source: *Buckner Passes 2023 Transit Omnibus Bill to Improve Safety, Equity, and Quality of Service, and Extend Farebox Recovery Relief*, StreetsBlog Chicago, 2023.
[170] Source: *HB1342, Transportation Omnibus Bill*, Illinois General Assembly, 2023.
[171] Source: Interview and email with CTA staff, October 2021.
[172] Source: Interview and email with CTA staff, October 2021.

risk of overpromising on delivery timelines while also having a longer time frame to expand and build upon their operational knowledge of BEBs and the associated charging infrastructure.

Figure 27: CTA Proterra BEB with Overhead Charger

4.4.3 Charging Configuration

To charge the BEBs, the CTA has installed five on-route overhead rapid-chargers located across the Chicago Avenue Garage and the Navy Pier and Chicago/Austin bus terminals.[173] To house the charging infrastructure for two 450-kWh Heliox overhead fast chargers at the Chicago/Austin Terminal, the CTA constructed a two-story brick building modeled after heavy-rail traction power substations with space for the future installation of an additional charger.[174] This infrastructure allows the CTA to keep the main charger cabinets indoors for consistent operation and ease of maintenance in inclement weather. In addition to protecting the electrical cabinets from severe weather, the CTA also installed weather shields surrounding the overhead pantograph units to protect against and mitigate the impacts of snow, ice, and rain. Within the Chicago Avenue Garage, both an overhead pantograph and a plug-in charger are available for bus charging. The overhead charger is located above the fueling lane and is used to charge the BEBs while daily vehicle cleaning tasks are being performed, whereas the plug-in charger is used for maintenance purposes. As part of this charging approach, buses are able to leave the garage with less than a full charge and charge at on-route chargers at both ends of the route.[175]

As the CTA continues to electrify their bus fleet, the agency intends to pursue a primarily garage-based charging approach.[176] To supplement garage charging, and to enable reliable service on the longest vehicle blocks, the CTA anticipates needing on-route charging infrastructure at 10 to 15 terminals. These locations will most likely be transit hubs that are served by multiple routes to centralize charging infrastructure and operations.

[173] Source: *CTA Unveils New Electric Buses as Part of City's Green Initiatives*, CTA, April 2021.
[174] Source: *Innovative Solutions Awards: Clean Technology*, Metro Magazine, October 2020.
[175] Source: Interview and email with CTA staff, October 2021.
[176] Source: Interview and email with CTA staff, October 2021.

4.4.4 Training Modules

Lesson Learned: Invest in developing thorough training modules for maintenance staff.

Based on their 2014 pilot program experience, the CTA has learned the importance of detailed hands-on training on the BEBs and their chargers for all maintenance staff, rather than just a select few. To maximize staff exposure to this training, the CTA rotates their two New Flyer BEBs through routes/blocks based out of each garage to allow staff located across their system to become well versed in the O&M of the BEBs.[177] Moving forward, the CTA plans to continue developing and implementing effective BEB and charger training modules and mock-ups for maintenance staff to increase their readiness for expanded BEB service.

4.4.5 Prioritization Method

As the CTA transitions to BEBs, the agency must decide how to prioritize the deployment of these buses across the region. The CTA's Proterra BEBs are being deployed on one of the highest ridership bus routes in the CTA system—#66 Chicago. In addition to high ridership considerations, this route was selected because it serves low-income and minority communities that experience some of the highest rates of asthma and other respiratory and chronic illnesses throughout Chicago. To inform the geographic sequencing of CTA's future BEB deployments, the agency conducted a comprehensive environmental and equity analysis based upon an Air Quality and Health Index created by the Chicago Department of Public Health (CDPH). This index followed methodology outlined in the CalEnviro Screen 3.0 and was composed of 21 variables grouped into one of four factors: health, social, air pollution, or polluted sites.[178]

The CTA verified the findings of the CDPH analysis with a similar analysis using two factors required for Title VI analysis: minority and low-income population percentage.[179] Based on the results of its analyses, the CTA plans to prioritize the 74th Street Garage, Chicago Avenue Garage, and the 103rd Street Garage as the first garages to be electrified. Bus routes/blocks operating from these garages serve areas with among the highest concentration of minority and low-income populations.[180] Going forward, the CTA plans to continue prioritizing the equitable deployment and implementation of BEBs by targeting the garages and routes serving communities with poor air quality and high proximity of Title VI populations, including the 77th and Kedzie facilities.

4.4.6 Lessons Learned

Lessons learned from CTA's implementation of BEBs include:

- Start the BEB process early in anticipation of a long lead time for utility coordination and charging infrastructure planning including design and permitting;
- Develop and implement effective BEB and charger training modules and mock-ups for bus O&M staff across all garages to be ready for BEB service; and

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[177] Source: Interview and email with CTA staff, October 2021.
[178] Source: *City of Chicago Air Quality and Health Report*, City of Chicago, 2020.
[179] Source: Interview and email with CTA staff, October 2021.
[180] Source: Charging Forward, CTA, 2022.

- Recognize the importance of modeling operational parameters including route characteristics, charging times, and vehicle/battery limitations in advance of deployment.

4.5 Toronto Transit Commission (Toronto, Ontario)

4.5.1 Zero-Emission Bus Program History

In July 2017, the Toronto City Council approved Toronto's ambitious climate action strategy, TransformTO, which included a goal of reducing GHG emissions by 80 percent from 1990 levels by 2050.[181] To align with this framework, the TTC developed a Green Bus Technology Plan that targeted a 20 percent zero-emission fleet by 2025, 50 percent zero-emission fleet by 2030, and 100 percent zero-emissions by 2040 for the city-owned fleet, including procurements of only ZEBs starting in 2025.[182,183] In addition to fleet transition targets, modeling for TransformTO also identified several transit-related actions[184] as a pathway to support achieving the city's transportation reduction goals. These actions included:

- TTC to increase service frequency on all transit routes over 2016 levels by:
  - 70 percent for bus
  - 50 percent for streetcar
  - Subway off-peak service increased to every 3 minutes
- TTC/city to convert one lane of traffic to exclusive bus lanes on all arterials
- City to implement a variety of strategies including no transit fares and tolls on all arterial roads

Figure 28*:* TTC BEB

The Green Bus Technology Plan was approved by the TTC Board in November 2017 and included a pilot program with 30 extended-range 40-foot BEBs, which entered service in 2019 (**Figure 28**). This procurement included ten extended-range BEBs each from New Flyer, Proterra, and BYD. For the initial procurement, all vehicles were required to be delivered no later than March 31, 2019, less than a year and a half after the Green Bus Technology Plan was approved. To meet the commitments set forth in the plan and in recognition that BEB industry standards are still developing, the TTC streamlined their procurement process, allowing bus manufactures to propose solutions that would meet TTC fleet requirements for this pilot program.[185] In June 2018, the TTC Board approved the expansion of the pilot program with the purchase of 30 additional extended-range BEBs evenly distributed between New Flyer and Proterra.[186]

Buses from the three manufacturers had a wide range of nominal battery capacities, indicating the theoretical capacity of the new battery pack. To preserve battery health, manufacturers typically protect

[181] Source: *Transform TO: Climate Action for a Healthy, Equitable & Prosperous Toronto*, City of Toronto, July 2017.
[182] Source: *Green Bus Technology Plan*, TTC, November 2017.
[183] Source: *TTC Green Bus Program – eBus Head-to-Head Evaluation*, TTC, December 2023.
[184] Source: *TTC Green Bus Program – eBus Head-to-Head Evaluation*, TTC, December 2023.
[185] Source: Interview and email with TTC staff, October 2021.
[186] Source: Interview and email with TTC staff, October 2021.

a fraction of this nominal capacity, only allowing agencies to use a portion in day-to-day use. Therefore, despite the variety in nominal battery capacities, the TTC has observed that the usable battery capacity was nearly equivalent between their three different types of BEBs, as each manufacturer protected a different fraction of the nominal battery capacity (**Table 17**).[187]

Table 17: Nominal and usable battery capacities of TTC BEBs from three manufacturers

--	Nominal Capacity (kWh)	Usable Capacity (kWh)
New Flyer	400	285
Proterra	440	271
BYD	360	291

As of 2023, the TTC operates 60 40-foot BEBs and is set to welcome an additional 340 40-foot BEBs by the end of 2025, which would bring TTC's bus fleet to approximately 20 percent zero emissions.[188] Over half of these newly purchased buses have been ordered from New Flyer, while the remainder are from Nova Bus. This recent purchase also includes potential options for over 800 additional BEBs.[189]

4.5.2 Battery Electric Bus Operational Experience

The TTC currently operates its BEB fleet out of three divisions/garages:

- New Flyer – Arrow Road Garage
- Proterra – Mount Dennis Garage
- BYD – Eglinton Garage

New Flyer and Proterra buses use the same charging equipment, while BYD buses require the use of proprietary alternating current charging infrastructure.

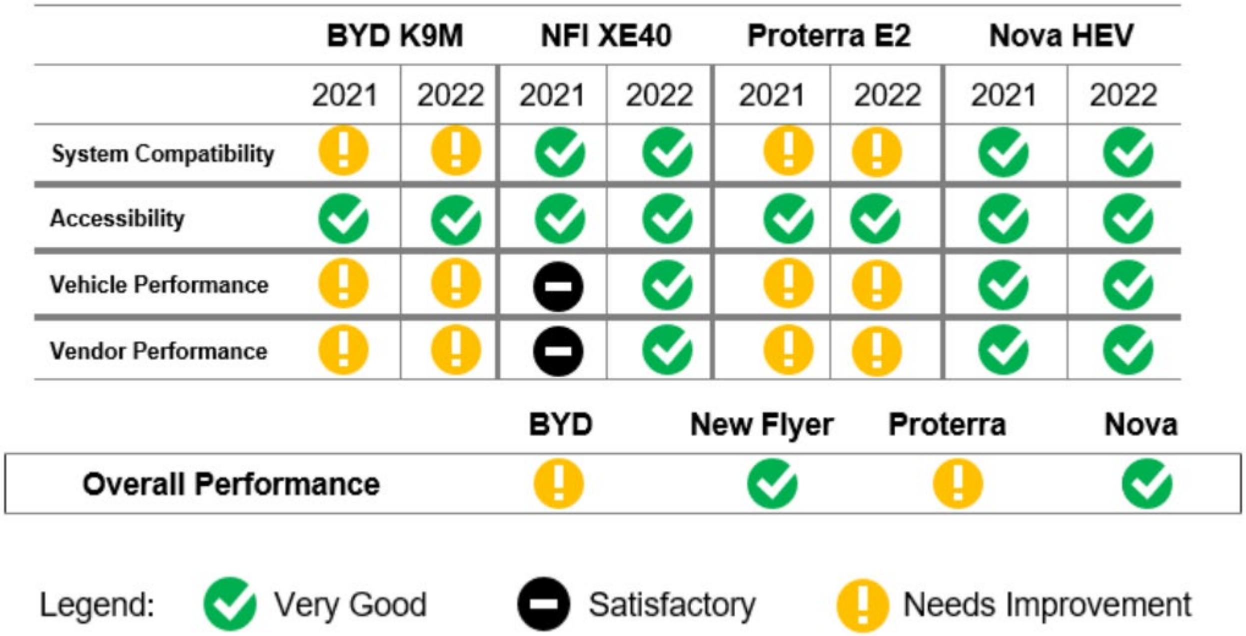
Lesson Learned: Plan for reliable operations in all weather conditions.

In October 2020, the TTC began a head-to-head assessment to evaluate and compare their three different BEB types. As route characteristics and topography vary from route to route, the TTC also operated the buses in simulated service to directly compare the buses against each other while minimizing other variables unrelated to the buses themselves. For this simulated service, the three buses (one from each manufacturer) operated back-to-back along 42 different routes through winter and summer seasons, loaded with ballast to represent the passenger weight of a fully loaded bus.[190] Doors were cycled at each stop to simulate typical TTC in-service conditions and performance data was captured using an onboard telematics system.[191] Results from this evaluation were shared with the TTC Board in April 2022 and focused on the performance of each bus across four key domains: System Compatibility, Accessibility, Vehicle Performance, and Vendor Performance.

[187] Source: Interview and email with TTC staff, October 2021.
[188] Source: *TTC Continues its Transition to be Zero-Emissions Before 2040*, April 22, 2024.
[189] Source: *TTC Orders up to 1,162 Nova Bus, New Flyer Electric Buses*, June 5, 2023.
[190] Source: Interview and email with TTC staff, October 2021.
[191] Source: Interview and email with TTC staff, October 2021.

Across these four domains, only New Flyer and its XE40 electric bus were found to deliver service at or above the performance required by the TTC (**Figure 29**).

Figure 29*:* TTC Results for Primary Evaluation Domains (2022)



Source: Green Bus Program Update, TTC, April 2022.

4.5.2.1 System Compatibility

For system compatibility, the TTC found that a key differentiator between the BEBs was that the Proterra buses were 42.5 feet long rather than 40 feet. Although this length offered the highest passenger capacity, the TTC determined that the increased length of the Proterra buses would result in a loss of storage capacity of approximately 10 percent at four of the TTC's eight garages.[192]

Additionally, while the New Flyer and Proterra buses had interoperable charging technology meeting charging system standards set from the SAE, the BYD buses procured by the TTC had a proprietary charging system. Consequently, the TTC evaluated the BYD bus as needing improvement from a system compatibility standpoint. Since the TTC conducted their head-to-head assessment, however, BYD has developed a bus that meets the SAE charging interoperability standards.

While the TTC's focus on streamlining the procurement process allowed bus manufacturers to flexibly develop innovative solutions and to meet goals set in the Green Bus Technology Plan, this flexibility has resulted in unintended consequences, including confusion regarding different operating procedures and features between the BEBs and traditional TTC buses. As a result, the TTC has had to make multiple modifications to the BEBs to allow for a more seamless transition between BEB buses and traditional TTC buses. Moving forward, the TTC has established that their procurement documents will be the TTC traditional procurement documents, other than the propulsion system, and that these documents should

[192] Source: *TTC's Green Bus Program: Preliminary Results of TTC's Head-to-Head eBus Evaluation*, TTC, April 2021.

require direct current charging capacity using SAE standards to allow for interoperability between all buses and chargers.[193]

4.5.2.2 Accessibility

All three bus manufacturers were found to be compliant with the Canadian Standards Association for accessible transit buses and the Accessibility for Ontarians with Disabilities Act. From the head-to-head evaluation, additional improvements to the BEBs were identified, including:

- Configuration of stop request button size;
- Configuration of priority stop request button size and location; and
- Minimize installation of securement equipment in personal mobility device floor area.

4.5.2.3 Vehicle Performance

The primary metrics the TTC measured to evaluate the BEB Vehicle Performance domain of the head-to-head evaluation were:

- Reliability
- Availability
- Energy consumption

When evaluating these measures, significant differences between the three bus types emerged. For reliability, the New Flyer buses were the only BEBs that consistently met or surpassed the TTC's reliability target threshold of a 30,000-km (approximately 18,700-mile) mean distance between failures.[194] To ensure greater BEB reliability in the future, the TTC intends to include reliability metrics to be achieved by the BEB manufacturers in future contracts with the stipulation that a failure to meet the reliability targets **will result in liquidated damages.**

The TTC also established a target of 80 percent fleet availability, defined as vehicles available for revenue service.[195] As of April 2022, the New Flyer and Proterra buses were achieving more than 90 percent availability with an upward trend, while BYD was performing at below 40 percent with a downward trend.[196, 197] In general, the majority of TTC's electric bus availability issues, particularly on the Proterra and BYD buses, are a result of general bus issues and defects rather than with the electric propulsion system itself.[198]

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[193] Source: *TTC's Green Bus Program: Preliminary Results of TTC's Head-to-Head eBus Evaluation*, TTC, April 2021.
[194] Note: While the New Flyer bus was found to be the most reliable BEB, it was still less reliable than the baseline hybrid diesel-electric Nova bus, which had a mean distance between failures nearly double that of the New Flyer BEB.
[195] Source: *TTC's Green Bus Program: Preliminary Results of TTC's Head-to-Head eBus Evaluation*, TTC, April 2021.
[196] Source: Green Bus Program Update, TTC, April 2022.
[197] Source: *TTC's Green Bus Program: Preliminary Results of TTC's Head-to-Head eBus Evaluation*, TTC, April 2021.
[198] Source: Interview and email with TTC staff. October 2021.

As the third evaluation metric in assessing vehicle performance, energy consumption, measured in kWh/km, is particularly important for TTC, as this variable ultimately translates to range and overall life cycle cost. Based on the results of the TTC's head-to-head simulated service evaluation, the TTC found that although the BYD and Proterra buses achieved the best energy consumption rates and longest bus range in the mild ambient temperatures of the fall season, buses from these two manufactures achieved 40 to 50 percent less range in the winter. Conversely, New Flyer had the worst energy consumption rate of the three buses during the fall season but had the best and most stable energy consumption and range in the winter season. Therefore, due to the large fluctuations in range for BYD and Proterra buses and lower overall winter range, the TTC concluded that the New Flyer buses performed best recognizing that predictable and reliable range is more important than achieving the lowest energy consumption.[199] To minimize battery consumption and preserve BEB range, the TTC's electric buses are equipped with auxiliary diesel heaters. Despite using diesel heaters, the TTC is committed to minimizing diesel usage. As such, diesel heaters are only allowed when the temperature is below 5 degrees Celsius (41 degrees Fahrenheit).[200]

Lesson Learned: Establish reliability metrics and non-compliance penalties in future procurement processes.

4.5.2.4 Vendor Performance

The TTC used the vendor performance domain to monitor the performance of vendors' quality and contractual requirements. Based on several metrics, including but not limited to compliance to vehicle delivery schedule, quality defects, 30-day reliability, and training, New Flyer and Proterra were deemed to have a satisfactory performance while BYD was evaluated as needing improvement. These overall performance ratings were largely driven by compliance with the vehicle delivery schedule. While all BEB manufacturers delivered the buses behind schedule, New Flyer and Proterra buses were approximately 1 to 2 months behind schedule, whereas BYD was over 6 months (186 days) behind schedule.[201]

4.5.3 Power Generation and Charging Configuration

In Ontario, generation of electricity for overnight charging is 100 percent nuclear and completely free of GHG emissions.[202] The TTC has partnered with Ontario Power Generation and Toronto Hydro-Electric Services Limited to support the further electrification of the BEB fleet. Given that 20 percent of the TTC bus fleet, as of 2018, is stored outdoors, 4 of the original 10 BEBs at each garage were stored and charged solely outdoors to assess environmental impacts.[203] As of October 2021, the TTC has observed no difference between storing and charging buses outdoors compared with indoor storage and charging. While the current fleet of 60 BEBs utilizes plug-in charging, the TTC envisions that in the future, garage charging will be supplied via overhead pantographs.[204] In 2019, 60 eBus charging systems were

[199] Source: *TTC's Green Bus Program: Preliminary Results of TTC's Head-to-Head eBus Evaluation*, TTC, April 2021.
[200] Source: Interview and email with TTC staff. October 2021.
[201] Source: *TTC's Green Bus Program: Preliminary Results of TTC's Head-to-Head eBus Evaluation*, TTC, April 2021.
[202] Source: *Green Bus Technology Plan*. TTC. November 2017.
[203] Source: *Green Bus Technology Plan Update*, TTC, June 12, 2018.
[204] Source: Interview and email with TTC staff, October 2021.

introduced with Toronto Hydro and 20 additional chargers were deployed by PowerON in 2023. Charging infrastructure was designed and built by PowerON, who also operate and maintain the equipment.[205]

4.5.4 Cost Benefit Analysis

Given the age of TTC's BEB fleet, most necessary repairs are currently being performed under warranty. As a result, a full cost benefit analysis of transitioning to an electric fleet has not been conducted. Based on energy costs by distance, however, the TTC has found that BEBs are the least expensive buses to operate, while hybrids, the second least expensive buses, have average energy costs approximately 31 percent higher (**Table 18**).[206] If charging optimization is introduced in the future, BEB energy costs are anticipated to further decrease.

Table 18: Preliminary energy operating cost per distance by propulsion type

--	Energy Operating Costs (CDN$/km)	Energy Operating Costs (USD$/mi)
BEB	0.32	0.41
Hybrid	0.42	0.54

Source: Interview and email with TTC staff, October 2021.[207]

4.5.5 Prioritization Method

In deploying their initial BEBs, TTC set a goal of operating BEBs on the maximum possible number of technically viable blocks. To accomplish this goal, TTC prioritized BEB vehicle assignments based on block distance and in-service times. When selecting home garages for the electric buses, the TTC focused on balancing BEB service with past transit investments so that BEB service covered the largest possible area of the TTC bus network while also ensuring that historically underinvested areas received BEB service.[208]

4.5.6 Lessons Learned

Lessons learned from the TTC's implementation of BEBs include:

- Open-ended procurement documents with additional flexibility for bus manufacturers necessitated multiple change orders to address unintended consequences, including confusion regarding different operating procedures and features between buses.
- Reliability metrics to be achieved by the BEB manufacturer in future procurement contracts. Failure to meet the reliability targets will result in liquidated damages.
- Predictable range allowing BEBs to reliably operate through all seasons is more important than achieving the lowest energy consumption.

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[205] Source: *TTC Green Bus Program – eBus Head-to-Head Evaluation*, TTC, December 2023.

[206] Source: *TTC's Green Bus Program: Preliminary Results of TTC's Head-to-Head eBus Evaluation*, TTC, April 2021.

[207] Source: Interview and email with TTC staff. October 2021.

[208] Source: Interview and email with TTC staff. October 2021.

4.6 Key Considerations and Best Practices Summary

Although each of the transit agencies included in the case studies have had unique ZEB experiences, several key themes and lessons learned were shared across the agencies, including:

- Expect the unexpected;
- Start the ZEB process early, as implementation takes much longer than for a diesel bus;
- Plan for longer ZEB and supporting infrastructure repair times;
- Incorporate flexibility into ZEB planning and implementation efforts where possible to accommodate technological advancements;
- Meet early and often with your electric utility;
- Elements of redundancy and contingency planning may alleviate potential challenges;
- Consistent range allows for reliable operation through all seasons. Plan for bad weather days;
- Predictable and reliable range is often more important than achieving the lowest energy consumption;
- Develop strong contractual language, including performance metrics;
- Clearly define successful ZEB implementation and deployment using comprehensible KPIs;
- When conducting an equity analysis, consider impacts to service reliability with emerging technologies; and
- Transparently set and manage expectations using a broad communication strategy with frequent stakeholder communication.

Based on BEB performance challenges, range limitations, and lessons learned, many transit agencies have begun exploring or implementing FCEB pilot programs to determine how these ZEBs perform differently than BEBs. Both Foothill Transit and King County Metro have experienced lower rates of availability associated with BEBs as compared to targets and CNG bus performance. While Foothill Transit experienced a 76 to 82 percent availability depending on the type of BEB, King County Metro reported that in 2024, approximately half of all New Flyer BEBs were out of service on a given day. In addition to performance challenges associated with BEBs, Foothill Transit also determined that maintaining their current level of service with ZEBs would require a 1.5 BEB to 1 CNG replacement ratio, whereas FCEBs could replace CNG vehicles 1 to1. For these reasons, Foothill Transit, King County Metro, and other transit agencies are pursuing FCEB pilot projects.

5 Metro Transit Bus System and Facilities

As Metro Transit transitions to ZEBs, two key questions must be answered:

- Which garages are most suitable to store ZEBs in the short term?
- Which bus service is most promising for ZEB deployment in the short term?

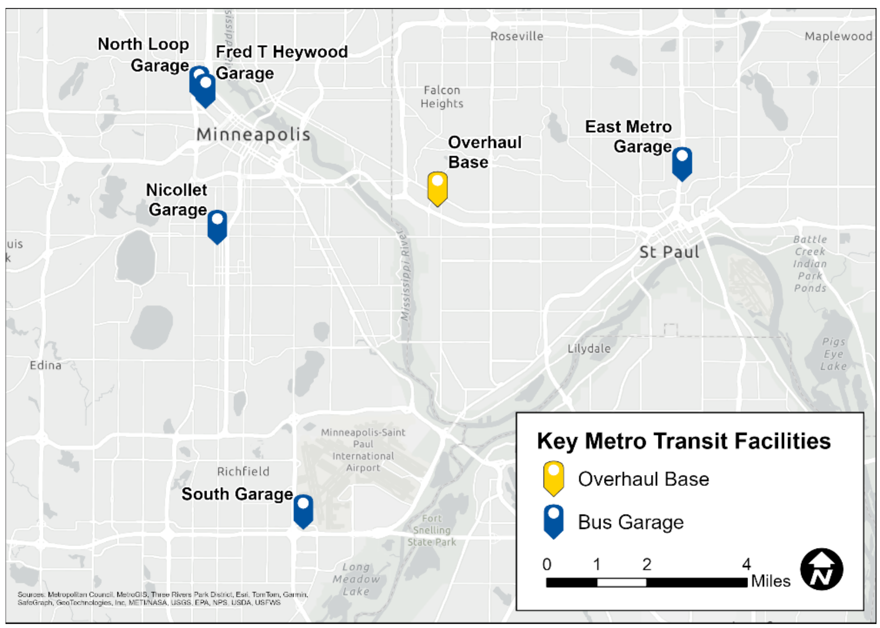
This section summarizes an inventory and overview of Metro Transit's existing bus garages and service in order to establish the existing conditions framework necessary to answer the aforementioned questions

5.1 Asset Inventory

This subsection provides an inventory of Metro Transit facilities including the OHB heavy maintenance facility and each of Metro Transit's five active bus garages (**Figure 30**). This information establishes a current infrastructure and facility baseline from which ZEB infrastructure requirements can be estimated and compared.

5.1.1 Overhaul Base

Figure 30: Metro Transit Garage and OHB Facilities[209]



While minor maintenance work can be performed at any Metro Transit garage, all major bus maintenance and repairs occur at Metro Transit's OHB located at 515 North Cleveland Avenue in Saint Paul. Work at this base includes mid-service life overhauls as well as collision repairs and other more significant work.

As of August 2024, there is no charging infrastructure at the OHB. As a result, when one of Metro Transit's existing eight BEBs needs to travel to the OHB, Metro Transit must carefully orchestrate its movements to ensure buses are fully charged when leaving the Heywood Garage while also monitoring the batteries' charge while at the OHB. In 2024, Metro Transit purchased four Heliox 50kW mobile chargers for maintenance use,[210] one of which will be located at the OHB. This maintenance charger, anticipated to be operational in early 2025, will significantly reduce the complexities associated with maintaining BEBs at the OHB.

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[209] Transit center and layover facilities are not included in this inventory based on the conclusions of the Metro Transit 2022 ZEBTP which recommended that "on-route charging strategies [would] not be pursued in the short term" due to a wide variety of challenges including, but not limited to, the increased number of operators and vehicles required to allow for longer layovers, outdoor maintenance challenges particularly in Minnesota winters, and higher capital and operational costs compared to garage charging strategies.
[210] Source: Metro Transit. *Electric Buses*. Accessed August 2024.

5.1.2 Garage Inventory

As depicted in **Figure 30**, Metro Transit operates bus service from five garages. All garages except for the North Loop Garage were originally designed for diesel buses and Metro Transit has worked with Xcel Energy to retrofit the Heywood Garage (northwest of Downtown Minneapolis) as well as the East Metro Garage in Saint Paul to accommodate BEBs. As of September 2024, the Heywood Garage houses the eight C Line 60-foot articulated BEBs as well as eight plug-in chargers. At East Metro Garage, construction began in June 2024 for new power feeders to support five new 60-foot articulated BEBs as well as four plug-in chargers, and one mobile maintenance charger, all of which are anticipated to enter revenue service in 2025.[211] Opened in March 2023, the North Loop Garage is Metro Transit's newest garage and is designed to support both diesel buses and BEBs.[212] In 2026, 20 40-foot BEBs, 18 plug-in chargers, and one mobile maintenance charger are anticipated to be in service at North Loop Garage.

5.1.3 Garage Storage

The quantity of buses associated with a given garage can be summarized in two ways:

- **Utilization:** The number of buses based out of the garage.
- **Design Capacity:** The optimal number of buses the garage was designed to support assuming diesel propulsion where adequate circulation and a fire lane is provided within the garage to move buses without shifting the fleet around. The design capacity includes both work positions in the bus maintenance area as well as the number of parking spaces in the general bus storage area. Therefore, total design capacity is calculated as the sum of the bus storage and bus maintenance capacity.

As shown in **Table 19**, Metro Transit is currently accommodating 310 fewer buses than its five existing bus garages were designed to accommodate. While this excess capacity provides Metro Transit with some flexibility as to which garage future BEBs could be operated out of, Network Now initiatives to grow transit service will also decrease excess capacity, limiting some of the opportunity for future BEB transition.

As a temporary measure (and pending the results of a fire hazard analysis) to reduce the chance of a fire in one bus causing damage to the entire fleet or facility, Metro Transit is parking BEBs further away from other buses in accordance with FTA's *Guidebook for Deploying Battery Electric Buses.*[213] As a result of this interim practice, every BEB requires a much larger parking space than an equivalent diesel vehicle and by-pass lanes were added adjacent to the lanes where BEBs are parked. For example, the eight C Line BEBs at the Heywood Garage are using the equivalent of 20 diesel parking spaces on an interim basis and the five Gold Line BEBs will be using the equivalent of 16 diesel parking spaces. These are currently viewed as interim measures pending results of the Fire Hazard Analysis, which is anticipated to be completed in 2025. The results will inform design criteria for facility improvements as well as long-term garage capacity.

[211] Source: *Metro Transit ZEB Transition 2023 Annual Report*, Metro Transit, June 2024, accessed August 2024.
[212] Source: *North Loop Garage*, Metro Transit, accessed August 2024.
[213] Source: *Guidebook for Deploying Battery Electric Buses*, Federal Transit Administration, August 2023.

Table 19: Metro Transit garage inventory and characteristics (effective September 4, 2024)

Garage	Address	Estimated Square Feet	September 4, 2024 Utilization (Fleet)	Design Capacity (Fleet)	In Excess of Total Design Capacity	Adjacent Power Utility Provisions
Fred T. Heywood (Heywood) Garage*	570 6th Avenue North, Minneapolis	290,000	131 • 40-foot: 67 • 60-foot: 56 • Coach: 8	• 214 • Storage: 194 • Maintenance: 20	-83	• Overhead Mainline • Future 2.5MW Transformer(s) Possible as of 2021 • 1500 kilovolt-amperes (kVa) transformer in place as of 2019
North Loop Garage	812 North 7th Street, Minneapolis	350,000	120 • 40-foot: 83 • 60-foot: 28 • Coach: 9	• 216 • Storage: 192 • Maintenance: 24	-96	• Overhead Mainline • 8MW ATO in place (2023) • Future 4MW transformer(s) possible as of 2019
East Metro Garage	800 Mississippi Street, Saint Paul	350,000	137 • 40-foot: 99 • 60-foot: 32 • Coach: 6	• 198 • Storage: 174 • Maintenance: 24	-61	• Overhead Mainline • 2.5MW transformer in place (2024) • Future 2.5MW transformer(s) possible as of 2024
Nicollet Garage	10 West 32nd Street, Minneapolis	190,000	119 • 40’: 119	• 162 • Storage: 146 • Maintenance: 16	-43	• Overhead Mainline • Future 2.5MW transformer(s) possible as of 2021
South Garage	2100 MTC Road, Minneapolis	210,000	96 • 40-foot: 78 • 60-foot: 18 • Coach: 0	• 123 • Storage: 107 • Maintenance: 16	-27	• Underground • Future 2.5MW transformer(s) possible as of 2021

Garage	Address	Estimated Square Feet	September 4, 2024 Utilization (Fleet)	Design Capacity (Fleet)	In Excess of Total Design Capacity	Adjacent Power Utility Provisions
Existing Total	--	1,390,000	603 • 40-foot: 446 • 60-foot: 134 • Coach: 23	• 913 • Storage: 813 • Maintenance: 100	-310	--

Source: Metro Transit Correspondence, July 2024. Data includes spare factor buses but excludes training buses.

** Heywood Garage utilization values are inclusive of the 20 Maple Grove Transit branded buses*

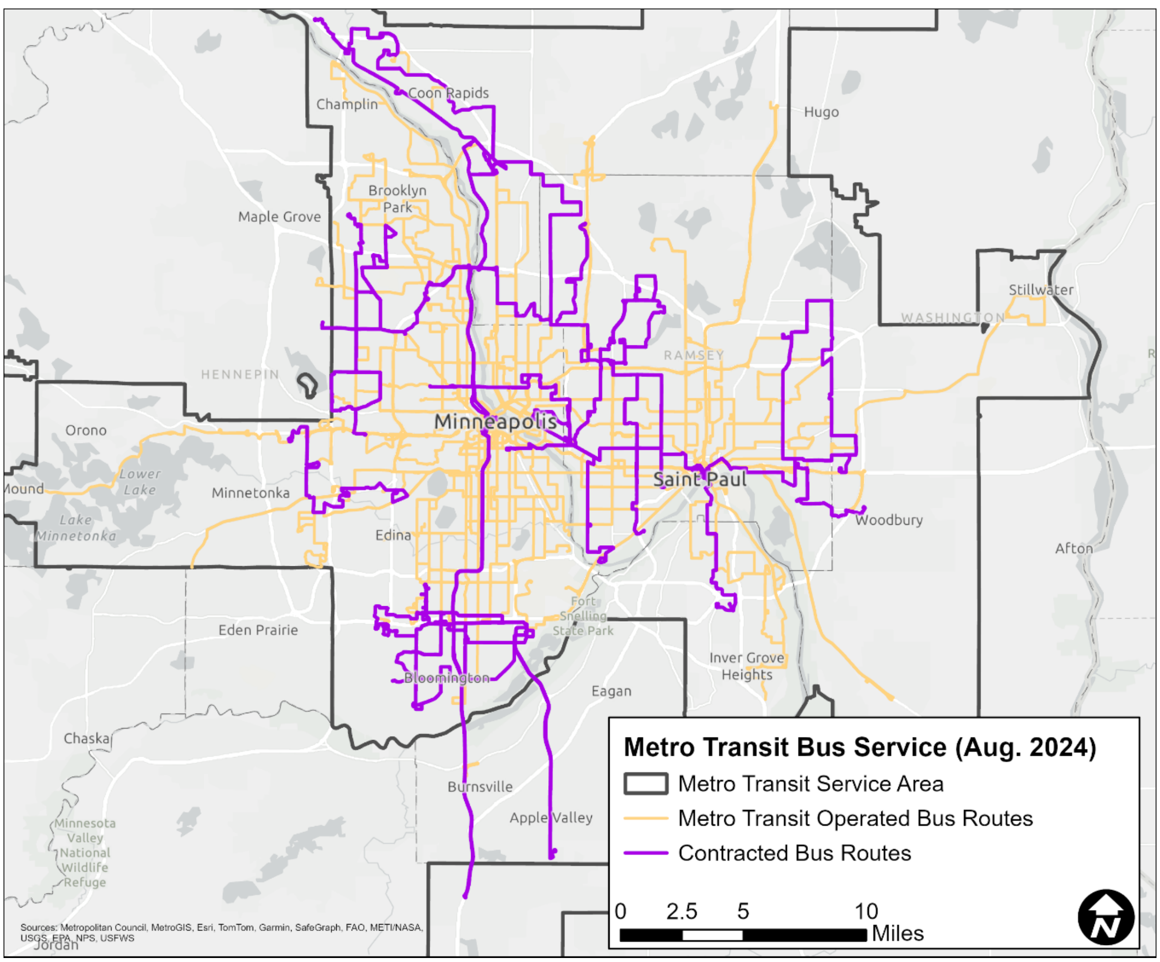
5.2 Bus Service Overview

Metro Transit's bus fleet is comprised of buses of varying lengths and propulsion types operating from a variety of home garages to provide a range of service types. This section provides an overview of these various components that influence the way in which Metro Transit operates its bus fleet of over 600 buses. Similar to the asset inventory baseline outlined in Section 6.1, the information contained in this section establishes a current service baseline, as of fall 2024, from which ZEB bus service can be estimated and compared.

5.2.1 Bus Service Provider

Although Metro Transit-branded buses operate on nearly 100 routes across the Twin Cities region, Metro Transit itself does not operate buses on all of these routes. Instead, select routes are contracted out by the Metropolitan Council to private providers (**Figure 31**). Together these contracted routes represent approximately a third of the regular-route bus routes in the metro area. For the purposes of this ZEBTP, only the bus service and routes operated by Metro Transit are considered and analyzed. The services that are contracted out by the Metropolitan Council are covered by MTS and STA ZEBTP, as discussed in Section 2.10.1.

Figure 31: Metro Transit Bus Service (August 2024)



Source: Metro Transit GTFS Schedule. Accessed August 2024.

5.2.2 Metro Transit Bus Service Types

Metro Transit operates a variety of fixed-route bus service. All fixed-route service operates along an established path with a published schedule and designated stops. Each of the different types of Metro Transit bus service, as defined in Appendix G of the Metropolitan Council's 2040 TPP, are summarized below.[214]

5.2.2.1 Local Service

Core Local routes typically serve the denser urban areas, usually providing access to a downtown or major activity center along important commercial corridors. They form the base of the core bus network and are typically some of the most productive routes in the system.

Supporting Local routes are typically designed to provide crosstown connections. Typically, these routes do not serve a downtown but play an important role connecting to Core Local routes and ensuring transit access for those not traveling downtown.

Suburban Local routes typically operate in a suburban context and are often less productive than Core Local routes. These routes serve an important role in providing a basic level of transit coverage throughout the region.

5.2.2.2 Commuter and Express Service

Commuter and Express Bus routes primarily operate during peak periods to serve commuters to downtown areas or a major employment center. These routes typically operate non-stop on highways for portions of the route between picking up passengers in residential areas or at park-and-ride facilities and dropping them off at a major destination.

