Metro Transit

Zero-Emission Bus Transition Plan

February 2022

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Prepared by Metro Transit in collaboration with AECOM.

1. Executive Summary

Under state statute, the Metropolitan Council is responsible for developing a zero-emission bus (ZEB) and electric transit vehicle transition plan:

> *The council must develop and maintain a zero-emission and electric transit vehicle transition plan. The council must complete the initial plan by February 15, 2022 and revise the plan at least once every five years. (Minn. Stat.473.3927)*

This document, the *Metro Transit Zero-Emission Bus Transition Plan*, is Metro Transit's initial zero-emission and electric transit vehicle plan submission.

The executive summary distills the content of this Transition Plan by answering five basic questions:

1. What are the benefits and challenges of zero-emission transit buses? **Section 1.1 and Section 1.2** discuss the benefits and challenges associated with zero-emission transit bus technology including a summary of zero-emission bus best practices from other transit agencies.

2. What barriers, constraints, and risks are associated with transitioning to zero-emission transit buses? **Section 1.3** describes risks associated with transitioning towards zero-emission transit buses and outlines objectives and strategies to address these issues moving forward.

3. How can Metro Transit transition to zero-emission transit buses? **Section 1.4** addresses implementation policies, guidance, and recommendations to prioritize Metro Transit's deployment of zero-emission transit buses.

4. How much will the implementation of zero-emission transit buses cost? **Section 1.5** outlines a program of projects to implement zero-emission transit buses as well as implementation costs associated with each project.

5. What milestones and performance measures will guide Metro Transit's transition to zero-emission transit buses? **Section 1.6** summarizes the transition milestones and performance measures used to evaluate and inform future directions and priorities for the transition towards a zero-emission fleet.

1.1. Benefits and Challenges of Zero-Emission Buses

The transportation sector is a major greenhouse gas (GHG) emitter in Minnesota. According to 2018 data from the Minnesota Pollution Control Agency (MPCA), the transportation sector is the largest source of greenhouse gases in Minnesota accounting for about one quarter of all statewide GHG emissions Although the transportation sector accounts for about a quarter of all Minnesota GHG emissions, buses (including school buses, transit buses, and intercity buses) make up only 0.7 percent of these transportation GHG emissions. Metro Transit's transition to ZEBs is one of many strategies the agency intends to implement to make meaningful impact on tackling climate change.

Three ZEB technologies are currently commercially available: electric trolleybuses, hydrogen fuel cell electric buses (FCEB), and battery electric buses (BEB). The advantages of ZEBs are well known, notably:

- Decreased carbon and greenhouse gas emissions;
- Reduced reliance on fossil fuel consumption;
- Improved air quality and less risk to human health; and
- Improved comfort for bus riders (decreased noise and vibration).

Similarly, many challenges to ZEB implementation have also been widely documented among transit agencies including:

- Higher capital costs for vehicles and supporting infrastructure;
- ZEB range limitations;
- Increased need for additional supporting infrastructure for refueling/recharging;
- Uncertain lifecycle operations and maintenance costs; and
- Potentially significant changes to bus service and operation.

ZEBs and the supporting technologies that enable them (e.g., fueling and charging infrastructure, and on-board batteries) have been maturing in the past decades with their pace of improvements in reliability and economies-of-scale accelerating in more recent years. While many transit agencies have had increasing interest in adopting ZEBs, commercial adoption of such technology has not been widespread yet. Procurement decisions in relation to an agency's fleet and propulsion technology make lasting impacts in its service availability and reliability; the inherent risk in adopting new technologies such as ZEBs poses a challenge to transit agencies such as Metro Transit which must strive to provide reliable transit service to its riders.

1.2. ZEB Case Studies

To identify and summarize best practices and lessons learned from North American transit agencies' own unique experiences of the benefits and challenges of ZEBs, case studies were developed based on formal interviews with four peer agencies in addition to an internal review of Metro Transit's own ZEB experience.

These case studies include the agencies with the longest track record operating ZEBs, as well as a heavy emphasis on northern agencies (located between 40- and 50-degrees latitude, other than Foothill Transit). To provide insight and lessons learned from a wide range of ZEB experiences, the case studies were specifically selected to encompass a variety of different technologies (buses and supporting infrastructure), fleet sizes, climates, and operating characteristics (urban, suburban, local service, express service). The case studies include:

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

Although each of the transit agencies included in the case studies have had unique ZEB experiences (Table 1), 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;
- Meet early and often with your electric utility;
- Consistent range allows for reliable operation through all seasons. Plan for bad weather days;
- Develop strong contractual language for vendor contracts including performance metrics;
- 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.

Table 1: ZEB case study summary (Data as of December 2021)

	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*
Total Bus Fleet	910	347		1,391		1,854	2,096
Type of ZEB	**BEB**	**BEB**	**FCEB**	**Electric Trolleybus**	**BEB**	**BEB**	**BEB**
Year of First In-Service ZEB	2019	2010	2022-2023	1940	2015	2014	2019
ZEBs in Service (Dec. 2021)	8	34	0	174	51	8	60
ZEBs on Order or Programmed	100	0	33	0	250	93	300
Programmed Time Horizon	2022-2027	2021-2024		2025-2028		2020-2027	2023-2025
Total ZEBs Identified	**108** (12% of bus fleet)	**67** (19% of bus fleet)		**475** (34% of bus fleet)		**101** (5.4% of bus fleet)	**360** (17% of bus fleet)
Current ZEB Transition Goal	20% of 40-foot bus replacement procurements from 2022-2027 will be BEB	100% zero-emissions by 2040 Set by CARB		100% zero-emissions powered by renewable energy by 2035 Set by King County Metro		100% zero-emissions by 2040 Set by City of Chicago	100% zero-emissions by 2040 Set by TTC
Year Goal Established	2022	2019		2020		2019	2017

1.3. Barriers, Constraints, and Risks

While good planning and foresight can help to lessen the impacts of the challenges associated with transitioning to ZEBs, some potential barriers to full implementation are a result of factors outside of Metro Transit's control including:

- The COVID-19 pandemic;
- A nationwide shortage of bus operators;
- ZEB and supporting infrastructure production and supply chain constraints;
- Electrical grid capacity; and
- The rapid pace of ZEB innovation.

Due to the COVID-19 pandemic, ridership has been severely reduced and travel behavior has been altered. In addition to these ridership impacts, transit agencies have also been contending with a labor shortage, particularly among vehicle operators which has led to additional service cuts to transit service nationwide. As Metro Transit transitions to ZEBs, long-term level of service changes driven by the COVID-19 pandemic, operator shortages, and other factors must be considered as these service changes have had significant impacts on the active fleet, defined as the total number of buses to operate current service, and may, in the long-term, also impact the total fleet size, defined as the number of buses owned by Metro Transit. In addition to these fleet size impacts, level of service changes can also impact the need for and quantity of future bus procurements, as well as the characteristics of individual routes including route alignment and frequency.

In addition to long-term level of service changes, another potential risk for transit providers transitioning to ZEBs is the limited production capacity of ZEB and supporting infrastructure manufacturers. Due to an increase in available federal funds for Low-Emission or No-Emission Buses and Bus Facilities (Low-No) Program vehicles as well as transit agencies' increasing emphasis and focus on sustainable operations, transportation economists are predicting that the electric bus market will grow by 31 percent between 2021 and 2026.[1] This trend may pose difficulties for hundreds of U.S. transit agencies as they all line up to acquire ZEBs and supporting infrastructure as it is likely that demand will continue to outpace the supply of these buses and supporting infrastructure as transit agencies place orders for vehicles and equipment faster than they can be built.

Furthermore, spare parts and replacement batteries may be just as difficult to acquire in the coming years. Although ZEBs share many parts with those of conventional buses, the drive trains, energy storage systems, related auxiliary systems, and monitoring systems are unique to ZEBs. As more agencies procure ZEBs, and as those vehicles and supporting infrastructure begin to require both scheduled and emergency maintenance, an adequate supply of spare parts will be critical to an agency's ability to provide uninterrupted service. When compounded by the complications to global supply chains as a result of the COVID-19 pandemic, it is clear that ZEB production and supply chain constraints could limit Metro Transit's ability to transition to ZEBs in the short-term.

[1] *U.S. Electric Bus Market Research Report: Industry Revenue Estimation and Demand Forecast to 2026*, Prescient and Strategic Intelligence, November 2021.

An additional supporting infrastructure risk associated with transitioning to ZEBs is the potential for constrained or limited available electrical capacity. Compared to conventional diesel buses, ZEBs require significant electrical power to operate. 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 a 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 also would require large amounts of electricity and could utilize the existing grid capacity. Therefore, although Metro Transit has collaborated with Xcel Energy to analyze available power connections to 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. For this reason, it will be essential that Metro Transit and Xcel Energy review project plans on an annual basis and stay in close coordination with each other's capital plans.

One of the factors that has permitted the rapid proliferation of BEBs is the speed at which lithium-ion battery technology is advancing. 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. It is reasonable to expect that this upward trend will continue, and with it, the range of BEBs. Similarly, while the first generation Buy American compliant charging equipment was available as recently as two years ago for some manufacturers, many manufacturers are selling third generation equipment in 2021 and 2022. Similar to BEB technology, other ZEB technologies including FCEBs are also rapidly advancing.

Although the speed with which the industry is advancing means that ZEBs and supporting infrastructure are becoming an increasingly viable technology, this speed of advancement is also, ironically, a liability for transit agencies. Manufacturers are offering new models of vehicles and supporting infrastructure almost annually, which means that multi-year procurements could translate to technologies being obsolete the moment they arrive at the garage. Conversely, shorter procurements could result in an agency purchasing the next generation of buses and chargers without an adequate opportunity to learn from the previous procurement or peer agencies.

In these ways, there is the potential for a ZEB fleet to become a victim of its own success. Overall, when planning the build-out of its ZEB fleet and facilities, Metro Transit will need to consider these barriers, constraints, and risks to ensure that the agency can continue to provide an excellent, safe, and reliable service to transit customers.

Throughout this Transition Plan, Metro Transit has identified several objectives and strategies to address and mitigate the aforementioned barriers, constraints, and risks associated with transitioning to ZEBs (Table 2). As Metro Transit's experience and knowledge of ZEBs grows, these strategies and objectives will be continuously updated to reflect current best practices and lessons learned as additional experience is gained.

Table 2: Strategies and objectives to address ZEB barriers, constraints, and risks

Barrier, Constraint, or Risk Addressed	Mitigating Strategy or Objective	Discussed in Section
Electrical Grid Capacity	**Metro Transit will collaborate with Xcel Energy to develop ZEB project timelines that coordinate with Xcel Energy timelines for planning, engineering, construction**	Section 8.2.2.2
Level of Service Changes	**Continually evaluate ZEB service implementation prioritization methodology to tailor service to ridership and available workforce levels**	Section 8.3.4
Speed of Innovation Level of Service Changes	**Identify learning objectives for each package of projects up front and pair ZEB projects with the development of other areas of the business including software tools and workforce development**	Section 10
Level of Service Changes	**Provide paid training to operators and mechanics**	Section 11.1.2
Speed of Innovation Supply Chain Constraints	**Evaluate multiple ZEB and supporting infrastructure manufacturers in smaller orders before proceeding to larger orders**	Section 11.3
Speed of Innovation Supply Chain Constraints	**Allow for approximately two years between procurements of ZEBs and supporting infrastructure to evaluate their performance and to understand how the industry is changing**	Section 11.3

1.4. ZEB Policies and Guidance

Three guiding principles and six supporting actions were established as the framework for the Transition Plan and for use in defining the definition of a successful transition to ZEBs (Figure 1). Building upon these principles, numerous additional policies and recommendations are identified and interspersed throughout the Transition Plan. The full list of implementation policies, guidance, and recommendations are summarized in Table 3.