5.2.2.3 Bus Rapid Transit

BRT is a package of transit enhancements that adds up to a faster trip and an improved experience. A network of BRT lines is planned for the Minneapolis-Saint Paul area. BRT is part of the METRO network, which provides fast and frequent all-day service. **Figure 32** depicts the METRO network including BRT.

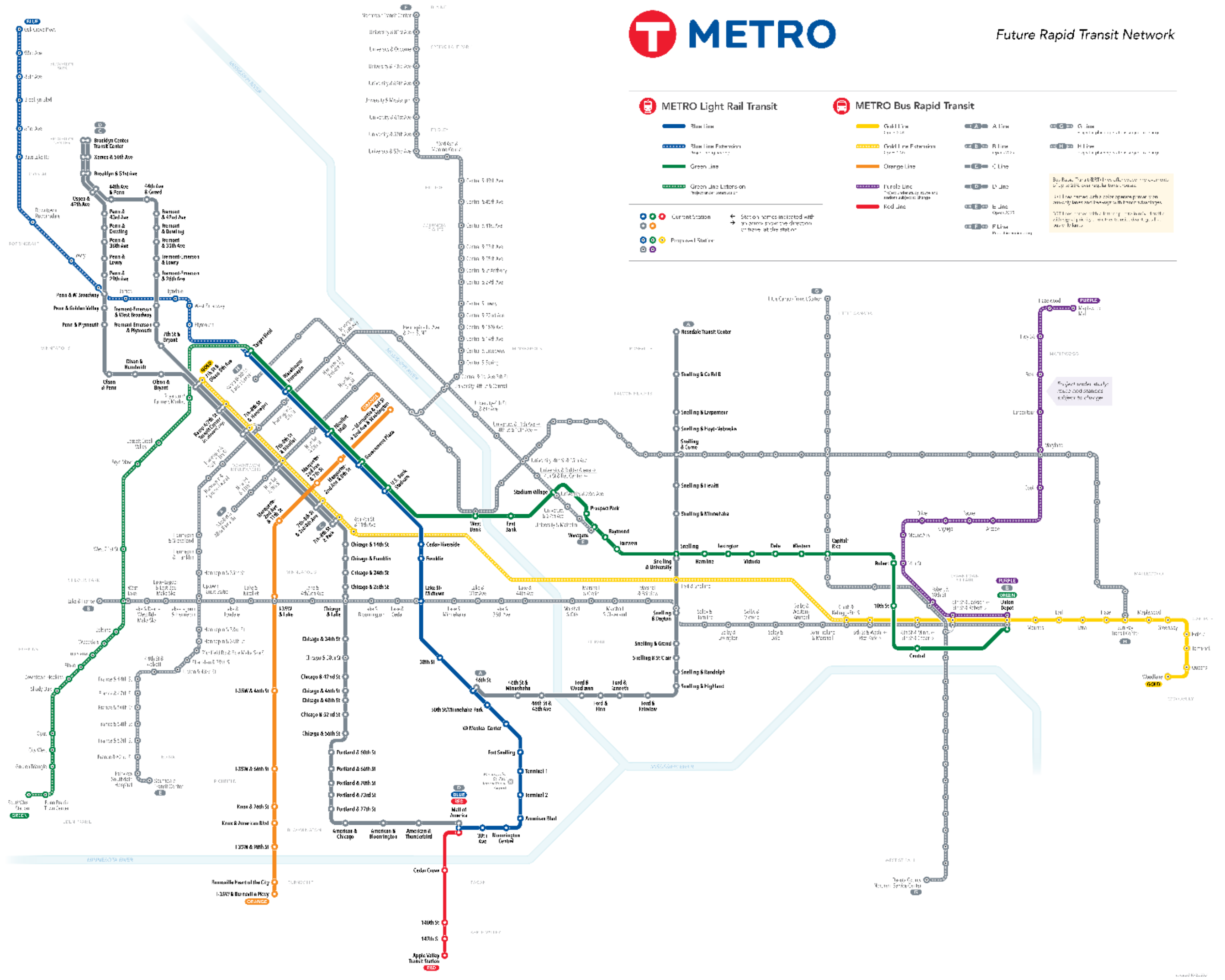
Arterial BRT lines operate in high demand urban arterial corridors with service, facility, and technology improvements that enable faster travel speeds, greater frequency, improved passenger experience, and better reliability. As of 2024, the current arterial BRT network consists of the A, C, and D lines in operation, with the B and E lines under construction, and F, G, and H lines identified for implementation between 2026 and 2030[215] (**Figure 32**). The next set of ABRT lines will be identified in 2025 for implementation beyond 2030 as part of the Arterial Bus Rapid Transit Plan anticipated in 2025 as discussed in Section 2.7.4.

Highway BRT lines operate in high-demand highway corridors with service, facility, and technology improvements providing faster travel speeds, all-day service, greater frequency, an improved passenger experience, and better reliability. Highway BRT lines include the Red and Orange lines.

[214] Source: *2040 Transportation Policy Plan, Appendix G: Transit Design Guidelines*, Metropolitan Council, January 2015.
[215] Source: *Arterial Bus Rapid Transit - 2024 Regional Solicitation*, Metro Transit, March 2024.

Dedicated BRT lines operate in dedicated right-of-way for the exclusive use of buses in high-demand corridors. Service, facility, and technology improvements are similar to light rail and provide faster travel speeds, all-day service, greater frequency, an improved passenger experience, and better reliability. Future Gold and Purple lines are planned as dedicated BRT.

Figure 32: Metro Transit Future Rapid Transit Network



Source: [METRO System Map - Future Rapid Transit Network (Updated 2024)](), accessed January 2025.

5.2.3 Bus Fleet

As of early September 2024, Metro Transit's bus fleet included 603 buses (**Table 20**). Metro Transit currently operates a BEB pilot program with eight 466-kWh 60-foot New Flyer BEBs operating exclusively on the METRO C Line. Building upon the C Line pilot program experiences, and in alignment with the 2022 ZEBTP, Metro Transit plans to significantly increase and diversify its ZEB fleet in the coming years, including:

- Five 690-kWh 60-foot New Flyer BEBs planned to enter revenue service in 2025 on the METRO Gold Line.
- Twenty 686-kWh 40-foot GILLIG BEBs planned to enter revenue service in 2026 on local service routes based out of the North Loop Garage.

Metro Transit continues to actively pursue additional funding opportunities to fund additional BEBs.

Table 20: Metro Transit bus fleet composition (September 2024)

Propulsion Type	40-Foot	60-Foot Articulated	45-Foot Coach
Diesel & Hybrid Electric	446	126	23
Battery Electric	0	8	0

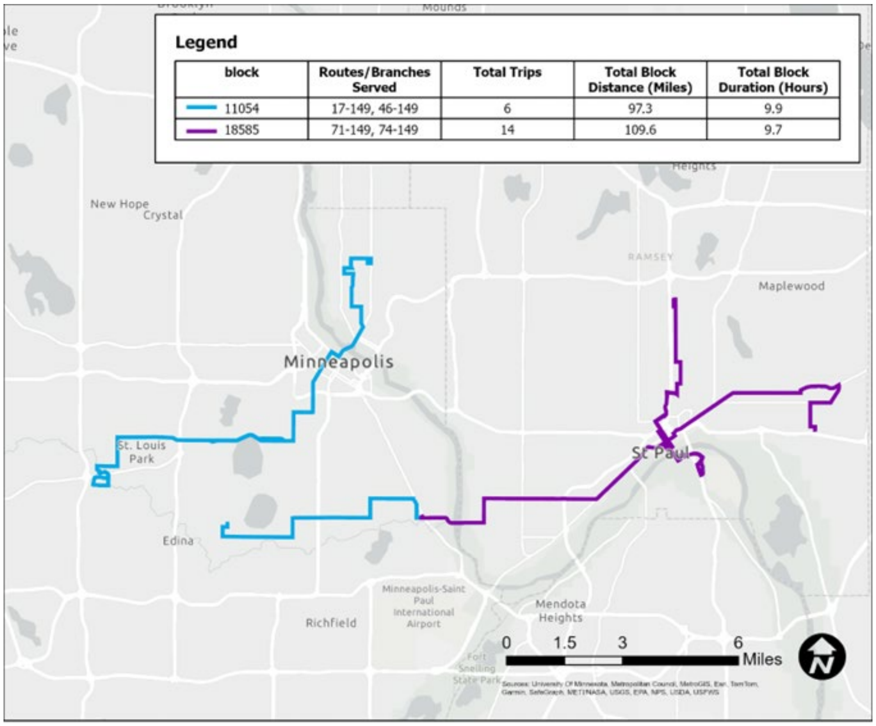
Source: Metro Transit Correspondence, July 2024. Data includes spare factor buses but excludes training buses.

Since 2018, Metro Transit has retired nearly all hybrid-electric 40-foot bus fleet technology, with only 5 of the 133 vehicles remaining. The remaining 5 hybrid-electric buses are scheduled for retirement in 2026, closing that propulsion type chapter for Metro Transit. The range of the hybrid buses matched that of diesel buses and, due to the hybrid technology, increased the productivity of fuel economy by 50 percent (increasing from 4 to 6 miles per gallon). At this time there are no plans to buy additional hybrid buses.

5.2.4 Metro Transit Scheduling Practices

Metro Transit uses advanced transit vehicle and operator scheduling practices to maximize efficiency and tailor service to ridership and the available workforce. Across its service types, Metro Transit divides its many routes into blocks. Each block represents a series of transit trips that are linked together and assigned to a single vehicle for operation. To illustrate the concept of blocks, **Figure 33** depicts two example blocks, each of which are made up of two routes.

Figure 33: Overview Map of Two Example Service Blocks (2024)



Vehicle blocks and operator assignments are reconfigured every quarter to maximize efficiency and tailor service to ridership and the available workforce even when service levels are relatively stable. Each update or reconfiguration is referred to in this document as a service schedule change. Many of these practices have implications for electric vehicle scheduling, including, for example, increasing interlining (mixing of routes on the same vehicle block) or scheduling vehicle blocks to be as long as possible in order to create cohesive, attractive work shifts for operators.

Transit scheduling software increasingly features electric bus scheduling tools that account for vehicle charging activities, rates of battery discharge, and other factors. On May 22, 2024, the Metropolitan Council authorized the regional administrator to execute a contract "to upgrade Metro Transit's bus and rail scheduling and operations software system (HASTUS)."[216] This will be Metro Transit's first upgrade to the scheduling software since 2015. This upgrade will allow Metro Transit to take advantage of new features and functionality, including scheduling for electric buses, which is anticipated to increase BEB-compatible service opportunities while continuing to provide efficient and consistent service to riders.

5.2.5 Service Blocks by Garage

As discussed in Section 6.2.5, block length and characteristics can vary between service schedules, which are updated four times a year. For the August 2024 schedule, Metro Transit built its schedule from 1,048 blocks in their original, long form (553 weekday, 267 Saturday, and 228 Sunday blocks). These blocks ranged in length from 9 miles to over 348 miles long. The average service block operated by Metro Transit in this August 2024 service schedule was approximately 142 miles long.

As shown in **Table 21** and **Table 22**, each garage stores buses assigned to blocks of differing lengths. For example, based on the August 2024 service schedule, the majority of 40-foot bus blocks at Nicollet Garage are less than 133 miles long, while the East Garage has the greatest number of blocks operated by 40-foot buses that are longer than 133 miles. As BEBs are more range-limited than traditional diesel or diesel-hybrid buses, block length is one of the critical determinants in assessing the suitability and implementation time frame of BEBs.

Table 21: August 2024 blocks using 40-foot buses by facility

Block Length*	North Loop	Heywood	East Metro	Nicollet	South	Total
≤ 133 miles	46	28	56	99	30	259
> 133 miles	113	51	135	92	68	459
Total	159	79	191	191	98	718

*Block length thresholds correspond with anticipated BEB battery technology ranges in Minnesota winters as outlined in Section 8.3. Blocks greater than 134 miles are assumed to require on-route charging, significant technology advancements, and/or to be divided into multiple blocks for short-term 40-foot BEB service.

Table 22: August 2024 blocks using 60-foot buses by facility

Block Length*	North Loop	Heywood	East Metro	Nicollet	South
≤ 104 miles	24	1	19	0	5
> 104 miles	9	0	14	0	4
Total	33	1	33	0	9

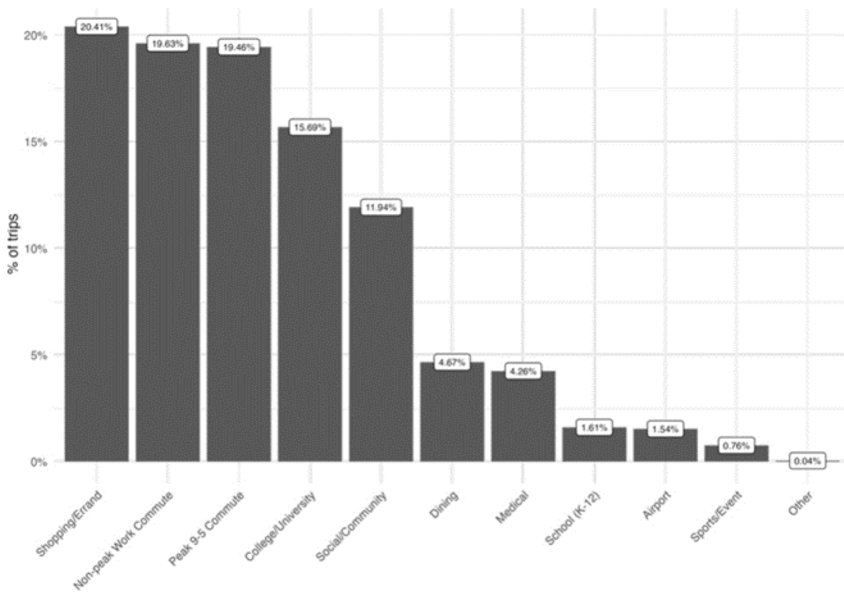
*Block length thresholds correspond with anticipated BEB battery technology ranges in Minnesota winters as outlined in Section 8.3. Blocks greater than 104 miles are assumed to require on-route charging, significant

[216] Source: _Committee Report Business Item 2024-108_, Metropolitan Council, accessed August 2024.

technology advancements, and/or to be divided into multiple blocks for short-term 60-foot BEB service. No 60-foot buses operate out of the Nicollet Garage.

5.2.6 Changing Travel Patterns

Figure 34: Bus Trips by Trip Purpose (Percent of Regional Total)



Since 2020, local and regional travel behavior has changed significantly due to the COVID-19 pandemic and other societal changes. In particular, Metro Transit's rush-hour ridership peaks have become less pronounced since the pandemic, with traditional commuter service recovering more slowly than midday, evening, and weekend trips. Metro Transit found that single-purpose work trips usually covered with commuter express routes were the least resilient during and following the pandemic, likely due to increased telecommuting, lower congestion levels, and lower downtown parking prices.[217] Prior to 2020, commute trips made up about 34 percent of trips on the network; as of 2023, they account for only 20 percent of trips. In total, only about half of trips on the bus network as of 2023 could be defined as some form of commuting (to either work or school), while other trip purposes have grown significantly, emphasizing the increased importance for routes with all-day service designed to serve a variety of trip purposes (**Figure 34**).

5.2.7 Changing Service Levels

Reflecting the low resiliency of single-purpose work trips and change in travel patterns, as of August 2024, Metro Transit has nearly returned to 2019 service levels for BRT, Local Bus, and light rail transit (LRT) service while providing just 26 percent of 2019 Commuter Express and Northstar service levels (**Figure 35**).[218]

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[217] Source: *Network Now Chapter 2: Network Performance and Opportunities*, Metro Transit, September 2023, accessed August 2024.

[218] Source: August 17, 2024 Workforce Update and Service Changes, Metro Transit, accessed August 2024.

Figure 35: August Service Levels by Route Type (2019 vs. 2024)

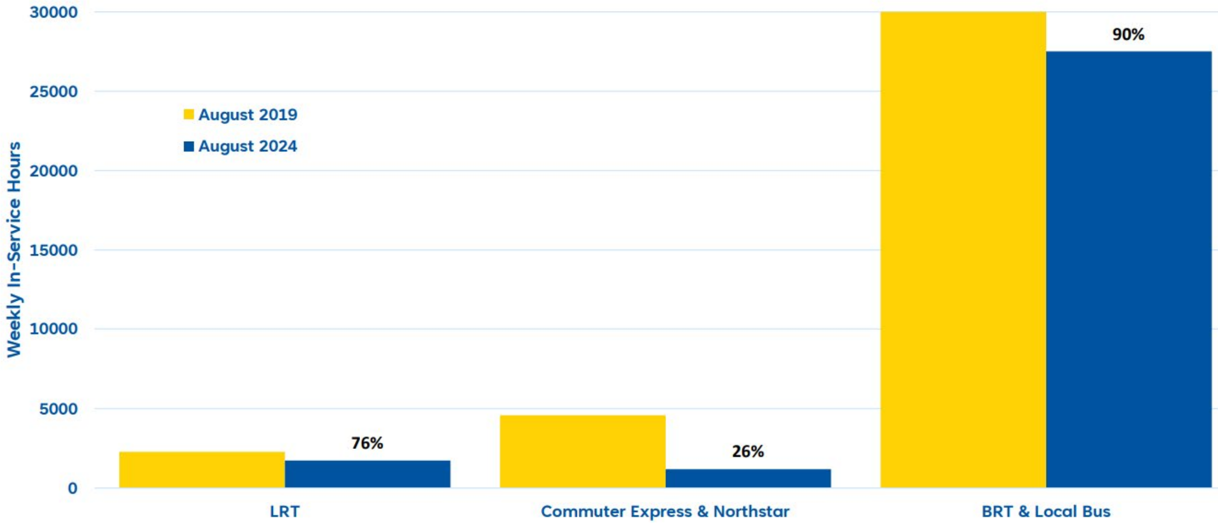
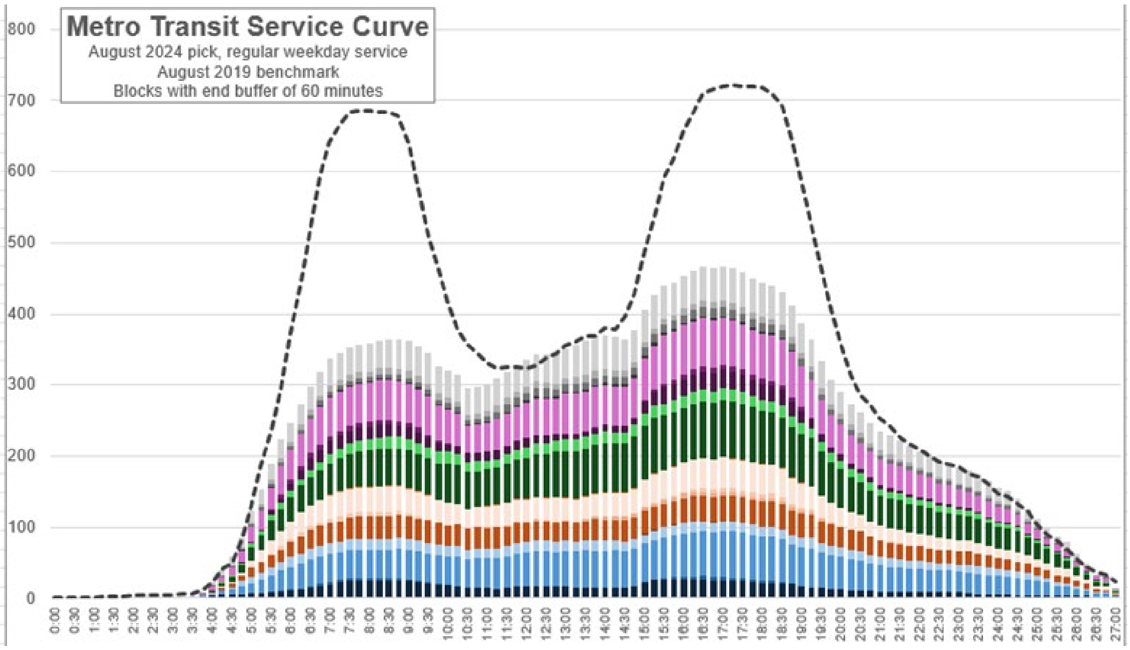


Figure 36: Metro Transit Service Curve by Time of Day (2019 vs. 2024)



Another way to visualize this change is through the lens of service provided by time of day. As seen in **Figure 36**, in 2019 there were greater levels of peak service with naturally shorter block lengths well suited for BEB operations. Under current service patterns (and those expected with the Network Now planned service profiles), there are few remaining short block options. As a result, there are less naturally occurring 1 to 1 BEB transitions from diesel buses to BEBs.

6 Outreach and Engagement

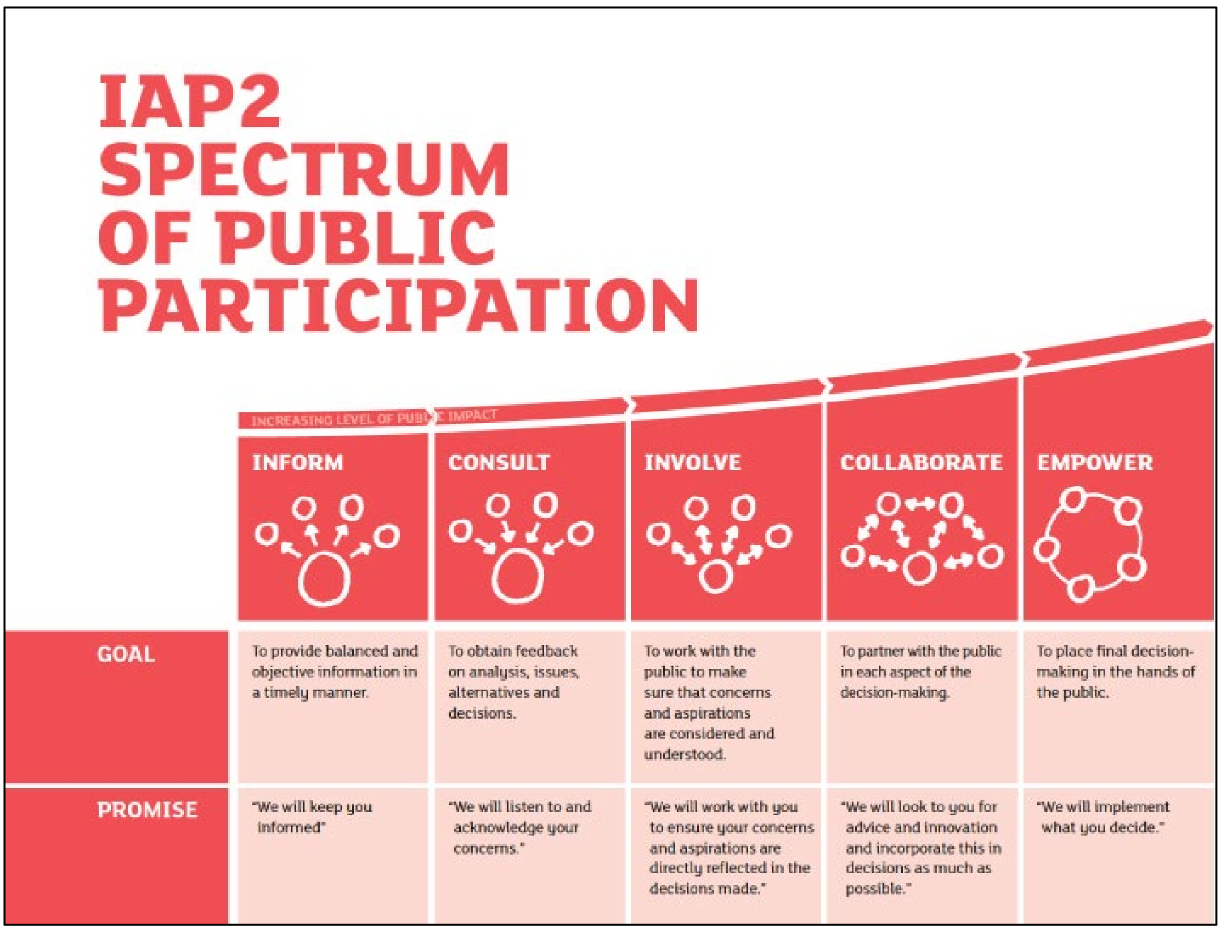
The outreach and engagement described in the plan occurred in 2021 as part of the development of the initial ZEBTP published in 2022. Metro Transit does engagement related to its ZEB program annually and develops a summary report. This is engagement implementation of strategies identified in Section 7.3.

6.1 Engagement Goals

The overall purpose of engagement for this ZEBTP was to build an understanding of ZEB opportunities, challenges, and risks with interested Twin Cities communities and to consult with interested stakeholders and the public to develop the ZEBTP. As a regularly updated plan, continued engagement is anticipated in future ZEB planning and implementation stages.

Engagement efforts focused on each of the ZEBTP's three guiding principles outlined in Section 3. To help define the public's role in the ZEBTP, an engagement goal (defined by the IAP2 Spectrum of Public Participation in **Figure 37**) was established for each guiding principle.

Figure 37*:* IAP2 spectrum of public participation[219]



[219] Source: *What is the Spectrum of Public Participation*, Sustaining Community.

6.1.1 Technical Viability Engagement Goal

The primary goal for technical viability engagement was to consult with the public to obtain feedback on the definitions and success metrics for technical viability developed by Metro Transit.

Consult – *To obtain public feedback on analysis, alternatives, and/or decisions.*

6.1.2 Equity and Environmental Justice Engagement Goal

Definitions and success metrics for EEJ were determined in partnership with stakeholders, affected communities, and the public. The primary goal for EEJ engagement was to collaborate with stakeholders, affected communities, and the public on alternatives and solutions for determining EEJ outcomes.

Collaborate – *To partner with the public in each aspect of the decision, including the development of alternatives and the identification of the preferred solution.*

6.1.3 Fiscal Impact Engagement Goal

Definitions and success metrics for fiscal impact were determined by Metro Transit, the Metropolitan Council, and the regional, state, and federal transit funders. The primary goal for financial impact engagement was to consult.

Consult *– To obtain public feedback on analysis, alternatives, and/or decisions.*

6.2 Definitions of Engagement Terms

It is essential to clearly define terms to set expectations for the public and staff involved in the project. Engagement, outreach, involvement, and input are often used interchangeably, but each term implies a different end goal.

Engagement – Promotes participation in community life, especially by those who are usually isolated or excluded, by engaging them in collective action to create a healthy community. Relationship and trust-building is the key to a strong engagement process. Strategies include one-on-one conversations, listening sessions, collaborative design exercises, and workshops.

Outreach – Means to disseminate information, educate, and build awareness. Strategies include presentations, social media, print media, distributing flyers, and open houses. Outreach is an essential first step to introduce the public to the project.

Involvement – Occurs when stakeholders participate in the designed planning or engagement activity. An engaged stakeholder is involved in the process, but involvement does not guarantee relationship-building or increased community capacity.

Input – Information and feedback provided by the public, communities, or stakeholders to the planning staff. Input is an important aspect of engagement, but on its own, it is insufficient because it does not require planning staff to relay information back to those who provided input or details on how their input influences decision-making.

Community – In this ZEBTP, community is defined as a group of individuals that share common geography or characteristic(s). Examples of community could be a classroom, an apartment building, the disability community, or the Latino community.

Underrepresented community – Within every community there are members whose voices are underrepresented in decision-making. This may include communities of color, disability communities, renters, youth, and transit riders.

Stakeholders – Organizations, communities, governments, property owners, businesses, transit riders, employees, and members of the public that the project impacts or benefits.

The public – Everyone.

6.3 Engagement Strategies

Acknowledging the compressed engagement time frame, engagement opportunities primarily targeted interested stakeholders with an outreach strategy (overviewed below) that was designed to inform the wider community. The ZEBTP is a step towards the transition to zero-emission transit vehicles. As a living plan, there will be opportunities for engagement in the future.

Figure 38: Transition Plan overview video screenshot

6.3.1 Engagement and Outreach Opportunities

Through both internal and external engagement efforts, the engagement team primarily targeted known interested stakeholders due to the compressed time frame for engagement.

6.3.1.1 Internal Engagement

Internal engagement targeted frontline staff, bus operators, and mechanics. This engagement included pop-ups at all five garage facilities, an informational slideshow on operator dayroom video screens, manager-direct report briefings (train-the-trainer model), and internal communications newsletters (**Figure 39**).

Figure 39: Bus operator outreach

6.3.1.2 External Engagement

External engagement efforts targeted interested stakeholders through three primary methods: external stakeholder workshops, short presentations/discussions with Minneapolis and Saint Paul neighborhood organizations, and a broader public survey.

6.3.1.3 Stakeholder Workshops

Two stakeholder virtual summit workshops were held in November 2021. Over 60 interested stakeholders participated in the afternoon and evening workshops. The initial stakeholder invite list was developed by identifying individuals who had expressed past interest in Metro Transit's electric vehicle or environmental sustainability projects as well as Twin Cities organizations with a known focus on electric vehicle or environmental sustainability. The workshops were also publicized on Metro Transit's social media pages and website.

6.3.1.4 Neighborhood Organization Updates

Thirty-two Minneapolis and Saint Paul neighborhood organizations were identified based on initial technical analysis and contacted to share survey information and an offer for project staff to provide an update at an upcoming meeting. As of December 31, 2021, ten organizations had participated or had scheduled update presentations for an upcoming meeting between November 2021 and February 2022. Two organizations indicated they did not have space on their upcoming agendas but felt that their members were likely supportive of Metro Transit's transition to ZEBs. Other neighborhood organizations responded that they would share the survey with members and share the request to update their governing body.

6.3.1.5 Online and Paper Survey

A 12-question public survey was publicized on Metro Transit's website, social media, and external newsletters. In total, 302 responses were collected between October 28, 2021, and December 12, 2021. Paper surveys were also distributed and collected at the METRO Orange Line opening on December 4, 2021. In addition to these survey responses, the stakeholder workshops and neighborhood updates also included similar polling questions.

6.4 What We Learned

Most stakeholders that were engaged in November and December 2021 supported Metro Transit's transition to ZEBs. Nearly 90 percent of survey respondents indicated that Metro Transit's transition to ZEBs was personally important or very important. A smaller number of participants emphasized that they had less concern with bus propulsion type and more interest in increasing transit frequency and access. In addition, a small number of participants emphasized that the transition to ZEBs was moving too slow. A compressed engagement timeline combined with the challenges many of our communities faced in 2021 likely resulted in engagement responses that were skewed toward high-interest stakeholders and community members.

6.4.1 Survey Question: What do you hope Metro Transit achieves in the transition to zero-emission buses?

Many respondents hope that transitioning to ZEBs will address climate change, equity, and public health concerns. Respondents recognized the impacts including health issues such as cancer and asthma that lower-income communities and communities of color have and continue to experience at a higher rate are due in part to past transportation decisions. Respondents hope that ZEBs will provide cleaner air quality in these communities to decrease these health issues and health disparities.

Many respondents also shared that they would like to see a continued focus on making transit more convenient than driving. Respondents felt that ZEBs, with a quieter and smoother ride as well as an emphasis on frequent and reliable transit service could help increase transit ridership and reduce single-occupant VMT. As noted in Section 2, Metro Transit's transition to ZEBs is one of the many strategies the agency intends to implement to make a meaningful impact on tackling climate change.

6.4.2 Survey Question: How should Metro Transit determine which areas zero-emission buses serve first?

Many respondents felt that it is essential that Metro Transit's ZEB implementation prioritize racial equity, socioeconomic issues, and health disparities. This includes areas with a high prevalence of residents who rely on transit, neighborhoods with younger people with rising health concerns, and communities adversely impacted by historical infrastructure decisions such as the location of highways. Respondents also suggested prioritizing areas with the most significant air and environmental pollution impacts, such as high-density areas with high vehicle traffic. As identified by survey responses, other areas to prioritize include frequent bus routes, BRT routes, areas with high potential for vehicle idling, and areas of environmental concern. Overall, respondents felt that ZEB deployment should be prioritized in neighborhoods that would use them the most, need them the most, and are most impacted by pollution. Several respondents expressed that density alone should not be the driving factor for prioritizing ZEBs.

6.4.3 Survey, Stakeholder Workshop, Neighborhood Presentation Question: Please rank the characteristics below (1=most important and 7=least important)

At each engagement event, and as part of the survey, participants were asked to evaluate and rank the relative importance seven unique population and environmental variables should have in identifying equitable and environmentally just areas within which to prioritize ZEB deployment.[220] Overall, engagement participants identified lifetime cancer risk from the inhalation of air toxics as the most important consideration followed by population density and the portion of a census tract's residents that identify as BIPOC (**Table 23**).

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[220] Note: The seven census-tract level variables participants were asked to rank include lifetime cancer risk from inhalation of air toxics, population density, portion of residents who identify as BIPOC, portion of households lacking a vehicle, the number of 5-year American Community Survey (ACS) datasets in which the census tract was designated as an area of concentrated poverty, the portion of households that are housing cost-burdened (housing costs are 30 percent of household income), and the average land surface temperature on a hot summer day (proxy for urban heat island effect). The selection of these variables will be described in Section 8.3.2

Table 23: EEJ engagement results

Characteristic	Final Rank
Cancer Risk	1
Population Density	2
% BIPOC	3
% Zero Car Household	4
Number of Years Area of Concentrated Poverty	5
Average Land Temperature (Heat Island Proxy)	6
% Housing Cost Burdened	7

6.4.4 Survey, Stakeholder Workshop, and Neighborhood Presentation Question: What other characteristics or factors would you use to measure equity and environmental justice?

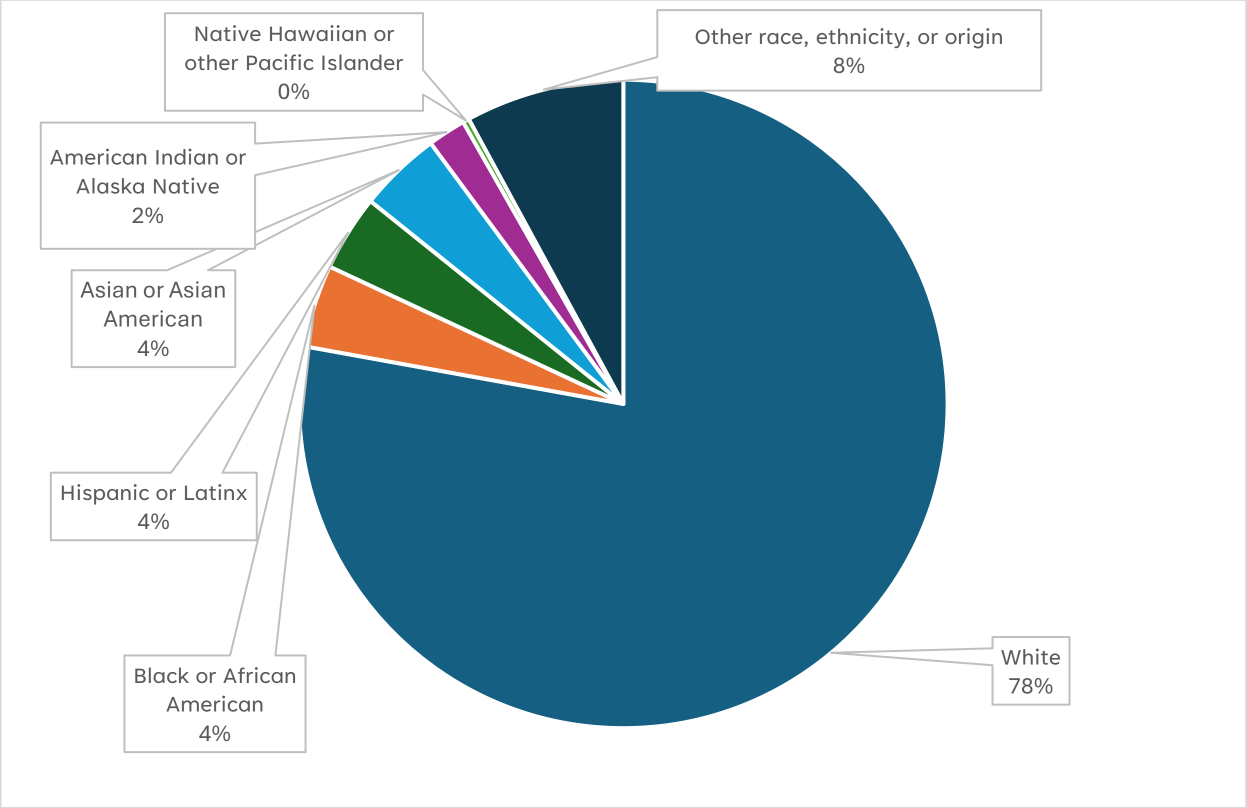
Respondents identified several characteristics and factors such as access to alternative transportation as well as access to essential services (e.g., grocery stores, hospitals, libraries) and health care that Metro Transit should consider when measuring EEJ. Several respondents also suggested looking at age demographics (youth and seniors), child asthma rates, other air pollution-related health concerns, and disabled communities. Other characteristics respondents suggested to consider when measuring EEJ include ridership rates, density of buses, high pedestrian environments, noise, and areas lacking trees and green spaces. These additional factors will be considered for inclusion in future updates to the ZEBTP.

6.5 Survey Demographics

Across the over 300 survey participants:

- 64 percent used transit at least “a few times a week” prior to COVID-19 (March 2020);
- 28 percent used transit at least “a few times a week” since March 2020;
- Most survey respondents were ages 25 to 34 (32 percent) or 35 to 44 (26 percent);
- 50 percent identified as male, 41 percent identified as female, and 9 percent identified as non-binary/third gender; and
- 22 percent identified as non-white (**Figure 40**).

Figure 40: Race/ethnicity of survey respondents



7 Zero-Emission Bus Policies and Guidance

This section describes the development of assessment criteria and the methodology used to evaluate and prioritize aspects of transitioning Metro Transit's operations to zero emissions. Following the selection of a ZEB propulsion technology for implementation in the short term, this section will then assess the suitability and readiness for ZEB service at key Metro Transit facilities before introducing and implementing a methodology to identify and prioritize the most suitable bus blocks for a transition to ZEB service in the short term.

7.1 Short-Term Zero-Emission Bus Propulsion Technology

As outlined in Section 4, there are three primary types of ZEBs currently operating in the U.S.: electric trolleybuses, BEBs, and FCEBs. One of the key decisions that transit agencies face when transitioning to ZEBs is determining how ZEBs will be powered, as trolleybuses, BEBs, and FCEBs each have unique operational characteristics.

In the short term, Metro Transit does not intend to pursue the implementation of electric trolleybuses given their limitations compared to BEB technologies. These limitations include:

- Limited flexibility for off-wire operation;
- Limited speeds, as faster speeds increase the likelihood that the bus will disconnect from the overhead wires, particularly around curves and corners;
- Limited ability to detour due to construction and potential disruptions to bus service;
- Construction impacts spread along roadways through the region;
- Extensive costs associated with building and maintaining a network of overhead wires; and
- Significant visual impacts from overhead wires which may be unfeasible on roads with narrow rights-of-way or in neighborhoods protected by historic preservation laws.

Metro Transit has selected BEBs as the short-term ZEB propulsion technology for implementation and deployment

Additionally, Metro Transit has dismissed using FCEBs in the short term due to the considerable upstream carbon emissions associated with creating and trucking hydrogen, the high cost of FCEBs, and the lack of hydrogen fueling stations in Minnesota. Instead, Metro Transit has selected BEBs as the short-term ZEB propulsion technology for implementation and deployment. In the future, Metro Transit will continually reassess this decision as ZEB technologies evolve.

Based on this selection of BEBs for implementation and deployment in at least the short term, Metro Transit's facility and service suitability is assessed in the following subsections based on the unique operational characteristics associated with BEBs. At the most fundamental level, two core elements are required for successful BEB integration:

- Facilities with the necessary electrical infrastructure to charge the BEBs; and
- Service where the blocks/vehicle tasks are supportive of BEB range limitations.

Based on Metro Transit's C Line experience, discussed in Section 5.1, Metro Transit is moving forward with garage-based charging options. As a result, Metro Transit will be looking at ways to integrate BEBs into its fleet while recognizing the range limitations of BEBs.

7.2 Facility Guidance

Electrical upgrades and BEB storage are not currently recommended at South Garage

The first of the two core elements required for successful BEB integration is suitable facilities. For the purposes of this analysis, two types of facilities were considered: OHB and garages. The primary characteristics affecting a facility's suitability for BEBs are the space and electrical capacity required to install and operate the supporting electrical infrastructure and chargers necessary to recharge BEBs. Therefore, to assess facility suitability, both spatial and electrical constraints associated with electrifying each facility were identified to determine the time necessary to perform these electrical upgrades and to quantify the amount of bus storage capacity lost to provide space for BEB charger installation and operation. Based on these constraints, Metro Transit's key facilities were categorized into two tiers indicating their suitability for BEB operation as well as their priority level for electrification. In addition to the two core elements, facilities were screened by property status to determine if the property is either owned or under a long-term lease. Based on this property status screening, electrical upgrades and BEB storage are not currently recommended at South Garage.

7.2.1 Overhaul Base

In the short term, one plug-in-style charger will be installed at the OHB

As mentioned in Section 6.1.1, the OHB does not currently contain any charging infrastructure and equipment. Therefore, when one of the eight BEBs currently in the fleet need to travel to the OHB, this movement is carefully orchestrated to ensure the BEB is fully charged when leaving the Heywood Garage. As Metro Transit incorporates the new BEBs into service in 2025 and 2026 and beyond, as discussed in Section 6.2.3, this detailed orchestration will become less practical and technically viable. Because of this, in 2024, Metro Transit ordered one 50kW mobile charger specifically for the OHB. The maintenance charger is anticipated to be installed and operational in early 2025. This first charger will provide operational flexibility for maintenance activities. Metro Transit plans to order another plug-in-style charger in the short term for the OHB for redundancy reasons. Currently, before the installation of any mobile chargers, the OHB has approximately 1MW of electrical capacity available for use and could support a maximum of seven 150kW charging stations prior to needing additional electrical upgrades.

7.2.2 Garage Modeling

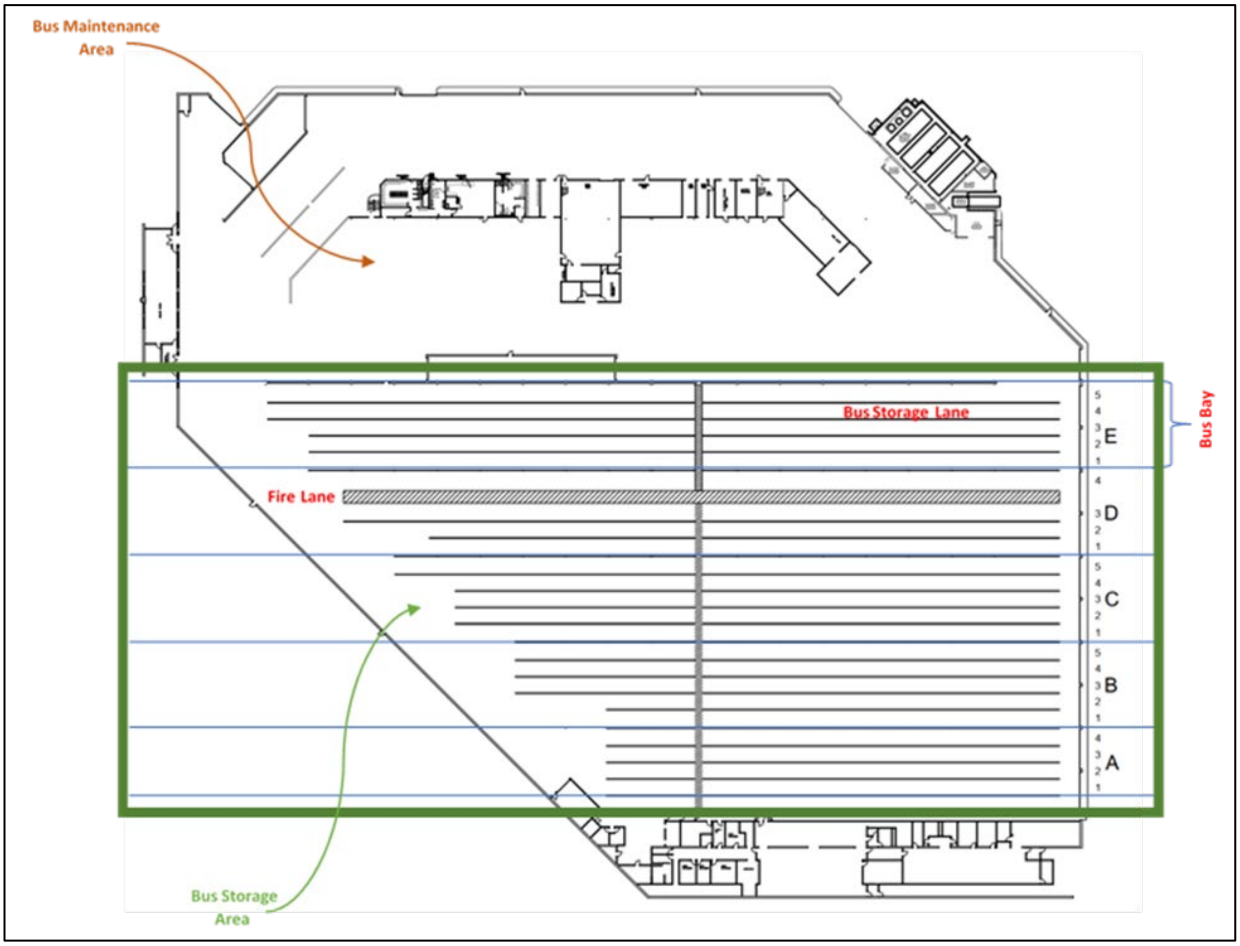
To assess garage suitability for BEB service, the electrical and spatial constraints of each of Metro Transit's five garages were analyzed. Based on the results of this analysis, each garage was placed into one of two ranked suitability tiers indicating their electrification priority. In a parallel effort, Metro Transit is currently updating its SFSP in coordination with this ZEBTP. Long-term recommendations for Metro Transit's facilities will be included in the SFSP.

7.2.2.1 Spatial Constraints

One of the most significant garage impacts associated with fleet electrification is the bus storage capacity (parking spaces) lost to provide adequate space for charging infrastructure. Whereas many peer agencies can minimize these impacts by installing chargers outdoors, due to the severe winter climate in Minnesota, it is essential that Metro Transit's chargers be located indoors to provide temperature-controlled conditions necessary for safely maintaining equipment and providing reliable operations regardless of weather conditions. Metro Transit will be undertaking a Fire Hazard Analysis as detailed in Section 12.7 that could further impact the spatial constraints. For the purposes of this report, the assumption is that this will not further impact capacity more then what is listed in assumptions below.

Functionally, Metro Transit's garages are divided into two primary areas: one for bus storage and a second for bus maintenance (**Figure 41**). Given the need to perform specialized operations within the maintenance area, with buses constantly rotating through work positions, only the bus storage capacity, rather than the total design capacity (storage + maintenance area) was used when modeling the storage area charger quantities that could have a potential impact on the storage space at each garage.

Figure 41: Example garage layout with bus storage and maintenance areas



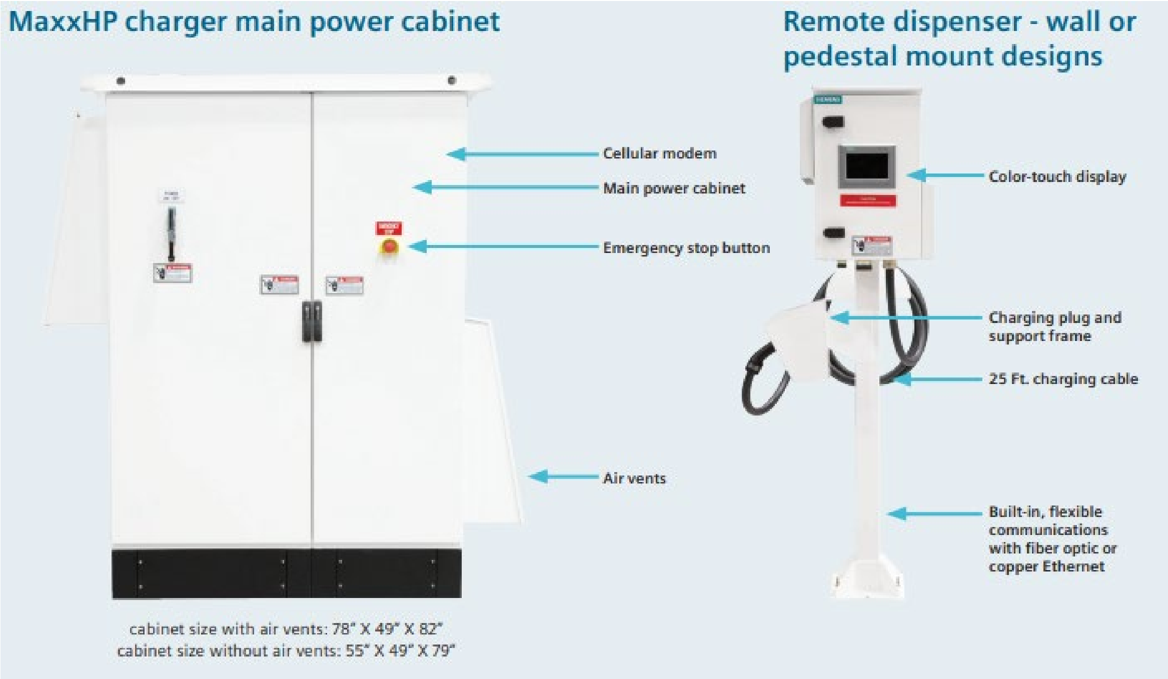
As BEBs are typically the same length as conventional buses, impacts to bus storage capacity associated with electrifying a garage are primarily due to the spatial requirements of the chargers themselves. As discussed previously, pending Metro Transit's Fire Hazard Assessment, the capacity within garages is temporarily lower than what is reflected in this analysis. To model these spatial impacts on bus parking capacity at each garage, two factors must be considered:

- Charger dimensions; and
- Charger quantity.

Only one of Metro Transit's existing five garages currently has sufficient space to accommodate the number of chargers necessary to support a fully electrified bus fleet assuming each charger has two dispensers (plug-in or pantograph) such that one charger is needed for every two buses in a garage's bus storage area. As space is limited within each garage, a select number of bus parking spaces must be eliminated to provide space for these chargers. To minimize parking impacts, it is assumed that the charger dispensers will either be mounted overhead or within the shadow of existing structural support columns within a garage and will not lead to a loss in parking capacity. As a result, the primary impact to parking capacity in four of Metro Transit's five garages is the space required for the charger bases/power cabinets. Metro Transit's newest garage, the North Loop Garage, which opened in March 2023, is the exception, as space was designed into the building to house chargers so as not to reduce bus storage capacity.

Charger size varies by manufacturer. For the purposes of this analysis, Metro Transit is using a 150kW charger, similar to the chargers currently at Heywood Garage (Siemens Versicharge MaxxHP) to assess spatial capacity constraints at each garage in order to provide a worst-case scenario for parking loss. The largest dimensions of this charger base are 78 inches wide, 49 inches deep, and 82 inches tall (**Figure 42**).

Figure 42: Siemens MaxxHP charger dimensions[221]



[221] Source: *VersiCharge MaxxHP Fleet Charger Dimensions*, Siemens.

Using these dimensions in tandem with existing floor plans and site pictures for each of the garages, new BEB parking layouts were created that focused on identifying an optimal balance maximizing charger quantity while minimizing parking loss within the bus storage area. To guide these calculations, several additional assumptions were made.

7.2.2.2 Garage Capacity Assumptions

- For operational efficiency, garage storage lanes can either hold chargers or buses, not both.
- Any buses stored in locations not designed to be parking spaces (e.g., drive aisles, outdoors, fueling lanes) are not included in calculating charger quantities and power requirements
- A fire lane must be retained at every garage.
- Fiber optic data lines connect the chargers to each bus location, reducing limitations on allowable distance between chargers and dispensers.

7.2.2.3 Charger Quantity and Power Assumptions

- 150kW of charging capacity is required per two bus parking spaces.
- 150kW of charging capacity is required per four bus maintenance bays.
- Sufficient space exists to house maintenance bay chargers without capacity losses.

Based on these assumptions, the number of chargers included in the bus storage area of the BEB parking layouts were incrementally increased until the ratio of parking spaces to charger bases at each garage met at a ratio of 150kW for every two buses. It was assumed that 150kW of charging capacity is enough to charge two buses once daily[222]. At this point, adding any additional chargers would have decreased BEB parking capacity to a point where there were more charging dispensers than buses in the storage area of a garage. BEB parking layouts were then compared with the existing parking layouts for each garage to identify the maximum amount of bus storage capacity lost to provide adequate space for BEB charging infrastructure. As charger quantity is proportional to bus quantity, the charger spare ratio is inherently the same as the bus spare ratio.[223] Metro Transit intends to review the ratio of plug-in chargers to BEB fleet count relative to the bus assignments to better inform what is possible.

If all five existing garages were to be fully electrified, it is estimated that 47 parking spaces would be lost compared with existing storage capacity (**Table 24**). Comparing the relative loss in bus storage capacity across each garage, the Nicollet Garage is estimated to lose the greatest percent of its existing bus storage capacity (11 percent) while the East Metro Garage is estimated to lose the least (2 percent) (when excluding North Loop Garage since this was designed to house chargers).

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[222] See Section 1078.2.3.4 for a discussion of charging strategies and assumptions.

[223] Note: The FTA states that the number of spare buses in the active fleet for grantees operating 50 or more revenue vehicles should not exceed 20 percent of the number of vehicles operated in maximum service. (Source: *Circular C 9030.1E: Urbanized Area Formula Program: Program Guidance and Application Instructions*, FTA, 2014)

Table 24: Fully electrified garage: bus storage capacity impacts

Garage	Design Capacity	Maintenance Capacity	Storage Capacity (Current)	Difference from Current Storage Capacity	Storage Capacity** (BEBs)	September 4, 2024, Utilization (Fleet)
East Metro	198	24	174	-4 (-2%)	170	137
Nicollet	162	16	146	-16 (-11%)	130	119
Heywood*	214	20	194	-17 (-9%)	177	131
North Loop	216	24	192	0	192	120
South	123	16	107	-10 (-9%)	97	96
Total:	913	100	813	-47 (-6%)	766	603

Note: South Garage was included in this analysis but is not recommended for electrical upgrades at this time. See South Garage section, below, for more details

*Heywood Garage utilization values are inclusive of the 20 Maple Grove Transit-branded buses

**Capacity at each garage will depend on composition of the fleet stored at each garage (e.g., the number of 40-foot, 60-foot, and coach buses)

Since 2020, Metro Transit has seen substantial changes in the demand for transit and its service. As a result, it has adjusted its fleet size. In 2020, Metro Transit had 904 buses; by September 2024 its fleet had been reduced to 603 buses. As discussed in Section 2.7.1 Network Now (2024), Metro Transit is planning to grow its bus service by 35 percent through 2027. In order to do this, Metro Transit will be expanding its fleet by 22 to 44 buses per year. Metro Transit's Capital Improvement Plan (CIP) proposes to continue this expansion through 2030. Metro Transit may consider up to 44 buses added per year depending on the rate of workforce hiring as well as the needs for supporting the fleet with additional vehicles and propulsion types.

7.2.2.4 Electrical Constraints

In addition to parking capacity, energy constraints are the second critical factor used to determine a garage's suitability for BEB service. In collaboration with Xcel Energy, existing electrical infrastructure and capacity limitations for each of the five Metro Transit garages were identified. This effort included the confirmation of available transmission capacity, transformer specifications, and the current peak power demands. Based on information provided by Xcel Energy, it was identified that the electrical transformers at all garages have limited available capacity except for the 6MW of capacity dedicated to charging at the North Loop Garage, which Xcel Energy upgraded specifically to accommodate BEBs at the site. Therefore, aside from the initial 6MW at the North Loop Garage, it is assumed that any electrical capacity necessary to support BEB charging will need to be newly installed at each garage.

To accommodate additional BEBs, multi-year electrical upgrades will be needed at all garages

Due to the limited available electrical capacity at all existing garages and to accommodate additional BEBs beyond what the existing 6MW will support at the North Loop Garage, multi-year electrical upgrades by Xcel Energy will be needed at all garages to support future BEB charging infrastructure. Each of these upgrades are estimated to take Xcel Energy between 2 to 5 years depending on whether the electrical lines feeding a garage are located overhead or underground, respectively. The expected timelines include coordination with Xcel Energy on needed capacity, the development of engineering drawings, and pulling cable from the line to bring new wires to the facility to support additional electrical capacity. Underground lines are expected to take more time to receive approvals from the city for trenching and digging as well as to confirm that the electrical ducts can support additional cables. As the electrical load is increased at each facility, upgrade timelines may be extended to allow time to confirm that Xcel Energy has sufficient grid capacity to support the added load. These timelines do not include the time needed for Metro Transit to design, procure, install, and commission the charging equipment. While some activities will be done concurrently, Metro Transit cannot complete installation and commissioning until adequate power is available at the facility. To facilitate a timely delivery and confirm that sufficient grid capacity exists to support added loads, Metro Transit will work in close collaboration with Xcel Energy to develop ZEB project timelines that coordinate with Xcel Energy's timelines for planning, engineering, and construction.

Metro Transit will continue to collaborate with Xcel Energy to develop ZEB project timelines that coordinate with Xcel Energy's timelines for planning, engineering, and construction

To quantify the scale of these upgrades, planning level estimates of the future electrical capacity needed to support a fully electric bus fleet at each garage were calculated. Under the assumption that every two parking spaces will require one 150kW charger and that every four maintenance bays will require one 150kW charger, future electrical capacity needs were estimated by multiplying a charger's power rating by the optimal number of chargers necessary to support a fully electrified garage.[224] For example, a hypothetical garage with 100 buses in the storage area and 20 buses in the maintenance area would require 50 storage area chargers (totaling 7,500kW) and five maintenance area chargers (totaling 750kW) assumed at each garage. Together, this would require a future electrical capacity of approximately 9MW (8,250kW). Combined, the quantity and time frame to complete these upgrades greatly influence the suitability of a garage for short-term BEB service.

It should be noted that Metro Transit continues to learn about the charging process and the need to use a BEB for more charge per day. As a result, Metro Transit needs to better understand the ability to conduct midday charging to facilitate buses going out for service both in the morning and in the afternoon. While two dispensers may be available for each 150kW charger, when both are used concurrently, the rate of charging drops by half. As a result, Metro Transit may need to gain experience with the charging technology and logistics of putting buses in service to truly understand the number of chargers needed and resulting power.

[224] As the types of chargers that are available may change in future years, it is important that Metro Transit has 150kW for every two buses to provide enough charging capacity to allow the buses to be ready for service. This could be accomplished with one 150kW charger for every two buses or one 300kW for every four buses. For the capacity analysis one charger for every two buses was chosen to provide a conservative estimate of the potential loss of parking and to leave Metro Transit with options to reduce the potential impact to its loss of parking capacity in the future.

Overall, each of Metro Transit's five garages can accommodate a unique number of BEBs and chargers resulting in a range of electrical impacts (**Table 25**). Each garage will require significant electrical capacity upgrades ranging from 9MW to 16MW to support BEB chargers. In the near term, upgrades will be focused on garages with available grid capacity that are served by overhead electrical lines, as these facilities require less time to retrofit.

Table 25: Fully electrified garage: electrical impacts

Garage	Storage Capacity* (BEBs)	150kW Storage Area Chargers	150kW Maintenance Area Chargers	MW Needed to Support Full Electrification
East Metro	170	85	6	14
Nicollet	130	65	4	11
Heywood	177	89	5	15
North Loop	192	96	6	16
South	97	49	4	8
Total:	766	384	25	64

Note: South Garage was included in this analysis but is not recommended for electrical upgrades at this time. See South Garage Section, below, for more details
*Capacity at each garage will depend on composition of the fleet stored at each garage (e.g., the number of 40-foot, 60-foot, and coach buses). Capacity may also be impacted by the results of Metro Transit's future Fire Hazard Assessment study.

If, in the long term, Metro Transit were to fully electrify its bus fleet, a total of 64MW of electrical capacity would be needed, which is more electrical capacity than what is used to power the existing light rail system including the Blue Line (29MW) and Green Line (21MW) (**Table 26**).[225]

Table 26: Fully electrified garage facility electricity needs compared with the light rail system

Garage Facility	MW	LRT System	MW
Metro Transit Garages*	64 MW	Existing LRT System *(Blue & Green Line)*	50 MW

*South Garage was included in this analysis but is not recommended for electrical upgrades at this time. See South Garage Section, below, for more details

More than electrical capacity used to power the existing light rail system would be needed to fully electrify Metro Transit's bus fleet

Substation level upgrades would need to be completed by Xcel Energy to support such a high-capacity addition. Before undergoing such upgrades, Metro Transit and Xcel Energy should leverage findings from short-term electrification and technological advancements to identify an optimal path forward. This could include installing distributed energy resources such as solar panels and energy storage systems or a microgrid system to reduce demand from the grid. Implementation of these systems could significantly reduce Xcel Energy's capital costs and Metro Transit's operating costs by mitigating the need for grid infrastructure upgrades, reducing peak demand, and lowering energy consumption. However, the

[225] Source: Email with Metro Transit staff, December 2021.

installation of the distributed energy resources would also lead to an increase in Metro Transit's capital costs.

7.2.3 Individual Garage Guidance

Using the methodology outlined above, the suitability and BEB readiness for each of Metro Transit's five bus garages are summarized below.

7.2.3.1 North Loop Garage

The North Loop Garage opened in 2023 and was designed to accommodate both diesel and electric buses (**Figure 43**). The North Loop Garage is located on the western edge of Downtown Minneapolis with close access to expressways and numerous routes.

The North Loop Garage has a current bus storage capacity of 192 diesel and electric buses. Each bus storage lane at the North Loop Garage was designed to accommodate six 40-foot buses or four 60-foot buses. There are electrical rooms on the street level of the building to house transformers and switchgear, and the adjacent spaces are planned for electric bus chargers. All charging power cabinets will be located on the street level while all dispensers, whether plug-in or overhead pantographs, will be housed on the main level in the bus storage area. There are columns located every three lanes in bus storage. If ground mounted plug-in dispensers are used to charge the BEBs, these dispensers would be located within this column space. Further structural analysis will be required to assess the feasibility of adding overhead pantograph or plug-in cable reel solutions. As the facility was designed to support electric buses, BEB infrastructure can be incorporated at North Loop Garage without losing any parking spaces.

Figure 43: North Loop Garage

As currently designed, the North Loop Garage has 6MW of electrical capacity to support an initial implementation of 80 BEBs.[226] To electrify the remainder of the bus fleet stored at the North Loop Garage, an additional 10MW dedicated to BEB charging infrastructure would need to be installed. Xcel Energy has stated that an additional 4MW of capacity is readily available but further capacity will require upgrades to the local substation. The additional 4MW of power could either be added to the Heywood Garage or the North Loop Garage, but not both, as they are served by the same utility feeder. Given that this connection is to an overhead line, it is anticipated that Xcel Energy would require approximately 2 years to complete this work. It is recommended that Metro Transit review charging configurations and on-site energy generation before reaching capacity limits that would require substation upgrades, as this would be a costly and time-intensive endeavor. The 20 686-kWh 40-foot GILLIG BEBs planned to enter revenue service in 2026 will be based out of the North Loop Garage, supported by 18 chargers. Metro Transit has

[226] 6MW is assumed to support 80 BEBs based on current charging practices of only charging once per day. Depending on the degree to which Metro Transit chooses to utilize midday charging of BEBs, this number may change. See Section 8.2.2.4 for more details.

also begun design on a pilot project in collaboration with Xcel Energy to install up to 2MW of solar panels on the roof with a complementary battery energy storage system (BESS) to gain experience with distributed energy resources.

7.2.3.2 East Metro Garage

The East Metro Garage is centrally located just north of downtown Saint Paul with close access to expressways and numerous bus routes (**Figure 44**). The bus storage area has an optimal layout with generous drive aisles and lane widths. The site is constrained by a highway and railroad tracks on three sides, which may make it challenging to bring additional power to the site. In collaboration with Xcel Energy, it was determined that there is one available power circuit running nearby as well as an adjacent overhead mainline. The facility had 5MW of capacity added in 2024. In June 2024, Metro Transit, in partnership with Xcel Energy, began modifying the East Metro Garage to add four chargers to support five BEBs operating on the Gold Line, starting in 2026.

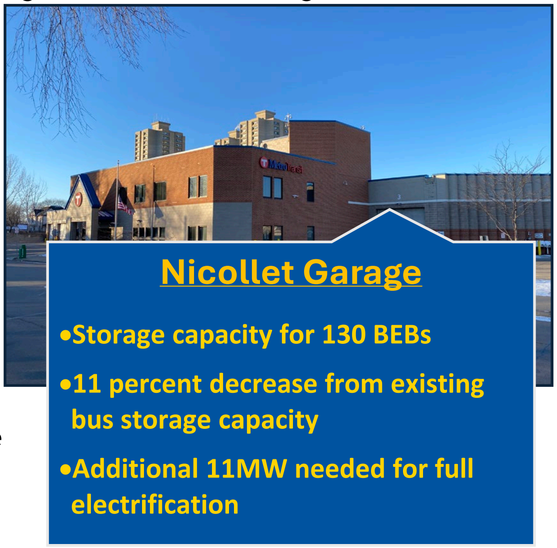
Figure 44*:* East Metro Garage

To support a fully electrified fleet of 170 BEBs at the East Metro Garage, the facility would require electrical capacity of 14MW.[227] Overall, it is estimated that one row (four buses) of existing bus storage space would be lost to provide space for the chargers.

7.2.3.3 Nicollet Garage

The Nicollet Garage is located in south Minneapolis and currently only operates 40-foot buses (**Figure 45**). It is a very long and narrow facility with bus lanes storing 10 to 12 vehicles. Based on conversations with Xcel Energy in fall 2021, it was determined that there are two power circuits running along 31st Street as well as an adjacent overhead mainline to support a larger amount of charging stations. Xcel Energy also identified that 5MW of capacity could be readily provided to this facility. Given that this power connection is to an overhead line, Xcel Energy estimates this work would take approximately 2 years to complete.

Figure 45*:* Nicollet Garage



To support a fully electrified fleet of 130 BEBs at the Nicollet Garage, the facility would require electrical capacity of 11MW.[228] Overall, it is estimated that one to two rows (16 buses) of existing bus storage space would be lost to provide space for the chargers.

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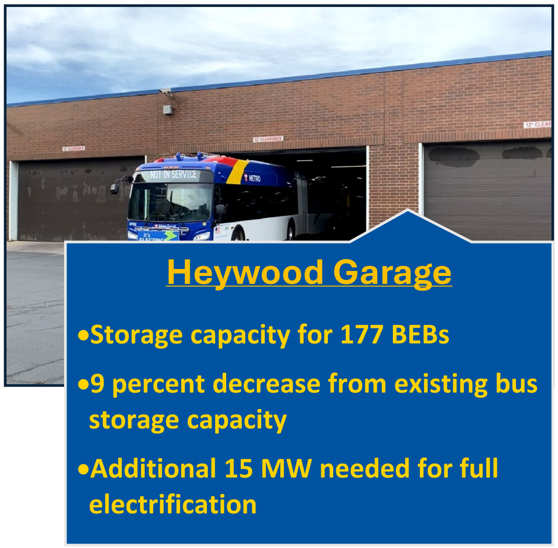
[227] See Section 8.2.2 for assumptions regarding garage capacity.
[228] See Section 8.2.2 for assumptions regarding garage capacity.

7.2.3.4 Heywood Garage

The Heywood Garage is centrally located on the western edge of Downtown Minneapolis adjacent to the North Loop Garage with close access to expressways and numerous routes (**Figure 46**). It is home to the C Line BEB pilot program. There are eight Siemens 150kW plug-in chargers already located at the facility. Each power cabinet has one dispenser but could be modified to add an additional dispenser in the future. There is a separate meter for the electric bus electrical feed that is sized to accommodate the C Line pilot. Additional capacity would need to be added in the future to accommodate additional electric buses.

Figure 46: Heywood Garage



To support a fully electrified fleet of 177 BEBs at the Heywood Garage, the facility would require electrical capacity of an additional 15MW.[229] Overall, it is estimated that one to two rows (17 buses) of existing bus storage space would be lost to provide space for the chargers. Due to the Heywood Garage's proximity to the North Loop Garage, close coordination will be required with Xcel Energy to phase adding power to the campus. After the next 4MW of power is brought to the campus, it is anticipated that Xcel Energy upgrades will require more complex construction requiring additional time to complete. A total of 31MW of power is estimated to be needed to fully electrify both the Heywood Garage and the North Loop Garage.

7.2.3.5 South Garage

The South Garage is located in the south metro area in the northeast quadrant of the interchange of I-494 and TH 77 on the Minneapolis-Saint Paul International Airport property (**Figure 47**). The land the garage is built upon is leased from the MAC. The property lease was renewed in 2020 for 15 years. A 500kVa transformer currently services the site with the potential available capacity to support one 150kW charging station based on the building's peak electrical demand. Power is supplied to South Garage through an underground line. The nearest electrical feeder to bring in additional capacity to the facility is located at East 77th Street (across Highway 77).

[229] See Section 8.2.2 for assumptions regarding garage capacity.

Due to the electrical complexities associated with upgrading the electrical feeders into the site, Xcel Energy anticipates that it may take up to 5 years, and possibly longer, before they could provide the type of electrical redundancy that would be required to support BEBs. In addition, Metro Transit anticipates that it would take one to 2 years to retrofit the garage following the electrical upgrades performed by Xcel Energy. As a result, the soonest the South Garage could be upgraded would be 2031 or 2032 if started at the beginning of 2025. Since the land upon which the South Garage is built is currently only leased through 2035, electrical upgrades and BEB storage are not currently recommended at this garage. As a result, the bus storage capacity at South Garage would remain consistent with the garage's current bus storage capacity.

Figure 47: South Garage

South Garage

- **Short-term property lease**
- **Electrical complexity adjacent to airport**
- **Not recommended for electrical upgrades or BEB storage**

7.2.4 Battery Electric Bus Suitability Tiers

Electrifying an existing bus garage requires significant renovations and detailed coordination with internal and external partners. During garage renovations and retrofitting, buses will need to be removed from portions of the renovated garage(s) to allow for sufficient space for construction and charger installation to occur efficiently. Without this approach, construction will take longer to complete and require more precise scheduling, leading to increased cost. As buses must be stored indoors due to the region's cold climate, it is recommended that the impacted buses be moved to and operated from an alternate garage for the duration of the estimated 1-year renovation period. To mitigate the operational impacts associated with these renovations, and to not exceed the excess storage capacity within the system as highlighted above, it is recommended that ideally one, but no more than two, garages are electrified at the same time. This approach will minimize adverse impacts to operations and system reliability while completing major construction projects in both a time and financially efficient manner.

A maximum of 2 garages can be electrified at the same time

When performing electrical infrastructure upgrades, additional electrical capacity will be incrementally added, rather than a facility becoming fully electrified in a single renovation period. Electrical capacity will be added in building blocks of either 2.5MW or 4MW depending on if Metro Transit is a primary or secondary voltage Xcel Energy customer at the site. If Metro Transit transitions to being a primary customer, whereby Metro Transit owns and is responsible for the maintenance of the electrical infrastructure, electrical capacity at a facility can be increased in increments of 4MW. Doing so impacts operational costs both for maintenance of equipment as well as which tariffs Metro Transit is eligible for with their electric bill. Any decision to upgrade a facility from secondary voltage to primary voltage would have to be studied further to better understand the capital and operating cost implications. As a secondary customer, whereby Xcel Energy owns and maintains the electrical equipment, electrical upgrades could be performed in only 2.5MW increments.

The North Loop and East Metro Garages are recommended as the first garages to be electrified

To guide this phased and incremental electrification process, all garages recommended for electrification have been placed into one of two electrification priority tiers (**Table 27**). These tiers are based on the total time required to electrify the facility as determined through the above assessment of each facility's unique spatial and energy capacity constraints. South Garage was not assigned a priority tier, as electrification upgrades are not recommended at the facility at this time due to uncertainty around the long-term lease status of the facility. Based on the two priority tiers shown in **Table 27**, it is recommended that the North Loop and East Metro garages are the first garages to be electrified followed by the Nicollet Garage and expanded electrification at the Heywood Garage.

Electrification work began with design in 2019 at the North Loop Garage, and 6MW of power was brought to the facility by Xcel Energy in 2020 for future charging. Therefore, the total time to electrify for the first 80 buses is significantly shorter at 12 to 18 months, as only the time to design, procure, install, and commission charging equipment is needed. Similarly, conceptual planning for the East Metro Garage began in 2020 to assess the technical viability of constructing chargers to support the future Gold and Purple BRT lines, and 5MW of power were added to the facility in 2024. As a result, slightly less time may be needed for Xcel Energy to complete their work given preliminary planning is complete. Subsequent facilities will take between 4 and 7 years from the time concept planning begins to when charging equipment can be in service depending on whether power lines are overhead with adequate capacity available or are underground or further away, resulting in more complex engineering and longer construction durations.

Table 27: Metro Transit garage electrification priority tiers

Tier	Garage Facility	Xcel Energy Timeline Horizon	Construction and Installation Timeline Horizon*	Total Time to Electrify	Total MW Needed to Support Full Electrification
Tier 1	North Loop Garage	First 40% ready	1 to 1.5 years	1 to 1.5 years	16MW
	East Metro	5MW added 2024	1.5 to 2 years	3 to 3.5 years	15MW
Tier 2 (Start TBD)	Nicollet	2 years	1.5 to 2 years	3.5 to 4 years	11MW
	Heywood				15MW
--	South	No upgrades recommended without long-term lease			

* Charger construction and installation timeline horizon assumes charging for up to 25 buses; more time needed for larger quantities.

Along with mitigating the operational impacts associated with garage renovations, electrifying garages on a tier-by-tier basis allows time to reflect on and apply the lessons learned from electrifying one tier of garages to subsequent tiers rather than attempting to electrify the entire system simultaneously. In addition to spacing out garage electrification over time, the tiered system also distributes electrification efforts across the system, allowing for greater system redundancy and resiliency than if all BEBs were consolidated at a single garage. Thus, in the event of an isolated garage power outage, BEBs could be moved from the affected garage to garages in the same or previous electrification tier, as these facilities would have the charging infrastructure necessary to support BEB operation in an emergency.

7.2.5 Xcel Energy Memo

Section 8.2.5 provided by Xcel Energy in December 2024, serves as the summary of the analysis Xcel Energy completed and their discussions with Metro Transit to analyze garages and transit centers for electrical capacity readiness (**Figure 48**).

Figure 48*: Xcel Energy memo*

Xcel Energy and Metro Transit have a strong partnership collaborating on sustainability goals and transportation electrification efforts. One of our recent efforts focuses on supporting Metro Transit's Zero Emission Bus Transition Plan (ZEBTP).