Figure 1: ZEB Transition Plan guiding principles and supporting actions summary

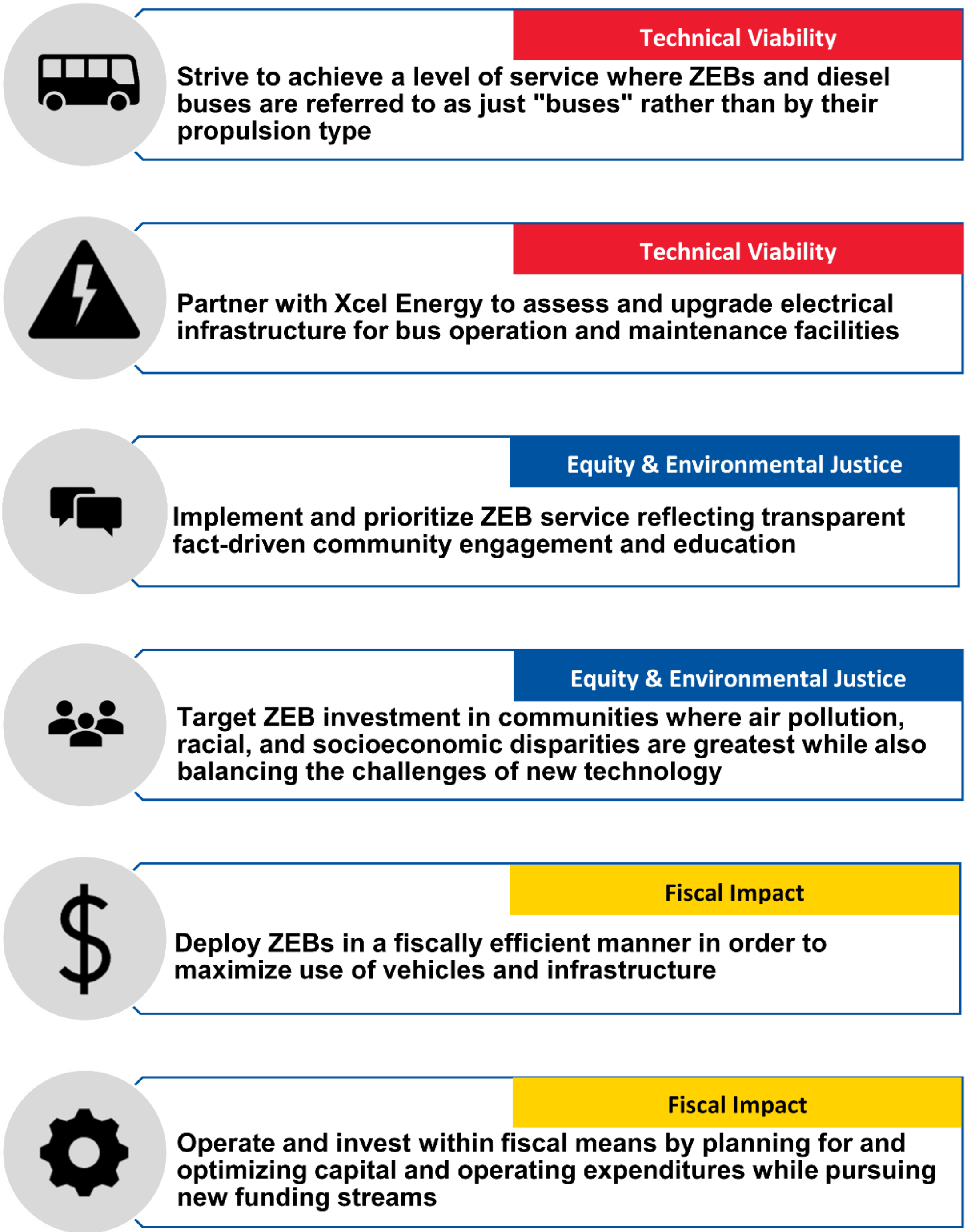


Table 3: Implementation policies, recommendations, and strategies summary

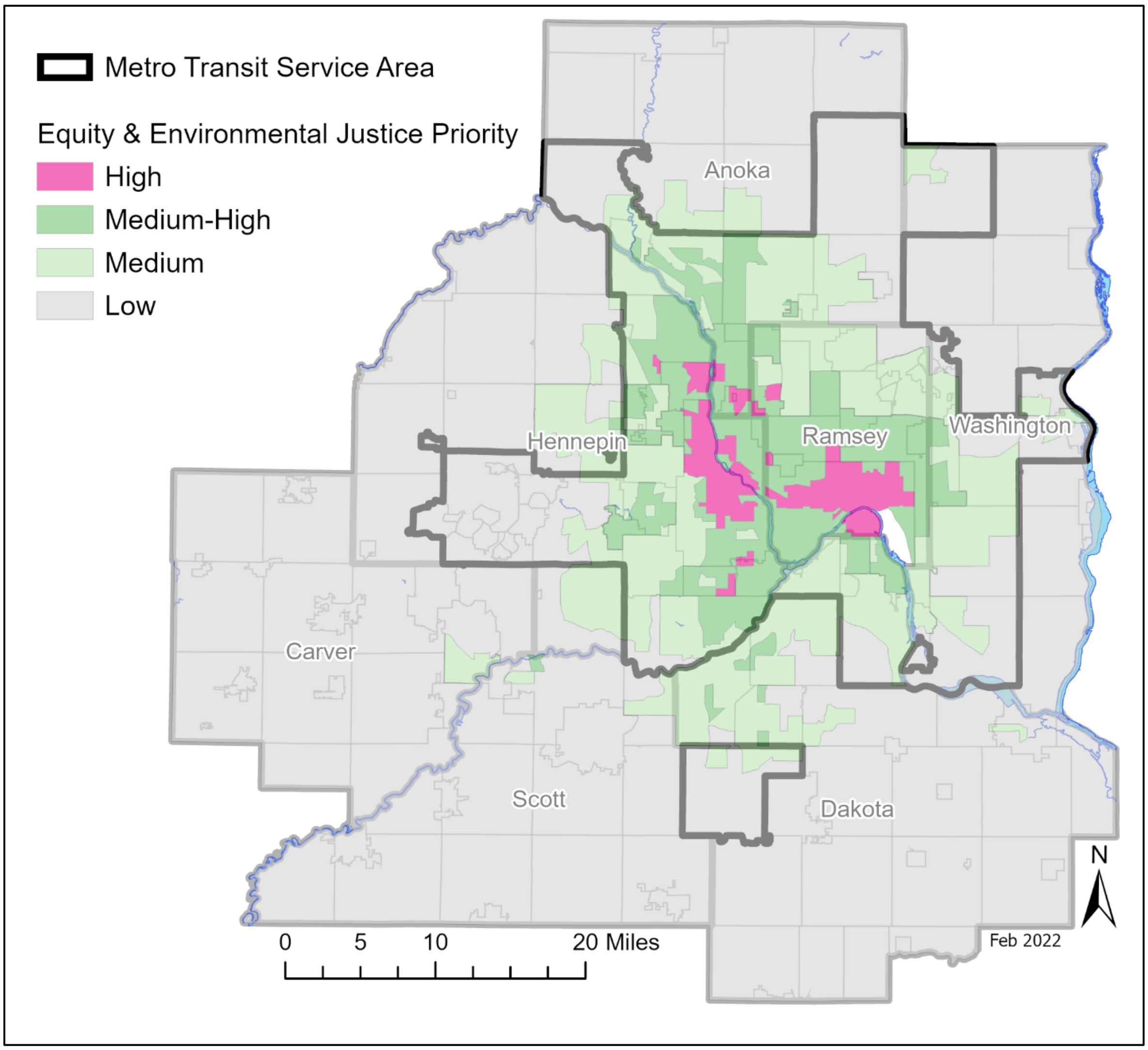
Report Section	Policies, Recommendations, and Strategies
Section 3.2: Principle 1: Technical Viability	Vehicle reliability target that 90 percent of buses should be available and ready for service
	Workforce development will be a part of every ZEB project *[Further discussed in Section 10]*
Section 8.1: Short-term ZEB Propulsion Technology	BEBs recommended as short-term ZEB technology for implementation and deployment
	Hydrogen fuel cell electric buses not recommended until hydrogen becomes a more viable ZEB solution for the region
	Metro Transit does not intend to pursue the implementation of electric trolleybuses given their limitations compared to BEB technology
Section 8.2.1: Overhaul Base	In the short-term, a minimum of two plug-in style chargers should be installed at the Overhaul Base to provide operational flexibility for maintenance activities
Section 8.2.2.1: Spatial Constraints	Each electrified garage will include (2) high-capacity overhead conductive chargers, (1) plug-in charger for every four maintenance bays, and at least (1) plug-in charger for every two bus parking spaces
Section 8.2: Facility Guidance	Electrical upgrades and BEB storage are not currently recommended at South Garage. This will be revisited if a long-term lease is secured
Section 8.2.2.4: BEB Suitability Tiers	Maximum of 2 garages under construction for supporting infrastructure at a time
	Minneapolis Bus Garage and East Metro Garage first to be electrified
Section 8.2.3: Transit Center and Layover Facility Suitability	On-route charging not recommended as a short-term strategy
Section 8.3.1.1: Service Prioritization Methodology and Implementation Guidance Assumptions	Metro Transit must plan BEB service around worst-case bus range estimates based on winter temperatures
Section 9.1 Milestones	The Transition Plan establishes targets and projections for vehicle procurement as well as annual communications and performance reporting milestones. *[Further discussed in Section 9.2]*
Section 12.1 Updates to the Transition Plan	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 Capital Improvement Plan and operating budgets. *[Further discussed in Section 9.2]*

1.4.1. Service Prioritization Methodology

As part of the Transition Plan's focus on ensuring an equitable and environmentally just transition towards ZEBs, Metro Transit engaged in public outreach and engagement efforts throughout fall

2021 to better understand the needs and priorities of communities where ZEB service may be deployed in the short-term. Overall, more than 800 participants attended one of these events and over 300 completed an online survey about the Transition Plan with nearly 90 percent of respondents indicating that Metro Transit's transition to ZEBs is either important or very important to them. When asked to rank the relative importance seven unique demographic, socioeconomic, and environmental variables should have on prioritizing ZEB service deployment, 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. Based on a weighted average formula informed by this feedback, each census tract in the Metropolitan Council's seven-county area was assigned an equity and environmental justice (EEJ) priority tier of either "High", "Medium-High", "Medium", or "Low" (Figure 2).

Figure 2: Census-Tract Equity and Environmental Justice (EEJ) priority areas



In the short-term, Metro Transit's ZEB plan is to utilize BEBs. Using this EEJ priority map in tandem with the other guiding principles, a three-step sequential methodology was developed to identify the most promising bus service suitable for a short-term transition to BEBs (Figure 3).

Figure 3: Block-level BEB prioritization methodology

1. Technical Viability
2. Equity & Environmental Justice
3. Fiscal Impact

To provide bus service across the region, Metro Transit divides its many bus routes into service blocks, defined as a series of transit trips that are linked together and assigned to a single vehicle for operation. Therefore, as one bus may provide service on multiple routes in a given day and as blocks are analogous to the service a bus provides between refueling/charging, the identification and prioritization of bus service most promising for BEBs was analyzed at the block-level.

As an illustrative example, upon applying the prioritization methodology to the bus blocks from Metro Transit's August 2021 schedule, it was determined that approximately half of these blocks, representing about a third of Metro Transit's annual bus hours and miles, are of sufficient length that they could be served by a 675 kWh 40-foot BEB like the ones Metro Transit is purchasing in 2022.

Using this methodology, 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 while the other principle has a "Medium-High" rating.

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.

1.5. Short-Term ZEB Transition Program of Projects

To guide Metro Transit's focus on and deployment of BEBs in the short-term, Metro Transit developed several sequential packages of projects to be initiated by 2027 (Table 4). These packages of projects were created based on Metro Transit's infrastructure priorities and industry best practices. Additionally, all packages include workforce development as the federal government estimates that five percent of project costs for FTA Low-No grants (A primary source of capital funding for ZEBs throughout the U.S.) should go towards workforce development.[2] Each of the packages is a steppingstone towards transitioning Metro Transit's fleet to ZEBs. The following sections summarize the proposed packages of projects. Together, the packages include up to 138 BEBs and up to 125 chargers totaling an estimated $236.8-$263.4 million in capital costs with energy operating costs of between $1.00/mile to $1.33/mile.

[2] Source: *H.R. 3684 Infrastructure Investment and Jobs Act*, November 2021.

Table 4: ZEB transition program of projects

Package	Description	Learning Objectives
A *C Line BRT 60' pilot* *(began service in June 2019)*	(8) 60' 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
B *40' local service pilot and distributed energy resources*	(8) 40' buses (8) plug-in chargers at the Minneapolis Bus Garage (MBG) Up to 2MW solar array at MBG Up to 2MWh/800 kW battery storage system at MBG (2) high-capacity overhead conductive chargers at MBG Enhanced telematics Workforce Development	**Pilot long range local service BEB and distributed energy resources** • Pilot local service BEBs with garage only charging strategy • Mix of lower power plug-in chargers & higher power overhead conductive chargers • Study distributed energy resources • Pilot enhanced telematics software

Package	Description	Learning Objectives
C *BRT Moderate Expansion*	Up to (22) BRT buses Up to (22) plug-in chargers at East Metro Garage Up to (2) high-capacity overhead conductive chargers at East Metro Garage Up to (2) high-capacity overhead conductive chargers on route Up to (6) maintenance chargers at East Metro Garage (2+) chargers at the Overhaul Base Enhanced software tools Workforce Development	• Scale up BRT BEB use • Expand to East Metro Garage • Pilot software tools to enable scaling up (demand, schedule, monitor, telematics)
D *40' Bus Moderate Transition*	Up to (30) 40' buses Up to (30) plug-in chargers Up to (6) plug-in maintenance chargers at MBG MBG & East Metro Garage Upgrades Software suite upgrades Workforce Development	• Scale up 40' BEB use • Scale up MBG & East Metro Garage • Workforce development focus
E *40' Bus Larger Transition*	Up to (70) 40' buses Up to (35) plug-in chargers Software suite expansion Workforce Development	• Larger procurement of BEBs and chargers • Operating BEBs at larger scale • Mix of MBG & East Metro Garage

1.6. Milestones and Performance Measures

As part of the state's requirements for this Transition Plan, Metro Transit is required to establish milestones and/or performance measures for the plan. Additionally, Metro Transit is required to submit an update to the Minnesota State Legislature at least every five years. The first update to the transition plan will be submitted in 2027. In accordance with these plan updates, Metro Transit has established time horizons for the short-, medium-, and long-term. The short-term aligns with the first Transition Plan update and extends from 2022 through 2027. The medium-term aligns with the second Transition Plan update and extends from 2028-2032. The long-term time horizon begins in 2033 and extends beyond this year into the future.

1.6.1. Milestones

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.

- **Vehicle Procurement:** Measured in percent of purchases over time horizon
  - **Target**: Between 2022 and 2027, at least 20% of Metro Transit's 40-foot bus replacement procurements will be electric.
    - Potentially accomplished by the purchase of 100-130 electric buses
    - Anticipated to represent 12-15% of 2021 total fleet
    - Anticipated to represent 20-24% of 2021 active fleet
    - Equates to maximum charging infrastructure achievable
  - **Projection**: Between 2028 and 2032, the percentage of Metro Transit bus procurements that are zero emission will be driven by key performance indicators and available budgetary resources.

1.6.2. Performance Measures

The performance measures will be used to assess the performance of the ZEBs. The performance measures will help Metro Transit ensure that customers continue to receive high-quality, reliable transit service throughout the transition to ZEBs. These indicators will be used to inform future decisions on the implementation of ZEBs.

- **Fleet Mileage**: How many miles vehicles are driven annually
- **Bus Availability**: % of calendar year ready for service
- **Infrastructure Availability:** % of calendar year infrastructure available for use
- **Bus Reliability:** Mean distance between road calls
- **Charger Reliability:** Warranty ticket volume
- **Cost/mile:** Energy cost per mile driven
- **Environmental Impact:** Emissions or cost of carbon
- **Equity and Environmental Justice:** Miles driven through high priority EEJ areas

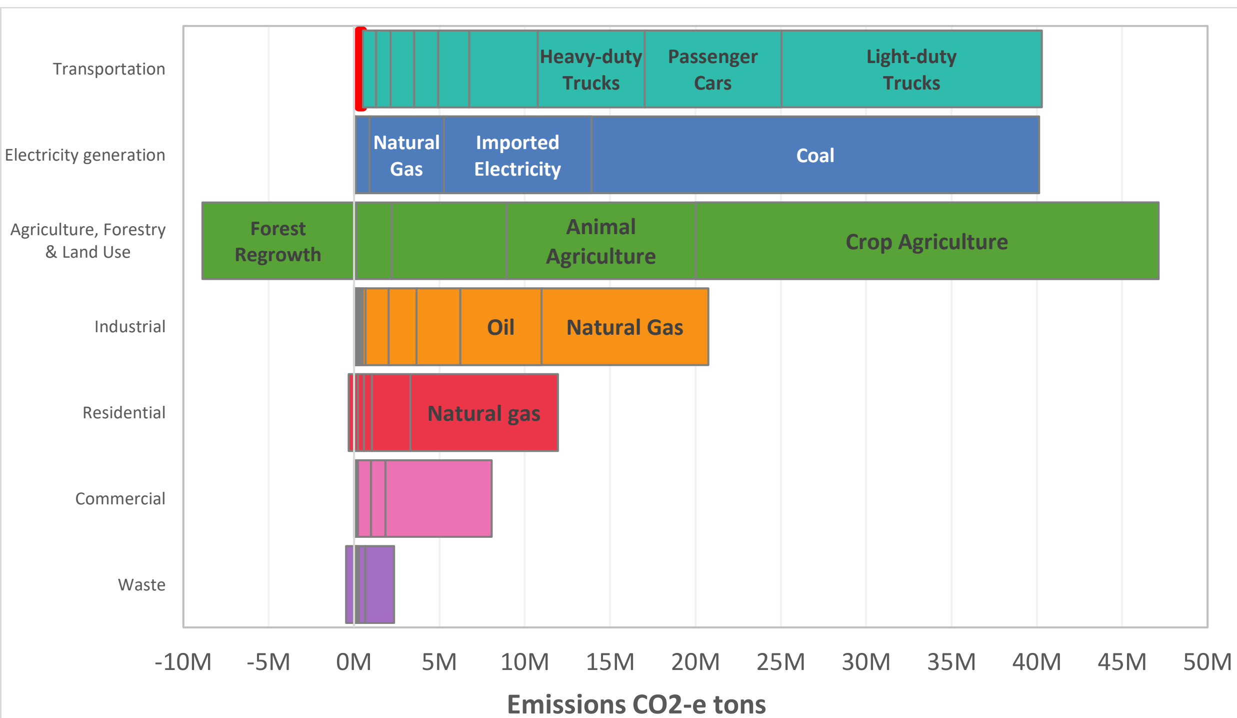
2. Transition Plan Purpose and Context

This section outlines the purpose and motivation for Metro Transit's Zero Emission Bus Transition Plan 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, Metro Transit's continued commitment to sustainability, and existing studies and initiatives with zero-emissions implications.

2.1. Transportation and the Environment

The transportation sector is a major greenhouse gas (GHG) emitter in Minnesota. According to 2018 data from the Minnesota Pollution Control Agency (MPCA), the transportation sector is the largest source of greenhouse gases in Minnesota accounting for about one quarter of all statewide GHG emissions.[3] Since 2005, due to more stringent vehicle tailpipe emission standards at the federal level as well as technological advancements, transportation GHG emissions decreased by about seven percent, but reductions have leveled off since 2016. Overall, in 2018, the transportation sector produced 40.3 million tons of CO_2-equivalent (CO_2e) emissions (Figure 4).[3] The majority (73 percent) of transportation-related GHG emissions came from light-duty trucks (including SUVs), passenger vehicles, and heavy-duty trucks.

Figure 4: Sector sources of GHG emissions and storage in Minnesota[3]



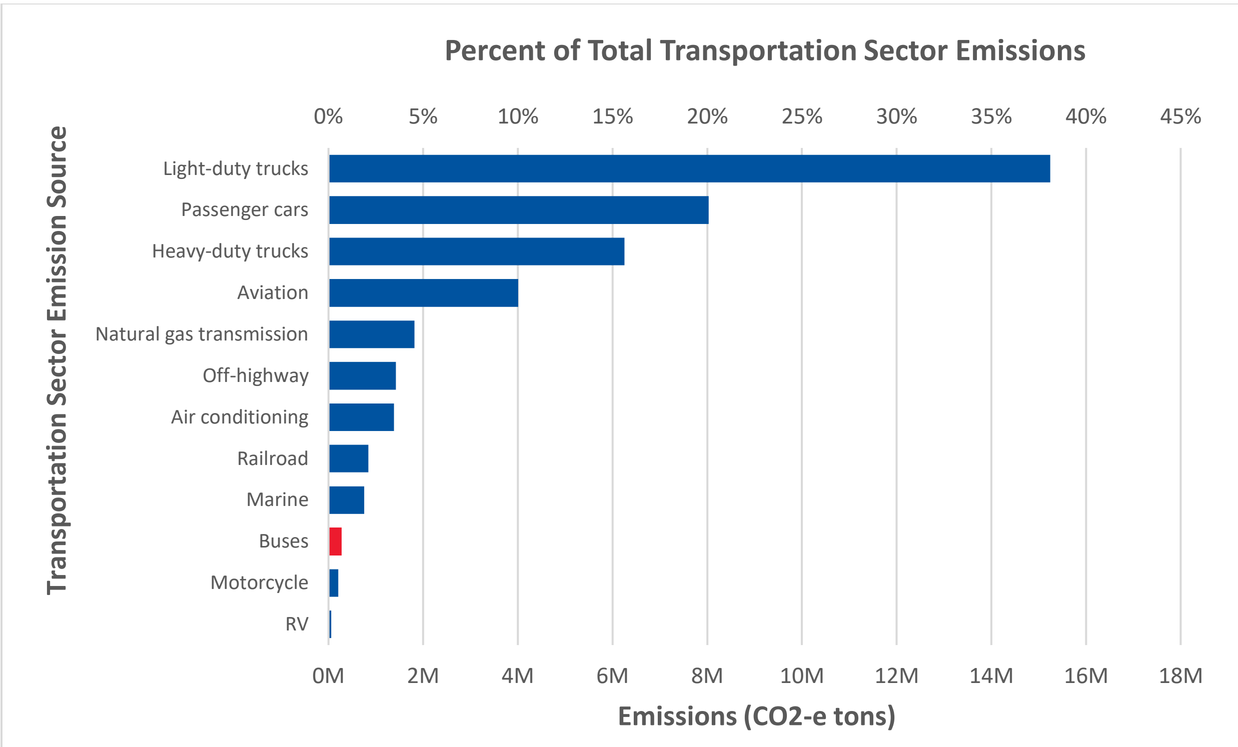
Note: The thin red bar in the transportation sector indicates the share of Minnesota Transportation GHG emissions attributable to all "Buses" including school buses, transit buses, and intercity buses.

[3] Source: *Climate change in Minnesota: Greenhouse gas emissions data*, Minnesota Pollution Control Agency, 2018

2.1.1. **Role of Public Transit & Climate Change**

Although the transportation sector accounts for about a quarter of all Minnesota GHG emissions, buses (including school buses, transit buses, and intercity buses) make up only 0.7 percent of these transportation GHG emissions at 272,030 CO2e tons (Figure 5). It is estimated that about 25 percent of all bus emissions statewide are emitted by Metro Transit buses[4]—the equivalent of 68,000 CO_2e tons of GHG. This equates to 0.04 percent of the state's overall GHG emissions.

Figure 5: Minnesota transportation sector GHG emissions by source[3]



With this 0.04 percent of statewide GHG emissions, Metro Transit provided 54.9 million rides on Metro Transit's buses in 2018.[5] 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 BRT network to provide fast, frequent, all-day service which has proven to increase ridership. 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 by attracting people to transit instead of driving their personal vehicles (which account for up to 58 percent of all statewide transportation emissions).[6]

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[4] Source: Metro Transit submittal to the Minnesota Department of Administration Office of Enterprise's Sustainability Climate Registry
[5] Source: *Metro Transit Factbook*, Metro Transit, 2018
[6] Note: Personal vehicle emissions include emissions from the 'Passenger Cars' category as well as the 'Light-Duty Trucks' category which includes SUVs.

2.2. 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 more energy-efficient than older garages and is the basis of design for next generation facilities.[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 and 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, introducing 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. Through 2015, Metro Transit has taken delivery of 136 hybrid electric buses, further demonstrating a commitment to emissions reductions and efficiency. 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.

2.2.1. 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-No Grant program at around 1.1 billion dollars annually from 2022 through 2026, which is a program within the FTA's Buses and Bus Facilities program. This discretionary grant program requires agencies to have a zero-emission fleet transition plan. It also requires that five 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. It should be noted, however, that federal transit funding focuses on

[7] Source: *Our Facilities*, Metro Transit
[8] Source: M. Porter, Metro Transit Statement, December 8, 2017

capital needs, not addressing the costs associated with operation and maintenance of ZEBs or other transit services.[9,10]

2.3. State Statute Requirement

Under state statute,[11] the Metropolitan Council is responsible for developing a ZEB and electric transit vehicle transition plan (Figure 6).

Figure 6: Text of Minnesota Statute 473.3927

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 plan by February 15, 2022, and revise the plan at least once every five years.

Subd. 2. **Plan development.** At a minimum, the plan must:

(1) establish implementation policies and guidance;

(2) set transition milestones or performance measures, or both, which may include vehicle procurement goals over the transition period;

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

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

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

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

(7) provide detailed estimates of implementation costs; and

(8) 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.

2.4. Existing Studies and Initiatives

This section provides a review of Metro Transit and Metropolitan Council studies and initiatives with zero-emissions implications. These studies and initiatives include an overview of Thrive MSP 2040, Stronger, Better: Metro Transit's Strategic Plan 2021-2022, the Everyday Equity Initiative, the Green Energy Partnership with Xcel Energy, the C Line Bus Rapid Transit (BRT) Electric Bus Pilot Program, the 2019 Minneapolis Bus Garage (MBG) BEB Feasibility Study, and future projects with planned ZEB implications.

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9 Source: [Fact Sheet: Buses and Bus Facilities Program](), Federal Transit Administration, December 9, 2021

10 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 operating and maintenance costs. However, funds provided for transit to large urban areas outside of COVID relief bills have been restricted to capital projects.

11 [State of Minnesota Statute 473.3927](), Minnesota Legislature Office of the Revisor of Statutes

2.4.1. **Thrive MSP 2040**

Adopted by the Metropolitan Council in May 2014, Thrive MSP 2040 is the region's comprehensive long-range plan. Thrive MSP 2040 sets the policy foundations for systems and policy plans, including the 2040 Transportation Policy Plan (TPP). The 2040 TPP describes how the transportation system will be developed and operated in a way that is consistent with the regional vision and goals described in Thrive MSP 2040. Thrive MSP 2040 lists five outcomes, including sustainability, that define its shared regional vision, aiming to provide leadership to support climate change mitigation, adaptation, and resilience. These outcomes include:

- Stewardship
- Prosperity
- Equity
- Livability
- Sustainability

2.4.2. **Stronger, Better: Metro Transit's Strategic Plan 2021-2022**

The Strategic Plan defines the goals and core elements of Metro Transit's work as the agency delivers environmentally sustainable transportation choices that link people, jobs, and communities conveniently and safely. It describes the initiatives Metro Transit will take to make meaningful progress – both in the work Metro Transit does and how the agency does it. In addition, the plan creates a shared vision for Metro Transit to work toward that will provide customers, partners, and other stakeholders with a better understanding of where the agency is focusing its efforts.

2.4.3. **Everyday Equity Initiative**

The Everyday Equity Initiative is an organizational assessment of equity aligned with Thrive MSP 2040. 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.

2.4.4. **Xcel Energy Green Energy Partnership**

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.[12] This partnership creates a framework which establishes goals for Xcel Energy to provide the Metropolitan Council with electricity from 60 percent renewable energy sources by 2030 and 100 percent renewable energy sources by 2040.[13]

2.4.5. **C Line BRT Electric Bus Pilot Program (2019)**

As will be discussed in greater length in Section 5.1, Metro Transit purchased eight New Flyer 60-foot Xcelsior Charge BEBs with 466 kilowatt-hour (kWh) batteries in 2018 for use on the METRO

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[12] Source: *Met Council, Xcel Energy Work to Get Council to 100% Renewable Energy By 2040*, June 8, 2018.

[13] Source*: Xcel Energy – Green Energy Partnership Update*, Presentation to the Metropolitan Council, September 16, 2020.

C Line, an arterial Bus Rapid Transit route, as part of the agency's effort to move to greener operations (Figure 7). In addition to the eight BEBs, two rapid on-route overhead conductive chargers were installed at the route's northern terminus at Brooklyn Center Transit Center, and eight plug-in garage chargers were also installed at the Fred T. Heywood (Heywood) Garage.

Figure 7: C Line BEB delivery

Since beginning the pilot 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. Other areas of success from this BEB pilot program include the development of key partnerships both internal and external to the agency as well as the effective creation and implementation of contingency plans. In addition to these areas of success Metro Transit also learned several valuable lessons including:

- Where possible, avoid BEB pilot 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.
- It is good to be an early adopter but not the first adopter; avoid low serial number equipment.

2.4.6. **Minneapolis Bus Garage (MBG) Battery Electric Bus (BEB) Feasibility Study (2019)**

While still working on the implementation for 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 Minneapolis Bus Garage in the future.[14] The BEB constraints and considerations identified in this study were, in turn, incorporated into the design of the MBG, the largest Metro Transit bus facility to date.

The MBG is scheduled to begin revenue service in early 2023 and has the capacity to house approximately 216 buses depending on the relative number of 40-foot or 60-foot buses stored at the facility. As the newest garage in Metro Transit's system, architectural, structural, mechanical, and electrical modifications were made to the garage to accommodate the future possibility for fleet electrification.[14] Although not part of initial construction, Metro Transit received funding from the Federal Transit Administration's (FTA) Low-No grant program in 2019 to install an approximately 2-megawatt (MW) rooftop-mounted photovoltaic array, a battery storage bank, and two indoor overhead conductive fast chargers to reduce reliance on peak-demand energy rates.