Xcel Energy has reviewed available electricity capacity at the Overhaul Base, six Metro Transit bus garages and seven key Transit Centers in the metro area. It is crucial we meet Metro Transit's power readiness timelines to serve the additional electrical needs for bus charging as Metro Transit expands its electric bus fleet. Our analysis included dividing capacity requirements into short-term (2022-2027), medium-term (2028-2032) and long-term (2033+) needs along with identifying the top garage locations for infrastructure support in the short-term. The analysis checked for a minimum of 2 MW of available capacity on the existing utility source, the proximity of other feeders in the area for additional capacity and redundancy and the current load on the facility's transformer. Our review identified that there may be adequate capacity forecasted at these locations, however there is a risk that additional electric load could be added from other customers during the same time period. In this case, Xcel Energy would need to build more capacity before connecting additional load.

Our analysis confirmed there is adequate capacity to serve the additional electric needs at the new bus garage in Minneapolis when it opens in 2023 and through the medium-term. An additional 2.5MW of power was constructed at the East Metro bus garage in St. Paul in 2024 with plans to expand to a total of 5 MW of capacity in the next several years. We anticipate the Nicollet garage in Minneapolis will require up to an additional 5MW of power in the medium term. Since we are in the early stages of the planning process, we do not foresee any obstacles to providing this additional capacity at this location. We anticipate that connections to overhead power lines where existing capacity is currently sufficient will take approximately two years to complete planning, engineering, and construction. Other locations where these pre-requisites are not in place, we estimate could take on the order of five years to complete. We will continue to work with Metro Transit on future capacity requirements to meet their medium- and long-term needs as part of their regular planning and budget updates.

In addition to the infrastructure support, Xcel Energy will work with Metro Transit on demand management and optimal charging strategies to lessen operating costs. This work will also seek out opportunities that may benefit the electrical grid in the area and Xcel Energy ratepayers.

Xcel Energy also offers a Renewable Connect program that Metro Transit is able to enroll in for all of their energy needs. Renewable*Connect is an easy way to subscribe to up to 100% of clean, local renewable energy, keep the Renewable Energy Credits (REC) without the hassle of purchasing, installing or maintaining onsite equipment.

Xcel Energy is committed to continuing to work with Metro Transit as they provide regular updates to their ZEBTP. This partnership team will continue to schedule regular check ins to ensure capacity requirements are met along with continuing long term planning exercises to meet future capacity needs.

7.3 Service Prioritization Methodology and Implementation Guidance

This subsection develops and presents a methodology used in analyzing the second of the two core elements necessary for successful BEB integration—service blocks with characteristics supportive of BEB range limitations and how they are arranged into vehicle tasks.

7.3.1 Service Prioritization Methodology

To identify the most-promising blocks suitable for a short-term transition to BEBs, this prioritization methodology uses a three-step sequential process based on the ZEBTP's three guiding principles of technical viability, EEJ, and fiscal impact as introduced in Section 3 (**Figure 49**). Drawing upon the words of caution and lessons learned from the peer transit agencies identified in Section 5, this methodology is designed to be conservative in identifying and prioritizing the most-promising blocks for BEB service. By using this conservative methodology based on current best practices, Metro Transit can confidently deploy BEBs on top priority blocks while maintaining reliable service for transit customers.

Figure 49*: Block-level BEB prioritization methodology*

7.3.2 Implementation Guidance

7.3.2.1 Service Scheduling

With the upgrade to its HASTUS scheduling software, which is expected to be implemented into its operations in 2026, Metro Transit will identify future service blocks with the assistance of the electric bus scheduling feature of the HASTUS scheduling software system. Revised results should be expected for the next update. BEB work is currently identified through a manual process, and it is unknown how much of an effect this will have on the assumptions made in this section.

After the software update Metro Transit will follow the methodology included to evaluate service according to:

1. Technical viability
2. EEJ score
3. Fiscal impact

As mentioned in Section 6.2.5, a block represents a series of transit trips that are linked together and assigned to a single vehicle from when it leaves its garage until it returns. Blocks may last anywhere from a few hours up to an entire service day of 22 hours. One bus may operate multiple shorter blocks if the timing allows. All the blocks one vehicle operates in one day is known as a vehicle task. The characteristics of these blocks and vehicle tasks may be modified up to four times a year as a result of Metro Transit's service changes—performed to alter service to best serve customers across the Twin Cities region given the agency's limited resources. In recognition of these frequent adjustments, rather than limiting the analysis of BEB service prioritization to a single service schedule change, this section documents a robust methodology that can be consistently applied in a standard manner across service changes to identify and prioritize the most suitable blocks for BEB service each quarter. Following the introduction of the methodology, this process will be applied to Metro Transit's August 2024 service schedule to provide an example and illustrate how this methodology can be used to inform transition policies and the prioritized deployment of ZEBs.

The first factor in determining whether a block is suitable for BEB service is if the block is technically viable. Technical viability is one of Metro Transit's three ZEB guiding principles, as BEBs must be able to provide an excellent, safe, and reliable service to transit customers similar to vehicles of all other propulsion types. A block is defined as technically viable if the block length, in miles that the vehicle travels between recharging, is less than a BEB's range in cold weather months If the block range requirements are unable to be met, other filtering criteria become irrelevant as the BEB will be unable to successfully provide service. As introduced in Section 4.3.2, the distance (range) that a BEB can travel is a function of two primary characteristics:

- Battery capacity; and
- Energy usage.

7.3.2.2 Battery Capacity Impacts on Battery Electric Bus Range

A BEB's battery is used to provide both the energy required to drive the bus as well as the energy necessary to operate all vehicle auxiliary functions including heating and cooling the passenger cabin. The amount of energy provided by the battery is described by its energy capacity measured in kWh. Analogous to a fuel tank on a diesel bus, larger battery capacities translate to increased energy (fuel) storage, and thus, increased range. As of 2024, BEB manufacturers offer onboard BEB batteries with capacities typically ranging from approximately 345 kWh to 738 kWh.[230,231] These advertised capacities, also referred to as nameplate or nominal battery capacities, indicate the theoretical capacity of a new battery pack. Unfortunately, however, not all the nominal battery capacity can be used for BEB operation. Instead, to calculate the usable battery capacity, three factors must be considered:

- Battery degradation;
- Battery life; and
- Operational flexibility.

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[230] Source: Xcelsior CHARGE NG, New Flyer, August 2024.
[231] Source: ZX5 Transit Bus, PhoenixEV, August 2024.

7.3.2.2.1 Battery Degradation

Batteries wear down and become less efficient over time as they are constantly charged and discharged. For example, as users of smartphones and laptops are aware, as these devices grow older, they require more frequent charging, as a "full charge" no longer provides power for as long as when the device was new. Based on manufacturer warranties, it is estimated that a BEB's battery capacity degrades by as much as 2.4 percent per year.[232] This equates to a capacity loss of up to approximately 16 percent after 7 years (bus mid-life) and up to about 30 percent after 14 years (bus end-life).

7.3.2.2.2 Battery Life Capacity Reservations

In addition to general battery degradation, charging a BEB to full capacity or charging it from a zero SOC increases the rate at which the batteries degrade, as this process puts additional strain on the physical and chemical components of the battery. Therefore, to prevent a more rapid degradation of battery capacity than the annual 2.4 percent described above, all battery manufacturers recommend reserving a portion of the battery's capacity to preserve battery life. The portion of the battery capacity that is protected and unavailable for use varies by manufacturer and can range from between 5 percent to approximately 35 percent of the battery's capacity.[233]

7.3.2.2.3 Operational Flexibility Capacity Reservations

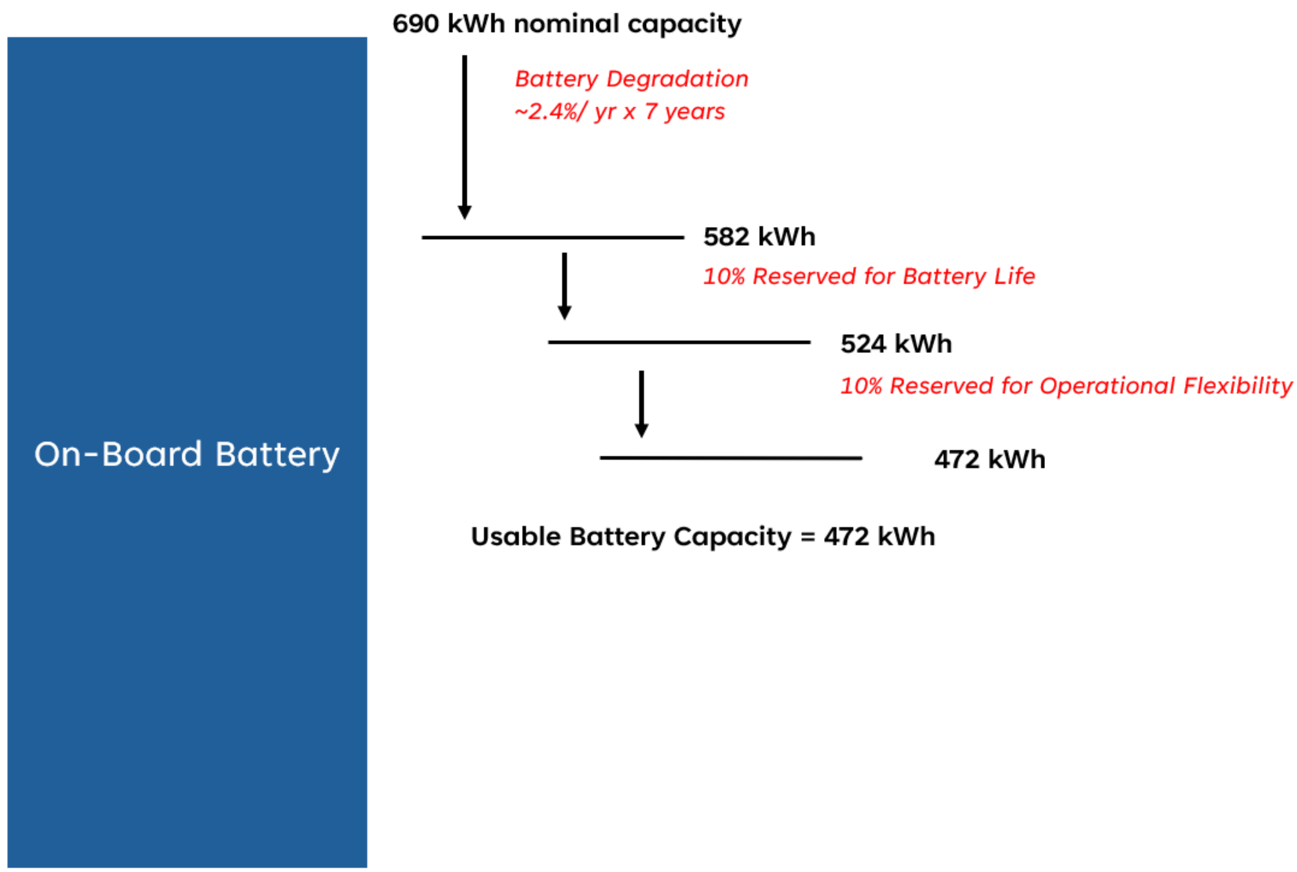
Additionally, just as operators avoid driving a conventional vehicle until the fuel tank is empty, a portion of a BEB's battery capacity is typically preserved for operational flexibility.[230] By preserving this capacity, transit agencies are able to ensure that BEBs will have sufficient range to return to the garage in the event of an unseen delay or other unexpected event requiring a BEB to remain in service longer than originally planned.

7.3.2.2.4 Usable Battery Capacity Calculation Summary

To account for battery degradation and capacity reservations, Metro Transit's BEB service planning is based upon a battery's usable, rather than nominal, capacity at bus mid-life. Based on an approximately 2.4 percent annual degradation in battery capacity as well as the reservation of 10 percent battery capacity for battery life and 10 percent for operational flexibility, the usable battery capacity at bus mid-life is calculated as 68 percent of the nominal (advertised) battery capacity. The process used to convert from nominal to usable battery capacity is outlined in **Figure 50** for a nominal battery capacity of 690 kWh, the nominal battery capacity of the 40-foot BEBs Metro Transit ordered in 2024.

[232] Source: *Battery Electric Bus and Facilities Analysis Final Report*, Milwaukee County Transit System, January 2020.
[233] Source: Interview with TTC staff, October 2021.

Figure 50*:* Calculation of usable battery capacity at bus mid-life



7.3.2.3 Energy Usage Impacts on Battery Electric Bus Range

In addition to the capacity of a battery, the amount of energy consumed by the bus (kWh/mile) also impacts BEB range. When the energy used to heat and cool the bus cabin is the same energy that would be used for the propulsion of the bus, bus range can be substantially reduced in cold weather, as increased energy must be devoted to maintaining a comfortable temperature in the passenger cabin. As discussed in Section 5.1.6, in the Twin Cities region, average monthly temperatures have historically been below freezing (32 degrees Fahrenheit) between 3 to 5 months out of the year.[234] In fact, based on 30-year average temperatures, the Twin Cities has, on average, the coldest winters of any major U.S. metropolitan area with an average temperature of 18.7 degrees Fahrenheit between December and February.[235] Additionally, the region experiences sub-freezing air temperatures on an average of 151 days per year, with 24 to 25 days of sub-zero air temperatures.[235] For example, in February 2021 the region experienced 13 days of below-zero air temperature, including one day reaching -19 degrees Fahrenheit.[236] Therefore, while many peer agencies experience single days of below-freezing weather and can largely plan service assuming warmer average ambient temperatures, Metro Transit must plan BEB service

[234] Source: *Climate Saint Paul – Minnesota*, U.S. Climate Data.
[235] Source: *America's 20 Coldest Major Cities*, NOAA, January 7, 2014.
[236] Source: *Twin Cities Weather - February 2021*, Weather.gov, 2024.

around range estimates based on winter temperatures to ensure reliable service can be maintained through all seasons.

Along with ambient temperature impacts, the speed at which a BEB operates also influences energy usage and therefore, BEB range. Typically, slower speeds are a result of either busy or congested environments. In busy environments, buses often see greater energy use owing to bus doors being open more often and for longer periods of time. When the doors are open, heating and cooling the bus cabin is more difficult as extra energy needs to be drawn from the battery. Additionally, when buses are stuck in congested environments, they spend an increased time idling and accelerating from rest, thereby also requiring greater energy usage. Due to these considerations, blocks with an average speed of 8 miles per hour or less are assumed to have too significant of an impact on energy consumption to be considered for short-term BEB service.

Metro Transit must plan BEB range estimates based on winter temperatures

7.4 Technical Viability

Using the impacts to BEB range described above, a BEB's range based on cold weather months can be calculated against block length to determine whether the block is technically viable for BEB service. **Table 28** summarizes the battery capacity and energy usage assumptions and criteria outlined above and used in assessing the suitability of Metro Transit's service blocks for BEB operation. Calculations were performed for 40-foot buses with 686-kWh nominal battery capacities in addition to 60-foot buses with 690-kWh nominal battery capacities. These values were selected based on the battery capacities of the next BEBs Metro Transit will be putting into service in 2025 and 2026. For reference, 60-foot buses with 466-kWh nominal battery capacities are currently being used for the C Line pilot. All calculations assume supplemental cabin heating via auxiliary diesel heater in below-freezing temperatures to mitigate the amount of battery energy necessary to heat the cabin. Additionally, all calculations assume the use of garage charging without range-extending on-route charging, as Metro Transit does not plan to pursue on-route charging at this time.

Table 28: Assumptions for BEB route and block analysis

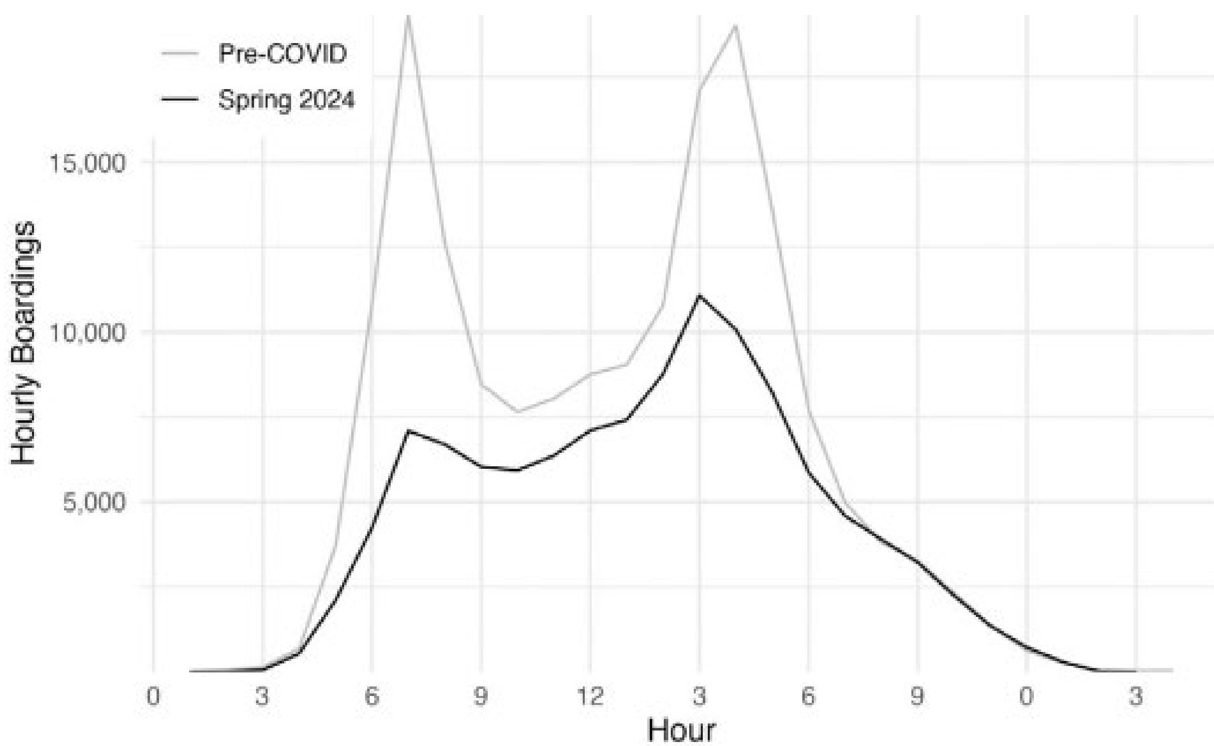
Item	466-kWh 60-foot buses with auxiliary diesel heater C Line	690-kWh 60-foot buses with auxiliary diesel heater Gold Line	686-kWh 40-foot buses with auxiliary diesel heater (planned for local service in 2026)
Battery size, nominal capacity	466 kWh	690 kWh	686 kWh
Battery size, usable capacity (68 percent of nominal) *	317 kWh	469 kWh	466 kWh
Average kWh per mile	3.5	3.5	2.2
Average range in miles	91	134	212
Cold weather kWh per mile	4.5	4.5	3.5
Cold weather range in miles	70	104	133
Minimum average speed	8 mph	8 mph	8 mph

*Usable battery capacity is defined as the bus mid-life battery capacity, or 68 percent of nominal battery capacity. This assumes a 2.4 percent annual battery capacity and a total of 20 percent capacity reserved for the combination of battery health and operational flexibility.

Metro Transit will implement five 60-foot BEBs on Gold Line in 2025.[237] Since the 2022 publication of this Transition Plan, Metro Transit has focused on the implementation of 40-foot BEBs, rather than 60-foot BEBs, to gain experience on other service types while it awaits delivery of the new 60-foot BEB vehicles.

As described in Section 6.2.6, following the COVID-19 pandemic, Metro Transit has seen a decrease in commuter trips and an increase in other types of trips, resulting in a far flatter service profile (**Figure 51**). Prior to the pandemic, Metro Transit's service profile was far more peaked, with shorter blocks for the morning and evening vehicle pullouts. Short blocks work better with the range limitations of BEBs. This change in service profile means that Metro Transit now, in 2024, has fewer naturally existing shorter blocks than it did when this ZEBTP was first written in 2022. Additionally, Metro Transit plans to substantially replace the existing Routes 3, 6, 10, 21, 62, and 68 with arterial BRT service. Similar to when Route 84 was substantially replaced by the A Line, when this replacement occurs, these future BRT lines will have a dedicated fleet of buses operating on redesigned blocks that are longer in length due to the nature of the arterial BRT service. Therefore, although some of the blocks currently serving these routes are technically viable, it is anticipated that many may not be technically viable in future service schedules. The service changes may necessitate additional buses and operators than originally predicted in the previous version of the ZEBTP.

Figure 51*: Changes in ridership over time by time of day*

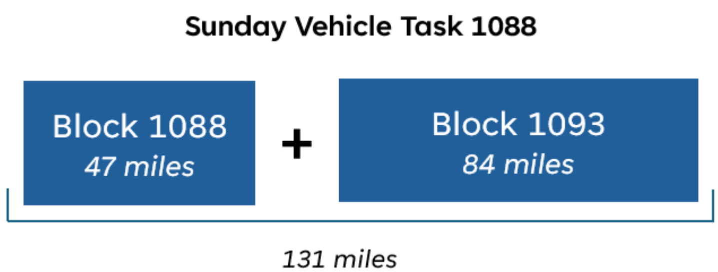


[237] Source: *Capital Investment Grants Policy Guidance Federal Transit Administration*, FTA, January 2023.

During Metro Transit's early BEB deployments, it was determined that while evaluating blocks was an important analysis to gauge BEB abilities in revenue service, vehicle tasks were a more appropriate way to plan the number of vehicles needed for service delivery. Vehicle tasks can help Metro Transit efficiently deploy BEBs by determining how many blocks a BEB can accomplish. This comprehensive look at the vehicle's block assignments throughout the day also allows for a better analysis of midday charging and how it may increase block viability with fewer buses.

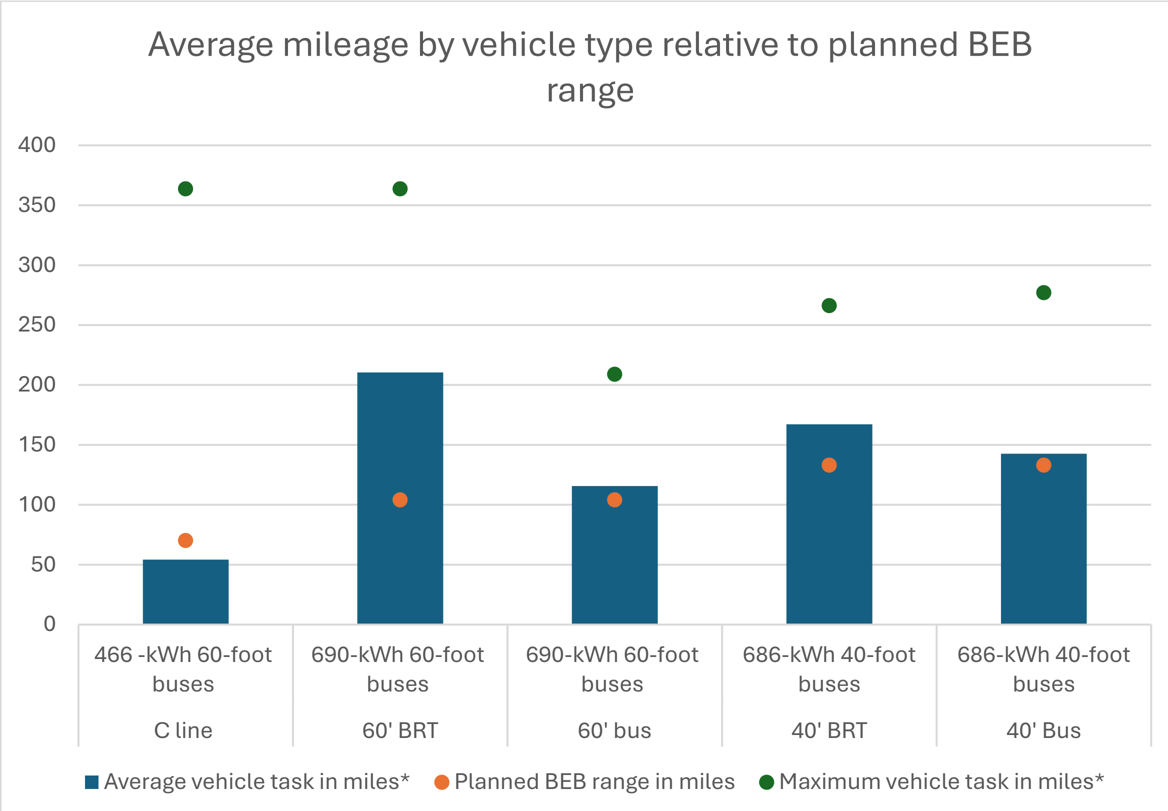
An example of how this approach may work from Metro Transit's most recent bid is Sunday's vehicle task 1088 operating out of the North Loop Garage. Comprised of block 1088, which travels approximately 47 miles, and block 1093, which travels about 84 miles, vehicle task 1088's mileage requirement on this task is 131, as illustrated in **Figure 52**. Assigning a BEB to this vehicle task would allow the vehicle to stay in service as long as possible instead of focusing on single blocks within the daily service delivery schedule.

Figure 52*:* Vehicle Task 1088



One of the benefits of considering vehicle tasks, rather than vehicle blocks, when deploying BEBs is that tasks align with the milage range needed from a single bus to complete the entire day. As seen in **Figure 53**, diesel buses consistently can travel many more miles than are needed to complete the average vehicle task, as of August 2024. However, all types of Metro Transit's BEBs average less range than the average vehicle task in miles. Since this is an average view, this does not mean that no vehicle tasks can be covered by a single BEB, as there are (and will likely be) shorter tasks that BEB range can cover. However, in general, more BEBs will be required to cover the same miles of service (meaning the same level of service) that Metro Transit covers today with diesel buses.

Figure 53: Average milage by vehicle type relative planned BEB range



As described in Section 5.1.7, evolving FTA guidance on allowed spare ratios of vehicles for BEBs will factor into Metro Transit's strategy for BEB deployment. Metro Transit faces the unique challenges of overlapping use of the same spares for Minnesota State Fair service vehicles.[238] Metro Transit needs greater clarity of FTA spare factor provisions in planning for future purchases of more BEB buses.

Metro Transit will continue to maximize opportunities for BEB deployment. As technology advances and increased battery range becomes available, Metro Transit will naturally have more opportunities to implement BEBs. Though it does not plan to utilize midday charging at this time, Metro Transit will continue to revisit the topic, as it may decide that on-route chargers are needed to extend the range of BEBs. When (or if) Metro Transit decides to pursue midday charging, it will work to provide adequate opportunities for midday charging to allow buses to be utilized for more than one block per day.

To assist with the development of blocks and vehicle tasks that consider the unique aspects of BEBs, Metro Transit has purchased an upgrade to its existing scheduling software designed for BEB's operating characteristics. The HASTUS scheduling software update (as detailed in Section 6.2.4) will be a vital tool in creating blocks and vehicle tasks that are technically viable and efficient uses of the fleet. The HASTUS update will be able to optimize Metro Transit's service to be delivered with its fleet of mixed propulsion types. Once the upgrade is in use, Metro Transit will update service planning policies and methodologies

[238] Metro Transit maintains a contingency fleet, primarily used for the Minnesota State Fair, which allows it to add additional service during the fair while maintaining regular route service. In 2024, Metro Transit provided nearly 376,000 rides to and from the state fair during its 12-day run. Source: *Metro Transit provides nearly 376,000 State Fair rides*, Metro Transit, September 4, 2024.

to develop efficient vehicle tasks for its BEBs. This will help Metro Transit to best understand the impacts and needs of service from today through a full ZEBTP.

7.5 Equity and Environmental Justice Modeling

To ensure that BEB deployment is prioritized in underserved and underinvested areas that have borne a disproportionate share of negative environmental consequences, all technically viable bus service blocks and vehicles tasks are assigned an EEJ priority score to guide block-level and vehicles tasks-level implementation in the short- and long-term future.

To identify the variables used in calculating these EEJ priority scores, an in-depth review of similar methodologies developed by Metro Transit's peer agencies as well as an inspection and evaluation of the nearly 300 variables related to EEJ from the Metropolitan Council's Equity Considerations for Place-Based Advocacy and Decisions in the Twin Cities Region dataset was conducted. Based on this review, a subset of seven key variables contained in both the peer agencies' methodologies as well as the equity considerations dataset were selected for use in calculating EEJ priority scores. These variables include:

- Lifetime cancer risk from inhalation of air toxics (persons per million)
- Census tract population density
- Percent of census tract population identifying as BIPOC
- Percent of census tract households lacking a vehicle
- Number of 5-year ACS datasets (2006 to 2010 through 2015 to 2019) in which the census tract was designated as an Area of Concentrated Poverty[239]
- Average land surface temperature on a hot summery day (proxy for the urban heat island effect)
- Percent of census tract households where housing costs make up 30 percent or more of the households' annual income

7.5.1 Equity and Environmental Justice Methodology

7.5.1.1 Census Tract Equity and Environmental Justice Methodology

Environmental and population characteristics are associated with the area through which a bus passes (census tracts) while completing its scheduled block. In order to calculate an EEJ score for each block and vehicle task, the relative EEJ priority of the surrounding areas must first be determined. Using the feedback provided by the over 300 survey responses as described in Section 7.3.1.5, a weighted average formula is used to calculate an EEJ priority score for each census tract in the seven-county metropolitan area. The respective weights in the weighted average formula are calculated as the share of engagement participants who ranked the given variable as their top factor to consider when prioritizing BEB deployment. Therefore, in a hypothetical example where 25 out of 100 participants ranked population density as the number one priority, the population density weight would be 0.25. The percent of survey responses ranking each variable as their first choice for how to prioritize deployment is summarized in **Table 29**.

[239] Areas of concentrated poverty are defined as census tracts where 40 percent or more of the tract population have a family income less than 185 percent of the federal poverty threshold, excluding tracts where either 50 percent or more of the tract population are college/graduate students or where one third or more of the tract percentage of people living in poverty are college/graduate students.

Table 29: EEJ engagement results

Characteristic	Final Rank
Cancer risk	1
Population density	2
% BIPOC	3
% Zero car household	4
Number of years area of concentrated poverty	5
Average land temperature (heat island proxy)	6
% housing cost burdened	7

To facilitate comparisons between census tracts, percentiles indicating the relative difference in a variable's value across all census tracts are used to normalize the variable. For example, comparisons with the broader region can be drawn from normalized variables such as if a given census tract has a higher population density than 75 percent of all other tracts. Each census tract's EEJ weighted average is calculated by taking the sum of the percent of survey responses where each variable was ranked first and multiplying it by the normalized percentile of that variable in the tract. This formula is as follows:

$$\begin{gathered}\boldsymbol{Census\ Tract\ EEJ\ Weighted\ Average} = 0.34 * (Cancer\ Risk\ Percentile) \\ +0.21 * (Population\ Density\ Percentile) \\ +0.17 * (BIPOC\ Percentile) \\ +0.11 * (Zero\ Car\ Household\ Percentile) \\ +0.10 * (Number\ of\ Years\ ACP\ Percentile) \\ +0.04 * (Average\ Land\ Temperature\ Percentile) \\ +0.03 * (Housing\ Cost\ Burdened\ Percentile)\end{gathered}$$

To simplify the interpretation of these weighted averages, these values are then scaled from 0 to 100 to produce a final EEJ priority score for each census tract, where higher values indicate higher EEJ priority. Census tracts are then categorized into one of four EEJ priority tiers based on naturally occurring breaks between groups of EEJ priority scores (**Table 30**).

Table 30: EEJ priority tier thresholds

Census Tract EEJ Priority Tier	Census Tract EEJ Priority Score Range
High	>=75
Medium-High	50-74.9
Medium	25-49.9
Low	<25

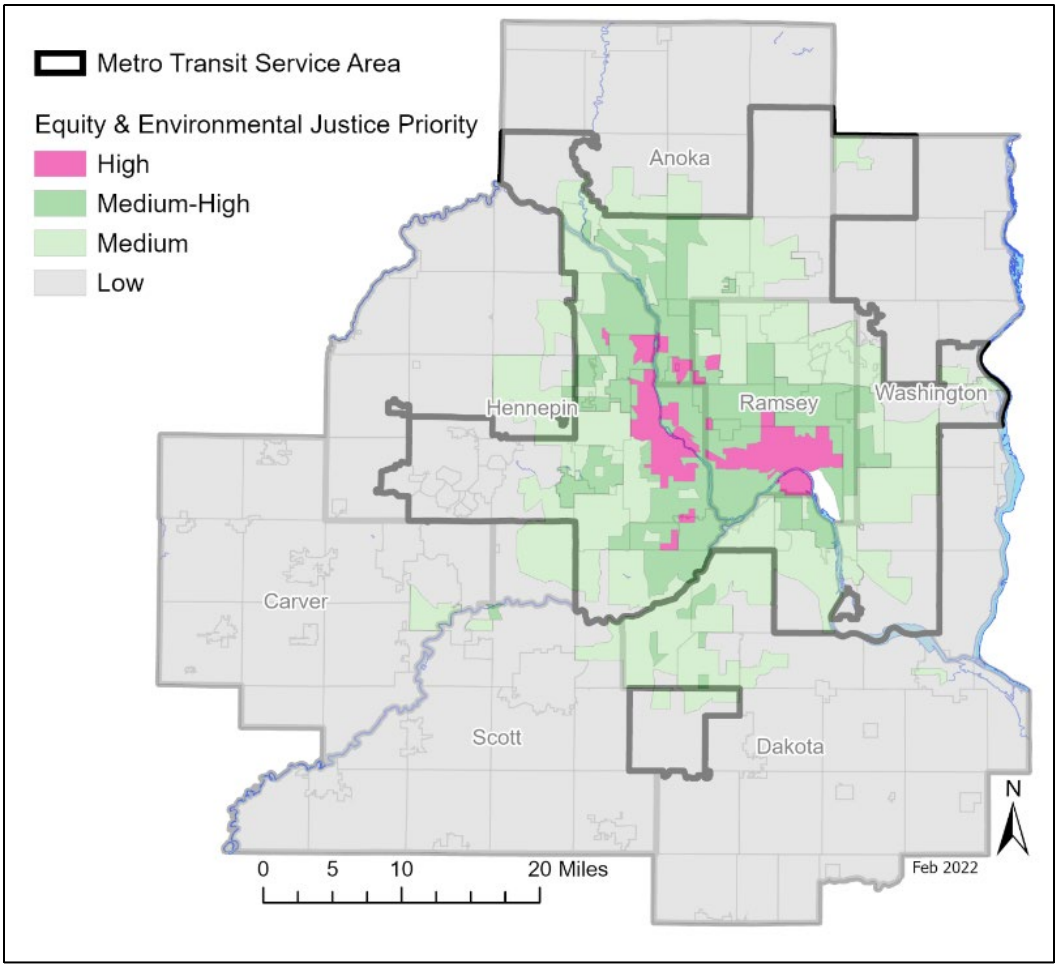
As shown in **Figure 54**, the areas of highest EEJ priority are primarily located in and around Downtown Minneapolis and Downtown Saint Paul as well as the neighborhoods of:

- Camden (Minneapolis)
- Central (Minneapolis)
- Dayton's Bluff (Saint Paul)
- Greater East Side (Saint Paul)

- Hamline-Midway (Saint Paul)
- North End (Saint Paul)
- Near North (Minneapolis)
- Northeast (Minneapolis)
- Payne-Phalen (Saint Paul)
- Phillips (Minneapolis)
- Powderhorn Park (Minneapolis)
- Summit-University (Saint Paul)
- Thomas Dale/Frogtown (Saint Paul)
- Union Park (Saint Paul)
- University (Minneapolis)
- West Side Community Organization (Saint Paul)

Outside of Minneapolis and Saint Paul, other areas with elevated EEJ priority tiers are found in Brooklyn Center, Columbia Heights, Hilltop, and portions of Richfield.

Figure 54*: Census Tract EEJ priority areas*



7.5.1.2 Bus Service Block Equity and Environmental Justice Methodology[240]

To understand the interaction between Metro Transit's bus service and areas of high EEJ priority at a more detailed level, each bus block is assigned an EEJ priority score and tier based on the weighted

[240] This evaluation provides an example how this analysis would be done at the block level. Metro Transit plans to conduct this analysis at both the block and vehicle task level.

average of the relative number of block miles in each EEJ priority area shown in **Figure 55**. The weighted average for each block is calculated as follows:

$$\begin{gathered}\boldsymbol{Bus\ Block\ EEJ\ Score} = (4 * (Miles\ in\ \text{“}High\text{”-}Priority\ EEJ\ Area) \\ +3 * (Miles\ in\ \text{“}Medium \text{ to } High\text{”-}Priority\ EEJ\ Area) \\ +2 * (Miles\ in\ \text{“}Medium\text{”-}Priority\ EEJ\ Area) \\ +1 * (Miles\ in\ \text{“}Low\text{”}\ Priority\ EEJ\ Area))\ /\ Total\ Block\ Miles\end{gathered}$$

Using this equation, the lowest EEJ score a block could receive is 1 (if the entire block was in a Low-Priority EEJ Area) while the highest value is a 4 (if the entire block was in a High-Priority EEJ Area). Similar to the categorization process performed on the census-tract-level data, the service blocks are then separated into one of four EEJ priority tiers using the thresholds outlined in **Table 31**.

Table 31: EEJ priority score thresholds

Block-Level EEJ Priority Tier	EEJ Priority Score Range
High	>= 3.5
Medium-High	3.25-3.49
Medium	2.75-3.24
Low	<2.75

7.5.2 Equity and Environmental Justice Methodology and Environmental Justice

EEJ is one of the three guiding principles outlined in Metro Transit's 2025 ZEBTP. Since development of the 2022 ZEBTP, differing state and federal definitions of EJ or disadvantaged areas have been advanced. The following section provides a brief overview of each methodology followed by a summary table and figures comparing the results of each methodology for the Seven-County Twin Cities Metropolitan Area.