The BEB Feasibility Study included planning for both 40-foot standard buses and 60-foot articulated buses for BEB consideration. The BEB Feasibility Study assumed the use of 150 kilowatt (kW) slow chargers with two dispensers per charger and a 9-hour charging availability period between 9:00 PM and 6:00 AM based on off-peak charging between 9:00 PM and 9:00 AM. From these assumptions, it was determined that three 2 MW substations would be necessary to serve the charging needs of approximately the first 80 BEBs at the new MBG.

Electrical Equipment Criteria

To serve the MBG, two 13.8 kilovolt (kV) services totaling 8 MW are required, 2 MW of which will serve the main facility and 6 MW which will serve bus charging needs. The three 2 MW substations dedicated to serving electric bus charger bases were included as part of the initial garage build. Multiple charger bases are planned near each substation to reduce the distance of large electrical AC feeds. Each charger base was assumed to feed two dispensers which connect the bus to the charging infrastructure. In the BEB Feasibility Study, dispensers were primarily assumed to include plug-in cable connections with powered reel or pull-down retractors although overhead conductive (pantograph style) dispensers were also considered.[14] With 6,000 kW of dedicated charger service capacity at the MBG, it was determined that there was capacity for approximately 40 concurrently operating charger bases, assuming 150 kW per charger.[14] To expand beyond the initial 40 concurrently operating charger bases, it was identified that Metro Transit would need to coordinate with Xcel Energy to install additional power feeders.

2.4.7. Gold Line BRT

The METRO Gold Line is a planned 10-mile dedicated BRT line running between Saint Paul and Woodbury near Interstate 94 which will include the purchase of 12 diesel buses.[15] In addition to the diesel buses, the Gold Line project also plans to purchase five BEBs to continue the zero-emission pilot project efforts underway by Metro Transit. As the Gold Line is serving the East Metro area, it is anticipated that the buses used for the Gold Line BRT will be based out of the East Metro Garage.

2.4.8. Purple (Rush) Line BRT

The Purple Line BRT, formerly referred to as the Rush Line, is a proposed 15-mile BRT line running primarily in dedicated bus lanes between Saint Paul and downtown White Bear Lake.

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[14] Source: Metro Transit Battery Electric Bus Feasibility Report, 2020.
[15] Source: *Electric Buses,* Metro Transit

Project plans assume an electric vehicle fleet will be used for the Purple Line BRT.[16] This will be confirmed during the engineering phase of the project over the next several years. As the Purple Line is serving the East Metro area, it is anticipated that the buses used for the Purple Line BRT will be based out of the East Metro Garage.

2.4.9. Support Facilities Strategic Plan

The Support Facilities Strategic Plan (SFSP) is a long-range planning process that identifies support facility expansion options potentially needed by Metro Transit through 2040. It considers both lower-growth and higher-growth futures, identifying possible facility needs gaps over time. Facility expansion options considered within the SFSP are intended to help Metro Transit solve for these potential needs gaps and prepare for an uncertain future. SFSP considerations about long-term bus storage capacity will be impacted by the findings of the Transition Plan on topics like diesel-to-electric bus replacement factors or garage capacity reductions resulting from charging infrastructure investments.

2.4.10. Metropolitan Council Climate Action Plan

The Metropolitan Council's Climate Action Plan, expected in late 2022, is a three- to five-year plan which will unify efforts across Metropolitan Council divisions, including Metro Transit, to reduce greenhouse gas emissions, adapt to climate impacts, and build resilience to potential changes. The Climate Action Plan will define goals and strategies that will strengthen the Council's ability to plan and deliver services to the region through leadership, collaboration, and stewardship. This plan will include current efforts as well as commitments to future actions.

2.4.11. Metropolitan Council Electric Vehicle Study

The Metropolitan Council's Electric Vehicle Planning Study will provide the technical background around the rapidly changing technology and landscape of transportation electrification including describing greenhouse gas reduction potential, charging infrastructure status and needs, vehicle availability, and equity impacts and opportunities. The project will evaluate and prioritize strategies that the Metropolitan Council can undertake to accelerate adoption of electric vehicles to reduce climate and health impacts from the region's transportation system. The study primarily focuses on light duty vehicles, but also includes strategies and considerations for medium and heavy-duty vehicles, including transit buses.

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[16] Source: *Metropolitan Council Transportation Division Proposed 2022-2027 Transit Capital Program*, Metropolitan Council, September 27, 2021

3. 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-, medium-, and long-term. To align with the Transition Plan's updates every five years the time horizons are defined as follows:

- Short-term: 2022-2027
- Medium-term: 2028-2032
- Long-term: 2033 and beyond

3.1. Guiding Principles Framework

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

- Thrive MSP 2040
- Stronger, Better: Metro Transit's Strategic Plan 2021-2022
- Cross-disciplinary workshop of Metro Transit staff.

3.1.1. Thrive MSP 2040

In recognition of the broader role the ZEB Transition Plan 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 5).[17]

Table 5: ZEB Transition Plan alignment with Thrive MSP 2040 regional outcomes

THRIVE MSP 2040	ZEB Transition Plan
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
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 sustainably	YES

[17] Source: *Thrive MSP Introduction*, 2014

3.1.2. **Stronger, Better: Metro Transit's Strategic Plan 2021-2022**

In addition to aligning with Thrive MSP 2040, the guiding principles and supporting actions defined in this plan also align with the goals and core elements defined in Metro Transit's Strategic Plan which supports and supplements the Metropolitan Council's long-range plan (Thrive MSP 2040) and Metro Transit's Transportation Policy Plan.

The five goals outlined in Metro Transit's Strategic Plan are:

- **Strategic Plan Goal 1**:
  We will transition from the pandemic to a stronger, better transit system
- **Strategic Plan Goal 2**:
  We provide service that is safe, welcoming, and comfortable
- **Strategic Plan Goal 3**:
  We provide service that is reliable and easy to use
- **Strategic Plan Goal 4**:
  We make our region more environmentally sustainable
- **Strategic Plan Goal 5**:
  We are a great place to work and build a career

These Strategic Plan goals are supported by four core elements as defined in the Strategic Plan:

- **Strategic Plan Core Element 1:**
  We advance equity inside our organization and in the region
- **Strategic Plan Core Element 2:**
  We communicate and engage with customers, stakeholders, and employees
- **Strategic Plan Core Element 3:**
  We evaluate our performance and foster innovation for continuous improvement
- **Strategic Plan Core Element 4:**
  We are responsible stewards of a transformative and financially sustainable transit system

3.1.3. **Cross-disciplinary Internal Workshop**

To assist in the creation of these guiding principles and the ZEB Transition Plan, 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 ZEB Transition Plan, 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 Metro Transit Strategic Plan, the cross disciplinary team established three guiding principles and six supporting actions that will guide the implementation of the ZEB Transition Plan (Figure 8).

Figure 8: ZEB Transition Plan guiding principles and supporting actions summary

Technical Viability
Strive to achieve a level of service where ZEBs and diesel buses are referred to as just "buses" rather than by their propulsion type

Technical Viability
Partner with Xcel Energy to assess and upgrade electrical infrastructure for bus operation and maintenance facilities

Equity & Environmental Justice
Implement and prioritize ZEB service reflecting transparent fact-driven community engagement and education

Equity & Environmental Justice
Target ZEB investment in communities where air pollution, racial, and socioeconomic disparities are greatest while also balancing the challenges of new technology

Fiscal Impact
Deploy ZEBs in a fiscally efficient manner in order to maximize use of vehicles and infrastructure

Fiscal Impact
Operate and invest within fiscal means by planning for and optimizing capital and operating expenditures while pursuing new funding streams

3.2. Principle 1: Technical Viability

The principle of technical viability relates to the first three goals and the third core element of the Metro Transit Strategic Plan for 2021-2022:

- **Strategic Plan Goal 1:**
  We will transition from the pandemic to a stronger, better transit system

- **Strategic Plan Goal 2:**
  We provide service that is safe, welcoming, and comfortable
- **Strategic Plan Goal 3:**
  We provide service that is reliable and easy to use
- **Strategic Plan Core Element 3:**
  We evaluate our performance and foster innovation for continuous improvement

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.

3.2.1. 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. 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 regarding the recharging/refueling of the buses, how an operator accelerates and decelerates, the 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 a 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, 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).

3.2.2. **Supporting Action: Partner with Xcel Energy 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 operations and maintenance facilities in order to recharge. To ensure that future ZEBs will have the support infrastructure necessary to operate consistently and reliably, we will build upon our existing partnership with Xcel Energy to assess the existing electrical infrastructure and capacity limitations at our bus operations and maintenance facilities and perform upgrades as necessary. This collaboration will include the confirmation of available electrical transmission capacity, transformer specifications, and the current peak power demands at each facility.

As part of the Transition Plan's technical analysis, Metro Transit and Xcel Energy collaborated on long-range planning to forecast future power needs at bus operation and maintenance facilities. This collaboration will inform Xcel Energy capital planning to 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.

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.

3.3. Principle 2: Equity and Environmental Justice

The principle of equity and environmental justice is based on the Metropolitan Council's and Environmental Protection Agency's (EPA) definitions of equity and environmental justice, 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.*

Complementing this definition of equity, the EPA defines environmental justice as,

> *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.*[18]

In addition, the principle of equity and environmental justice relates to the following goals and elements of the Metro Transit Strategic Plan:

- **Strategic Plan Goal 4:**
  We make our region more environmentally sustainable
- **Strategic Plan Goal 5:**
  We are a great place to work and build a career
- **Strategic Plan Core Element 1:**
  We advance equity inside our organization and in the region
- **Strategic Plan Core Element 2:**
  We communicate and engage with customers, stakeholders, and employees

In alignment with the above definitions and to maximize equity and environmental justice, 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 the communities where poor air quality, racial, and socioeconomic disparities are greatest while also balancing the challenges associated with new technology.

3.3.1. **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.[19] As shown in Figure 9, the Twin Cities region has some of the largest disparities between white communities and communities of color. In recognition of these wide disparities, Metro Transit is focused on delivering a ZEB Transition Plan that considers the social, political, economic, and environmental impacts to a corridor or neighborhood so that the benefits of ZEB service are

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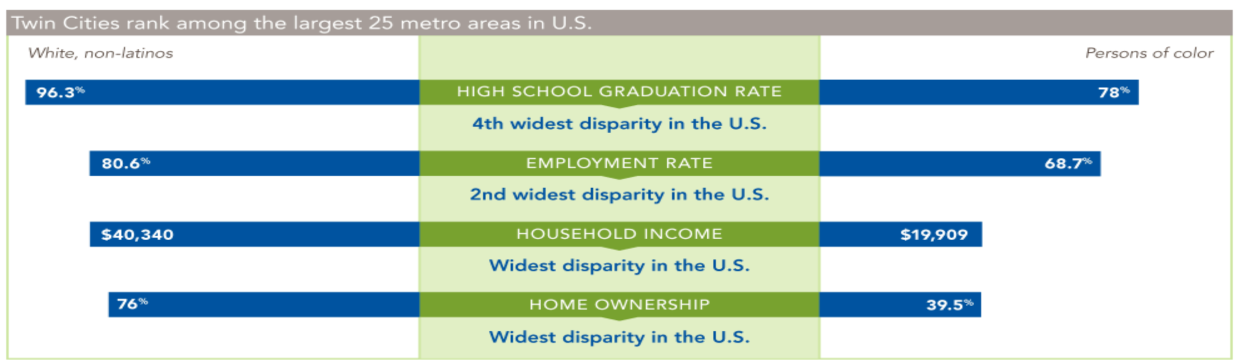
[18] Source: *Learn About Environmental Justice,* EPA
[19] Source: *Environmental justice and air,* Minnesota Pollution Control Agency

equitably distributed without disproportionately attributing the risk of deployment to the same communities. To guide this focus on equity and environmental justice and to ensure that the ZEB transition plan aligns with communities' needs and wants, Metro Transit established that the prioritization and implementation of ZEB service should reflect transparent fact-driven community engagement and education.

Figure 9: Inequities in the Twin Cities region



Source: metrotransit.org

To best align with the many competing interests and priorities within communities, Metro Transit engaged in a public outreach effort 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 Fall 2021, internal and external engagement events were held to educate and inform interested stakeholders about the ZEB Transition 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 completed the online survey with nearly 90 percent of respondents rating Metro Transit's transition to ZEBs as either important or very important.

3.3.2. 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 within the highest impact communities that have and continue to face significant historical disinvestment and/or poor air quality. 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 high impact communities 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.[20] Reflecting this feedback, Metro Transit has identified priority areas for ZEB service based on the relative percentage of first choice votes engagement participants assigned to each of the aforementioned equity and environmental justice variables.

3.4. Principle 3: Fiscal Impact

The principle of fiscal impact relates to the following goals and elements of the Metro Transit Strategic Plan:

- **Strategic Plan Core Element 3:** We evaluate our performance and foster innovation for continuous improvement
- **Strategic Plan Core Element 4:** We are responsible stewards of a transformative and financially sustainable transit system

The principle of fiscal impact means that we are responsible stewards of a transformative and financially sustainable transit system. To be responsible stewards, we will continuously evaluate our 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.

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

The current capital cost of putting a ZEB on the road for Metro Transit is at least 2.5 times as expensive as a diesel bus.[21] As ZEBs represent such a significant financial investment, 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 our customers.

3.4.2. 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. This is particularly important given that the current capital cost of putting a ZEB on the road for Metro Transit is at least 2.5 times as expensive as a diesel bus.[21] Metro Transit's potential capital funding

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[20] 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 Black, Indigenous, or a person of color, 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).

[21] Source: Metro Transit Statement, C. Desmond, September 2021

options for ZEB systems may be increasing in the near future. In particular, with the Federal IIJA being signed into law, $1.1 billion will be annually appropriated to the FTA Low-No program in federal fiscal year 2022-2026. The FTA's Low-No program is a discretionary grant program which historically has been awarded to less than 30 percent of the applicants through 2021.[22] In addition, Xcel Energy currently has a proposed $30 million Electric Bus Rebate Program under review by the Minnesota Public Utilities Commission. This rebate program has been the subject of substantial comments, including interest from the MN Department of Commerce and Attorney General's office, and if approved, it may be in a different form than is currently conceived. As a result, Metro Transit will need to continue to identify capital funding from a variety of sources to help to cover all of the costs of transitioning to a zero-emission fleet.

Beyond the capital costs associated with ZEBs, Metro Transit will also need to ensure that it can fund ongoing operation and maintenance (O&M) costs. These costs may initially be higher than the O&M costs associated with conventional diesel buses due, in part, to the challenges of working with emerging technology resulting in excess costs attributed to less reliable chargers and vehicles. As Metro Transit gains additional ZEB experience and develops a more complete understanding of the practical operating and maintenance costs associated with ZEBs, Metro Transit will collaborate with our 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 likely include implementing smart charging, modifying service delivery methods, and working with Xcel Energy to optimize specific utility rate selections and metering systems. Additionally, where financially possible, 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. Oftentimes, extended warranties can 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.

As Metro Transit implements items to control and reduce O&M costs, the agency will gain increased budget predictability, which in the longer-term may result in operational cost stability as unexpected costs and investments are reduced which could otherwise have resulted in cost overruns. Currently, Metro Transit's diesel fleet is dependent on diesel rates which are subject to market volatility despite a purchasing strategy to lock-in rates at levels advantageous to 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, as provided 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 thereby increasing overall energy operations costs. From the opening of the C Line in June 2019 to February 2021, the average energy cost per mile for the BEB fleet was $1.00 compared with $0.46 for the diesel bus fleet.[23]

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[22] *FFY 2016-2021 Low or No Emission Grant Program Projects Selections*. (Representative link for FY2020), FTA

[23] Source: *C Line Electric and Diesel Bus Performance Comparison Data*, Metro Transit

4. ZEB Technologies

This section introduces and outlines the strengths and weaknesses of the three ZEB technologies that are currently commercially available: electric trolleybuses, hydrogen FCEB, and BEB. This section aims to discuss and compare different ZEB technologies in a holistic, comprehensive manner to guide the process of selecting a short-term ZEB technology, without ruling out adopting other technologies in the long-term as ZEB technologies and markets change.

4.1. 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.[24]

4.1.1. 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 which power a pair of electromagnets on the switches.

Figure 10 Trolleybus in operation with two trolley poles in Seattle, WA

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 10). Operators usually raise and lower the trolley poles manually, by 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.

4.1.2. 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:

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

- Trolleybuses require overhead catenary wires to be installed throughout the corridors and in garages where trolleybuses are assigned to, which requires extensive initial capital investments for new systems;
- Garages need overhead clearance and need to be retrofitted with overhead wires to accommodate trolleybuses for storage and maintenance needs;
- 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.
- Placement of catenary poles can impact accessibility of sidewalk, underground utilities, and/or underground vaults.

4.1.3. **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 MBTA Silver Line in Boston, for the portion of the alignment under Boston Harbor. See Table 6, below, for a summary status of electric trolleybus usage in the United States.

Table 6: Current applications of electric trolleybuses in the United States

Agency	Fleet Size	Routes Served	Notes
San Francisco Municipal Transportation Agency *(SFMTA)*	**284** 185 (40’ New Flyer) 99 (60’ New Flyer)	**15**	Steep incline in the system necessitated trolleybus.
King County Metro	**174** 110 (40’ New Flyer) 64 (60’ New Flyer)	**15**	Steep incline in the system necessitated trolleybus. King County Metro plans to acquire 30 additional trolleybuses by 2037.
Massachusetts Bay Transportation Authority *(MBTA)*	**60** 32 (60’ Neoplan) 28 (40’ Neoplan)	**7**	Silver Line uses dual-mode trolleybus that are also capable of running on diesel when off-wire. MBTA intends to transition to BEB by 2023.
Greater Dayton Regional Transit Authority *(GDRTA)*	**45** (40’ Gillig)	**7**	
Southeastern Pennsylvania Transportation Authority *(SEPTA)*	**38** (40’ New Flyer)	**3**	

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. As other electric propulsion technology matures, MBTA plans to replace their existing trolleybus fleet with BEBs by 2023.[25]

King County Metro, with the support of Seattle Department of Transportation (SDOT) 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.[26] 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.[27]

4.2. Hydrogen Fuel Cell Electric Buses (FCEBs)

As the name suggests, a hydrogen FCEB uses an on-board fuel cell as its power source. A fuel cell is an electrochemical device that converts the chemical energy of a fuel and an agent into electricity through chemical reactions. A hydrogen fuel cell uses hydrogen as its fuel, burned with oxygen. Although fuel cells are a relatively new technology, 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.

4.2.1. Current Applications

As of December 2020, less than 10 percent of all active transit ZEBs nationwide were FCEBs. These FCEBs were operated by transit agencies in only four states: California, Illinois, Michigan, and Ohio.[28,29] California has been an early-adopter state when it comes to FCEBs as nearly 90 percent of all FCEBs operated by U.S. transit agencies, as of December 2020, were located in California. Programs developed under California Assembly Bill 32 (AB 32), such as the Low Carbon Transit Operations Program (LCTOP), have been incentivizing California transit agencies to invest in ZEBs including FCEBs, funded by California's Cap-and-Trade program.

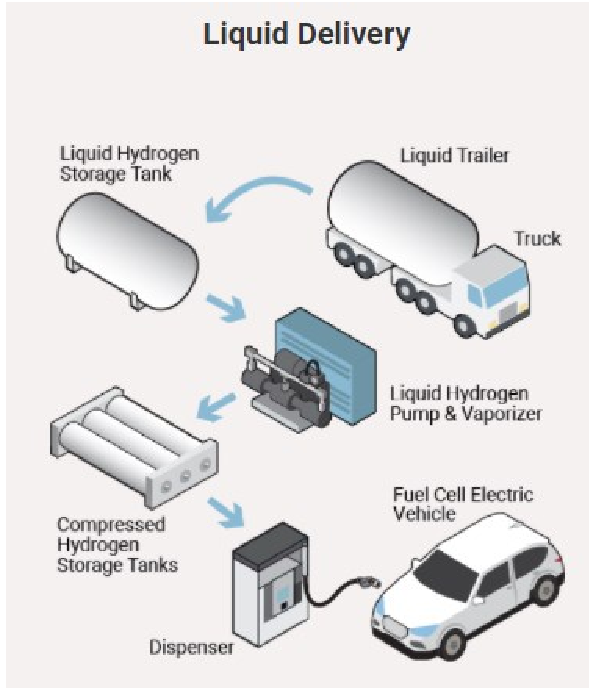
As an emerging technology, real world applications of hydrogen fuel cell buses are mostly limited to trial applications by a few transit agencies; the U.S. Department of Energy (DOE) and the FTA are funding a series of evaluation studies of fuel cell transit buses conducted by the National Renewable Energy Laboratory (NREL) to determine the status of bus fuel cell systems and establish lessons learned to aid other fleets in implementing the next generation of these systems.

[25] Source: *Modernizing Our Bus Fleet and Facilities*, MBTA, November 2020
[26] Source: Interview and email with King County Metro staff, October 2021
[27] Source: *Madison BRT nearing 90-percent design*, Madison Park Times, January 2019
[28] Source: *FCEV Sales, FCEB, & Hydrogen Station Data*, California Fuel Cell Partnership, 2021
[29] Source: *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2020*, NREL, March 2021

4.2.2. **Fueling Infrastructure**

The majority of industrially generated hydrogen gas is produced from natural gas, or other fossil fuels (e.g., oil or coal), by steam reforming. Steam reforming consists of heating the gas with steam and a catalyst to break up carbon monoxide and hydrogen from steam. This hydrogen can then be delivered in either a gaseous or liquid form.[30] Hydrogen gas is compressed and stored in storage tanks when delivered, whereas hydrogen liquid is vaporized first before being compressed and stored (Figure 11). For transit bus usages, hydrogen is typically transported and stored in liquid form, as it allows for higher storage capacity. FCEBs require hydrogen to be dispensed at a specific pressure level, which makes hydrogen fueling dispensers for FCEBs not suitable for other types of fuel cell vehicles.

Figure 11: Hydrogen fueling infrastructure[30]



Hydrogen fueling infrastructure and its associated fueling stations operate similarly to compressed natural gas (CNG) fueling infrastructure. If hydrogen is purchased from a supplier, the physical footprint for the equipment needed to accommodate hydrogen fueling is similar to that of diesel fueling infrastructure. While it is possible to produce hydrogen on-site through electrolysis or by natural gas reformation, this requires high electricity consumption and significant capital investment in ground storage. As of December 2020, only two U.S. transit agencies produced hydrogen on-site: AC Transit (Oakland, CA) and SunLine Transit Agency (Riverside County, CA).[29,31]

Reliable access to hydrogen fuel production sources and fueling stations is a significant challenge associated with FCEBs. Currently, the vast majority of transit agencies with FCEBs do not produce hydrogen on-site. 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. For example, as of 2019, hydrogen used to fuel Stark Area Regional Transit Authority's FCEBs (Canton Ohio), was trucked nearly 300 miles from Sarnia, Ontario.[32] Additionally, before installing an on-site hydrogen station at its facility, Orange County Transportation Authority, had to drive its FCEB to local retail stations to refuel.[29] As of January 2022, however, there are only 67 hydrogen fueling stations nationwide, of which 47 (67 percent) are located in California.[33] Therefore, although FCEBs are most feasible in California due to a

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[30] Source: *Hydrogen Costs and Financing*, California Fuel Cell Partnership
[31] Source: *Zero Emission Transit Bus Technology Analysis*, AC Transit, 2021
[32] Source: *Zero-Emission Bus Evaluation Results: Stark Area Regional Transit Authority Fuel Cell Electric Buses*, NREL 2019.
[33] Source: *Alternative Fueling Station Counts by State*, U.S. Department of Energy, January 2022

higher prevalence of hydrogen fuel production sources and retail stations, these sources are still very limited in number and currently none exist in Minnesota.

4.2.3. Operating Characteristics

FCEBs have a proven range of 250 to 300 miles per day,[29] which is a large enough range that FCEBs can be introduced for operation as a 1-to-1 replacement of diesel or hybrid diesel-electric bus fleets in most cases without the need for additional service or schedule changes. The following are some of the primary operating characteristics of FCEBs:

- Refueling for FCEBs can be done in a similar amount of time as a diesel bus;
- Fueling infrastructure and fuel storage is typically located outdoors;
- No requirement for roadside or on-route infrastructure to operate FCEBs;
- Operationally, FCEBs can be managed similar to diesel or CNG fleets;
- Fuel cost estimations are easy to perform as fuel is usually measured in kilograms. A FCEB usually needs 20 to 30kg per day per vehicle.

Although FCEBs allow for the one-to-one replacement of an existing bus fleet in most cases due to similar bus range and refueling times as conventional diesel buses, at this time, significant barriers largely negate these benefits:

- As of January 2022, there are currently no hydrogen fueling stations in Minnesota, so hydrogen would have to be created off-site and trucked to Metro Transit garages over long distances, most likely by diesel powered trucks.
- 95 percent of hydrogen currently produced in the United States involves the use of natural gas.[34] As a result, while FCEBs have zero tailpipe emissions, the production of this fuel is considerably more carbon-intensive than the generation of electricity required to power BEBs.
- Average capital cost of a FCEB vehicle is approximately 36 percent more expensive than a BEB.[35]
- Access to inexpensive and reliable hydrogen fuel sources remains a challenge for transit agencies deploying FCEBs.[29]

4.3. Battery Electric Buses (BEBs)

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.

4.3.1. Vehicles

Currently available BEB vehicles can be generally categorized into two types: (1) extended-range BEBs and (2) fast-charge BEBs.

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[34] Source: *Hydrogen Production: Natural Gas Reforming*, U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy

[35] Source: *Final Guidebook for Deploying Zero-Emission Transit Buses*, TCRP Project J-11/Task 33, April 2020

4.3.1.1. Types of BEBs

Extended-range BEBs have larger battery packs installed onboard to maximize their operating range between charges; operationally, they're typically charged once or twice per day (overnight or midday). Depending on the size of the battery and charger output, a full charge cycle can take up to 6 hours or more. While their advertised range may be longer, reliable range in transit service for currently available BEB models is typically under 130 miles per charge in Minnesota winters. With the currently available BEB models, it may be difficult 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.

Fast-charge BEBs have smaller battery packs onboard that are capable of high-powered charges. Fast-charge BEBs typically charge several times per day, charging for 5 to 20 minutes at higher power, often on-route. When implemented effectively, fast-charge BEBs can have essentially indefinite range of operations throughout the day. While fast-charge BEBs tend to be more expensive compared to extended-range BEBs, fast-charge BEBs can be considered for closer to 1-to-1 replacements of conventional diesel buses but may require longer layovers to provide adequate time for on-route charging. If longer layovers are necessary, an additional bus and operator or two may be needed per route to provide the same level of service. Compared to the typical layover duration necessary for a diesel bus, the initial service plan for the C Line provided longer layovers for on-route charging. Metro Transit has found that this layover strategy required two additional operators, or approximately 10 percent more operators, to provide the same level of service on the C Line.

4.3.1.2. 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 2021, BEB manufacturers offer on-board BEB batteries with capacities typically ranging from approximately 215 kWh to 686 kWh.[36,37] 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 of 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 able to ensure 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

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[36] Source: *Electrifying Transit: A Guidebook for Implementing Battery Electric Buses*, National Renewable Energy Laboratory, April 2021

[37] Source: *GILLIG's next-generation battery to provide 32 percent increase in onboard energy*, Gillig, November 2021

planned. These factors translate to usable battery capacities between approximately 145 kWh and 465 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. Typically, slower speeds are a result of either busy or congested environments. In busy environments, buses often see greater energy usage, 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.

4.3.1.3. Manufacturers

Available BEBs on the market, as of 2021, are listed in Table 7 below. 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. Both extended-range BEBs and fast-charge BEBs are included.