7.5.2.1 Metro Transit 2022 Zero-Emission Bus Transition Plan Equity and Environmental Justice Methodology

Census tracts in the seven-county metropolitan area were assigned an EEJ priority tier (Low to High) based on public feedback provided during the 2022 ZEBTP outreach process, Section 6. As part of this outreach, respondents were asked to evaluate and rank the relative importance of seven variables from the Metropolitan Council's Equity Considerations for Place-Based Advocacy and Decisions in the Twin Cities Region dataset should have on identifying equitable and environmentally just areas within which to prioritize ZEB deployment. An EEJ priority tier was then assigned to each census tract using a weighted average formula based on census tract percentiles and the share of engagement participants who ranked the given variable as their top factor to consider when prioritizing BEB deployment. The 2022 ZEBTP EEJ priority tier layer is summarized in previous Section 7.3.

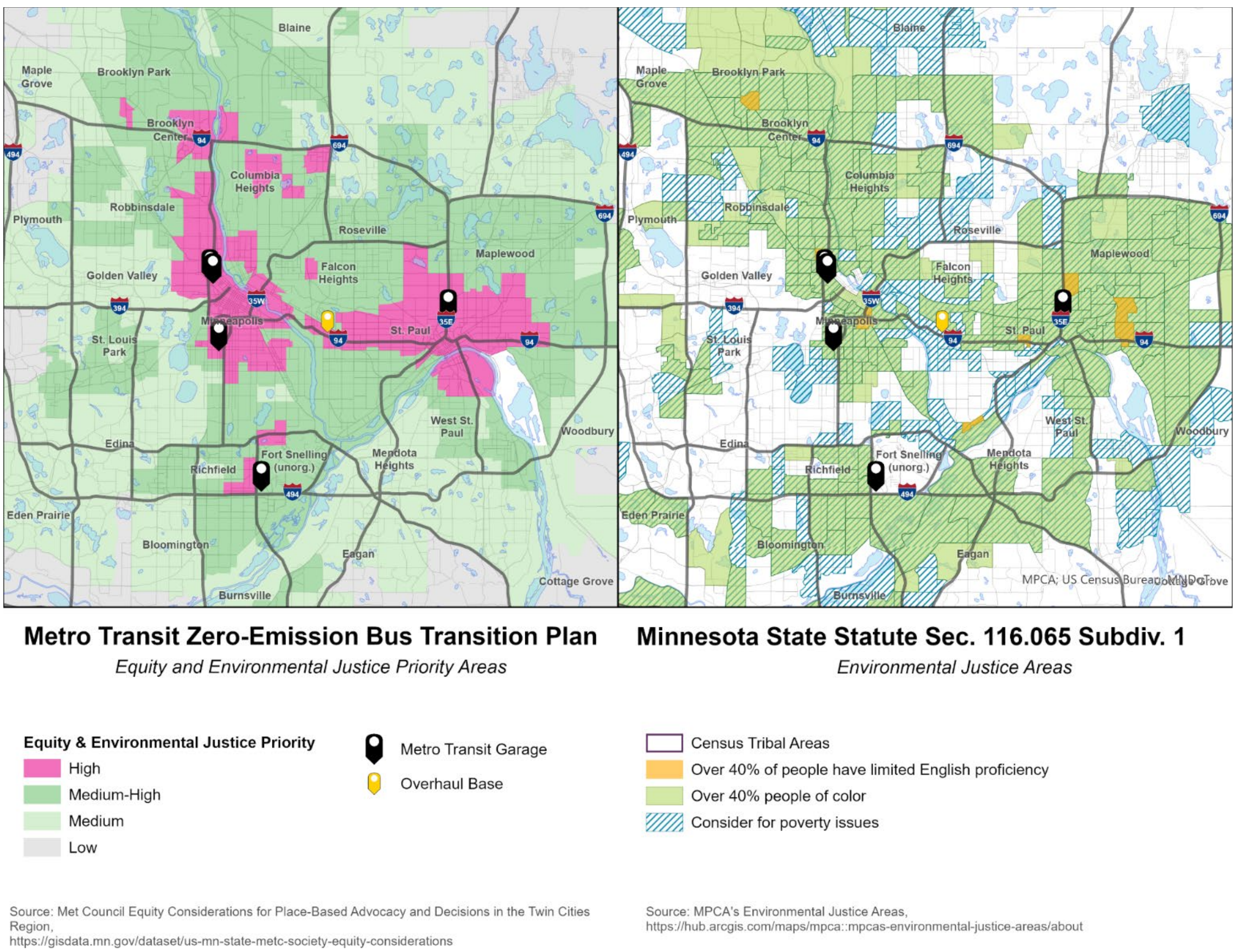
7.5.2.2 2023 Minnesota State Statute Section 116.065 Subdivision 1

According to Minnesota State Statute[241] Section 116.065 Subdivision 1, EJ areas are defined as:

"one or more census tracts in Minnesota:
(1) in which, based on the most recent decennial census data published by the United States Census Bureau:
(i) 40 percent or more of the population is non-white;
(ii) 35 percent or more of the households have an income at or below 200 percent of the federal poverty level; or
(iii) 40 percent or more of the population over the age of 5 has limited English proficiency; or
(2) located within Indian Country."

As shown in **Figure 55**, the EEJ priority areas identified in the Metro Transit 2022 ZEBTP closely aligns with the 2023 Minnesota Statues Section 116.065 Subdivision 1 EJ Areas.

Figure 55: Metro Transit 2022 ZEBTP EEJ Areas Compared to 2023 Minnesota Statutes Section 116.065 Subdivision 1 EJ Areas



[241] Minnesota Legislature. 2023. [Section 116.065 Subdivision 1](#).

7.5.2.3 Federal Justice40 Initiative

The federal government's Justice40 initiative is intended to "confront and address decades of underinvestment in disadvantaged communities [by bringing] resources to communities most impacted by climate change, pollution, and environmental hazards." The goal of this initiative is to deliver 40 percent of the overall benefits of relevant federal investments to disadvantaged communities. Recently, the FTA's 5339(c) Low or No Emission Grant program and 5339(B) Grants for Buses and Bus Facilities Competitive program have given priority consideration to projects that support the Justice40 initiative, indicating that "Applicants should use the Climate and Economic Justice Screening Tool (CEJST), a tool created by the White House Council on Environmental Quality (CEQ)...to help identify disadvantaged communities."[242] Version 1.0 of the CEJST tool identifies a community as disadvantaged if it is "(1) at or above the threshold for one or more environmental, climate, or other burdens, and (2) at or above the threshold for an associated burden."[243] CEJST evaluation is based on census tract percentiles.

7.5.2.4 Federal Transit Administration Recipient Environmental Justice Policy Guidance

Beyond defining what constitutes an EEJ area, FTA recipients are required to follow the FTA's EJ policy guidance outlined in FTA Circular C 4703.1[244] when conducting an EJ Analysis prior to project implementation. In particular, the FTA states that:

> *"Disproportionately high and adverse effects, not population size, are the bases for environmental justice. A very small minority or low-income population in the project, study, or planning area does not eliminate the possibility of a disproportionately high and adverse effect on these populations. Some people wrongly suggest that if minority or low-income populations are small ("statistically insignificant"), this means there is no environmental justice consideration. While the minority or low-income population in an area may be small, this does not eliminate the possibility of a disproportionately high and adverse effect of a proposed action. EJ determinations are made based on effects, not population size. It is important to consider the comparative impact of an action among different population groups."*[244]
>
> DOT Order 5610.2(a) defines "disproportionately high and adverse effect on human health or the environment" to include *"an adverse effect that: (a) is predominantly borne by a minority population and/or a low-income population, or (b) will be suffered by the minority population and/or low-income population and is appreciably more severe or greater in magnitude than the adverse effect that will be suffered by the non-minority population and/or non-low-income population."*[244]

As shown in **Figure 56**, the EEJ priority areas identified in the Metro Transit 2022 ZEBTP closely aligns with the CEQ CEJST V1.0 Disadvantaged Communities (Justice 40).

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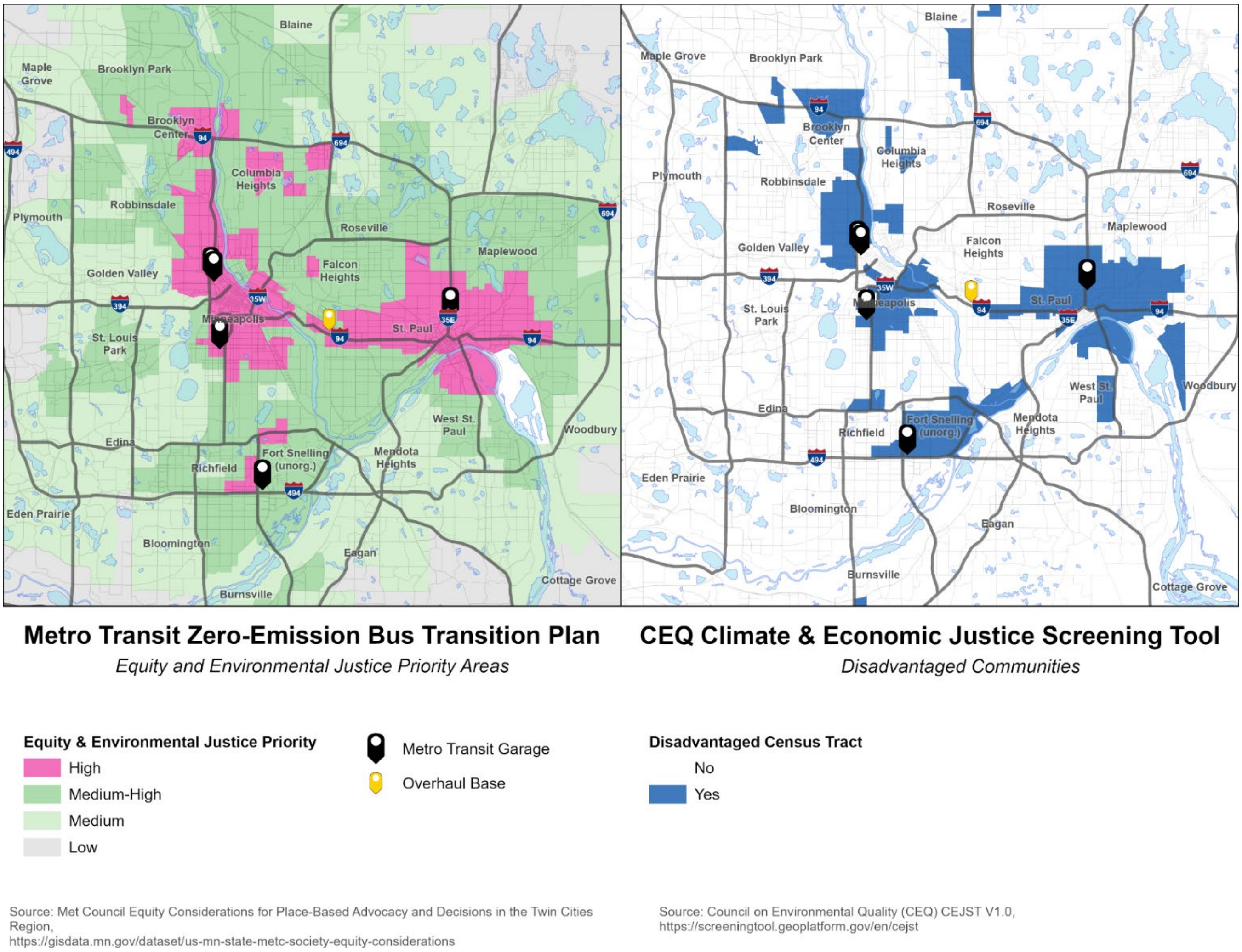
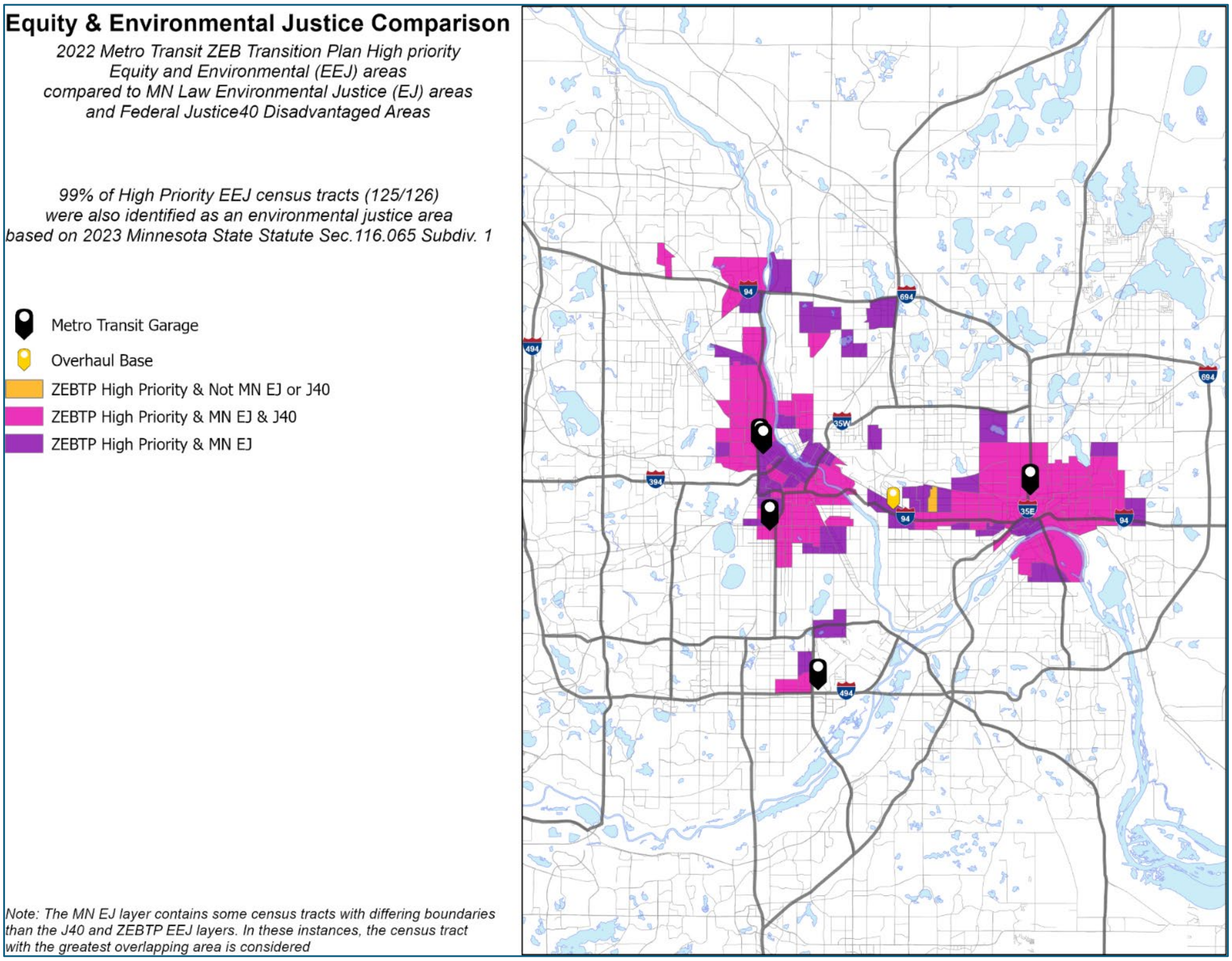
[242] ,FTA. February 8, 2024. *Low or No Emission and Grants for Buses and Bus Facilities Competitive Programs FY2024 Notice of Funding Opportunity.* accessed June 2024.
[243] CEJST, November 22, 2022, *CEJST Methodology*, accessed June 2024.
[244] FTA, August 15, 2012, *Environmental Justice Policy Guidance for Federal Transit Administration Recipients – Circular 4703.1*, accessed June 2024.

Figure 56: Metro Transit 2022 ZEBTP EEJ Areas Compared to CEQ CEJST V1.0 Disadvantaged Communities (Justice 40)



In a combined view, **Figure 57** shows the comparison of High-Priority EEJ Areas as identified in the 2022 ZEBTP to the Justice 40 and Minnesota state definitions. In total, 99 percent of High-Priority EEJ census tracts were also identified as an EJ area by the State of Minnesota.

Figure 57: Metro Transit 2022 ZEBTP High-Priority EEJ Areas Compared to CEQ CEJST V1.0 Disadvantaged Communities (Justice 40) and 2023 Minnesota Statutes Section 116.065 Subdivision 1 EJ Areas



The reason for the large overlap in the measures of ZEBTP High-Priority EEJ Areas, CEQ CEJST V1.0 Disadvantaged Communities (Justice 40), and 2023 Minnesota Statutes Section 116.065 Subdivision 1 EJ Areas is because the various analyses use similar criteria, or they are trying to measure related factors through slightly different but highly correlated criteria. **Table 32** provides a side-by-side comparison of the criteria use for each measure.

Table 32: EEJ Area component comparison

Variable	2022 ZEBTP	CEQ CEJST Justice40[245]	Minnesota Law *Sec. 116.065 Subdiv 1*
Climate Change	Average land temperature weighted percentile score	Expected agriculture loss rate OR expected building loss rate OR expected population loss rate OR projected flood risk OR projected wildfire risk	--
Energy		Energy cost OR PM2.5 in the air	--
Health	Cancer risk weighted percentile score	Asthma OR diabetes OR heart disease OR low life expectancy	--
Housing	Housing cost burdened weighted percentile score	Historic underinvestment OR housing cost OR lack of green space OR lack of indoor plumbing OR lead paint	--
Legacy Pollution	--	Abandoned mine land OR formerly used defense sites OR proximity to hazardous waste facilities OR proximity to Superfund sites OR proximity to Risk Management Plan facilities	--
Limited English Proficiency	--	Described within the Workforce Development Category below	40%+ of the population age 5+ has limited English proficiency
Low-Income / Workforce Development	Number of years area of concentrated poverty weighted percentile score	Linguistic isolation OR low median income OR poverty OR unemployment AND More than 10% of people ages 25+ whose high school education is less than a high school diploma	35%+ of households have an income at or below 200% of the federal poverty level
Non-White Population	Percent BIPOC weighted percentile score	--	40%+ non-white
Population Density	Weighted percentile score	--	--
Transportation	Zero-vehicle household weighted percentile score	Diesel particulate matter exposure OR transportation barriers (average cost and time spent on transportation relative to all other tracts) OR traffic proximity and volume	--

245 All CEJST criteria also require that the census tract be "at or above the 65th percentile for low income."

Variable	2022 ZEBTP	CEQ CEJST Justice40[245]	Minnesota Law *Sec. 116.065 Subdiv 1*
Tribal Areas	--	"Federally Recognized Tribes, including Alaska Native Villages"	"Located within Indian Country"[241]
Water and Wastewater	--	Underground storage tanks and releases OR; Wastewater discharge	--

7.5.2.5 Bus Service Block Equity and Environmental Justice Methodology

Table 33 summarizes the percentages of block miles according to the Metro Transit 2022 ZEBTP-EEJ Methodology across four area classifications:

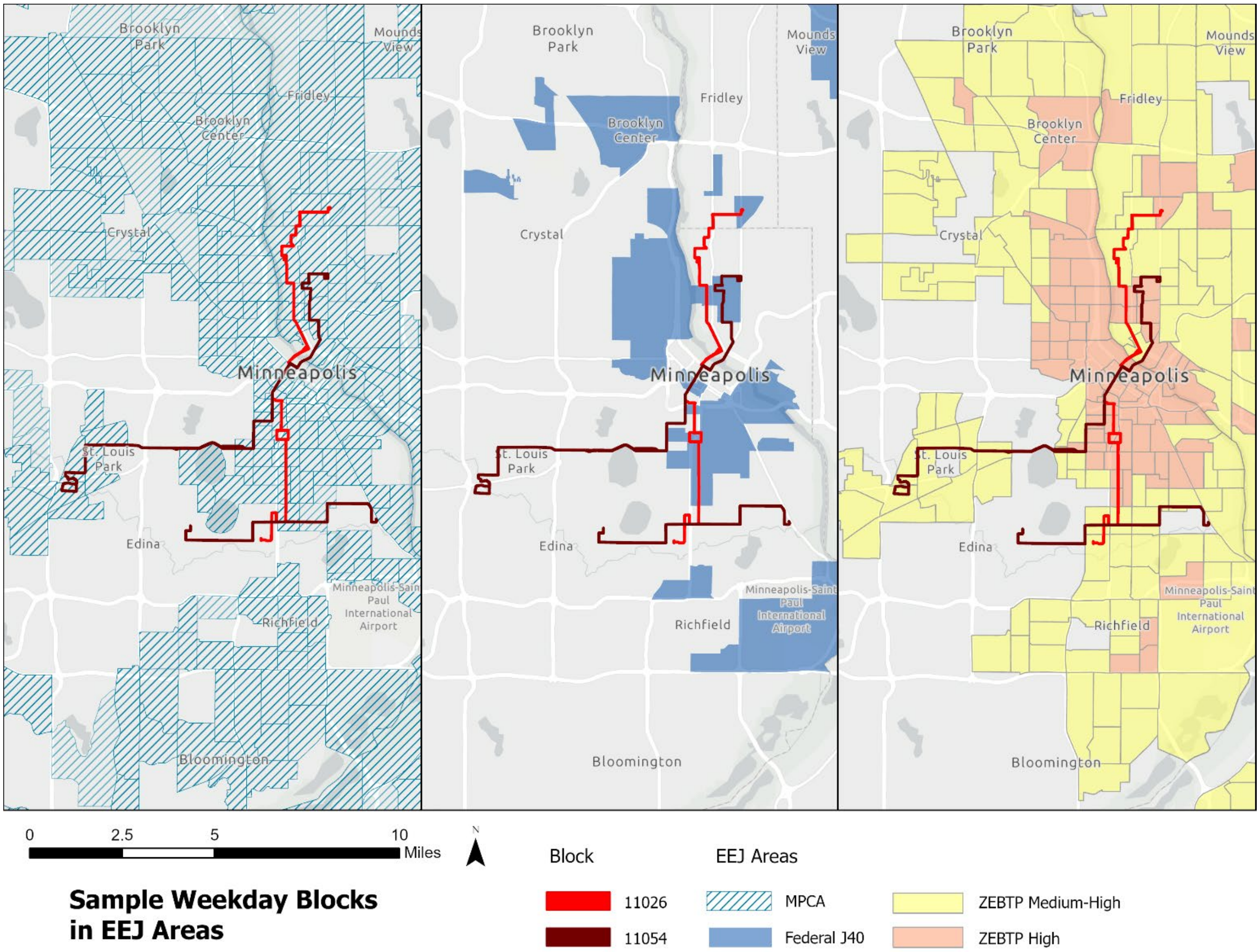
1. MPCA: State MPCA EJ Areas
2. Federal J40: Federal Justice40 Initiative Areas
3. ZEBTP: 2022 ZEBTP Definition "Medium-High"-Priority Areas
4. ZEBTP: 2022 ZEBTP Definition "High"-Priority Areas

Two blocks from the August 2024 data (11026 Weekday, 11054 Weekday) were used as an illustrative example, and percentages were calculated using a 50-foot buffer around block lines to account for blocks traveling along census tract boundaries, reflecting the area percentage as it is proportional to block mile percentage. As seen in the two-block sample below, this approach demonstrates that the ZEBTP methodology is typically more constrained than the MPCA methodology.

Table 33: Percentage of weekday block miles in EEJ Areas (August 2024 Sample Blocks)

	State MPCA	Federal J40	ZEBTP (Medium-High)	ZEBTP (High)
Block 11026 *High Priority Block Example*	84%	35%	42%	58%
Block 11054 *Medium Priority Block Example*	68%	18%	43%	42%

Figure 58: Sample Weekday Blocks in EEJ Areas



7.6 Fiscal Impact

Currently, the purchase cost of a BEB for Metro Transit is about 2.25 times as expensive as a diesel bus.[246] To be responsible stewards of a transformative and financially sustainable transit system, Metro Transit is focused on deploying BEBs in a fiscally efficient manner where the maximum benefit and usage can be gleaned from these significant investments.

Metro Transit is focused on deploying BEBs in a fiscally efficient manner to maximize vehicle and infrastructure usage

[246] Source: Metro Transit Statement, D. Hass, September 2024.

7.6.1 Fiscal Impact Methodology

To achieve a fiscally efficient deployment of BEBs, Metro Transit plans to prioritize BEB deployment on the longest technically viable vehicle tasks. As such, the tasks for each battery capacity are categorized into four fiscal priority tiers based on the naturally occurring groups and breakpoints in total vehicle tasks distance (**Table 34**). Using this methodology, the high fiscal efficiency tier contains the longest technically viable blocks, while the low fiscal efficiency tier contains the shortest technically viable vehicle tasks.

Table 34: Fiscal efficiency by technically viable vehicle tasks distance

Block-Level Fiscal Efficiency categories	Percent of technically viable range for particular vehicle type	466-kWh 60-foot buses with auxiliary diesel heater C Line	690-kWh 60-foot buses with auxiliary diesel heater Gold Line	686-kWh 40-foot buses with auxiliary diesel heater
High	>80%	>55 Miles	> 85 Miles	> 105 Miles
Medium-High	60% to 79%	40 to 54 Miles	60 to 85 Miles	80 to 105 Miles
Medium	40% to 59%	30 to 39 Miles	40 to 60 Miles	55 to 80 Miles
Low	<40%	< 35 Miles	< 40 Miles	< 55 Miles

7.7 Service Prioritization Summary

By combining the three guiding principles of technical viability, EEJ, and fiscal impact, the most-promising blocks suitable for short-term BEB deployment can be identified. The most-promising blocks for BEB deployment in the short term are defined as blocks that are technically viable, in a high EEJ priority area, and have high fiscal efficiency, while secondary priority blocks include blocks where one of either the EEJ priority or fiscal efficiency have a “high” rating and the other principle has a “medium-high” rating.

Overall, this section has established a service prioritization methodology informed by the experiences of peer transit agencies and community engagement and based upon the guiding principles of technical viability, EEJ, and fiscal impact. As BEB technology improves, the parameters of this model will continue to be refined to ensure that the deployment of BEBs continues to be prioritized in a technically viable, fiscally efficient manner that maximizes the benefit to historically underserved and underinvested communities with poor air quality while meeting ridership and available workforce levels.

Metro Transit will continually evaluate ZEB prioritization methodology to ensure consistency with the ZEBTP’s guiding principles while meeting ridership and available workforce levels

8 Milestones and Performance Measures

Metro Transit is committed to delivering environmentally sustainable transportation choices that are safe, convenient, comfortable, and reliable for customers. The recommendations outlined in this plan are a critical component of achieving Metro Transit's mission. Deploying ZEBs will create environmentally sustainable transportation choices that will deliver public health and environmental benefits to the region. As Metro Transit moves forward with the transition to ZEBs, it is important to establish milestones and performance measures to maximize the benefits to the region while staying true to the mission to provide reliable service to customers.

Mission Statement

We at Metro Transit deliver environmentally sustainable transportation choices that link people, jobs, and community conveniently, consistently, and safely.

As part of the state's requirements for this ZEBTP, Metro Transit is required to establish milestones and/or performance measures for the plan. The milestones and performance measures outlined throughout this section allow Metro Transit to track its progress of successful ZEB deployment and achieving its mission. The milestones establish targets and projections with defined timelines. These milestones are intended to help Metro Transit stay on track with the transition to ZEBs. The performance measures, on the other hand, will be used to assess the performance of the ZEBs and supporting infrastructure. These performance measures will help Metro Transit ensure that customers continue to receive high-quality transit service throughout the transition to ZEBs. These indicators will be used to inform future decisions on the implementation of ZEBs and supporting infrastructure.

Service Excellence

We go beyond the expectations of our customers to deliver convenient, comfortable, and reliable service; we don't accept today's best as tomorrow's limitations.

8.1 Milestones

Milestones establish key targets and projections for the transition to ZEBs over a set period of time. Metro Transit intends to establish milestones for the transition to ZEBs that align with its CIP, as well as identify milestones that Metro Transit plans to achieve beyond its current CIP. Metro Transit's CIP is published as part of the Metropolitan Council's 2025 Unified Budget.[247] Metro Transit's current CIP covers a 5-year period of 2025 to 2030. This ZEBTP establishes targets and projections for vehicle procurement as well as annual communications and performance reporting milestones. These targets define specific metrics that Metro Transit will aim to achieve in the short term. Projections, on the other hand, are more generalized statements on the direction Metro Transit hopes to go in the long term. Unlike targets, projections do not define specific numbers or metrics. Experience in the short term will inform projections for future ZEBTP updates.

Since the initial ZEBTP was published in 2022, Metro Transit has gained additional experience with BEB, most notably as discussed in Section 5.1.8. Metro Transit learned the importance of scheduling BEB based on the range they can provide on a single charge. To assist with this scheduling for BEBs and other vehicle

[247] Metropolitan Council, *2025 Unified Budget*, https://metrocouncil.org/About-Us/Publications-And-Resources/BUDGETS-FINANCE/2025-Budget-Tables-A-1-through-H.aspx, accessed Oct. 2024.

types, Metro Transit is upgrading its scheduling software to better take the operating characteristics of different buses into account.

Metro Transit ordered 20 40-foot Gillig buses in 2024. These buses are anticipated to be in service in 2026.

Metro Transit ordered five 60-foot buses in 2023. These buses will be reserved for the Gold Line and are anticipated to be in service in 2025.

8.1.1 Vehicle Procurement

Vehicle procurement is an important metric for tracking Metro Transit's progress towards transitioning its fleet to ZEBs. Vehicle procurement measures the percentage of transit vehicle procurements that are ZEBs over a specific time period. For the short-term target, Metro Transit is aiming for at least 20 percent of 40-foot bus replacement procurements to be electric from 2025 to 2030, which aligns with the same period as the CIP. This target was set based on the maximum amount of charging infrastructure that could be installed within the short-term time frame.

Beyond the current CIP, the percentage of Metro Transit bus procurements that are ZEBs will be driven by KPIs and available budgetary resources. Metro Transit is committed to continuing to transition its fleet to ZEBs. An official target will be reflected in future updates of this plan based on realized experience in the short term as well as industry advancements.

As discussed in Section 12, Metro Transit has programmed funding through its CIP to meet its target of at least 20% of its 40-foot replacements will be electric. As seen in **Table 35**, so far, looking at what has already been programmed through 2026, Metro Transit is well above this target. However, since Metro Transit is planning to evaluate the performance of the buses purchased in 2024-2026 to inform its next ZEB procurement. It is anticipated that by 2030 its cumulative BEB replacement of 40-foot buses may be closer to it target of 20%.

Table 35: Metro Transit's budgeted and programmed 40-foot bus replacements 2024 to 2026

Year shown in CIP	2024	2025	2026
40' standard & 40' hybrid eligible for replacement	78	59	39
20% of replacement target for BEB	16	12	8
Planned BEB in CIP (for revenue service 2 yrs later)	20	18	17
Cumulative 40' replacement BEBs in CIP	20	38	55
Anticipated entering Revenue Service	2026	2027	2028
CIP percentage of BEB replacements (cumulative)	26%	28%	31%

8.1.2 Infrastructure Procurement

An important component of ZEB implementation is having the necessary infrastructure in place to support the growing ZEB fleet. To this end, as a part of both the 40- and 60-foot BEB purchases in 2024, Metro Transit included 26 chargers and charge management software. With these additional chargers, Metro Transit will have chargers from four manufacturers, as seen in **Figure 59**. Metro Transit plans to evaluate the performance of the BEB chargers and bus manufactures to inform future procurement decisions.

Figure 59: Metro Transit's BEB suppliers

8.2 Performance Measures

Metro Transit will continue to utilize performance measures to analyze progress against the milestones, inform plan updates, and drive decision-making for future procurements. Performance measures evaluate the vehicle and infrastructure usage, availability, reliability, cost, impact on the environment, and the degree to which ZEBs are deployed in an equitable and environmentally just manner. These measures will continue to be used to regularly assess the performance of the ZEBs and associated infrastructure. The evaluations will help Metro Transit compare different ZEB and infrastructure vendors and will inform decisions on future procurements.

To establish performance measures for ZEBs, Metro Transit conducted peer agency research. The most commonly used performance measures utilized by these peer agencies include battery efficiency (kWh/mi), fleet availability, fleet reliability (MBRC), and maintenance and fuel costs per mile. In addition to these most common measures, some peer agencies also tracked the ambient temperature and average ZEB speed.

To follow industry best practices, Metro Transit will continue to use similar performance measures to evaluate ZEBs and supporting infrastructure within its system. In the short term, Metro Transit's ZEBTP is to utilize BEBs. The following sections summarize the performance measures that Metro Transit will continue to use to assess the BEBs and infrastructure.

- **Fleet Mileage:** Total number of miles driven by BEBs each year
- **Bus Availability:** Percentage of BEBs available for use in service
- **Bus Reliability:** Mean distance between chargeable road calls
- **Environmental Impact:** GHG emission reductions compared to baseline diesel fleet
- **Equity and Environmental Justice:** Percentage of BEB deployments on "High-Priority" EEJ service blocks
- **Cost/mile:** Energy cost BEBs use per mile driven
- **Infrastructure Availability:** Percentage of chargers available to charge a bus
- **Infrastructure Reliability:** Quantity of incidents that take a charger out of service

These eight KPIs align with the three guiding principles as defined in Section 2 (**Table 36**).

Table 36: ZEBTP KPIs

KPI	Guiding Principle		
	Technical Viability	Equity and Environmental Justice	Fiscal Impact
Fleet Mileage	◆	--	◆
Bus Availability	◆	--	◆
Bus Reliability	◆	◆	◆
Environmental Impact	--	◆	--
EEJ	--	◆	--
Energy Cost/Mile	◆	--	◆
Infrastructure Availability	◆	--	◆
Infrastructure Reliability	◆	◆	◆

The subsequent sections below describe each KPI in more detail, defining what is being measured and how as well as why it is important to measure.

8.2.1 Fleet Mileage

8.2.1.1 What is Being Measured?

- The total number of miles driven by BEBs each year

8.2.1.2 How is it Being Measured?

- Total odometer miles for the BEBs

8.2.1.3 Why is it Important?

- As Metro Transit makes progress towards transitioning its fleet to ZEBs, including BEBs, the total number of fleet miles driven by ZEBs will increase. Comparing annual vehicle mileage for BEBs using the **fleet mileage** metric will help depict how they perform in our service environment.

8.2.2 Bus Availability

8.2.2.1 What is Being Measured?

- The percent of BEBs available for use in service

8.2.2.2 How is it Being Measured?

- The total number of days each bus is available for use in service divided by the total number of planned service days

8.2.2.3 Why is it Important?

- The **Bus Availability** metric quantifies bus readiness and helps Metro Transit assess product availability to consistently provide reliable service.

8.2.3 Bus Reliability

8.2.3.1 What is Being Measured?

- The mean (average) distance between chargeable road calls. Chargeable road calls are defined as instances when a bus requires unplanned maintenance attention while in service.

8.2.3.2 How is it Being Measured?

- The number of miles traveled divided by the number of chargeable road calls

8.2.3.3 Why is it Important?

- The **Bus Reliability** metric will help Metro Transit evaluate how often a bus breaks down while in service to assess the impact BEBs have on service reliability and customer experience.

8.2.4 Environmental Impact

8.2.4.1 What is Being Measured?

- GHG emission reductions compared to a baseline diesel fleet

8.2.4.2 How is it Being Measured?

- Well-to-wheel GHG reductions calculated using the Argonne National Laboratory's 2023 Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) model.[248] Well-to-wheel GHG estimates include the GHGs produced during fuel production and delivery (well-to-pump) in addition to GHGs produced during vehicle operation (pump-to-wheel).

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[248] Historically, Argonne National Laboratory's AFLEET model has been updated every 2-3 years to add additional features and reflect updated vehicle emissions factors. The 2023 Annual Report uses the most recent 2023 AFLEET model and MROW eGRID 2022 Table 2 resource mixes.

8.2.4.3 Why is it Important?

- The **Environmental Impact** metric quantifies the impact transitioning towards ZEBs has on reducing transit vehicle emissions and demonstrates the community benefits that BEBs deliver to the region.

8.2.5 Equity and Environmental Justice

8.2.5.1 What is Being Measured?

- The percent of BEB deployments on "High-Priority" EEJ service blocks as defined in Section 8.5. High-priority service blocks have the greatest portion of bus mileage in High-Priority (pink) EEJ Areas (**Figure 60**). EEJ priority areas were identified based on community input and ranking of seven different factors from the Metropolitan Council's Equity Considerations for Place-Based Advocacy and Decisions dataset. Community input coalesced around cancer risk (a proxy for air quality), population density, and the percent of census tract population that identified as BIPOC as the top three factors when calculating census tract equity tiers.

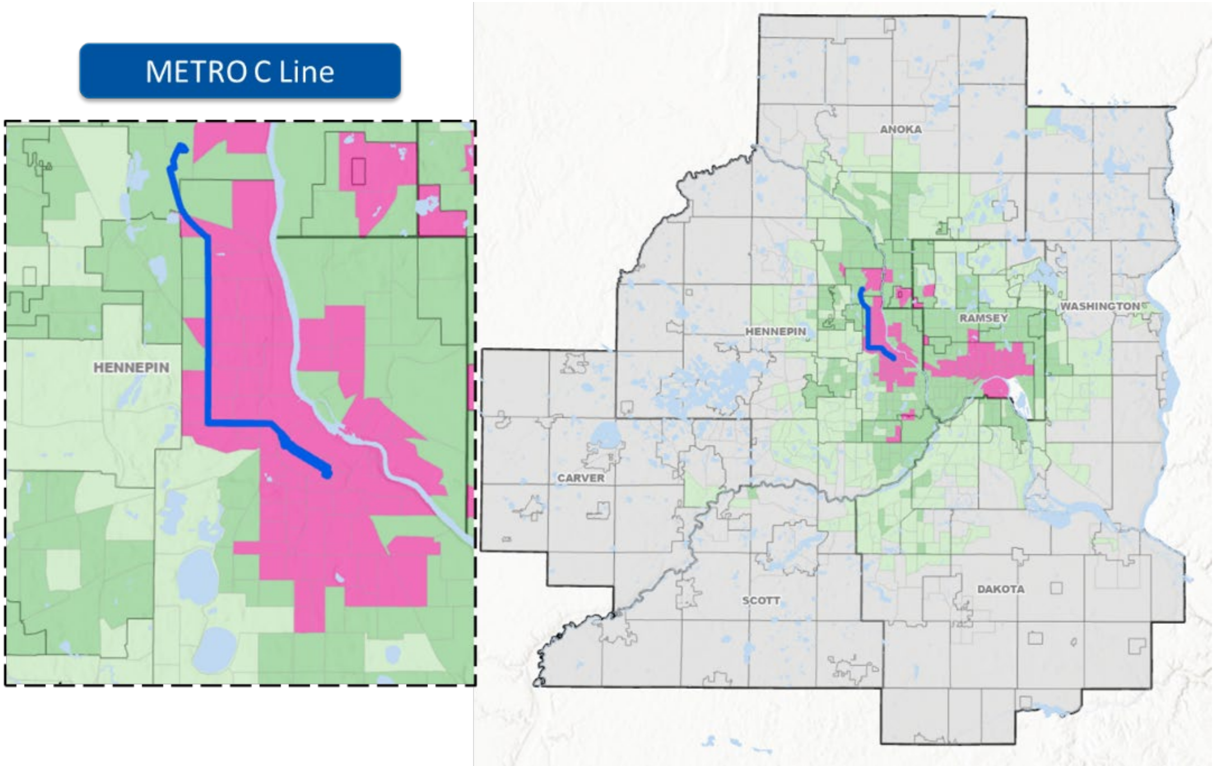
8.2.5.2 How is it Being Measured?

- The number of BEB deployments on "High-Priority" EEJ service blocks divided by the total number of BEB deployments

8.2.5.3 Why is it Important?

- The EEJ metric will help Metro Transit understand the impact BEB deployment prioritization is having in the community based on environmental, racial, and socioeconomic considerations.

Figure 60: EEJ Priority Areas and 2023 BEB Deployments



8.2.6 Energy Cost/Mile

8.2.6.1 What is Being Measured?

- Energy cost a bus uses to travel one mile inclusive of propulsion energy (diesel or electricity) and diesel fuel for bus auxiliary heat[249]

8.2.6.2 How is it Being Measured?

- The total energy cost by vehicle group divided by the total miles traveled by that group

8.2.6.3 Why is it Important?

- The **Energy Cost/Mile** metric will help Metro Transit understand the ongoing energy costs and necessary budget to operate BEBs

8.2.7 Infrastructure Availability

8.2.7.1 What is Being Measured?

- Percent of chargers available to charge a bus for revenue service

8.2.7.2 How is it Being Measured?

- Total number of days each charger is available to support deploying buses in revenue service divided by the total number of planned service days

8.2.7.3 Why is it Important?

- Historically, fuel pump availability was not a concern; however, early charger deployments have had lower availability. The **Infrastructure Availability** metric will help Metro Transit assess technology ability to consistently provide reliable service.

8.2.8 Infrastructure Reliability

8.2.8.1 What is Being Measured?

- The quantity of incidents that take a charger out of service

8.2.8.2 How is it Being Measured?

- Number of incidents that take a charger out of service

8.2.8.3 Why is it Important?

- The **Infrastructure Reliability** metric will help Metro Transit understand how often chargers must be temporarily removed from service for unplanned maintenance. This will help Metro Transit assess technology ability to consistently provide reliable service.

[249] Note: All Metro Transit buses regardless of propulsion type include auxiliary diesel heaters for passenger comfort.

8.2.9 Annual Report

Since publishing the initial ZEBTP in 2022, Metro Transit has released the *2022 ZEBTP Annual Report* and the *2023 ZEBTP Annual Report*.[250, 251] Annual KPI performance for calendar year 2023 is summarized in **Table 37** compared to calendar year 2022. Key takeaways from 2023 include:

- Fleet KPIs (mileage, bus availability, bus reliability) declined from 2022 to 2023 largely due to an increased need to replace failed battery packs under warranty and retiring the on-route chargers at BCTC.
- Energy cost per mile for BEBs remains higher than diesel buses.
- Plug-in chargers are working as planned following replacement under warranty in 2021.
- 100 percent of 2023 BEB deployments were on "High-Priority" EEJ blocks/vehicle tasks.

Table 37: Metro Transit 2023 annual KPI summary

KPI	BEB 2022	BEB 2023
Fleet Mileage*	175,300	117,400
Bus Availability *(% of BEBs Available for Use in Revenue Service)*	71%	49%
Bus Reliability *(Mean Distance Between Chargeable Road Calls)*	4,870	2,668
Environmental Impact** *(GHG [CO_2e] Reduction in Metric Tons)*	145	60
EEJ *(% of BEB Deployments on "High-Priority" EEJ Blocks)*	100%	100%
Energy Cost/Mile	$1.17 *($1.02 for diesel bus)*	$1.21 *($0.76 for diesel bus)*
Infrastructure Availability *(Avg. Full Days Available to Charge a Bus for Use in Revenue Service)*	Garage: 99.8%	Garage: 92%
Infrastructure Reliability *(Total incidents that take chargers out of service)*	Garage: 2	Garage: 8

*Rounded to the nearest 100 miles

**Rounded to the nearest 5 metric tons

[250] Metro Transit, *2022 ZEB Transition Plan Annual Report*, https://www.metrotransit.org/Data/Sites/1/media/about/improvements/electric_buses/2022-zeb-transition-plan-annual-report.pdf, October 2023.
[251] Metro Transit, *2023 ZEB Transition Plan Annual Report*, https://www.metrotransit.org/Data/Sites/1/media/about/improvements/electric_buses/2023annualupdate_final.pdf, July 2024.

9 Workforce Development

Due to the complexity of ZEBs and the extent to which they differ from conventional diesel buses, transitioning towards a ZEB fleet will require substantial changes to the O&M of buses and fueling systems. To increase the share of existing Metro Transit staff that are well versed in the rapidly evolving intricacies of ZEB technology and to avoid displacement of the existing workforce, Metro Transit has identified that workforce development and training will be a dedicated part of every ZEB project. Considering this emphasis on training and workforce development, this section examines Metro Transit's existing training programs and assesses the impact that transitioning to a ZEB fleet will have on Metro Transit's current workforce.

To identify potential skill gaps as well as the unique training and retraining needs required to support expanded ZEB operation, Metro Transit conducted an internal review of five departments' existing workforce training programs related to Metro Transit's transition to ZEBs. The departments selected for this review encompass those that most closely interface with either the day-to-day O&M of ZEBs and their supporting infrastructure or agency-wide workforce development programs:

- Human Resources/Workforce Development
- Bus Maintenance
- Engineering and Facilities
- Bus Transportation
- Service Development

Other departments also regularly support Metro Transit's transition to ZEBs, although they will not be explored in depth as part of the ZEBTP.

This chapter will be updated to incorporate comprehensive changes in staffing complement as a result of an expanded ZEB fleet upon the completion of Metro Transit's program of studies; in particular, modifications to staffing complement will be dependent on future service level, propulsion type, replacement ratio, and facility needs studies.

9.1 Metropolitan Council Workforce Development Department

Metro Transit is the largest operating division of the Metropolitan Council (Met Council) the "regional policy-making body, planning agency, and provider of essential services for the seven-county Twin Cities metro area."[252] Located within Human Resources, the Met Council's Workforce Development department plays a vital role in training individuals in support of the agency's current and projected workforce needs. In particular, the department designs and delivers a variety of training programs (also known as pathways) focused on preparing individuals for a career in one of a variety of different fields, including but not limited to the construction trades, environmental services, and bus O&M. Given its pivotal role in training staff across a variety of departments and focus areas, the Workforce Development department will continue to play a vital role in retraining existing staff as well as recruiting and providing new staff with the technical training necessary to support the continued O&M of a ZEB fleet.

[252] Source: *Who We Are*, Metropolitan Council.

9.1.1 Existing Training Programs and Accomplishments

The Met Council has been recognized as an industry leader in delivering innovative workforce development programs/pathways. In particular, the Metro Transit Technician (MTT) Pathways Program, described below, was awarded Governor Dayton's 2017 Better Government Projects award under the Great Place to Work category. In 2017, the Met Council also won the Model Program award from the National Transit Institute, which recognized the MTT pathway as an "industry-leading workforce development program" for bus and rail technicians.[253]

9.1.1.1 Metro Transit Technician Pathways Program (2015 to 2022)

Figure 61: MTT 2020 graduation ceremony

The MMT – Bus program was founded in 2015 in partnership with Twin Cities R!SE, the Amalgamated Transit Union (ATU) Local 1005, and Hennepin Technical College (**Figure 61**). This program was supported through awarded FTA grant monies and Minnesota legislative appropriations totaling over $800,000 and was designed to attract and prepare individuals from non-traditional sources with limited experience and educational backgrounds, putting them "on a path to full-time roles as bus technicians through a combination of job and skills training, a paid internship, and support toward earning an associate's degree."[254253] In 2022, the MTT program transitioned to the Technician Apprentice Program. Throughout the program's duration, 29 participants completed the MTT Pathways Program and earned employment as full-time bus mechanic-technicians at Metro Transit.

As part of the MTT Pathways Program, a technician mentors at all five Metro Transit garages, and the OHB provided 3,884 hours of hands-on structured staff mentor support and instruction to program participants across the three cohorts. As a testament to the program's success, many participants from past cohorts of the program now serve as program mentors. Specific elements of the MTT program include:

- Math tutoring;
- An emotional intelligence course provided by Twin Cities R!SE, a community partner whose mission is to "transform the lives of those impacted by racial or socioeconomic barriers through Personal Empowerment, career training, and meaningful employment"[255];
- Completion of exposure and career readiness sessions;
- Enrollment and completion of AAS Mechanic Diesel degree through an academic partner; and
- A paid 2-year full-time transit internship.

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[253] Source: *Technician training program gets national recognition*, Metro Transit, March 2017.
[254] Source: *Technician training program gets national recognition*, Metro Transit, March 2017.
[255] Source: *Who We Are*, Twin Cities R!SE.

The MTT program has made an immediate impact on Metro Transit's workforce by increasing both the number of bus technicians as well as the diversity of the workforce. For example, comparing the bus technician workforce prior to the MTT program to the workforce in September 2020 after the first three MTT cohorts graduated, the total number of bus technicians increased by 13 percent, the number of female bus technicians at Metro Transit nearly tripled, and the number of technicians that identify as BIPOC increased by approximately 44 percent. In addition to increasing the diversity and size of Metro Transit's bus technician workforce, Metro Transit has also observed that the retention rate for MTT program graduates is particularly high compared to other bus technicians, as 86 percent of MTT program graduates remained employed at Metro Transit as of April 2022.

Figure 62: Mechanic-technician outreach event

To recruit participants for the program and attract young talent, Metro Transit mechanics and technicians visited local high schools to share their experiences and facilitate hands-on activities mimicking the work done by Metro Transit mechanic-technicians (**Figure 62**).

9.1.1.2 Planned Workforce Training

With the benefit of experience and learned lessons from the MTT Pathways Program, both the Met Council and Metro Transit are aggressively pursuing career pathways into additional transportation positions, including pathways that will incorporate the training necessary for staff to successfully support Metro Transit's transition towards ZEBs. It is anticipated that the transition towards ZEBs will have a limited impact on the day-to-day work of the Workforce Development department because the existing training programs were designed to be malleable and flexible. Moving forward, Metro Transit plans to explore introducing additional training modules dedicated to ZEB technologies into existing pathway programs to meet training/retraining needs identified in coordination with other departments. Given the flexible nature of the pathways developed by the Workforce Development department in partnership with Metro Transit's Bus Maintenance department, it is anticipated that these future efforts to add additional modules on ZEB technologies will be relatively straightforward.

9.1.2 Technician Apprenticeship Program

One such initiative designed to build upon the successes of past training programs was Metro Transit's transition of the MTT Pathways Program into the Technician Apprenticeship Program in 2022. The 3-year joint registered apprenticeship program is designed to provide participants with on-the-job experience and mentorship as well as the training equivalency of a 2-year associate's degree (**Figure 63**). In partnership with the local transit union (ATU 1005), selected participants are hired as technician trainees, full-time positions with benefits, almost immediately. Upon the successful obtainment of skills and knowledge gained through 2 years of training, trainees advance to Phase 4 of the program as a bus technician. In Phase 4, bus technicians continue to receive structured training while working more independently and taking on additional responsibilities. After 1 year as a bus technician and 3 years in the program—achieving 6,000 hours of training—participants graduate as a journeyperson. In 2022, the first cohort included 14 participants; 7 were existing Metro Transit bus cleaner/fuelers and 7 were external to the agency using the Technician Apprenticeship Program as their gateway into the transit workforce. These 14 participants were hired as technician trainees in 2023. The second apprenticeship cohort of 14 participants is targeted to begin in January 2025, with plans to have a new cohort annually thereafter. For further discussion of the registered apprenticeship program for bus technicians see Section 10.3 below.

Figure 63*: *Apprenticeship Program model

Phase 1
Recruitment and Selection (2 to 4 Months)

Phase 2
Participant Readiness (2 Months)

Phase 3
Technician Trainee Position (24 Months)

Phase 4
Technican Position // Continued Structured Training (12 Months)

The apprenticeship program is included in Metro Transit's Affirmative Action Plan and 2024 Work Plan; it is funded through the 2021 Equity Grant, FY2023 Low-No Grant, Minnesota Department of Transportation (MnDOT) IIJA Match Program, and departmental workforce development standing budgets. Metro Transit has committed to a customized internal workforce development curriculum that would biennially:

- Allow up to 100 individuals to complete program application and assessments;
- Allow up to 25 participants to complete the 2-month Awareness and Readiness preparatory program;
- Offer 14 participants employment as trainees.

9.2 Metro Transit Structural Reorganization

In 2023, Metro Transit underwent a significant reorganization of its existing workforce to increase collaboration between related job skills. Rather than dividing departments' responsibilities by mode, Metro Transit reorganized the departments based on job skills and tasks. For example, whereas Metro Transit's Operations department was historically divided into distinct Bus and Rail Operations groups, the department was realigned to contain two primary groups—Transportation and Maintenance—each of which include both rail and bus modes. As part of this restructuring, Metro Transit created new deputy chief operating officer (DCOO) positions to lead each of the new Operations groups. These DCOOs are tasked with, among other responsibilities, "team building across all divisions" within their department as well as developing "plans, training, and programs to ensure that future workforce staffing and development needs are met."

One of the intended benefits of this reorganization is to increase workforce development and training opportunities by aligning and consolidating staff expertise and training resources by job task. For example, under the new departmental structure, maintenance staff will have access to the expertise and expanded training resources from instructors of both the former Bus Maintenance and Rail Maintenance groups. In addition to expanding training opportunities, this reorganization provides staff with a broader support structure that supports skill transferability across both rail and bus modes within their overarching department. The goal of this reorganization is intended to enable higher rates of retention of the existing workforce and streamlined opportunities for internal advancement.

In alignment with this reorganization and heightened focus on collaboration between related job skills, an opportunity exists to strategically evaluate the various roles and responsibilities related to ZEBs between departments. The results of the evaluation can be used to build upon and develop the internal competency and training programs necessary to support an expanded transition towards ZEBs utilizing Metro Transit's existing workforce. In particular, this reorganization sets the groundwork for Metro Transit to explore transitioning towards a more wholistic approach to ZEB training and operation where ZEBs are emphasized as a system rather than individual components isolated between departments.

9.3 Bus Maintenance Department

Metro Transit's Bus Maintenance department is comprised of four sub-groups, each of which plays an important role in maintaining the hundreds of buses Metro Transit uses to deliver service throughout the region. These groups include Administration, Vehicle Engineering, Fleet/Training, and Garage Maintenance. As outlined in Section 4 and Section 5, ZEB technology and components differ substantially from conventional buses. For example, unlike diesel buses, BEBs have an increased quantity of software and programming onboard and utilize a wide variety of components unique to BEBs such as battery strings or other high-voltage equipment. Due to its direct interface with these new components and techniques, Bus Maintenance was identified as a key department to include in assessing ZEB training and retraining needs.

9.3.1 Existing Training Programs

Currently, Metro Transit's Bus Maintenance department offers nearly 100 named classes totaling over 600 hours utilizing several different training methods, including:

- One-on-one expert field training;
- Internal classroom and online (eLearning) training; and
- Vendor training hours purchased through the procurement process.

Figure 64*:* One-on-one expert field training

9.3.1.1 One-on-One Expert Field Training

Metro Transit currently utilizes one-on-one on-site training delivered by experts to build staff competencies for both traditional buses and ZEBs (**Figure 64**). With this type of individualized training, an expert is dispatched to the field to directly train a technician. As part of this training, technicians typically perform a hands-on demonstration of skill to verify comprehension.

9.3.1.2 Internal Classroom and Online (eLearning) Training

In addition to hands-on field training, Metro Transit also provides a wide variety of classes and training modules in both a traditional classroom setting as well as through online (eLearning) modules. Online training is typically limited to a select number of more general topics including safe garage training, high voltage awareness, and general SOPs. Technicians enrolled in online training can complete the training online from any of Metro Transit's facilities. At the end of eLearning modules, participants' comprehension of the material is typically verified through online exercises

To deliver the wide variety of internal classroom training, the Bus Maintenance department has its own in-house training and development group currently staffed with two technical trainers and one instructional designer. The group offers a wide variety of classes covering topics ranging from basic safety to advance troubleshooting. Although the majority of these classes are not specific to ZEBs, a select number focus on increasing technicians' comfort with and basic knowledge of electrical systems while many additional classes provide training on components that are similar across all bus types, including ZEBs. Each month, Bus Maintenance's training department publishes a calendar of courses for technicians working during each of the three shifts in order to provide sufficient training opportunities for all technicians.

9.3.1.3 Vendor Training Hours

Beyond internal training programs, the Bus Maintenance department also uses training hours purchased from the OEM during the procurement process. These training hours can typically be used either with the OEM or on a subcomponent built by a sub-manufacturer. Vendor training hours typically focus on user-interface training but can also include troubleshooting and repair training for technicians. These trainings can be conducted either through in-person instruction or via online webinars or eLearning modules. In addition to using these vendor hours to train maintenance technicians, Bus Maintenance's internal trainers also attend these trainings. With this train-the-trainer framework, Metro Transit can further expand trainers' mastery in specific subject areas, thereby expanding internal support and training opportunities for Bus Maintenance staff in the future.

As ZEB prevalence grows and as the technology matures, ZEB manufacturers are increasingly expanding their field training capabilities to cover a wider range of topics including, for example, charger training. In the short term, Metro Transit will continue to closely monitor and utilize vendor course offerings to best prepare and develop its workforce to support expanded BEB operations.

9.3.1.4 Existing Zero-Emission Bus Training Programs

Metro Transit has operated BEBs as part of the C Line BRT service since spring 2019. During this introduction to BEBs, the Bus Maintenance department formed a dedicated BEB support team of technicians and engineering staff. To prepare for an expanded number of ZEBs, efforts are underway to expand and strengthen the internal maintenance support team. To ensure that maintenance staff have the training necessary to succeed when working on these BEBs, the Bus Maintenance department has also made several modifications to the existing training curriculum to incorporate BEB-specific training. For example, although Metro Transit's bus fleet currently includes a total of 114 hybrid electric buses that involve high-voltage power, training requirements were altered in line with the introduction of the C Line such that high voltage awareness training became a required training course for all maintenance staff, including maintenance staff that did not work on hybrid buses or BEBs. In addition to this high voltage training, several powertrain technicians at each garage are selected to be responsible for BEB propulsion maintenance and high-voltage systems, while other maintenance staff are primarily responsible for the maintenance of BEB components that are similar to the components found in traditional diesel buses. To support the maintenance of BEB propulsion systems, powertrain technicians receive further electrical training and are fitted and trained for high voltage personal protective equipment.

As of fall 2024, the Bus Maintenance department has 21 named training courses totaling approximately 145 hours related to BEBs (**Table 38**). The majority of these offerings are vendor trainings focused on how to maintain components specific to the C Line New Flyer BEBs, including doors, steering and suspension, and articulated joints. However, several courses are also offered related to general maintenance and safety principles generalized to BEBs and chargers from all vendors.

Table 38: Existing bus maintenance BEB course catalog

Course	Description/Topic	Hrs.	Method
Arc Rated and Flame-Resistant Personal Protective Equipment: It's Your Life – Protect It	How to properly put on, wear, and adjust personal protective equipment.	1	In the field
Garage Charger Operation	How to operate a Siemens Garage Battery charger, including plugging/unplugging an electric bus and general operations and safety requirements.	0.5	In the field
High Voltage Awareness	Required for all garage maintenance employees: general high voltage safety, injury prevention, how to handle standing water and how to wash/clean a BEB.	0.5	ELearning
High-Voltage Bus Inspection	High voltage safety awareness during the preventative maintenance inspection process of a BEB.	4	In the field
Troubleshooting J1939	This course covers the J1939 Network bus wiring basics and how to troubleshoot CAN wiring with a multi-meter using a consistent process.	4	In house
Logging a Network	How to record a log of what is happening over a J1939 Network using a CAN logger and the software required.	4	In house
Troubleshooting with Vansco	How to operate, troubleshoot, and program Vansco Software, including Vansco Mutiplexing Module Software and troubleshooting bugs on a bus using the Vansco Software.	8	In house
Advance E-bus Troubleshooting	How to use a VN1610 to live log an E-bus using CANalyzer to diagnose faults and troubleshoot with the software Vansco and SIADIS Expert.	16	In house

Course	Description/Topic	Hrs.	Method
CANalyzer	How to read CAN logs using the software CANalyzer and to troubleshoot intermittent CAN errors that are difficult to diagnose.	4	In house
Low-Voltage Bus Inspection	Low voltage safety awareness during the preventative maintenance inspection process of a BEB.	4	In the field
New Flyer: Anti-lock Braking System Brakes and Air Systems for Electric Bus	Theory of the New Flyer BEB Air systems, braking factors, and mechanical/pneumatic factors involved.	8	Vendor
New Flyer: Articulated Joint for Electric Bus	Preventative maintenance, troubleshooting, and safety topics related to New Flyer’s Articulation Joint on BEBs.	8	Vendor
New Flyer: Duration and Cooling for Electric Bus	New Flyer’s duration and cooling for BEBs.	8	Vendor
New Flyer: Ethylene Oxide Vapor Doors and Wheelchair Ramp for Electric Bus	New Flyer’s vapor doors and wheelchair lift for BEBs.	8	Vendor
New Flyer: Steering and Suspension for Electric Bus	Variety of topics including preventative maintenance, troubleshooting, and safety related to New Flyer BEB steering and suspension.	8	Vendor
New Flyer: Towing Recovery and Electric Axle for Electric Bus	How to properly tow a New Flyer BEB including a review of inspecting, lifting capacity, and recommended practices for towing.	8	Vendor
New Flyer: Troubleshooting and Preventive Maintenance for Electric Bus	How to properly troubleshoot and perform preventative maintenance on a New Flyer BEB including high voltage safety, the preventative maintenance schedule, and basic BEB troubleshooting.	8	Vendor
New Flyer VIC Electric Bus	Learn all about a New Flyer BEB including high-level basic information along with tips and tricks for working with BEBs.	24	Vendor
Preventative Maintenance for E-Bus	How to properly perform preventative maintenance on a New Flyer BEB including a review of the preventative maintenance schedule and how to perform inspections.	8	Vendor
Quantum Q'Straint	How to operate and provide general maintenance for the BEB wheelchair system.	2.5	Vendor
Xalt Software Training	Hand-on training focused on lithium cells/batteries, lithium battery configurations and architectures, and how to replace a battery pack.	8	Vendor

9.3.2 Zero-Emission Bus Impact and Training/Retraining Needs

Currently, BEBs only operate on one route—the C Line. However, as Metro Transit transitions towards a ZEB fleet, the number of BEBs to maintain will significantly increase. In recognition of this transition, the Bus Maintenance department has proactively identified several key aspects of the department's work that will be most significantly impacted by the transition as well as ZEB training/retraining needs and strategies to address the identified needs.

Over the course of nearly two decades, a total of 136 hybrid electric buses have been integrated into Metro Transit's bus fleet. Given that these buses utilize high-voltage power, a significant number of bus technicians are already familiar with working on high voltage, a key prerequisite to working on BEBs. However, as Metro Transit increases the number of BEBs in its fleet, a much larger portion of bus maintenance technicians will need to become technically proficient and comfortable working safely with these high-voltage systems and technically complex buses.

Reflecting on the agency's experience integrating hybrid buses into the bus fleet, the biggest challenge facing the Bus Maintenance department as it relates to the transition towards ZEBs is the concern of the paradigm shift. In particular, given that ZEBs are technically complex and that many technicians are not as comfortable performing electrical work as they are working on the non-electrical systems of a conventional diesel bus, a key concern for the Bus Maintenance department is ensuring that the department has enough technicians that gravitate toward the challenge of working on a new type of bus propulsion system. To address this concern, Bus Maintenance plans to expand and enhance training opportunities to develop and build the technicians technical skills and conceptual background to a level at which they are equally confident working safely on ZEBs and conventional diesel buses. These expanded training opportunities are planned to strengthen the technicians' basic electrical/electronic knowledge before building upon this foundation to provide more advanced ZEB maintenance and repair skills.

9.3.2.1 Progress Towards Future Training

Bus Maintenance has identified several strategies for implementation in the short term and long term to address the impacts and challenges associated with transitioning towards ZEBs as outlined above. These strategies include expanded training topics and additional trainers, enhanced powertrain technician training and support structure, the development of a registered joint apprentice program, and a long-term agency schema shift. As of fall 2024, Metro Transit has filled two technical training positions, hired a heating, ventilation, and air conditioning (HVAC)/electrical fleet supervisor (50 percent time), and implemented the registered joint apprentice program, with its first cohort established in 2023 and second cohort planned for 2025.

9.3.2.2 Expanded Training Topics and Hiring Additional Trainers

In recognition of the growing range of training tropics and needs, including for ZEBs and electrical systems, in the short term, the Bus Maintenance department has hired two technical trainers, a HVAC/electrical fleet supervisor (50 percent time), and an instructional designer for its internal training and development group. Technical trainers are responsible for developing and conducting training for maintenance staff, including supporting the Apprenticeship Program. The HVAC/electrical fleet supervisor is a technical expert that assists with troubleshooting BEB issues and providing training on a one-on-one basis; the position also supports the development of SOPs and contact with OEMs. Beyond hiring additional trainers, Bus Maintenance also incorporated additional in-house high voltage training into its curriculum along with updating its Fall Protection Rescue Plan to incorporate specific fall protection training for BEBs, as battery storage is often located on the roof of a BEB.

In 2025, new bus manufacture training will occur for two additional facilities receiving charging infrastructure, the East Metro and North Loop Garages.

9.3.2.3 Enhanced Powertrain Technician Training and Support Structure

To gradually build internal comfort and competency on BEBs, in the short term, Bus Maintenance is planning to build upon the technical expertise of the existing powertrain technicians located at each garage. In total, Metro Transit employs 50 powertrain technicians across the five garages and the OHB. The powertrain technicians are a natural first step in building internal competency working with high-voltage systems and ZEBs because these powertrain technicians have built experience working with the high-voltage systems on Metro Transit’s existing fleet of hybrids and have received additional electrical training. Therefore, in the short term, Bus Maintenance plans to focus the responsibility for ZEB propulsion maintenance on the existing teams of powertrain technicians located at each garage, each of whom would receive additional OEM training dedicated to ZEB systems. It is anticipated that the powertrain technicians would then leverage this OEM training to instruct and train other maintenance technicians on ZEB propulsion maintenance. As ZEBs are deployed in additional garages and in greater numbers, it is likely that the number of staff trained as powertrain technicians will increase and that powertrain technicians will receive additional ZEB training to further build their subject mastery and comfort with training other technicians on ZEB propulsion systems.

Using this enhanced powertrain technician training strategy, Bus Maintenance can extract the maximum benefit from OEM training hours while providing a support structure and familiar peer resource to the remainder of the existing bus technician workforce as they increase their comfort with both ZEBs and electrical systems in general. In particular, by concentrating ZEB propulsion maintenance responsibilities to a sub-group of the technician workforce, the majority of existing technicians can primarily focus on maintaining the components on ZEBs that are similar across all bus types while gradually learning about the intricacies of ZEB propulsion systems. Bus Maintenance is optimistic that by the time a significant portion of Metro Transit’s fleet is comprised of ZEBs, this training strategy will have elevated a comparable portion of the existing workforce of bus technicians to a level at which they have the technical competency and comfort needed to safely maintain the ZEB fleet.

9.3.2.4 Technician Apprenticeship Program

As an additional training resource to build ZEB competency, Metro Transit established a registered joint Technician Apprenticeship Program with the local transit union (ATU 1005) in 2022, as introduced in Section 10.1 above. As a registered apprentice program, upon completion, technicians receive a journeyworker card from the State of Minnesota, which enables them to earn journeyworker wages anywhere throughout the U.S. and Canada. The first cohort of the program included 14 participants who were hired as technician trainees in 2023, with a second cohort of 14 to begin in January 2025. Metro Transit plans to establish a new cohort every year thereafter.

Metro Transit was awarded a FY2023 Low Emissions - No Emissions (Low-No) and Buses grant to purchase additional BEBs and supporting infrastructure, in addition to advancing workforce training and development. The grant includes $660,000 that has been earmarked for the development and implementation of the Bus Maintenance registered joint apprentice program, as well as for tools and learning opportunities such as travel, conferences, and peer exchanges.

9.4 Engineering and Facilities Department

Metro Transit's E&F Department manages the planning, engineering, design, and construction of Metro Transit bus and rail facilities. To support the C Line BEB pilot program, starting in 2018, E&F's responsibilities expanded to include the design, construction, testing, and commissioning of ZEB infrastructure. In addition, once the ZEB's enter service, E&F is also responsible for the day-to-day maintenance of the supporting infrastructure (including chargers), while the buses themselves become the responsibility of the Bus Maintenance and Bus Transportation departments. As the O&M of BEB chargers is an integral component of keeping BEBs in service and on the street, E&F was identified as a core department to include in assessing ZEB training and retraining needs.

9.4.1 Creation of Specialized Electric Bus Infrastructure Team

As Metro Transit transitions from individual BEB pilot programs such as the C Line toward a more widespread integration of ZEBs, the quantity of ZEB infrastructure, and need for expanded workforce development is anticipated to grow substantially over the next several years. In recognition of this growth, in 2021 the E&F department formed a dedicated Electric Bus Infrastructure Engineering Team to support ZEB infrastructure engineering, including the design, testing, and commissioning of BEB chargers. This specialized team was formed through the internal reassignment of one support facilities engineer from a part-time electric bus infrastructure position to a full-time electric bus infrastructure engineer. The creation of this team represents a significant change in the way the E&F department has historically supported ZEB infrastructure. Rather than spreading ZEB responsibilities across multiple teams within the department and adding ZEB tasks to staff's existing workload, the formation of the Electric Bus Infrastructure Team allowed the E&F department to build upon existing internal expertise while formalizing and dedicating staff resources directly to ZEB infrastructure support and training. The creation of this specialized team also provides the opportunity to increase the department's emphasis on formalized ZEB training by consolidating and documenting the wealth of experience and skill within the dedicated team. By formally documenting ZEB training, staff could be trained in a more standardized manner without the risk of losing significant institutional knowledge if internal staff or external contractors depart.

As of fall 2024, the Electric Bus Infrastructure Team is composed of 3.5 full-time employees: one manager, one engineering project manager, one operations project manager, and one part-time construction manager that shares duties with other projects. This number is expected to grow in coming years.

9.4.2 Future Electric Bus Infrastructure Workforce Development Plans

9.4.2.1 Expansion of Electric Bus Infrastructure Team

Recognizing the need for increased electric bus infrastructure staff support, Metro Transit anticipates doubling the size of its Electric Bus Infrastructure Team over the next several years. As of fall 2024, two positions equating to 1.5 full-time employees have entered the hiring process. The first position is a business systems analyst (full time), which will support the team by focusing on performance management, data analytics, and smart charging implementation. The second position is an energy policy project coordinator; this role will split its time among other projects. Future proposed positions could include a ZEBTP planner, assistant engineering project manager, assistant construction manager, and/or a charger maintenance manager.

The operations arm for ongoing maintenance of equipment complements the capital arm of the work E&F performs in support of ZEB infrastructure (engineering, construction, testing, and commissioning). E&F plans to develop a long-term sustainable resource plan for BEB infrastructure maintenance, including staffing and training needs. Using funds from the FY2023 Low-No Grant, Metro Transit hired an operations project manager position (50 percent time) to develop BEB charger training and maintenance programs and materials as well as standard operation procedures tailored to each of Metro Transit's charger models. The charger purchases associated with the Gold Line, as well as the Low-No purchase, afford Metro Transit the opportunity to self-maintain equipment or contract with a third-party vendor for maintenance. As such, Metro Transit plans to continue to operate with a third-party service contract through 2025. A long-term maintenance strategy alternatives analysis is slated for 2025.

9.4.2.2 Expanded Hands-On Vendor Training

Currently, E&F uses on-the-job, over-the-shoulder vendor training to supplement institutional knowledge and training from existing staff and SOPs. Including both training hours purchased at the time of procurement as well as hands-on training during unplanned warranty repairs, E&F uses this vendor training to develop the problem solving and critical thinking mindset necessary for staff to successfully support ZEB systems. For unplanned warranty repairs, when an issue is identified, local electricians and Metro Transit work with the OEM to both resolve the issue and use the repair process as a learning opportunity for its own staff. In particular, Metro Transit has structured the repair process so that it is either conducted by a vendor with E&F staff by their side or directly by a local electrician with step-by-step instructions from the vendor. Field reports are generally generated documenting procedures learned during this on-the-job training for future reference. Metro Transit maintains electronic files with relevant email communications, photos, and other details to supplement field reports.

Based on the successes and lessons learned from this training strategy, when purchasing ZEB equipment, the E&F department has continued to include vendor training hours that can be scoped out for use by either Metro Transit staff or a third party to expand the training resources available for ZEB equipment. Additionally, Metro Transit added contractual language in its procurement documents that requires OEMs to provide both general troubleshooting training and hands-on preventative maintenance training for recent Gold Line purchases. By adding the requirement for hands-on preventative maintenance training, the E&F department will be able to maximize the vendors' technical expertise in applied situations rather than confining the training opportunity to basic troubleshooting actions. Through this expanded vendor training, E&F will be able to efficiently build internal competency on a much wider range of topics and skills, thereby putting the department in a position to succeed when the products' warranty periods expire.

9.4.2.3 FY2023 Low-No Grant Award

Metro Transit was awarded a FY2023 Low-No grant, which earmarks $100,000 for E&F workforce development. These monies will advance the creation of approximately 40 SOPs between 2024 and 2025. Before the end of 2024, Metro Transit will establish an interdepartmental SOP committee to guide the creation of E&F SOPs and identify mechanisms to leverage expertise from other departments to guide this effort, including referencing relevant examples from LRT/traction power and bus maintenance specific to high-voltage procedures. The grant also includes $40,000 earmarked for E&F staff training and peer exchange opportunities.

9.5 Bus Transportation Department

Metro Transit's Bus Transportation department is responsible for ensuring service for the millions of bus trips taken annually in the Twin Cities. As the home department for a total of over 1,000 bus operators and dispatchers, Bus Transportation is the largest department within Metro Transit and consists of three primary groups: Administration/Training, Field Operations/Transit Control Center (TCC), and Garage Operations. Given the size of the department, consideration of the training and retraining needs for Bus Transportation staff is a core element in ensuring successful ZEB service in the future.

9.5.1 Existing Training Programs

An excellent bus operator apprenticeship program that includes core skills training, workshops, and peer-to-peer mentoring is a top priority for Metro Transit. To deliver this high-quality apprenticeship program, Bus Transportation draws upon a team of over 50 internal instructors and 60 peer mentors located both at Metro Transit's own Instruction Center as well as at each bus garage. This team has strong and extensive experience operating in-service transit buses as well as classroom instruction, facilitation, and on-the-job bus training skills.

9.5.1.1 Bus Operator Apprenticeship Program

The Bus Operator Apprenticeship Program is 2 years in length and comprised of 5 levels. Level 1 includes initial training on core skills as well as behind-the-wheel training and testing. Trainees requiring a commercial driver's license (CDL) or the addition of a passenger endorsement also complete the federally required Entry-Level Driver Training curriculum as part of this level. Levels 2 through 5 consist of supplementary workshops, peer-to-peer mentoring, and performance evaluations all while accumulating field experience. Workshop themes include technical skills, soft skills, and transit specific knowledge skills.

9.5.1.2 Supplementary Training

To further expand our operators' skills, a variety of supplemental courses are also offered to all operators:

- Annual Hand-held Chemical Aerosol Training;
- Smith System Defensive Driving Course;
- Route Familiarization;
- BRT Training;
- Professional Operator Development Training;
- Annual Safety and Occupational Safety and Health Administration (abbreviated as OSHA) Right to Know Training;
- Ongoing Ride-along Observations and Evaluations;
- De-escalation Training; and
- Equipment Training on different bus types including articulated buses and coach buses as well as different propulsion types.