Table 7: Currently available BEB manufacturers as of 2021

Manufacturer	Bus Length	Battery Capacity	Advertised (Nominal) Range	Usable Range in Minnesota Winter*
BYD[38]	30’ – 60’	215 kWh – 578 kWh	157 mi – 193 mi	42 mi – 112 mi
GILLIG	35’ – 40’	490 kWh – 686 kWh	150 mi – 210 mi	95 mi – 133 mi
Green Power	30’ – 45’	260 kWh – 600 kWh	163 mi – 212 mi	51 mi – 117 mi
New Flyer	35’ – 60’	350 kWh – 525 kWh	153 mi – 251 mi	68 mi – 102 mi
Nova Bus	40’	564 kWh	211 mi – 292 mi	110 mi
Proterra	35’ – 40’	450 kWh – 675 kWh	240 mi – 329 mi	87 mi –131 mi

** Usable range assumed to be 68 percent of usable winter battery capacity. See, Section 8.3.1, for detail on the motivation and rationale used in developing this conversion rate.*

4.3.2. **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 12). Plug-in chargers are more commonly used at garages, whereas overhead and inductive chargers are mostly used for on-route charging. BEB

[38] Note: As of December 20, 2021, FTA funding of procurements of rolling stock from any manufacturer that is “owned and controlled by, is a subsidiary of, or otherwise related legally or financially to a corporation based in” certain foreign countries are generally prohibited. See Section 7613 of the National Defense Authorization Act for FY 2020 and 49 U.S.C. § 5323(u).

charging infrastructure typically includes transformers, switchgear, chargers (charger "bases" where the majority of equipment is housed) and dispensers (e.g., pantographs or plugs).

Figure 12: BEB charging infrastructure

Plug-in

Overhead Conductive

Inductive

4.3.2.1. Types of Chargers

Plug-in chargers typically have between one and four dispensers allowing for scheduled charging of multiple buses. Charge power for plug-in chargers ranges from 50 to 180 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, 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 you to fill your gas tank 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 150 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. Currently, there is no national standard for inductive charging. As a result, each bus manufacturer could approach this charging strategy differently meaning that different charging 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 not compatible with smartphones from different manufacturers or how smartphone companies can change the charging port between phone versions.

A summary of BEB charging infrastructure is shown in Table 8.

Table 8: Comparison of different 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 • Not all manufacturers offer overhead conductive charging
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	• Higher 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 • May not be compatible with snow-covered pavement in winter

Note: Adapted from TCRP Research Report 219: Guidebook for Deploying Zero-Emission Transit Buses[39]

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

4.3.2.2. Garage Charging and On-route Charging

All types of chargers discussed above are capable of garage charging (often for longer 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 durations during layovers. Table 9 summarizes the key benefits and challenges associated with on-route charging.

Table 9: 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
Provides greater flexibility in service design	More expensive to operate due to daytime electricity premium
Smaller batteries, greater efficiency	Requires more operators and vehicles to allow for longer layovers for charging
Provides greater flexibility in service design	Adds operational complexity

4.4. Comparison of ZEB Propulsion Technologies

Having introduced each of the three types of ZEBs as well as their operating characteristics and fueling/charging infrastructure above, Table 10 presents a direct comparison of several critical aspects across each of the three ZEB technologies.

Table 10: Comparison of ZEB propulsion technologies

Consideration	Electric Trolleybus	Battery-Electric Bus (BEB)	Hydrogen Fuel Cell Electric Bus (FCEB)
Range	Unlimited range on overhead catenary wire. Limited auxiliary off-wire operations around 15 to 20 miles	Limited range (likely less than 150 miles on a single charge) influenced by battery capacities, challenging climates, and topographies	Proven range of 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	Garage or On-Route Charging • Plug-in charging • Overhead conductive charging • Wireless inductive charging	Hydrogen Storage and Fueling Station • Purchase gaseous or liquid hydrogen • Produce hydrogen on-site
Capital Costs	High initial capital cost as overhead wires are required throughout the corridor for power supply Significant capital cost to retrofit garages with overhead wires	More expensive than diesel buses Charging infrastructure costs vary depending on the number of buses/chargers Infrastructure is scalable Incremental costs or space requirements increase with fleet size	More expensive than both diesel and BEBs Significant capital cost of fueling infrastructure Additional buses may not require additional fueling infrastructure
Operating Cost Considerations	Higher maintenance costs to maintain overhead wire system Increased electricity usage during peak (more expensive) periods	Longer layover times to allow for on-route layover charging require more operators and vehicles Greater flexibility to charge during off-peak (less expensive) periods Increased budget predictability due to stable utility rates	Require less operators and vehicles compared to BEBs due to greater vehicle range Significant fuel costs ($13 to $16 per kg)
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 to HFCBs Charging times can last up to 8 hours Major facility and operational changes are often required	Significant upstream carbon emissions to extract and transport hydrogen Refueling times of 5-10 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[39] and California Fuel Cell Partnership[30]

5. ZEB 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 and best practices as well as words of caution to consider when transitioning to ZEBs.

To identify and summarize best practices and lessons learned from North American transit agencies that have implemented or piloted a wide variety of ZEB types and systems, Metro Transit conducted a review of five transit agencies' ZEB experience including Metro Transit's own experience operating BEBs as part of the C Line pilot program.

These case studies include the agencies with the longest track record operating ZEBs, as well as a heavy emphasis on northern agencies (located between 40- and 50-degrees latitude, other than Foothill Transit) (Figure 13). To provide insight and lessons learned from a wide range of ZEB experiences, the case studies were specifically selected to encompass a variety of different technologies (buses and supporting infrastructure), fleet sizes, climates, 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 (KCM) – King County, Washington
- Chicago Transit Authority (CTA) – Chicago, Illinois
- Toronto Transit Commission (TTC) – Toronto, Ontario, Canada

Figure 13: Geographic distribution of case studies

In addition to the formal case studies presented below, Metro Transit staff engage in peer discussions to exchange ZEB experiences, challenges, and successes two to three times a month. Metro Transit has learned a great deal from the exchanges. In addition, Metro Transit's Principal Engineer for Electric Bus Infrastructure serves as an officer of the American Public Transportation Association's (APTA) Zero Emissions Fleet Committee and as a member of the Electric Bus Charger Procurement Standards working group. The Zero Emissions Fleet committee is an industry forum for the discussion and sharing of information and best practices around zero-emission buses and infrastructure.[40] Metro Transit staff also participate in the North American eBus Experience Group hosted by Toronto Transit Commission. This group meets several times per year to share experiences and challenges with electric bus deployment and includes over thirty North American transit agencies.

Additionally, Metro Transit staff participated in the APTA's 2021 ZEB Virtual Study Mission to Europe which included peer exchanges with:

- Groningen, Netherlands
- Drenthe, Netherlands
- Paris, France
- Cologne, Germany
- London, United Kingdom

5.1. C Line Experience (Minneapolis-Saint Paul, Minnesota)

5.1.1. **ZEB Program History**

As part of Metro Transit's long-standing efforts to move toward greener operations, in 2018, Metro Transit established a BEB pilot program as part of its implementation of the METRO C Line, 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 kilowatt-hour (kWh) batteries in addition to two on-route overhead conductive chargers installed at the Brooklyn Center Transit Center, the route's northern terminus, as well as eight plug-in garage chargers and other associated charging infrastructure 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 (Figure 14). This selection was driven in part, due to an emphasis on targeting the investment in 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.

[40] Source: *2021 40 Under 40: Carrie Desmond, PE*, Mass Transit

Figure 14 Metro Transit C Line 60-foot articulated BEB

The high levels of anticipated ridership along the C Line, meant that Metro Transit needed to utilize 60-foot buses to provide the necessary capacity. At the time of procurement for the C Line, the vast majority of in-service BEBs across the country were 40 feet long. In 2018, when Metro Transit was ordering buses for the C Line, 60-foot BEBs were a very new technology as 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. Although BYD now also produces 60-foot BEBs that have passed Altoona quality and safety testing, as of December 20, 2021, BYD is no longer eligible for FTA funding.[41] Therefore, at this time, New Flyer continues to be the only manufacturer offering 60-foot BEBs that have passed Altoona testing and are eligible for FTA funding.

As the C Line was a 60-foot pilot program, much of the program's infrastructure incorporated new technology, some of which was being utilized for the very first time including the:

- First eight 60-foot articulated BEBs produced at New Flyer's St. Cloud facility
- Siemens HPC 1.0 300kW on-route overhead conductive chargers with serial numbers 1 and 2
- First eight Buy America compliant Siemens RAVE 150 150 kW plug-in chargers (Figure 15).

[41] Note: As of December 20, 2021, FTA funding of procurements of rolling stock from any manufacturer that is "owned and controlled by, is a subsidiary of, or otherwise related legally or financially to a corporation based in" certain foreign countries are generally prohibited. See Section 7613 of the National Defense Authorization Act for FY 2020 and 49 U.S.C. § 5323(u).

While the C Line continues to provide valuable insight on the operation of 60-foot articulated BEBs operating on arterial BRT routes, the majority of Metro Transit's bus fleet (70 percent) is comprised of 40-foot buses. Therefore, to complement the C Line BEB pilot and to gain an understanding of how 40-foot BEBs perform in the Twin Cities region, Metro Transit plans to begin a second BEB pilot program with the purchase of eight 40-foot BEBs in 2022.

Figure 15: Siemens RAVE 150 plug-in chargers at the Heywood Garage

5.1.2. **BEB Operational Experience**

Based on the experiences from the first two years of the C Line Electric Bus Pilot Program, Metro Transit has identified many aspects of the program that have succeeded as well as areas to improve upon.

Since beginning the BEB pilot 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. On several occasions as a revenue service test, with range extending on-route charging at Brooklyn Center Transit Center, the BEBs were able to operate on two blocks in a single day with a combined mileage in excess of 170 miles without midday charging at the garage.[42] Additional areas of success for Metro Transit's C Line BEB pilot program include:

- Partnerships and Relationship Building;
- The formation of an interdepartmental working group; and
- Contingency Planning.

5.1.2.1. 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.[42] The establishment and maintenance of these relationships has allowed Metro Transit to create cutting edge technical and financial partnerships vital for managing costs and 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. Additionally, Xcel Energy has also proposed an Electric Vehicle Rebate Program that is currently under review by the Minnesota Public Utilities Commission (MPUC). The proposed rebate program includes $30 million dollars available to all

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

Minnesota Xcel Energy customers for the purchase of BEBs including both transit and school buses.

In addition to its partnership with Xcel Energy, Metro Transit has also 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. Moving forward, Metro Transit intends to establish a broader communication strategy with more frequent stakeholder communication designed to transparently set and manage expectations and timelines while clearly outlining the BEB transition goals that define a successful project.

5.1.2.2. Interdepartmental Working Group

Metro Transit has also successfully established an interdepartmental working group with bi-monthly meetings at the staff level to ensure that front-line staff have the latest information and are able to react to potential issues as they arise in real time. To further streamline communications and improve the delivery of BEB projects, Metro Transit plans to explore establishing a standing internal project team dedicated to BEB project work rather than adding BEB work to staff's regular daily responsibilities.

5.1.2.3. Contingency Planning

While developing its first BEB pilot program, Metro Transit knew that things would not always go according to plan as 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.[42] 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 have had an average monthly availability of approximately 71 percent between June 2019 and February 2021, compared to an 89 percent availability for the C Line diesel buses.[43]

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 months of the pilot program while the installation of on-route overhead conductive chargers was finalized.

Due to these contingency plans, Metro Transit has not missed service for the C Line as a result of vehicle unavailability or charger issues despite, at times, experiencing technical difficulties with

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

various aspects of the charging equipment and BEBs including, blown fuses, blank charging interface screens, chargers not restarting in extreme cold, transformer failures, and longer than expected charging infrastructure construction and installation 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. Technology reliability will need to improve to reduce the need for contingency planning as Metro Transit continues to add more BEBs to the fleet.

5.1.2.4. Climate and Range Challenges

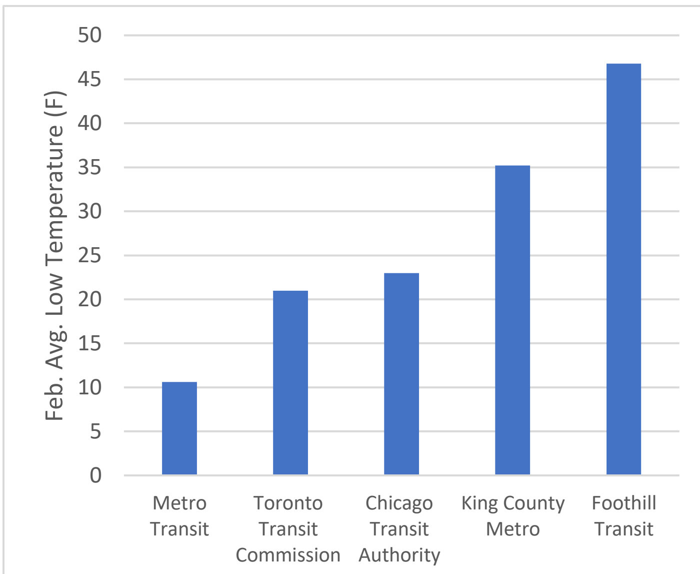
In addition to the aforementioned areas of success, Metro Transit has been able to use the C Line pilot program to identify and correct shortcomings and other challenges the agency faced leading to increased operational knowledge and understanding of BEB intricacies as well as an improved service for Metro Transit's riders.

One of the biggest challenges that Metro Transit faces in implementing BEBs is the climate in Minnesota. 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 United States.