9.5.1.3 Existing Zero-Emission Bus Training Programs

As of fall 2024, the C Line's dedicated fleet of eight electric buses, representing approximately 1 percent of Metro Transit's total bus fleet, are BEBs. Given the limited number of current BEBs, the Bus Transportation department does not offer a course at the Instruction Center dedicated to learning about BEB operation. Instead, BEB training is presented at the garage level in the context of the C Line BRT service. As a route-specific rather than bus propulsion curriculum, much of this course is focused on general aspects of the C Line service including general differences between a local route and an arterial BRT route as well as station familiarization and fare information.

The core elements of the C Line training curriculum specific to BEBs include an overview of where the onboard batteries are stored, how to charge an electric bus using on-route charging, and electric bus safety. Based on the department's experience with the C Line, operators and trainers alike recognized that on-route charging training is one of the most important aspects of BEB training for operators providing service on a route utilizing this charging strategy. This is because connecting BEBs to the chargers is a substantial difference, as compared to operating a conventional diesel bus. Though the C Line's on-route charging system was retired in 2023, the lessons learned will prove to be valuable in the event of future on-route charging utilization. To this end, the Bus Transportation department's 5-page SOP on safely charging an electric bus with on-route overhead charging stations, accompanying instructional video, and presentation materials are valuable training resources that constitute critical institutional knowledge in a scenario where Metro Transit returns to on-route charging.

Operators are also trained to monitor the SOC on the bus dash and call the TCC if their SOC is getting low. This is new compared to diesel buses, which do not include a fuel gauge.

9.5.2 Zero-Emission Bus Impact and Training/Retraining Needs

As Metro Transit transitions towards a ZEB fleet, an increasing number and percentage of Bus Transportation's operators will interface with ZEBs on a daily basis. Given that ZEB training is currently performed at the garage level, the impact to the Instruction Center due to the ZEB transition is expected to be very small. In contrast, the impact at the garage level is expected to be much more pronounced, as nearly every operator that comes into a garage operating ZEBs will need to receive ZEB training. However, given that on-route overhead charging is not recommended as a short-term charging strategy and that garage charging is not the responsibility of the bus drivers, this training will primarily be focused on ZEB safety and the select number of different gauges unique to ZEBs, as there are no additional skills specifically required to operate and drive a ZEB. Examples of such differences that ZEB training will cover include a basic overview of ZEB SOC and how fast batteries deplete. Metro Transit has retained its on-route overhead charging SOP, instructional videos, and other training materials in the event that the agency pivots back to on-route charging in the future.

9.5.3 Future Training Strategies for Exploration and Implementation

Although the ZEB impacts to Bus Transportation's training and retraining needs are anticipated to be more minor than for other departments, several strategies were identified to address these needs and avoid displacement of the existing workforce.

In the short term, while ZEBs represent a minor portion of the total bus fleet, ZEB training for operators will continue to be focused on the garage level. However, to ensure that ZEBs are scheduled and deployed only on pieces of work that they have sufficient battery capacity to complete, basic ZEB training will be expanded to dispatchers in tandem with Service Development staff.

In the longer term, once ZEBs become sufficiently integrated into the fleet and comprise a significant share of all Metro Transit buses, ZEBs will be used for CDL training and exams, and Bus Transportation will restructure the department's curriculum such that all new hires will be given basic ZEB training so that all operators have a basic level of comfort operating ZEBs. Additionally, to ensure that the TCC can answer operators' ZEB questions such as determining if they have sufficient battery charge to complete their run, it is anticipated that TCC staff will also receive this basic ZEB training. As Metro Transit adds more ZEBs to its bus fleet, ZEB training will be integrated with additional training programs.

In both the short and long term, Bus Transportation trainers also plan to seek additional opportunities to directly meet with ZEB OEMs to identify differences in the new buses and glean the most important "need-to-know" information that they can, in turn, convey to bus operators to ensure that the operators have the information and training necessary to be successful.

9.6 Service Development

Metro Transit's Service Development team consists of five teams and nearly 30 employees helping to achieve the mission to plan and schedule an efficient, effective, and equitable transit system that meets the needs of customers and community. With responsibilities including route planning, transitway planning, speed and reliability efforts including bus lanes and stop spacing, rail and bus scheduling, crew and vehicle scheduling, and analyzing services of run time plus span of service, the Service Development team must be considered in the widespread integration of ZEBs.

9.6.1 New Software Program

Following the publication of the 2022 ZEBTP, it became apparent to Metro Transit that in order to incorporate ZEBs into their local bus fleet, the Service Development team would need tools designed to account for the unique operating characteristics of BEBs. Considering this, Metro Transit is currently procuring the HASTUS software update. Currently utilizing HASTUS 2014, this latest update will bring improved functionality to the Service Development team. HASTUS offers solutions specifically for electric bus scheduling and operations.[256] The software purchase will include on-site training provided by external trainers. Training for the Service Development team is anticipated for 2025, with the goal of implementing the updated software into Metro Transit operations in 2026.

Service Development plans to leverage the upgraded HASTUS tool to better understand the fleet and operator needs with ZEB transition. It is anticipated this tool will help to provide more data to forecast impacts and costs.

9.6.2 Conferences and Peer Learning

Metro Transit leverages its workforce training budget for both frontline and administrative staff to engage in peer forums and attend conferences. For example, Metro Transit staff attended the HASTUS International User Group 2024 Conference in Montreal, Canada in September 2024 to learn from the

[256] GIRO Inc., 2024, Electric Buses, https://www.giro.ca/en-us/our-solutions/segments/electric-buses/.

experiences of other transit agencies worldwide. This ongoing training and support assists Service Development staff in learning about new tools and peer agencies experiences with schedule for ZEBs.

Members of Metro Transit ZEBTP leadership team are also members of the APTA Zero-Emission Fleet Committee where information sharing by other North American transit properties occurs. Several staff with key leadership positions attended APTA Transform Conference in Anaheim, California, in fall 2024, learning about ZEB projects as well as participating in a site visit to Orange County Transportation Authority's Garden Grove bus facility actively using BEB technology.

9.7 Summary

Based on a review of existing and planned workforce development programs and initiatives across the Met Council and Metro Transit, several key impacts and training needs associated with the transition towards ZEBs and potential training/retraining strategies for future consideration and implementation were identified and are summarized in **Table 39**. Going forward, Metro Transit will continue to engage staff and frontline workers from the wide variety of departments that interface with ZEBs to develop and deliver the most effective and beneficial training programs necessary to support expanded ZEB operation. Although the transition towards ZEBs will require significant training as staff learn the intricacies of this new technology, Metro Transit is committed to retaining the agency's existing workforce. The agency has and will continue to utilize their FY2023 Low-No Grant award monies to advance the joint registered Technician Apprentice Program, purchase maintenance tools, develop SOPs, and allow frontline and administrative staff to attend learning opportunities, such as conferences and peer exchanges. Through the expansion of existing workforce development programs and the exploration and implementation of the strategies contained in **Table 39**, as well as those yet to be identified, Metro Transit is confident in its ability to successfully provide its existing workforce with the training necessary to utilize ZEBs to their fullest extent.

Table 39: ZEB training/retraining needs with associated strategies for exploration and Implementation

ZEB Impact/Training Need	Training/Retraining Strategy
Expand basic ZEB training across the existing workforce agency-wide to increase awareness and address the concern of the paradigm shift	Transition towards a more wholistic approach to ZEB training and operation emphasizing ZEBs as a system rather than individual components. Develop ongoing training and informational items focused on the salient aspects of ZEBs applicable to a wide variety of departments. Examples include information training videos played at each garage or email/mailbox bulletins highlighting the core aspects and safety considerations for ZEBs.

ZEB Impact/Training Need	Training/Retraining Strategy
Formalize and increase the scope and opportunities for ZEB safety, operations, and maintenance training	Expand ZEB-focused training modules in existing training pathways/programs. Continue registered joint apprentice program for bus maintenance technicians, including curriculum dedicated to safety basics and ZEB maintenance. Require OEMs to provide hands-on side-by-side training for preventative maintenance in addition to troubleshooting training for both chargers and buses Implement and expand high voltage training for Bus Maintenance and E&F staff. Monitor and utilize vendor course offerings in addition to apprentice program to best prepare and develop the existing workforce to support expanded ZEB operation. Build out a library of over 40 ZEB-specific SOPs.
Increase interdepartmental knowledge exchange and training opportunities	Strategically evaluate roles and responsibilities between departments related to ZEBs.

10 Barriers, Constraints, and Risks

In this section, potential obstacles to Metro Transit's implementation of ZEBs are discussed.

The advantages of ZEBs are well known, notably decreased carbon and GHG emissions, reduced reliance on fossil fuel consumption, better human health, and a more pleasant experience for riders. Similarly, many challenges to ZEB implementation have also been widely documented among transit agencies—higher capital costs for vehicles and supporting infrastructure, increased energy costs per mile, vehicle range limitations, the need to coordinate with utilities on electrical upgrades and special rates for electricity, and potential changes to service and operations.

While good planning and foresight can help to lessen the impacts of these challenges, some potential barriers to ZEB implementation are a result of factors outside of Metro Transit's control—operator shortages, battery reliability, BEB and infrastructure production and supply chain constraints, and the rapid pace of ZEB and infrastructure innovation that can threaten a long-term deployment strategy.

10.1 Operator Shortages

Metro Transit has taken efforts to expand and retain its existing workforce, including providing paid training and flexible job requirements

Metro Transit, like many transit agencies, struggled with a bus operator shortage for many years. To address this constraint, Metro Transit has taken efforts to expand and retain its existing workforce, including providing paid training, bonuses, increased pay, and flexible job requirements, all meant to enhance the quality of life of employees across Metro Transit.[257] Metro Transit has added more than 200 net-new operators to its workforce in 2024, and Metro Transit is committed to attracting and retaining a strong workforce. However, as described in previous chapters, the range limitations of BEBs require more, shorter vehicle tasks, which in turn requires more vehicles and more operators. Moving forward, the lack of operators may have negative impacts on Metro Transit's ability to transition to ZEBs.

10.2 Battery Reliability

Battery reliability is inconsistent and can reduce operational capacity for extended periods of time.

Battery reliability has been one of the substantial challenges faced by Metro Transit throughout the C Line's operation. Because Metro Transit was an early adopter, real-world battery life data was not readily available during the pilot's planning phase. The agency began with the assumption that batteries would require mid-life overhaul, but this has not been Metro Transit's experience. Instead, batteries have required replacement on a pack-by-pack basis. Early in the pilot, individual batteries needed to be replaced only occasionally, but this has become more prevalent over time. Because battery failure occurs sporadically, it is challenging to proactively address, and it serves as the primary cause for bus unavailability. Supply chain challenges exacerbate disruption, extending the timeline to obtain replacement batteries. While Metro Transit's extended warranties have shielded the agency from additional financial burden

[257]Source: *Network Now Draft Concept Plan*, page 10, Metro Transit, September 2024.

associated with battery replacement, BEB unavailability means that Metro Transit cannot operate at full capacity.

10.3 Battery Electric Bus Production and Supply Chain Constraints

In addition to an increasing shortage of operators being a major risk for Metro Transit's operations, another potential stumbling block associated with transitioning to BEBs is the limited ability of BEB manufacturers to scale up with the increased demand.

The IIJA increased the annual Low-No Program from $55k to $1.1B

The passage of the IIJA in November 2021 increased the annual authorization for the Low-No Program from $55k to $1.1B.[258] As a result, there has been an increased demand for BEBs.

When this ZEBTP was published in 2022, there were four BEB manufacturers approved to sell BEBs to U.S. transit agencies: New Flyer, Proterra, Gillig, and Novabus/Volvo.[259] Novabus has since decided to leave the U.S. market,[260] and Proterra has filed for bankruptcy. Proterra is restructuring under Phoenix, but in the meantime, it has limited production.[261] This leaves only two BEB manufactures whose buses can be purchased with federal funds, which are the primary source of Metro Transit's capital funds.[262] Although other manufacturers exist in the BEB market, each of these manufactures would need to have their buses pass Altoona Testing, be cleared by the FTA as compliant with Buy America requirements, and meet other federal requirements before FTA funds can be used to purchase the vehicles. Obtaining these approvals can be a multi-year process, which is likely a large barrier for additional manufacturers entering the U.S. transit market. Positively, Metro Transit has a long-standing relationship with New Flyer and Gillig, with their vehicles representing nearly the entirety of Metro Transit's fleet.

Increased federal funding for ZEBs has also placed financial burdens on bus manufactures, as illustrated by Proterra filing Chapter 11 bankruptcy as they attempt to increase production to meet the increased demand. Bus manufacturers are transitioning their assembly facilities to produce more ZEBs, which is forcing them to make substantial capital investments. Bus procurements have traditionally involved contracts where no payment, or relatively small payments, pass from transit agency to manufacturer until the delivery of vehicles and passed inspections. This practice places substantial financial risk on the bus manufacturers and requires large financing to purchase the necessary materials and transition their facilities to increased production of ZEBs. This has become a serious enough concern that in February 2024, the FTA issued a *Dear Colleague Letter* where they encouraged transit agencies to modify contracts so that agencies pay for vehicles in progress payments, thus sharing some of the financial risk and cost with the bus manufactures. The FTA also encouraged standardization, with larger orders across agencies via state contracts, and performance-based specifications to allow for economies of scale and therefore, cost savings and faster production times.[263]

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[258] Source: *Bipartisan Infrastructure Law Fact Sheet: Grants for Buses and Bus Facilities*, FTA, January 2022.
[259] Note: In December 2021, a ban on federal funds to the Chinese went to affect, which precluded agencies from using federal funds to procure electric buses from BYD, a company headquartered in China (*Source*).
[260] Source: *Nova Bus to leave New York, close Plattsburgh facility*, NBC5, June 22, 2023.
[261] Source: *The remaining parts of Proterra Inc find a buyer in Phoenix Motorcars*, electrive.com, January 2024.
[262] Source: National Transit Database, *2023 Annual Agency Profile – Metro Transit*, October 2024.
[263] Source: *FTA BUS MANUFACTURING DEAR COLLEAGUE 2024*, Nuria I. Fernandez, February 7, 2024.

Though this is new guidance from the FTA, Metro Transit's latest two orders for 40- and 60-foot BEBs are structured in the traditional style, where payment is not required until after bus delivery.

Makers of BEB chargers such as ABB, ChargePoint, Heliox, and Siemens are working with vehicle manufacturers on charger compatibility and to have their products accompany BEB deployments. As some charger manufacturers supply chargers not only for BEBs but also for electric cars, firetrucks, and other vehicles, charger manufacturers may be even more constrained than BEB manufacturers as charger manufacturers work to meet demand for all these different vehicles. Thus, manufacturing capacities for both BEB and charger manufacturers are likely to constrain BEB deployment in the U.S. for the next several years.

Metro Transit's latest BEB order contracts are traditional payment terms, with payment due at time of delivery and passed inspections

With the increase in available federal funds and agencies being compelled to go green, transportation economists are predicting that the electric bus market will grow by 31 percent between 2021 and 2026.[264] This trend may pose difficulties for hundreds of U.S. transit agencies, including Metro Transit, as they all line up to acquire BEBs and charging infrastructure.

In addition to the buses and chargers themselves, spare parts and replacement batteries may be just as difficult to acquire in the coming years. Although BEBs share many parts with those of conventional buses, the drive trains, energy storage systems, related auxiliary systems, and monitoring systems are unique to BEBs. As more agencies procure BEBs, and as those vehicles begin to require both scheduled and emergency maintenance, an adequate supply of spare parts will be a critical aspect in Metro Transit's ability to provide uninterrupted BEB service.

10.4 Speed of Innovation

Traditionally, Metro Transit has issued large multi-year procurements for its buses. However, ZEB manufacturers are offering new models of vehicles and supporting infrastructure (e.g., chargers, hydrogen fueling stations) almost annually, which means that multi-year procurements could translate to technologies being obsolete the moment they arrive at the garage. Conversely, shorter and smaller procurements could result in Metro Transit paying a premium for each bus as well as the supporting infrastructure, as manufacturers are generally more price competitive for larger orders. Many of Metro Transit's internal costs associated with a procurement are generally the same regardless of the size of the procurement. However, doing procurements more often would increase Metro Transit's staff time spent to complete the work.

Metro Transit ordered 20 40-foot BEBs in 2024 and has funding programmed to order more in 2025 and 2026. After that, Metro Transit will pause ordering buses to evaluate and learn from its experience. Metro Transit has program funds to continue BEB purchase in 2029.

[264] *U.S. Electric Bus Market Research Report: Industry Revenue Estimation and Demand Forecast to 2026*, Prescient and Strategic Intelligence, November 2021.

One of the factors that has allowed for the rapid proliferation of BEBs is the advancement in lithium-ion battery technology. For example, whereas the standard BEB battery had a nominal capacity of around 200 kWh only a few years ago, batteries are now available with over 600 kWh of capacity.

Metro Transit is evaluating multiple ZEB and supporting infrastructure manufacturers in smaller orders before proceeding to larger orders

To mitigate the impacts of this rapidly advancing technology becoming obsolete in the vehicles and charging equipment that Metro Transit is currently pursuing, Metro Transit has started diversifying its efforts with smaller ZEB and supporting infrastructure procurements before gradually increasing procurement size in the future. Metro Transit is evaluating multiple manufacturers in these smaller orders before proceeding to larger orders. Metro Transit ordered 20 40-foot BEBs in 2024 and has funding programmed to order more in 2025 and 2026. After that, Metro Transit will pause ordering buses to evaluate and learn from its experience. Metro Transit has program funds to continue BEB purchase in 2029. Metro Transit intends to continue allowing approximately 2 years between procurements of ZEBs and supporting infrastructure to evaluate the performance of the equipment and understand how the industry is changing. This will allow Metro Transit the necessary time to make modifications to its procurement documents between procurements.

Another risk for Metro Transit to consider is the burden of training O&M staff on these rapidly evolving ZEB technologies. Unlike conventional buses, whose fueling and maintenance procedures have more or less remained consistent for decades, the pace with which the ZEB industry is developing can pose issues in the training of operations staff, as these training programs will have to be continuously updated and reworked to keep pace with ZEB technology advancements.

10.5 Fire Hazards

While extremely rare, BEBs are known to catch fire. When they do, the result can be catastrophic because the batteries in BEBs generate their own oxygen, making it extremely difficult to suppress the fire. As result, the effect of BEB fires can completely destroy the bus and other items in the vicinity (**Figure 65**).

As mentioned in Section 6.1.3, in response to FTA's *Guidebook for Deploying Battery Electric Buses,*[265] Metro Transit is currently parking BEBs further away from other buses and bypass lanes were added adjacent to the lanes where BEBs are parked to reduce the chance of a fire in one bus causing damage to the entire fleet or facility. This practice means that each BEB takes up substantially more space in the garage than diesel counterparts, in addition to the concern of possible runaway fire should a BEB battery ignite. As the number BEBs in the fleet increases, Metro Transit will be limited in space to park buses. Metro Transit needs to identify steps that will allow buses to be parked closer together or identify additional facilities to house its bus fleet.

[265] Source: *Guidebook for Deploying Battery Electric Buses*, FTA, August 2023.

Figure 65: Bus after a 2022 BEB fire in Hamden, Connecticut[266]

10.6 Fleet Transition and Service

10.6.1 Fleet Mix and Adoption Rate

As Metro Transit develops a plan to understand the impacts of transitioning to ZEBs, questions arise regarding the direct impact to operations and service planning. As discussed in Section 4, there are currently multiple types of ZEBs, including BEB and FCEB. Metro Transit needs to evaluate the appropriate combination of different propulsion vehicles for its fleet. Developing a pace of the transition to 100 percent ZEB fleet will occur over many years to decades. Metro Transit also needs to identify its fleet composition as it transitions to ZEBs. It will be important that this transition is done in a methodical manner, taking time to learn with each step along the way. There are pros and cons of transitioning too fast *and* too slow. This transition is more complicated and will take more planning resources to navigate than if Metro Transit operated a fully diesel fleet.

Metro Transit's direct BEB experience has shown that high-voltage battery reliability degrades as the buses age, but this is limited to their experience with one particular vehicle size and make. Metro Transit anticipates learning more about BEB performance when the five new 60-foot BEBs are expected to go into service by mid-2025 and 20 new 40-foot BEBs are expected to go into service in 2026. Early performance of these vehicles will likely be favorable before the next ZEBTP update due in February 2028 and could prematurely inform the update with inflated performance results. Uncertainty of how BEB performance will continue in later years remains, as well as uncertainly around the actual usable range between charges, realized recharge time, reliability of smart charging, and the ability to charge to meet service demands (including the need for midday charging). From experience, Metro Transit has seen that battery performance degrades with age, but BEB technology is quickly changing. Metro Transit's experience with their ordered BEBs may differ in terms of age-related degradation than what it has seen in the past. Motortrend recently published a study that concluded "...the average EV battery studied degraded by just 1.8 percent per year, which is an improvement from 5 years ago when the average degradation was 2.3 percent per year. The best-performing EVs in the new study degraded at just 1.0 percent per year."[267]

The average EV battery studied degraded by just 1.8 percent per year, which is an improvement from 5 years ago when the average degradation was 2.3 percent per year. The best-performing EVs in the new study degraded at just 1.0 percent per year.

Metro Transit does not yet have direct experience with FCEBs. Temporary hydrogen fueling stations currently exist and may be possible for a pilot of FCEBs, but many questions exist surrounding when BEBs will no longer be the best option and when/if Metro Transit should launch a pilot FCEB program.

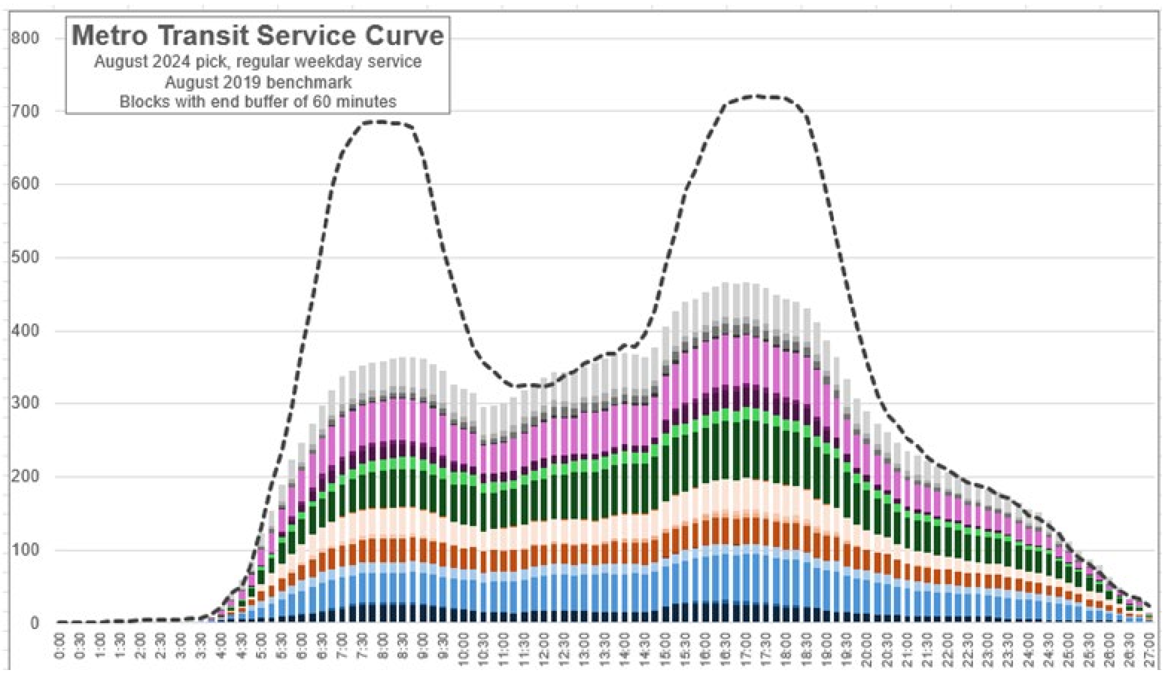
[267] Source: Stop Worrying About EV Battery Failure, Motortrend, September 19, 2024.

10.6.2 Service Delivery with Zero Emission Buses

The reduction of peak only service levels resulting in fewer short blocks/ vehicle task that naturally fall within current BEB range, there are limited opportunities for BEBs to replace diesel buses at a 1 to 1 ratio.

In the past few years Metro Transit has made substantial changes to how it meets the evolving transit demand in the Twin Cities region. As documented in Metro Transit's recently published Network Now and the ABRT Plan updates, both described in Section 2.7, these plans focus on expanding and improving bus service.[268] Network Now expands transit service by more than 35 percent, improving frequency on 60+ routes. ABRT service operates long spans of frequent service that exceed the range limitations of current BEB technology. Metro Transit is seeing a more level, less peaked, demand for vehicles (**Figure 66**). As Metro Transit is expanding and improving its service it anticipates this trend will continue. With the reduction of peak only service levels resulting in fewer short blocks/vehicle task that naturally fall within current BEB range, there are limited opportunities for BEBs to replace diesel buses at a 1 to 1 ratio. Metro Transit is confident that it can get a better understanding of the potential 1 for 1 replacements of diesel buses and what is achievable when it has both the HASTAS scheduling software update operational and experience operating 40-foot BEBs in Metro Transit's fleet through a Minnesota winter. Metro Transit also hopes to better understand how many more BEBs will be required to operate the same service levels versus the current fleet composition and how that varies by service operation, vehicle type, and block length.

Figure 66: Blocks by time-of-day comparison



[268] Source: Metro Transit, *Network Now*, September 2024.

10.7 Coordination with External Partners

10.7.1 Electrical Grid Capacity

Compared to conventional diesel buses, BEBs require significantly greater electrical power to operate. For example, the electrification of Metro Transit garages would require roughly 64MW of power from the grid, which is more than Metro Transit's light rail system. Currently, the electrical grid has a finite capacity to deliver power. Once this capacity has been reached, costly and time-intensive upgrades to the electrical grid will be necessary to support additional electrical loads. Grid capacity, however, is constrained not only by Metro Transit but also other Xcel Energy customers. As a result, the available electrical capacity on the grid could be utilized by other Xcel Energy customers. For example, entities such as large delivery or commercial fleets adopting electric vehicles (e.g., FedEx, UPS, Amazon, Spee-Dee, municipal fleets) or new customers such as a data center would also require large amounts of electricity and could deplete the existing grid capacity. Therefore, although Metro Transit has collaborated with Xcel Energy to analyze available power connections to its facilities as part of this plan, it is a snapshot in time and subject to change if another customer requests the power before Metro Transit does. For this reason, it will be essential that Metro Transit and Xcel Energy continue to review project plans on an annual basis and stay in close coordination with each other's capital plans.

Electrification of Metro Transit garages would require roughly 64MW of power from the grid, which is more than Metro Transit's light rail system

Should Metro Transit take steps to reduce its reliance on the existing electric grid, they could decrease their peak energy draws, thus reducing impact on the larger grid. Examples of this could include producing some of its own power and/or introducing BESS. However, given Metro Transit's lack of experience with power generation and large-scale BESS, it is unsure of the potential costs, benefits, limitations of these tools, or other requirements.

10.7.2 Fuel/Energy Availability and Timing

Building on the challenges with improving the electric grid discussed above, similar concerns exist around hydrogen production. Currently, there is no source for hydrogen production in Minnesota. However, with funding authorized by IIJA, the U.S. Department of Energy is investing $7 billion in the development of regional hydrogen hubs,[269] including providing up to $925 million for the HH2H, which will provide funding to support projects in multiple locations across Minnesota, North Dakota, and South Dakota.[270] The changing availability of hydrogen production and supply could affect the planned transition to ZEBs.

Up to $925 million invested in the HH2H in Minnesota, North Dakota, and South Dakota

[269] Source: U.S. Department of Energy, Regional Clean Hydrogen Hubs,

[270] Source: U.S. Department of Energy, Biden-Harris Administration Announces $7 Billion For America's First Clean Hydrogen Hubs, Driving Clean Manufacturing and Delivering New Economic Opportunities Nationwide, October 13, 2023.

10.8 Coordination with Internal Partners

10.8.1 Fleet Planning

As Metro Transit transitions from a predominantly diesel fleet to a predominantly ZEB fleet, and eventually to a fully ZEB fleet, Metro Transit has established the target that 20 percent of its 40-foot bus replacements will be BEBs under its current CIP.

Beyond the timeline of Metro Transit's current CIP, careful planning will need to occur so that Metro Transit has the buses necessary to deliver its service plans identified in the Network Now and Updated ABRT Plans, as described in Section 2.7. Metro Transit's expansion of its BRT and ABRT network requires the separation of the Metro Transit fleet into sub-fleets. These sub-fleets would then be subdivided, by bus size (40 to 60 feet), service type (traditional BRT), and propulsion type (diesel, hybrid, BEB) since certain buses can only be used for certain types of work. Operating sub-fleets, including BEBs, out of multiple garages further impacts fleet deployment and necessary spare bus ratios. As a result, Metro Transit needs to carefully plan for both the changes within its fleet composition and the services that it provides (and will provide in the future). As BEBs represent a larger portion of its fleet, the service level vehicle tasks will need be modified to align with the fleet composition. Metro Transit has learned from its experience with the C Line pilot that BEBs cannot deliver the same number of miles (see Section 5.1). As a result, as the number of BEBs in the fleet increases, Metro Transit will need to identify how many more buses it will need to be able deliver the current and planned expansions of its bus service.

Metro Transit has established the target of 20 percent of its 40-foot bus replacements will be BEBs.

10.8.2 Support Facilities

Closely integrated with the changes in the Metro Transit fleet are the facilities to store and maintain its buses. Different vehicles require different equipment to maintain and charge them as well as different needs for storage space. Depending on the results of the Fire Hazard Assessment (FHA), Metro Transit will need to make changes at their facilities to align with those recommendations. As Metro Transit's fleet changes, upgrades to the Metro Transit facilities will be required to ensure the ZEBs can be utilized to their potential. This could include electrical upgrades, charger installation, fire suppression/isolation upgrades, and/or hydrogen storage. When and where these investments are made will need to be evaluated on an ongoing basis. In addition, as Metro Transit's fleet changes, there may be a need for additional support facilities to house and maintain the fleet.

10.9 Evaluation of Alternatives

10.9.1 Costs of Zero-Emission Bus Transition and Operations

A guiding principle of Metro Transit's ZEBTP is fiscal impact. Therefore, it is critical that Metro Transit understand the costs of transiting its fleet to ZEBs. Metro Transit recognizes that the purchase cost[271] of a BEB for Metro Transit is currently more than 2.25 times that of a diesel bus.[272] When you consider that

[271] Purchase cost here is for both the vehicle and charging equipment.
[272] Source: Metro Transit Statement, D. Haas, September 2024.

Metro Transit's fleet currently consists of more than 600 buses, this cost difference could add up significantly. In addition to the price differential, the current range limitations of BEBs are anticipated to have a substantial financial impact and require Metro Transit to significantly increase its fleet size and operator headcount to deliver the same level of service.

The purchase cost of a BEB for Metro Transit is currently more than 2.25 times that of a diesel bus. When you consider that Metro Transit's fleet currently consists of more than 600 buses, this cost difference could add up significantly.

Metro Transit is also evaluating how to increase the daily assignments by the BEB fleet as a fiscally responsible measure. A 40-foot diesel bus typically operates more than two daily assignments. Metro Transit needs to gain experience with midday charging of BEBs to achieve more than one daily assignment that fits Metro Transit's service profile.

In addition to the costs associated with transiting to ZEBs, there is also a need to understand the changes in the operating costs of ZEBs. Metro Transit has taken advantage of the C Line pilot to track and compare the energy cost per mile of BEBs and diesel buses.[273] However, a substantial amount of the maintenance required for the C Line BEBs and charging equipment has been done under warranty while buses are still early in their life cycle, so Metro Transit does not have a complete understanding of the full costs to maintain BEBs, especially as a fleet ages. Also, only a limited number of ZEBs in the U.S. have reached the end of their useful life, meaning it is unclear what to expect regarding the maintenance costs of ZEBs and how that will change over the life of a bus.[274] As Metro Transit moves forward with ZEBs, it will be important that it has a strong understanding of the fiscal impacts over the full lifetime of a ZEB.

Current range limitations of BEBs are anticipated to have a substantial financial impact and require Metro Transit to significantly increase its fleet size and operator headcount to deliver the same level of service

10.9.2 Changes by Different Departments

As Metro Transit transitions to a ZEB fleet, it will affect how work is done within Metro Transit. Some departments will only see minor changes to their responsibilities, while other will experience substantial changes to their daily routine. As tasks associated with ZEBs are introduced and take a larger portion of the work performed by various Metro Transit staff, additional staffing may be required in some roles and less staffing in others. It is important that Metro Transit proactively manage this change so that it has the correct staffing numbers and so it is investing in training and developing the workforce it will need in the future (see Section 10).

[273] Source: Metro Transit, *Zero-Emission Bus Annual Report 2023,* July 2024.
[274] Although some ZEBs have reached the end of their useful lives with U.S. transit agencies, there is limited experience across the country. Changes to ZEB technologies over the past decade indicate that the experience of the first ZEBs in use in the U.S. market are likely not representative of the cost to maintain the buses that are currently on the market. Gillig, one of two BEB bus manufactures, only introduced BEBs in 2016 and as recently as 2021 had only produced 100 BEBs. Source: Gillig, *Gillig reaches 100th BE buses produced*, October 2021.

10.9.3 Greenhouse Gas Emissions

As discussed in Section 2.1, light-duty truck and passenger vehicles make up the majority of the transportation-related GHG emissions in Minnesota,[275] while Metro Transit's heavy-duty buses generate only 0.04 percent of Minnesota's GHG emissions. As a result, while Metro Transit strives to lower its own GHG emissions, it is important that it does not allow its quality of service to suffer in the process, as losing riders to the personal vehicles (e.g., light-duty truck, passenger vehicles) could mean an overall increase in GHG emissions.

ZEBs produce less GHGs emissions than diesel buses. With just the eight BEBs introduced on the C Line, Metro Transit has achieved a cumulative reduction of approximately 430 metric tons of CO_2e from June 2019 through 2023.[276] Metro Transit strives to explore what additional steps could be taken to reduce GHG emissions and at what cost. Metro Transit could explore sourcing its electricity from clean energy exclusively where available. Metro Transit requires insight and guidance on fleet alternatives and the GHG emission implications from well to wheel for FCEB, hybrid, and diesel buses to inform future fleet planning decisions.

10.9.4 Mutual Aid Commitments

Metro Transit has mutual aid commitments during which another governmental entity within Minnesota can require Metro Transit's assistance in an emergency. For example, Metro Transit buses are used a portable shelter for fires, providing safe climate-controlled environments for first responders and/or victims of a fire to shelter in as the fire is being extinguished. Other past uses have included distribution of COVID-19 vaccines to various locations throughout the State of Minnesota. Diesel buses have long ranges and the ability to easily refuel throughout the state, which made them ideal candidates to assist during the pandemic.

Due the limited battery range of BEBs as well as limited locations to recharge, it is unclear how future needs would be addressed with a full conversion to ZEBs. Metro Transit will need to understand the various commitments it has under mutual aid agreements to determine how best to continue to meet its critical commitments to assist during emergencies.

10.9.5 Infrastructure Maintenance

As Metro Transit's portfolio of charging infrastructure grows, there may be a point where it is most beneficial or cost-effective to adjust their approach to infrastructure maintenance. Strategies considered may include Service Level Agreements with equipment manufacturers, third-party contracted maintenance, and in-house maintenance. Maintenance performed by Metro Transit would consider facilities electricians, traction power maintainers, or possibly a new team of maintainers. Metro Transit needs visibility into when and how to determine when one strategy should be pursued over another.

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[275] Source: MPCA Data Services Greenhouse Gas Emissions Data, MPCA, 2020, *MPCA Data Services Greenhouse Gas Emissions Data*.
[276] Metro Transit, *Zero-Emissions Bus Annual Report 2023*, July 2024.

11 Program of Projects and Opinion of Probable Costs

Metro Transit will continually identify learning objectives for each package of projects up front while pairing the packages with the development of other areas of the business

To continue the goal of transitioning to ZEBs, Metro Transit developed several packages of projects. These packages were created based on Metro Transit's fleet, service, and infrastructure priorities and industry best practices. Each of the packages is a steppingstone towards transitioning Metro Transit's fleet to ZEBs. For each package of projects, Metro Transit will identify learning objectives up front while pairing the projects with the development of other areas of the business, including software tools and workforce development. The steppingstone approach also allows Metro Transit to gain experience with different ZEBs and infrastructure manufacturers at a moderate scale while gaining experience with different aspects of its service to inform future decision-making and proceed with greater confidence on larger-scale procurements in the future. The following sections summarize the draft packages of projects. Final project packages will be informed by performance measures and continued reassessment of the state of the industry to support larger-scale deployments.

11.1 Package A: C Line Bus Rapid Transit 60-Foot Pilot

Package A began revenue service in June 2019, which consisted of piloting BEBs on the C Line BRT service. The project included procuring eight 60-foot buses, eight plug-in chargers at Heywood, and two overhead conductive chargers at Brooklyn Center Transit Center and was done on an expedited schedule. Significant failures in first-generation charging equipment resulted in an agreement with the vendor to replace all charging equipment under warranty. This program has provided Metro Transit with valuable insight into how BEBs perform on BRT routes. Piloting the BEBs on the C Line BRT has allowed Metro Transit to do a head-to-head comparison of diesel vehicles versus BEBs, as both vehicle types were purchased new to operate this service. Additionally, because this pilot program includes both plug-in and overhead conductive chargers, Metro Transit has learned firsthand how a range extension (garage and on-route) charging strategy may function within Metro Transit's system. **Table 40** summarizes Package A. As a result of this pilot, Metro Transit has chosen not to pursue on-route charging in the short term. Metro Transit experienced a higher than anticipated number of high voltage batteries needing to be replaced under warranty.