In February 2021, the region experienced 13 days of below zero temperatures including -19 degrees F

Based on 30-year average temperatures, Minneapolis averages the coldest winters of any major U.S. city.[44] Additionally, compared to other peer cities, Minneapolis has the coldest historical low temperature for the month of February (Figure 16).[45] 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 negative 19 degrees Fahrenheit.[46]

Figure 16: February average low temperature in case study cities



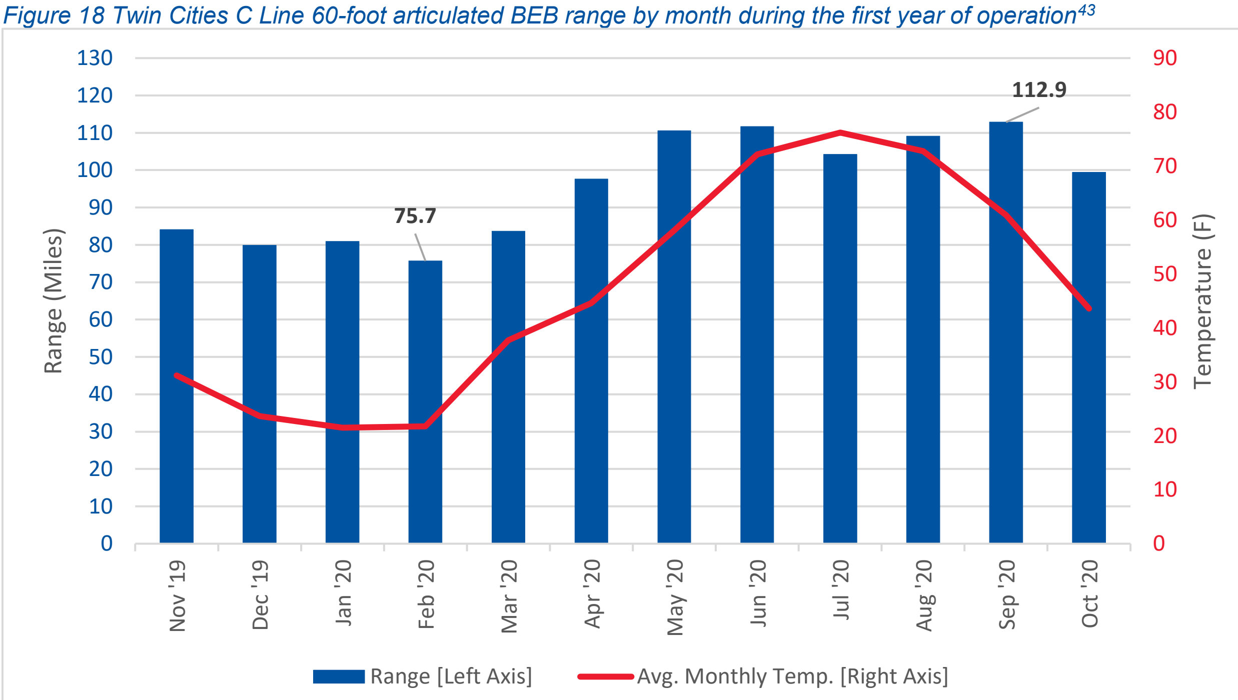
[44] Source: *America's 20 Coldest Major Cities*, NOAA, 2014
[45] Source: https://www.weather-us.com/
[46] Source: *Twin Cities Weather - February 2021*, Weather.gov, 2014

These extreme low temperatures are particularly problematic for the operation of Metro Transit's outdoor on-route overhead conductive chargers which have a minimum operating temperature of negative 20 degrees Fahrenheit, a temperature the Twin Cities occasionally drops below. To address this challenge and to restart chargers in these cold temperatures, Metro Transit has had to build temporary structures around the chargers and blow hot air on to them in order to warm the equipment to a temperature at which they can turn on (Figure 17).

Figure 17: Temporary charger structure

To reduce the impact on bus range due to cold weather, Metro Transit's BEBs are equipped with diesel auxiliary heaters, which can be used in cold weather to heat the cabin, allowing the electricity from the battery to primarily be used to propel the bus. During the first year of C Line service, BEB range varied significantly depending on the temperature (Figure 18). A theoretical maximum average daily range by month of approximately 113 miles was achieved in September 2020, when very little electricity was needed for heating or cooling the buses compared with a low in February 2020 of approximately 76 miles.[47] This represents a 33 percent reduction in the range, the equivalent of four fewer one-way trips in February than in September per overnight charge.

Figure 18 Twin Cities C Line 60-foot articulated BEB range by month during the first year of operation[43]



[47] Note: C Line Pilot theoretical range calculated assuming 70 percent of nominal battery capacity to account for 10 percent of battery capacity reserved for battery life preservation and 20 percent of nominal battery capacity reserved for operational flexibility.

5.1.2.5. 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. In addition, the pilot program also utilized technology and equipment that had never been implemented before including:

- First eight 60-foot articulated BEBs produced at New Flyer's St. Cloud facility
- Siemens HPC 1.0 300kW on-route overhead conductive chargers with serial numbers 1 and 2
- First eight Buy America compliant Siemens RAVE 150 150 kW 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 correct these shortcomings – ultimately leading to an improved service for Metro Transit's riders and improved products for future customers.

As part of these efforts to monitor performance and resolve potential shortcomings, Metro Transit tracks the number and frequency of C Line road calls, defined as operating problems that occur during revenue service that necessitate removing the bus from service until repairs are made. 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 10 months of the pilot program (June 2019-March 2020), C Line BEBs had poor reliability with an average of nearly twenty road calls per month or about every 620 miles (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. As a result of these collaborative improvements, between April 2020 and February 2021, BEBs traveled nearly three times further between road calls compared with their first ten months in operation.[43]

Table 11 C Line BEB road call performance

Timeframe	Total Number of Road Calls	Average Miles Between All Road Calls
June 2019 – March 2020	199	622
April 2020 – February 2021	116	1,833

Overall, 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. In particular, 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.[42] 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. Since March 2019, 25 updates, or nearly one update every month, have been made to the C Line's BEB software.[42] Although each update improves BEB operation, Metro Transit must relearn the intricacies of the BEB software with each update. 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 which led to lower output voltages and the occasional need to replace individual batteries.[43]

Beyond bus-specific challenges, garage chargers have occasionally had their interface screen go blank and stop charging due to the main breaker being tripped and several semiconductors being blown. Additionally, all garage chargers were replaced under warranty in 2021 due to insufficient structural support of transformer windings leading to premature transformer degradation. On-route overhead conductive chargers used for the pilot program have also contributed to Metro Transit's early adopter challenges as these chargers have had dozens of blown fuses as well as a premature transformer failure leading to the chargers being out of service for extended periods of time.

As a result of these challenges, the BEB pilot program has been suspended three times between launch and November 2021, and C Line service has had to rely more heavily on diesel buses than originally planned.[43] These outages lasted approximately one week in July 2019, approximately one month in October 2019, and nine months from March 2021 through November 2021. In Fall 2021, all garage chargers were replaced under warranty and Siemens agreed that the on-route overhead conductive chargers were eligible for replacement under warranty after extensive component failures. 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 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 times and construction times to install the significant electrical infrastructure necessary to support successful BEB operation. Additionally, Metro Transit has learned the benefits of including performance metrics in contracts to define acceptable availability of BEB equipment to sustain operations.

5.1.2.6. Lessons Learned

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

- 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

5.2. Foothill Transit (Greater Los Angeles, California)

5.2.1. **ZEB 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. Since then, Foothill Transit's BEB fleet has driven nearly two million miles and grown to include a total of 34 electric buses in revenue service (Table 12) including the first two double-decker BEBs purchased by an United States public transit agency (Figure 19).[48]

Table 12: Current Foothill Transit BEB fleet by in-service year[49]

In-Service Year	Quantity	BEB Type
2010	2†	35-foot Proterra Catalyst Fast-Charge
2014	11*	35-foot Proterra Catalyst Fast-Charge
2016	2	40-foot Proterra Catalyst Fast-Charge
2017	14	40-foot Proterra E2 Extended-Range
2018	3	35-foot Proterra E2 Extended-Range
2021	2	45-foot ADI Enviro500EV Double Decker
TOTAL	**34**	

†One bus exchanged with Proterra for a 40-foot Proterra E2 extended-range bus
**One bus retired early due to technological challenges*

Foothill Transit estimates that between 2010 and 2016, their electric buses have saved over 200,000 gallons of natural gas and have eliminated 2,616 tons of greenhouse gases.[50] To continue their ongoing commitment to sustainability, in 2016, Foothill Transit set a goal of transitioning its fleet to be fully electric by 2030.[50] Based on their experience with early BEBs and to align with the California Air Resources Board's (CARB) Innovative Clean Transit Program, in 2019, Foothill Transit updated their transition goal to target a 100 percent zero-emissions fleet by 2040 (previously 2030).[51] As of 2021, approximately ten percent of their bus fleet are ZEBs.

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[48] Source: *Foothill Transit Sustainability*, Foothill Transit
[49] Source: *Executive Board Meeting*, Foothill Transit, July 23, 2021.
[50] Source: *Foothill Transit Announces All Electric Bus Fleet By 2030*, Foothill Transit, May 2016.
[51] Source: Interview and email with Foothill Transit staff, October 2021

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 hydrogen FCEBs and the associated fueling infrastructure on Line 486 which provides service between El Monte and Pomona. The completion of project construction as well as the delivery of the FCEBs is expected by the third quarter of 2022.[52]

Figure 19: Foothill Transit Enviro500EV double decker BEB

5.2.2. **BEB Operational Experience**

Foothill Transit operates BEBs out of both of its operation and maintenance facilities (garages): Arcadia and Pomona. All of Foothill Transit's current BEBs, with the exception of the two double-decker BEBs, are Proterra buses and utilize Proterra's lighter weight composite-body (Figure 20). As of Fall 2021, Foothill Transit operates its extended-range BEBs out of the Arcadia garage while the fast-charge BEBs operate out of the Pomona garage.

5.2.2.1. Fast-Charge BEB Experience

Foothill Transit primarily operates its 15 fast-charge BEBs on Line 291, a 16-mile round-trip local route running between the cities of La Verne and Pomona. The first BEB servicing this route was deployed in 2010 and by 2014, the route was exclusively served by BEBs, making it the first all-electric fast-charge bus line in the nation.[48] Currently, 13 of the 15 fast-charge BEBs operating on this route are 35-feet long, while two are 40-feet long.

Figure 20: 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).[53] 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 and did not match the 94 percent availability achieved by the baseline compressed natural gas (CNG) buses during the same timeframe.[53]

[52] Source: *Foothill Transit Governing Board Meeting*, Foothill Transit, October 1, 2021.
[53] Source: *Foothill Transit Battery Electric Bus Evaluation: Final Report*, NREL, June 2021.

Table 13: Summary of fast-charge BEB 2014-2020 evaluation results[53]

	Fast-Charge 35-Foot BEBs	Fast-Charge 40-Foot BEBs	CNG 40-Foot Buses (Baseline)
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	$0.28
Miles between roadcalls (MBRC) – (4,000 Target)	5,680	8,050	25,100
MBRC – Propulsion System Only	13,400	17,000	37,900
Total Maintenance cost ($/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' recent performance. 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. Since then, however, BEB availability has steadily declined from approximately 85 percent in 2017 to about 60 percent in December 2020.[53]

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

Overall, after between seven to eleven years of operation, Foothill Transit's 35-foot fast-charge buses have reached the halfway point of the 12-year/500,000-mile useful life benchmark for buses, regardless of propulsion type, set by the FTA. As a result, the electrical components and general body of these BEBs are starting to show signs of wear. Specific issues with the bus body include cracking as well as the deformation of plastic interior panels, front wheel cabinets and driver bulkheads due to the exposure to heat and sunlight.[49] Additionally, as the BEBs get older, their availability has decreased. Since the BEB technology is still relatively new, it has been challenging to find replacement parts for the vehicles-See Early Adopter Challenges (Section 5.2.3) below.

5.2.2.2. Extended-Range BEB Experience

In addition to short-range BEBs, Foothill Transit also operates 17 extended-range BEBs. These buses are based out of the Arcadia facility and primarily operate on Line 280, a 22-mile round trip 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 are also able to take advantage of the overhead fast-charger at the Azusa Intermodal Transit Center in order to extend the bus range since some of the route blocks go beyond the 150-mile range of these buses.[53]

To evaluate the performance of their extended-range BEBs, Foothill Transit compared several Key Performance Indicators (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 this year long evaluation conducted in 2020, Foothill Transit has 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 has remained fairly stable throughout 2020.

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 roadcalls for the extended-range BEBs was nearly comparable to that of the CNG buses.

Table 14: Summary of extended-range BEB 2020 evaluation results[53]

	Extended-Range 40-Foot BEBs	CNG 40-Foot Buses (Baseline)
Availability (85% Target)	82%	94%
Fuel economy	1.90 kWh/mile	3.38 mpgge*
Fuel Cost ($/mile)	$0.42	$0.37
Miles between roadcalls (MBRC) – (4,000 Target)	23,100	24,600
MBRC – Propulsion System Only	33,800	31,500
Total Maintenance cost ($/mile)	$0.36	$0.35
Maintenance cost- Propulsion System Only	$0.10	$0.12

**Mpgge defined as the miles per gasoline gallon equivalent*

5.2.2.3. Express Service BEB Experience

To broaden the types of bus service BEBs were operated on, 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. While the Double Decker BEBs have not been in service long enough to generate robust data for performance comparisons, 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.[51]

5.2.3. 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.

One issue Foothill Transit is working with manufacturers to resolve is that the reliability and overall "fit-and-finish" quality of the buses, and in particular the fast-charge BEBs, has been steadily degrading over the past five years. For example, since 2019, the BEBs have been out-of-service between 30 to 67 percent of the time and as of July 7, 2021, only three of the 15 fast-charge BEBs on Line 291 were available for service.[49] As a result, CNG buses have had to be deployed on Line 291 to compensate for the lack of BEBs available for service.[49]

The high out-of-service rates of the BEBs largely stem from general bus issues and the availability of replacement parts rather than the chargers and bus propulsion systems.[49] 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. As a result, these buses use an overhead fast-charge solution that is obsolete and no longer the preferred charging option as Proterra and other manufactures now build to recently adopted industry standards.[49] 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.[49] 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.[51]

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.[51] 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 one-to-one 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 one replacement of existing CNG buses.[51,54] This increased fleet size would, in turn, lead to further increases in capital and operating costs. Due to these fleet implications, in the short-term, Foothill Transit plans to explore the implementation of FCEBs as hydrogen fuel sources are available in California and because FCEBs, if reliable, would allow for a one-to-one replacement of CNG or diesel buses without significant operational changes.

5.2.4. **Charging Configuration**

Foothill Transit's existing BEB charging infrastructure consists 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.[53] 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.[51] 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.

[54] Source: *In Depot Charging and Planning Study*, Burns & McDonnell, September 2019.

5.2.5. **Cost Benefit Analysis**

Based on over six 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.[53] When comparing the lifecycle 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.[54] This estimation is based on Foothill Transit's experience over the last 11 years as they approach completing the first full lifecycle of a BEB in the United States. However, as no transit agency has yet run a BEB through an entire lifecycle, the true lifecycle costs are unconfirmed.