Table 40: Package A summary table

Package	Description	Learning Objectives
A *C Line BRT 60-foot pilot (began service in June 2019)*	(8) 60-foot buses (8) plug-in chargers at Heywood Garage (2) high-capacity overhead conductive chargers at Brooklyn Center Transit Center Plug-in chargers replaced under warranty High-capacity overhead conductive chargers replaced under warranty Workforce Development	**Pilot electric buses** • Range extension charging strategy (garage and on-route) • Pilot BRT BEB • Head-to-head comparison of diesel buses and BEBs • Impacts of co-mingled fleet propulsion types • Assess technology performance and reliability

11.2 Package B: Bus Rapid Transit-Dedicated Guideway Pilot

Package B was initially set for moderate BRT BEB expansion on the Gold Line routes. Currently, Package B is to complete a BRT-dedicated guideway BEB pilot exclusively on the Gold Line route. The Gold Line package is anticipated to begin revenue service in 2025, with several key components supporting Metro Transit's transition to ZEBs. As of June 2024, five 60-foot 690-kWh BEBs, four bus storage plug-in chargers, one mobile maintenance charger, and smart charging software have been procured.[277] Infrastructure construction for this package began in June 2024.[278] **Table 41** provides a summary of Package B.

Table 41: Package B summary table

Package	Description	Learning Objectives
B *BRT-Dedicated Guideway Pilot (anticipated to start service 2025)*	(5) BRT buses (4) plug-in chargers at East Metro Garage (1) mobile maintenance charger Charge Management Software Workforce Development	• Assess the benefits of multiple garages with charging infrastructure • Pilot BRT-dedicated guideway BEB use • Expand to East Metro Garage • Pilot software tools to enable scaling up (demand, schedule, monitor, telematics) • Assess the performance of the latest technology improvements in the 60-foot BEB platform • Impacts of co-mingled fleet propulsion types

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[277] Source: *2023-121 SW: METRO Gold Line Bus Rapid Transit – Electric Bus and Charger Purchase*, Metropolitan Council Transit, June 2023.
[278] Source: *Zero Emissions Bus Transition Plans 2023 Annual Report*, Metropolitan Council, June 2024.

11.3 Package C: 40-Foot Local Service Pilot and Distributed Energy Resources Pilot

Metro Transit has already begun the implementation of Package C, which involves piloting 40-foot, extended-range BEBs on local transit routes. This package includes trialing multiple charger products and vendors to determine their viability on Metro Transit operations. This pilot project includes procuring twenty 40-foot buses, 18 plug-in chargers, and charge management software at North Loop Garage. The plug-in chargers will come from three manufacturers, each deploying six units. Three mobile chargers for maintenance use are also included for use at North Loop Garage, Heywood Garage, and OHB, respectively. In addition to buses and chargers, Package C also includes the installation of an approximately 2MW solar array on the roof of North Loop Garage and an approximately 2MWh/800kW BESS at North Loop Garage. Package C will give Metro Transit the opportunity to test multiple charger products and expand workforce training activities. It will also provide information on how a garage-only charging strategy could work within Metro Transit's system. This package will offer Metro Transit experience in distributed energy resources for power generation and storage. Additionally, Package C includes charge management software, which will allow Metro Transit to gain experience in optimizing when charging occurs to manage operating costs better. In May 2024, Metro Transit contracted with Gillig to purchase the twenty 40-foot BEBs—8 with a FY21 Low-No Grant and 12 with a FY23 Low-No Grant.[279] The plug-in chargers from ABB, Heliox, and Chargepoint are also on order.[280] **Table 42** summarizes Package C.

Table 42: Package C summary table

Package	Description	Learning Objectives
C *40-foot local service pilot and distributed energy resources (service anticipated to begin in 2026)*	(20) 40-foot buses (18) plug-in chargers at North Loop Garage (3) mobile maintenance chargers at North Loop Garage, Heywood Garage, Overhaul Base Up to 2MW solar array at North Loop Garage Up to 2MWh/800kW battery storage system at NLG Charge Management Software Workforce Development	**Pilot long-range local service BEB and distributed energy resources** • Pilot local service BEBs with garage-only charging strategy • Test three charge manufacturers to advance infrastructure workforce development • Study distributed energy resources • Pilot charge management software • EEJ prioritization at the vehicle block level • Assess the technology performance and reliability in the 40-foot BEBs • Assess service and products from a second vehicle OEM

11.4 Package D: Implementation of HASTUS Update

Package D will upgrade Metro Transit's bus and rail scheduling software from HASTUS 2014 to HASTUS 2025. Metro Transit uses the HASTUS software program to create bus and rail schedules and to manage

[279] Source: Metropolitan Council Minutes, April 24, 2024.
[280] Source: 2025-2030 CIP Summary for ZEBTP 2025 Update, Metro Transit, July 2024.

operator work selections, daily operator and vehicle assignments, as well as payroll data. This is the first software upgrade since 2015 and is expected to result in various improvements including more efficient schedules, an improved end-user experience working in the software, and the ability to utilize features and functions specifically for scheduling BEBs.[281] **Table 43** summarizes Package D.

Table 43: Package D summary table

Package	Description	Learning Objectives
D *HASTUS Update*	Upgrade scheduling software	• Building blocks and vehicle task designed for Metro Transit's fleet mix • Optimizing the use of BEB regular bus service

11.5 Package E: 40-Foot Battery Electric Bus Replacement Transition

Package E supports the 20 percent of 40-foot bus replacement strategy by increasing the deployment of 40-foot BEBs by procuring up to 35 40-foot buses and increasing charging capacity up to 4.5MW. As part of Package E, Metro Transit will install chargers at the North Loop and East Metro garages and focus on developing more of its workforce on operating and maintaining BEBs. Package E may include mobile chargers at the North Loop Garage maintenance shop. Experience with Package C should help to inform the rate of transition. **Table 44** summarizes Package E.

Table 44: Package E summary table

Package	Description	Learning Objectives
E *40-foot BEB Replacement Transition*	Up to (35) 40-foot buses Up to 4.5MW charging capacity Portable mobile chargers for North Loop North Loop and East Metro Garage Upgrades Workforce Development	• Assess optimization of BEB deployment with upgraded software suite • Scale up 40-foot BEB use • Scale up North Loop and East Metro Garage • Assess performance of latest 40-foot BEBs and charging infrastructure • Workforce development focus

11.6 Package F: Replacement Heywood Garage Chargers

Useful life of first-generation base charging units is within 6 years. As discussed in Section 5.1, C Line buses operate from the Heywood Garage and rely on eight Siemens chargers that were replaced under warranty in 2021. The Siemens chargers are reaching the end of their useful life (6 years) and are scheduled for replacement in 2027. Package F is essential to the continued utilization of the 8 60-foot C Line buses.

[281] Source: *Transportation Committee Business Item*, Metropolitan Council, May 2024.

11.7 Package G: Fire Hazard Assessment and Mitigation

The FHA focuses on analyzing fire risks within Metro Transit facilities, identifying potential mitigations, and determining their impact on existing infrastructure. This assessment is intended to minimize capacity losses at garages housing BEBs. The FHA will develop design criteria for future infrastructure projects and help incorporate necessary fire risk mitigations. These mitigations will aim to balance safety with operational efficiency by addressing risk tolerance levels and providing actionable solutions for facility design enhancements.

Metro Transit anticipates that, as a result of this FHA, mitigation measures will need to be implemented at its bus facilities that operate BEBs. Scope of these mitigations will be directed by this package. However, in an attempt to implement the recommendations of the Preliminary Hazard Assessment (PHA) Metro Transit previously completed, Metro Transit is budgeting $15M in 2026 to 2028. The recommendations from the FHA and the pace those mitigations can be implemented could affect the rate at which Metro Transit transitions to ZEBs.

11.8 Future Packages

With the implementation of Packages B, C, D, and E, Metro Transit will be growing its fleet of BEBs from 8 buses to as many as 68 buses, a 750 percent increase in BEB over a few years. The buses purchased as part of Packages B and C are anticipated to enter revenue service in 2025 and 2026 while Package D is expected to be implemented in 2026. The buses identified in Package E could enter service in 2027 and 2028.

Metro Transit is planning for up to a 750 percent increase in BEB over the course of a few years

Metro Transit plans to evaluate the ZEB program continually. It intends to take a short break in procuring additional BEBs following Package E to assess and learn from its real-world experience with buses and chargers from multiple manufacturers. It will also evaluate the effectiveness of charge management solutions and scheduling software designed to address the unique operating characteristics of BEBs. In addition, Metro Transit is committed to conducting several evaluations from Section 10 regarding how to implement ZEBs. Learning from these studies, as well as the additional experience in running equipment from multiple BEB and charger manufacturers, should provide Metro Transit with the data necessary to shape its future ZEB procurements. Metro Transit's CIP includes $32 million dollars in 2028 to 2030 to support the next phase of its ZEB transition.

11.9 Summary of Capital and Energy Operating Costs

Metro Transit is committed to implementing a fiscally feasible and responsible plan for the deployment of ZEBs and supporting infrastructure. Fiscal Impact is one of the three guiding principles for the transition to ZEBs, as discussed in Section 3.4. As such, all costs associated with the implementation of ZEBs and supporting infrastructure need to be within the constraints of Metro Transit's capital and operating budgetary constraints. To achieve this, capital cost estimates for the packages outlined in this chapter have been developed as well as monitored the operational energy cost on a per mile basis. These cost estimates will help Metro Transit plan for the expenditures associated with the transition to ZEBs and identify funding sources to cover the costs as well as funding gaps.

Metro Transit is currently exploring numerous funding sources to cover the capital costs associated with the transition to ZEBs. Two of many options include competitive grant applications at the federal level and partnerships with Xcel Energy. The IIJA renewed several existing funding programs for procuring ZEBs and supporting infrastructure at significantly higher funding levels. In response to the passage of IIJA, the State of Minnesota created the IIJA Discretionary Match Program, which is a $205 million fund Minnesota local and state governments can use to match federal discretionary grant authorized by IIJA.[282] Metro Transit is also exploring the potential of a partnership with Xcel Energy, which could further provide funding for the capital costs of transitioning to ZEBs. Additional resources will continue to be explored, including possible funding from the State of Minnesota.

For operational costs, Metro Transit is working to stabilize and reduce energy costs per mile. To accomplish this, operational cost estimates will continue to be studied and optimized to understand the long-term recurring costs that will be associated with the transition to ZEBs. Metro Transit plans to build on its partnership with Xcel Energy. The shared commitment to further study the operating costs will help to a degree, but additional funding and policy support will likely be required for the long-term success of operating BEBs.

The following sections summarize the estimated capital costs for the packages of projects that are described throughout Section 12 as well as a discussion of energy costs per mile and other operational cost considerations.

11.9.1 Estimated Capital Cost for Packages

Understanding the capital costs of the packages for the transition to ZEBs is an important aspect of developing a fiscally feasible plan. However, it can be challenging to estimate accurate capital costs, as they can be volatile. Above average year over year price increases are currently being seen due to manufacturing, supply chain, and shipping constraints. As a result, the capital costs shown in this plan are estimates, and the actual costs to implement the project may be higher than anticipated. **Table 45** shows an overview of the anticipated capital costs for each package.

Table 45: ZEB transition costs by package

Package	Category
A: C Line BRT 60-foot pilot*	$14.7 M
B: BRT-Dedicated Guideway*	$13.5 M
C: 40-Foot Local Service Pilot and Distributed Energy Resources Pilot*	$44.6 M
D: Implementation of HASTUS scheduling software update*	$1.7M
E: 40-Foot BEB Replacement Transition**	$76.6 M
F: Replacement Heywood Garage Chargers***	$4.0 M
G. PHA Electric Bus Fire Protection****	$15.5 M
Future Packages**	$32.0 M
ZEB Program Funding	$202.6 M

* Funding included in previous budgets and CIPs.

** Funding included in 2025 to 2030 CIP M22002 and 64707.

[282] Source: MnDOT, *Infrastructure Investment and Jobs Act Match Program*.

*** Funding included in [2025 to 2030 CIP] M24044.
**** Funding included in [2025 to 2030 CIP] M25017.

11.9.1.1 Sources of Capital Funds

Metro Transit's capital funding comes from a variety of sources. The largest source of capital funding for Metro Transit is from the FTA, which typically funds between 40 to 80 percent of all capital costs associated with transit projects. The IIJA provides formula and discretionary funding that can be used to procure ZEBs and supporting infrastructure. Formula funds are funds that are distributed to the Twin Cities region from the FTA for prioritization locally by the Metropolitan Council. Discretionary funding is supplemental funding, which is distributed at the discretion of the FTA on a project-by-project basis.

The FTA also requires that all projects contain a non-federal match.[283] Metro Transit's non-federal funds come from a variety of sources, including RTC, county sales taxes, Regional Railroad Authority property taxes, and other state and local funds.

The seven metropolitan area counties have a local transportation sales tax. In addition, County RRAs are authorized to levy a property tax. This funding is assumed for capital and operating purposes for those dedicated transitway projects being developed in the individual counties, including the planned Gold Line BRT projects in Package B.

In addition to these historical funds, in 2023, a sales and use tax was passed that provides funding to the Metropolitan Council. As described in Section 2.5.3, a portion of the funds raised by this Minnesota State Statute Regional Sales and Use Tax must be spent on ZEB procurements and associated costs.

11.9.2 Operating Cost Considerations

There are many different types of operating costs to consider when analyzing the fiscal impact of a ZEB fleet. While there are fewer mechanical parts requiring maintenance or repair in a ZEB compared to a diesel bus, there is an increased level of software and electrical components, which require specialized training to work on, as well as the charging systems, which are a new technology to maintain. As a result, it is anticipated that a significant investment in workforce development will be required to ensure maintenance personnel have the specialized training and safety equipment necessary to perform these new job functions. Additionally, workforce development will be essential for operators to learn the differences of the new vehicles being driven. All support roles will also require training on these new technologies, including engineering, scheduling, dispatch, transit control, street operations, safety, and more to ensure reliable, safe operations as more ZEBs are added to the fleet.

In addition to the workforce development considerations, it is anticipated that batteries will need to be replaced as part of the mid-life overhaul of the vehicles to ensure range requirements can continue to be met to meet service needs. Whether through an extended warranty at the initial purchase, or purchasing at the time of use, this represents a significant cost that must be budgeted for.

Only a handful of agencies in the U.S. have operated an electric bus for its full FTA-required 12-year or 500,000-mile (whichever comes first) vehicle life. Due to the technological advances since those initial buses entered revenue service, these agencies' experiences are not representative of buses that are currently on the market. Therefore, a meaningful estimate of life cycle operating cost cannot be

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[283] Note: Non-federal matching requirements were waived for projects funded by individual COVID-19 relief funds.

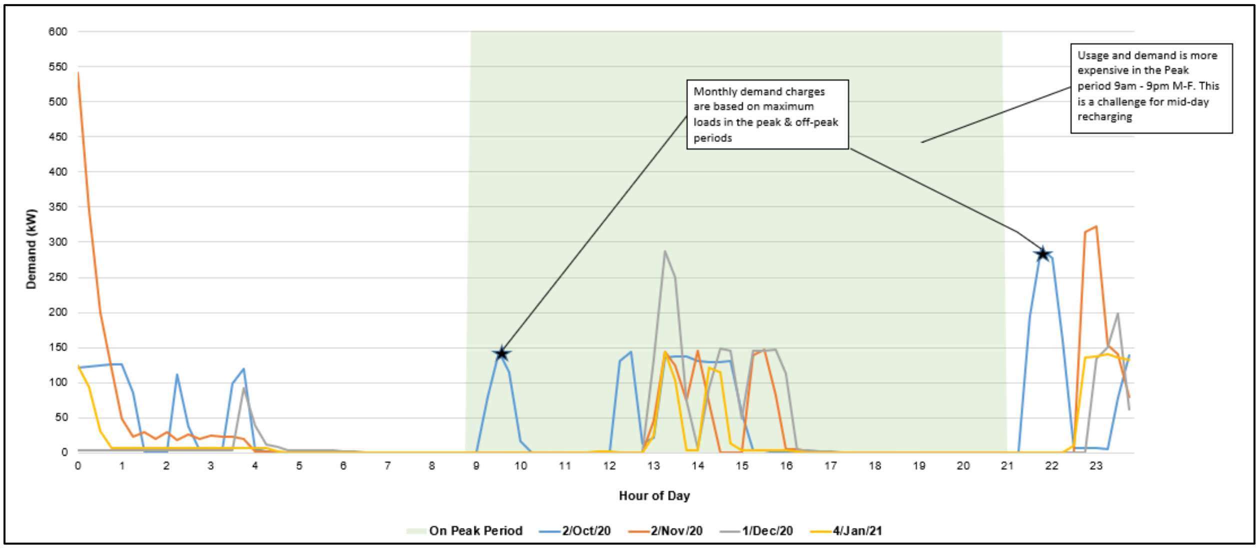
calculated. However, this is something Metro Transit intends to monitor closely as it gains more experience.

11.9.3 Energy Cost Per Mile

As part of Package A (C Line BRT 60-foot pilot), Metro Transit has calculated energy costs per mile for the 60-foot electric and diesel buses operating on the route. In 2023, the average energy cost per mile for the electric buses was $1.21/mile, while the average energy cost per mile for the diesel buses was $0.76/mile.[284] Both the diesel and electric buses have auxiliary diesel heaters to augment their HVAC system. Auxiliary diesel heater use is necessary on BEBs to preserve range in cold weather. The energy cost per mile for both the electric buses and diesel buses include the diesel cost for operating the auxiliary heaters in cold weather months.

Unlike diesel costs, which are measured on a per gallon basis, electricity costs include multiple cost drivers including fixed charges, demand charges based on load peaks, usage charges based on time of day, and taxes and fees. Additionally, applicable charges vary by season. **Figure 67**, below, illustrates an electric bus charging load and how it is billed under Xcel Energy's Electric Vehicle Fleet pilot.

Figure 67*:* C Line BEB charging load by time of day



As **Figure 67** shows, the bus charging load incurs peak demand charges in the peak period (weekdays 9:00 AM to 9:00 PM) and in the off-peak period (only if greater than peak demand). The demand charge is based on 15-minute peaks and the charge is higher in the summer months. The usage charges shown by the areas under the load graph (rate of charge * time = usage) are also differentiated by peak versus off-peak periods.

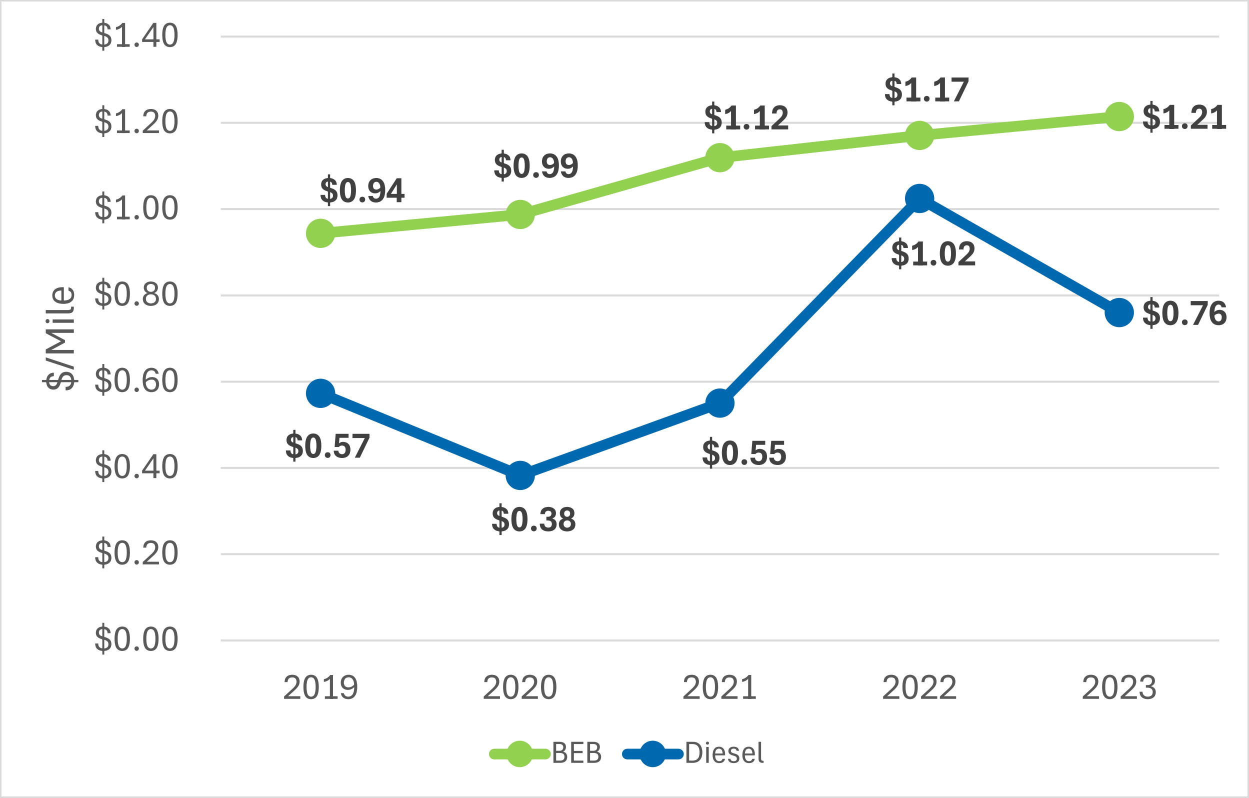
Therefore, the time-of-day buses are charged, how many buses are charged concurrently, and the rate at which they are charged all can have a significant impact on the electricity cost per mile for an electric bus. This is the premise of what Xcel Energy and Metro Transit have committed to study further together and work to optimize within Metro Transit's operational constraints required to provide reliable service.

[284] Source: Metro Transit, *Zero Emission Annual Report 2023*, July 2024.

To assist with this, Metro Transit has purchased a charge management system that it will be piloting as part of Package B discussed above.

Figure 68 shows the comparison of energy costs per mile for BEBs and diesel buses included in Metro Transit's C Line pilot project from 2019 to 2023[285]. Compared to diesel, which can be a volatile commodity, electricity costs per unit volume are more stable in part due to multi-year utility rate structures. Despite this relative stability of electricity per unit volume, BEB energy costs per mile in Metro Transit's experience are more expensive than diesel buses and have continued to increase in recent years.

Figure 68*: Average Annual Energy Cost per Mile by Propulsion Type (2019 to 2023)*



11.9.4 Sources of Operating and Maintenance Costs

Historically, more than 60 percent of Metro Transit's operating funds were provided by the State of Minnesota, primarily through the Minnesota Vehicle Sales Tax and the state general funds (**Table 46**). In 2023, Under state statute,[286] the Metropolitan Council must impose a 0.75 percent regional transportation sales tax on retail sales and uses in the metropolitan area to use for transportation activities. The legislation includes funds for "zero-emission bus procurement and associated costs in conformance with the zero-emission and electric transit vehicle transition plan." These new funds are anticipated to provide approximately 25 percent of Metro Transit's operating revenue in FY2025.

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285 Source: Metro Transit, *Zero Emission Annual Report 2023*, July 2024.
286 Source: *State of Minnesota Statute 297A.9915*, Minnesota Legislature Office of the Revisor of Statutes, 2023.

Table 46: Sources of Metro Transit O&M costs

Funding Source	FY25[287] % of Total Annual Revenue
Motor Vehicle Sales Tax + Other State Revenue	58%
Regional Sales Tax	25%
Federal Revenue	6%
Local Revenue	0.3%
Fares	9%
Other Revenues	2%
Total:	**100%**

11.10 Future Studies

Metro Transit is committed to making informed decisions about how best to move forward with its transition to ZEBs. The transition will be costly and is anticipated to exceed $200 million by 2030, as shown in **Table 46**. Metro Transit believes that, as a steward of public funds, it is crucial the investments it makes provide a long-term benefit to the Twin Cities community. It also understands that underinformed decisions could also affect Metro Transit's ability to meet local transportation and mobility needs. To help inform this process, Metro Transit will conduct a series of studies led by different Metro Transit departments to leverage the expertise and knowledge of the entire organization. These studies will evaluate a common set of scenarios defined in the Propulsion Type Performance and Alternatives Analysis. Combining these studies will help inform Metro Transit's decisions regarding the composition of its future ZEB fleet and the rate of ZEB adoption.

11.11 Scenario Assessments and Analyses

11.11.1 Propulsion Type Performance and Alternatives Analysis (BEB, FCEB, etc.)

One of the key considerations in transitioning to a ZEB fleet is the performance and reliability of the BEB technology and alternative propulsion systems like hydrogen-powered FCEBs. The focus of this planning study will be to evaluate alternatives for the transition to a 100 percent ZEB fleet. These scenarios will consider different multiple vehicle propulsions, potential fleet distributions (e.g., 100% BEB, 75% BEB/25% FCEB, 50% BEB/50% FCEB, 25% BEB/75% FCEB, 100% FCEB), and different rates of ZEB. The study will include scenarios where lower-emission buses, such as diesel-electric hybrid (hybrid) buses, are increasingly deployed to reduce emissions as capital improvements to Metro Transit facilities and electrical infrastructure can be completed.

11.11.2 Service Evaluation

In light of transitioning to ZEBs and its impact on service delivery, Metro Transit will work on conducting a service evaluation that considers its implications for both current and projected future service under the "Network Now" and 2025 ABRT Plan update. The service evaluation will utilize the scenarios identified in

[287] Source: *2025 Unified Budget*, 2025 Unified Budget for Public Comment, October 2024.

the *Propulsion Type Performance and Alternatives Analysis*. This study will identify the benefits and limitations different fleet mixes and adoption rates may have on Metro Transit's planned service enhancements.

"Network Now," which is designed to guide future service improvements, was initially developed before the State Legislature updated the ZEBTP requirements, as discussed in Section 2.7.1. The plan expected greater opportunities for ZEB to replace diesel buses 1:1 than may be available. The complete conversion to the ZEB introduces various operational challenges, such as an increased operator headcount needed to operate the same level of service with diesel buses, higher platform hour costs for routes due to shorter range of BEB vehicles, and decreased vehicle productivity rate. Further ZEB expansion could impact Metro Transit's ability to expand service as the prioritization between adding transit routes and deploying BEBs creates new conflicts. This evaluation will weigh the environmental benefits of ZEBs against the potential opportunity costs of reduced service expansions, balancing customer priorities with carbon reduction goals.

Expected service evaluation topics:

- Lessons learned from the C Line on-route charging pilot should be further assessed and criteria for potential future on-route charging should be identified as part of a service delivery strategy.
- Deployment of ZEBs on BRT guidance on topics such as impacts on range based on vehicle length, mixed propulsion fleet impacts on scheduling, on-route charging feasibility, and on service components of span, operating speed, and length. Also include state of the industry update on expected range for Minnesota operating environment.
- Potential adjustments to EEJ prioritization approach.
- Development of tradeoffs to carbon reduction strategies for our funding and operator resources. Evaluate increased service levels benefit to carbon reduction goals compared to expanded ZEB.

11.12 Scenario and Evaluations with External Partners

11.12.1 Electrical Grid Capacity

Metro Transit will conduct a study on assessing a ZEB fleet's electrical demand against the utility grid's capability to support the transition. The planning study will focus on opportunities to collaborate with electrical providers, primarily Xcel Energy, to address anticipated power needs in power supply and distribution. This study will evaluate the scenarios developed in the *Propulsion Type Performance and Alternatives Analysis* to understand how much power is needed to support a ZEB fleet. As Metro Transit continues collaborating with Xcel Energy to align power supply with projected transit demands, the study will explore strategies to manage potential capacity limitations and increased regional energy needs. The study will evaluate the opportunities, benefits, and constraints of on-site power generation and BESS. By examining these challenges, Metro Transit will aim to support a smooth integration of ZEBs within its zero-emission goals.

11.12.2 Fuel/Energy Availability and Timing

Metro Transit will continue to evaluate the availability and timing of fuel sources for ZEBs, focusing on electrical power through Xcel Energy and the future of hydrogen fuel availability in the Twin Cities. The evaluation is intended to cover the readiness of energy sources, capacity, and delivery methods to provide stable operations for the ZEB fleet. This study will consider the feasibility and opportunities created by the scenarios developed in the *Propulsion Type Performance and Alternatives Analysis*. Establishing a reliable fuel source is critical, and Metro Transit aims to get clarity on resources available to align with future transit goals by examining both electric and hydrogen options. This study will support planning efforts to ensure fuel availability and infrastructure align with Metro Transit's timeline for ZEB transition.

11.13 Scenario and Evaluations with Internal Partners

11.13.1 Fleet Replacement Plan Review

Metro Transit will work on reviewing and refining its Fleet Replacement Plan with internal partners, exploring the potential for shifting from a year-based replacement schedule to one based on mileage. Through this approach, Metro Transit aims to optimize the use of its buses and consider the possibility of adjusting major replacements to better align with ZEB integration into the fleet. This plan includes a target of 20 percent of all 40-foot replacement buses being zero-emission; however, balancing this target with the technology's operational considerations and Metro Transit's facility capacity remains crucial. This study will consider the feasibility and opportunities created by the scenarios developed in the *Propulsion Type Performance and Alternatives Analysis*. As the transition unfolds, Metro Transit will continually assess whether BEB's ability to meet the duty cycles of Metro Transit service may require the procurement of additional buses. This will be especially important as Metro Transit creates sub-fleets dedicated to specific service types (e.g., traditional routes, ABRT, dedicated BRT), limiting the agency's ability to combine trips/blocks for more efficient vehicle tasks.[288]

11.13.2 Facility Master Plan / Support Facility Strategic Plan Update

To support its ZEBTP, Metro Transit intends to update its Facility Master Plan and the Support Facility Strategic Plan (SFSP) in collaboration with internal partners. This study will address timing, costs, and departmental responsibilities, focusing on facility capacity upgrades to meet Metro Transit's planned service enhancements and its fleet transition to ZEB. This study will consider the feasibility and opportunities created by the scenarios developed in the *Propulsion Type Performance and Alternatives Analysis*. The SFSP update, to be led by the agency's E&F team, will build on insights from FHA and service evaluation. This study will continue to identify cost-effective upgrades and identify steps needed to prepare facilities to handle the increased needs associated with the growing ZEB fleet.

11.14 Evaluation of Alternatives

11.14.1 Summary of Capital and Energy Operating Costs

Metro Transit plans to evaluate the life cycle costs of operating a 100 percent ZEB fleet, including capital and operating expenses. This study will examine the expenses of purchasing BEBs and FCEBs along with prices related to chargers, fueling stations, and day-to-day operations. The study will consider the scenarios identified in the *Propulsion Type Performance and Alternatives Analysis*. It will seek to identify appropriate useful life benchmarks of different equipment necessary to support a transition to ZEBs. It

[288] FTA's definitions of both fixed guideway BRT and corridor-based BRT require that "The provider must apply a separate and consistent brand identity to stations and vehicles," FTA, Capital Investment Grants Policy Guidance, January 2023. This requirement prevents interlining of BRT routes with traditional bus routes because the BRT routes cannot use the same vehicles.

will also include an analysis of service provisions where ZEBs cannot replace current buses on a 1:1 basis. This research will provide a clearer picture of midday charging opportunities and how effective various chargers would be in bus maintenance settings.

11.14.2 Impacts by Department

Metro Transit will work with various internal departments to assess the staffing and structural changes needed for a 100 percent ZEB fleet. This study will be based on the scenarios identified in the *Propulsion Type Performance and Alternatives Analysis*. This includes determining the number of employees necessary to operate and maintain a fleet of ZEBs as well as identifying potential changes to existing job functions, roles, and responsibilities that may need to be modified as a ZEB fleet expands. The transition may require adjustments across several departments, and this evaluation will help the agency better understand staffing needs in the future.

11.14.3 Greenhouse Gas Emissions Study

Metro Transit will conduct a study focused on GHG associated with converting 100% of the fleet to ZEB based on the scenarios identified in the *Propulsion Type Performance and Alternatives Analysis.* This study will assess GHG emissions from BEBs and FCEBs and compare them with hybrid and diesel buses to capture the “wells-to-wheels” environmental impact specific to the region. While BEBs and FCEBs are central to the ZEB strategy, Metro Transit has already observed a roughly 20 percent reduction in fuel consumption with hybrid buses, which serves as an immediate alternative. Although hybrids involve higher initial capital and maintenance costs compared to diesel, they are cost effective and can be a near-term solution for routes or facilities where full BEB deployment may not yet be viable.

This study will provide guidance on alternative fleets and other options that will maximize GHG reductions, before fully adopting a ZEB fleet. By examining the life cycle emissions of each technology, Metro Transit aims to determine the most sustainable and practical solutions for reducing emissions.

11.14.4 Mutual Aid Requirements Assessment

Metro Transit will study how transitioning to a 100 percent ZEB fleet could impact its ability to fulfill mutual aid responsibilities during emergencies. Metro Transit mutual aid agreements focus on how communities are served during times of emergency. The assessment will review Metro Transit’s current mutual aid commitments, evaluate how the operational range and duration of ZEBs affect these obligations, and identify ways to mitigate any potential reductions in aid capabilities. This study will explore the steps necessary for Metro Transit to fulfill its responsibilities under each scenario identified in *Propulsion Type Performance and Alternatives Analysis*.

11.14.5 Infrastructure Maintenance Approach

Metro Transit will conduct a study exploring various approaches to maintaining ZEB-related infrastructure, including chargers and other necessary equipment, identified for each scenario in *Propulsion Type Performance and Alternatives Analysis*. This study will examine options such as service agreements with bus manufacturers, contracting third-party maintenance, and expanding in-house capabilities. The goal is to determine the best approach to support a growing number of BEB chargers and fueling dispensers, which may involve adding new maintenance roles or cross-training existing staff, such as electricians. This study will act as a guide for the agency in selecting the most cost-effective and reliable maintenance solutions as the ZEB fleet grows.

11.15 Final Evaluation

Following the multi-disciplined studies identified above, Metro Transit will work towards selecting a preferred path for transitioning to a fully ZEB fleet. At this stage, the agency will integrate all findings from previous studies and ongoing assessments covering factors like fleet replacement, facility upgrades, mutual aid requirements, and infrastructure needs to determine the most effective and sustainable approach. This will inform a new fleet composition target and rate of ZEB adoption.

12 Updates to the Transition Plan

Metro Transit envisions the ZEBTP to be a living document that will be revised and updated periodically as Metro Transit and the transit industry's knowledge of ZEBs continues to grow. At a minimum, Metro Transit will update the ZEBTP every 3 years for submittal to the Minnesota State Legislature. With each update to the ZEBTP, Metro Transit will provide an update regarding the progress Metro Transit has made in working towards and achieving the transition milestones set in the previous version of the plan as well as establishing the transition milestones for the next 5 years.

12.1 Measuring Progress Toward Milestones

It is important to Metro Transit that the agency's progress towards achieving ZEB milestones and improved performance be tracked in a clear, understandable, and transparent manner. This will allow stakeholders, vehicle and charger manufactures, and Metro Transit staff to understand how the transition is progressing and enable them to use this information as they make key decisions regarding the next step in Metro Transit's transition to ZEBs. To assist with the transparency, Metro Transit will develop a standardized report, to be updated on an annual basis, which will track ZEB performance within Metro Transit's fleet in addition to providing public outreach updates and updates to the CIP and operating budgets. The key performance measures that will be tracked, as outlined in Section 9.2, include:

- **Fleet Mileage:** Total number of miles driven by BEBs each year
- **Bus Availability:** Percentage of BEBs available for use in service
- **Bus Reliability:** Mean distance between chargeable road calls
- **Environmental Impact:** GHG emission reductions compared to baseline diesel fleet
- **Equity and Environmental Justice:** Percentage of BEB deployments on "High-Priority" EEJ service blocks
- **Cost/mile:** Energy cost BEBs use per mile driven
- **Infrastructure Availability:** Percentage of chargers available to charge a bus
- **Infrastructure Reliability:** Quantity of incidents that take a charger out of service

In addition, Metro Transit will provide annual updates to the Metropolitan Council regarding the performance measures referenced above as well as the agency's progress toward its overall vehicle procurement milestone:

- **Vehicle Procurement:** Measured in percent of purchases over time horizon
  - **Target:** Between 2025 and 2030, at least 20 percent of Metro Transit's 40-foot bus replacement procurements will be electric.
  - **Projection:** Beyond the current CIP (2025 to 2030), the percentage of Metro Transit bus procurements that are zero emission will be driven by KPIs and available budgetary resources.

As discussed in Section 12, Metro Transit has programmed funding through its CIP to meet its target of at least 20 percent of its 40-foot replacements will be electric. As seen in **Table 47**, so far, looking at what has already been programmed through 2026, Metro Transit is well above this target. However, since Metro Transit is planning to evaluate the performance of the buses purchased in 2024 to 2026 to inform its next ZEB procurement, it is anticipated that by 2030 its cumulative BEB replacement of 40-foot buses may be closer to its target of 20 percent.

Table 47: Metro Transit's budgeted and programmed 40-foot bus replacements 2024 to 2026

Year shown in CIP	2024	2025	2026
40-foot standard and 40-foot hybrid eligible for replacement	78	59	39
20% of replacement target for BEB	16	12	8
Planned BEB in CIP (for revenue service 2 yrs later)	20	18	17
Cumulative 40-foot replacement BEBs in CIP	20	38	55
Anticipated entering Revenue Service	2026	2027	2028
CIP percentage of BEB replacements (cumulative)	26%	28%	31%

12.2 Conclusion

As ZEB technology improves, this ZEBPT will continue to be refined to ensure that the deployment of ZEBs continues to be prioritized in a technically viable, fiscally efficient manner that maximizes the benefit to historically underserved and underinvested communities with poor air quality.