5.2.6. **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 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.[51]

5.2.7. **Future Fuel Cell Electric Bus Procurement**

As an industry leader in the adoption and integration of ZEBs, Foothill Transit has learned the importance of having ZEB transition plans that flexibly and dynamically respond to technology advancements. For example, while simultaneously working towards solutions addressing current BEB challenges, Foothill Transit has continued to explore other additional ZEB technologies. In an effort to operate and deploy ZEB service where buses can quickly be refueled and then run for more than 300 miles, in the third quarter of 2022, Foothill Transit plans to implement a hydrogen FCEB pilot program. As of December 2020, only four states (California, Illinois, Michigan, and Ohio) had transit agencies operating FCEBs of which, only California had more than 10 FCEBs in active transit service.[29] FCEBs are of specific interest to Foothill Transit as operating data from the dozen transit systems using FCEBs indicate that these buses have ranges that are comparable to conventional CNG buses.[29,52] Unlike BEBs, the increased range of FECBs would allow Foothill Transit to have a one-to-one bus replacement.[55] Additionally, there are multiple producers of hydrogen fuel in the state of California allowing the fuel to be readily delivered to agency operations and maintenance facilities.

5.2.8. **Lessons Learned**

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

- Expect the unexpected
- Recognize that until a transit agency has run a BEB to the end of its life, true BEB lifecycle costs are unconfirmed

[55] Source: *Foothill Transit Governing Board Meeting*, Foothill Transit, October 1, 2021.

- ZEB transition plans 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

5.3. King County Metro (King County, Washington)

5.3.1. ZEB Program History

King County Metro (Metro) is a national leader and early adopter of alternative-fuel buses including diesel-electric hybrids, electric trolleybuses, and most recently, BEBs.[56] Metro operates the second largest electric trolleybus fleet in the country, behind MUNI in San Francisco, and has for decades.[57] 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.[58] 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 five transit agencies across the country operate trolleybuses.[57] As a result, Metro operates more trolleybuses than the rest of the country combined, excluding MUNI.[57]

Metro began exploring BEBs in the fall of 2015, conducting a 106-day comprehensive test on a leased Proterra Catalyst BEB. During this testing, the BEB operated 24 hours per day achieving a 98 percent uptime with only six out-of-service days, including three holidays.[59]

Based on the success of this rigorous test, in February 2016, Metro began piloting three fast-charge 40-foot Proterra 2015 Catalyst BEBs on two interlined routes (Routes 226 and 241) in Bellevue, WA. Over the course of four months, the BEBs were nearly as reliable as diesel buses with an overall average availability of 84 percent versus 88 percent, respectively.[60] Funding for the program came from FTA Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) grants and local funds.

In 2017, Metro committed to transitioning to a 100 percent ZEB fleet powered by renewable energy by no later than 2040.[56] In recognition of the worsening climate crisis, in February 2020, the King County Council adopted an ordinance to shorten the previous transition timeline by five years, setting a 2035 target for a 100 percent ZEB fleet.[61] To reach this ZEB goal, Metro plans to continue to utilize electric trolleybuses where they are currently operating while primarily implementing BEBs elsewhere.[62] In the short-term, Metro has focused on expanding their BEB fleet as the trolleybus fleet has stayed nearly the same size for the last twenty years. By 2037, however, Metro plans to order 30 additional electric trolleybuses and is exploring the possibility of expanding their overhead electrified catenary wire system to increase the area within which

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[56] Source: *Metro is transitioning to a zero-emissions bus fleet,* King County Metro, August 2019.
[57] Source: *The National Transit Database (NTD)*
[58] Source: *King County Trolley Bus Evaluation*, King County Metro, May 2011
[59] Source: *Proterra Completes Toughest Road Test to Date*, Mass Transit, April 2016.
[60] Source: *King County Metro Battery Electric Bus Demonstration – Preliminary Project Results*, NREL, May 2017.
[61] Source: *Council Approves Plan to Accelerate Conversion of Metro Fleet to All-Electric,* February 4, 2020.
[62] Source: Interview and email with King County Metro staff, October 2021

zero-emission trips can be provided by the electric trolleybuses.[62] As of January 2021, 185 buses or twelve percent of Metro's fleet were ZEBs including 174 trolley buses and the 11 Proterra BEBs.[63]

In 2019, Metro conducted a head-to-head comparison of BEB buses from three manufacturers (Proterra, New Flyer, and BYD), see Head-to-Head Analysis section below. Based on the results of this analysis, Metro recently announced the purchase of 40 New Flyer Xcelsior CHARGE BEBs for delivery in 2021. These BEBs were funded through a combination of funds from the Volkswagen Settlement program, the FTA (including a Low or No Emission Vehicle Grant), and the new Washington Department of Transportation's Green Transportation Capital Program. Following this procurement, Metro has plans for an additional procurement of 250 BEBs for delivery between 2025 and 2028.[62,64] By spacing out their BEB procurements and selecting this timeline, Metro anticipates being able to learn from their past BEB procurements and gain valuable operational experience and knowledge based on two to three years of revenue service with large scale BEB deployment, before purchasing more BEBs. In addition, this lengthened timeline will provide Metro with sufficient time to work with their utility provider to make the necessary electrical infrastructure upgrades required to support BEB service.

5.3.2. **BEB Operational Experience**

As of late Fall 2021, Metro's operational experience with BEBs is centered around two unique pilot programs: the fast-charge Bellevue Service and the leased BEB head-to-head analysis.

5.3.2.1. Bellevue Service

For its fast-charge Bellevue Service, 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, Metro uses a unique charging setup with three on-route chargers affixed to a single overhead gantry with space for two additional chargers (Figure 21). 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. As the fast-charge BEB's 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 charging rates

Figure 21: King County Metro overhead gantry charging system

[63] Source: *Battery-Electric Bus Implementation Report*, King County Metro, January 2020
[64] Source: *Executive Constantine announces purchase of up to 120 battery-electric buses from New Flyer of America, Inc.* King County Metro, January, 2020

exceeded 50 kW.[65] To supplement this layover charging, Metro also uses a low-power plug-in maintenance charger and overhead charger located at the base (garage).[62]

From their experience on the Bellevue BEB service, Metro has realized the importance of understanding the impact BEBs' operational differences can have on route scheduling and training needs.[65] 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.[65] To emphasize the heightened importance of BEB layover time and to highlight other operational differences between BEBs and conventional buses, Metro has focused on developing specific training programs for all operators and staff working on routes serviced by BEBs.

5.3.2.2. Head-to-Head Extended-Range BEB Analysis

Complementing their experience with short-range fast-charge BEBs on the Bellevue Service, Metro leased a mix of 10 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 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 does not manufacture 60-foot BEBs (Table 15). To ensure that the test BEBs would have sufficient range to cover the majority of the routes/blocks in the system, 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.[62] To meet this requirement, all buses had battery packs with capacities of at least 500 kWh. At the end of this testing period, the 10 buses and charging infrastructure were returned to their manufacturers.

Table 15: King County Metro 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, Metro drove the buses in all types of weather and on all route types ranging from freeway service to local service with hills.[66] For this lease period, Metro'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, 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).[66]

[65] Source: *Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses*, FTA, February 2018.
[66] Source: *Zero-Emission Battery Bus Preliminary Implementation Plan*, King County Metro, September 30, 2020

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

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.[62] Additionally, the BYD buses were found to perform poorly in King County's hilly topography.[66] 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.[66]

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. Metro was then able to use this information to provide detailed feedback to each of the bus manufacturers. Overall, the head-to-head pilot program has provided Metro with a wealth of information that the agency can use to further improve their future procurement and operation of BEBs.

5.3.3. KPI Reporting

To monitor BEB performance and identify areas for future improvement, Metro tracks several Key Performance Indicators (KPIs). When initially presenting KPIs, Metro included multiple pages of graphics and numbers summarizing BEB performance. Over the course of their BEB pilot programs, however, 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, Metro 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. 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:

- 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 to distill the vast amounts of performance data into the most useful and usable reports, moving forward, Metro plans to explore pursuing the inclusion of telematics packages with custom report templates on all vehicles. To improve KPI comprehension, Metro 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.[62]

5.3.4. **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, Metro has decided to rely primarily on extended-range buses charged with a combination of fast and slow chargers located at their bases (garages) as well as charging at select on-route locations.[62,66] 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 to longer length routes and blocks. For buses with a low midday charge status or those that need to return to service quickly, Metro anticipates utilizing its fast chargers.[66] If the agency were to only utilize its garage-based lower-power chargers, Metro estimates that 70 percent of their existing service could be supported with no route structure changes assuming a BEB range of 140 miles.[62,67] Metro recognizes, however, that BEBs are different than diesel and diesel-electric hybrid buses and may therefore require some changes in operating strategy to extract the maximum utility from these vehicles. In the short-term, however, Metro does not intend to change route structures of their block build-up given that nearly three quarters of their existing service can be served with the current technology and the charging scheme outlined above.[62]

5.3.5. **Base (Garage) Transition**

To support the agency's growing BEB fleet and to provide the space necessary to install and operate BEB charging infrastructure, Metro is implementing significant facility renovations. As part of this effort, Metro is building a twelve-charger installation located at its South Campus known as the South Base Test Facility (SBTF).[62] 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 Metro to demonstrate interoperability between various charger and bus manufacturers as well as serving as a facility for the development of training and maintenance practices.[63] By the end of 2021, the facility is expected to include three overhead gantry systems (with both a pantograph and plug-in dispenser), three mast-style overhead pantograph chargers, and three ground-mounted plug-in chargers.[62]

In addition to the SBTF, Metro is currently constructing its Interim Base (garage) at the South Campus, which is expected to be completed between 2024 and 2025. The Interim Base (garage) is intended to be a prototype for future BEB deployment and electrification. At the Interim Base (garage), Metro plans to utilize 100 dispensers/pantographs and 35-50 chargers. It is anticipated that for every higher-power charger located at the Interim Base (garage) there will also be approximately 12 lower-power chargers.[63] To allow for service delivery during extended-duration power outages, Metro has implemented an operating plan for its Interim Base (garage) where diesel-hybrids would replace BEBs until power is restored.

5.3.6. **Cost Benefit Analysis**

As 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, Metro conducted an updated cost benefit analysis of

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[67] Note: In Section 8.3.1.2, it is stated that Metro Transit is assuming a lower range for BEBs than King County Metro. This is due to the need to accommodate colder temperatures in Minneapolis and Saint Paul than King County, Washington.

transitioning to a zero-emission fleet using BEBs. The analysis examined capital, operating, disposal, and societal costs. In this analysis, Metro ran two scenarios: the moderate/current case and a favorable BEB case which assumed that the costs for BEBs decreases over time as technology develops.[66] Although the capital and operating costs were found to be more expensive for BEBs than diesel-hybrid buses, 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, Metro found that overall, a BEB fleet would be one 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.[66]

5.3.7. Prioritization Method

When planning and implementing ZEB service, Metro considers technical and physical viability criteria, in addition to equity considerations and community feedback. In particular, Metro 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, 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.[68] Based on this analysis, for the initial transition to ZEB service 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, Metro is able to provide the greatest benefit to communities that have historically been disproportionately affected by air pollution.[66]

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 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, Metro 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, 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.

5.3.8. 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

[68] Source: *Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet*, King County Metro, March 2017

with new technology that may negatively impact service reliability until the industry advances the technology to resolve these challenges

- 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

5.4. Chicago Transit Authority (Chicago, Illinois)

5.4.1. ZEB Program History

The Chicago Transit Authority (CTA) first implemented ZEBs over two decades ago with a pilot of three hydrogen FCEBs between 1997 and 2000.[69] 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 80-120 miles. When these two BEBs entered service in 2014, CTA became one of the first U.S. transit agencies to use BEBs as part of regular service.[70] Since their initial deployment, CTA has retrofitted the two New Flyer BEBs to add charge rails to the roofs of the buses for compatibility with overhead conductive chargers. Following this initial procurement of BEBs, four years later, in 2018, CTA executed a contract for 20 Proterra 40-foot BEBs, which was later expanded to include a total of 23 (rather than 20) BEBs.[71] In 2019, the City of Chicago made a commitment for all CTA buses to be electric by 2040. As part of its effort to achieve this goal, the CTA recently established a contract with Proterra for 23 40-foot BEBs.

To ensure the successful deployment of the Proterra BEBs and to mitigate any potential challenges associated with this new technology, the CTA plans to gradually introduce the BEBs into their fleet. In April 2021, the first six 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.[72] 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.[72] Building upon the Proterra deployment, the CTA plans to purchase six 40-foot Nova Bus BEBs to begin service in 2023 or 2024 as the agency works towards their goal for a 100 percent electric fleet by 2040. Following these deployments, by 2024, approximately one to two percent of the CTA’s fleet of over 1,850 buses is anticipated to be ZEBs. Further in the future, the CTA has identified five-year funding between 2022-2026 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.[73]

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[69] Source: *Chicago Transit Authority Concludes Fuel Cell Bus Demonstration Program*, CTA, March 2000.
[70] Source: *CTA Announces First Electric-Powered Buses Added to its Fleet*, CTA, October 2014.
[71] Source: *CTA Expands Electric Bus Fleet*, CTA, June 2018.
[72] Source: *CTA Unveils New Electric Buses as Part of City’s Green Initiatives*, CTA, April 2021.
[73] Source: *President’s 2022 Budget Recommendations*, CTA, 2021

5.4.2. **BEB Operational Experience**

As of late fall 2021, the CTA has completed the initial testing and pilot phase of revenue service for the first six Proterra BEBs (Figure 22). Results from the CTA's current test pilot have been positive as the electric vehicles have generally met anticipated performance metrics.[74] Following the arrival and entry into service of all 23 new Proterra BEBs, CTA plans to comprehensively evaluate and track BEB availability as a metric to compare BEB performance with the rest of their bus fleet.[74]

BEBs require unique electrical infrastructure to support their operation and maintenance. 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 risk of overpromising on delivery timelines while also having a longer timeframe to expand and build upon their operational knowledge of BEBs and the associated charging infrastructure.

Figure 22: Chicago Transit Authority Proterra BEB with overhead charger

5.4.3. **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.[72] 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.[75] This infrastructure

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74 Source: Interview and email with CTA staff, October 2021

75 Source: *Innovative Solutions Awards: Clean Technology*, Metro Magazine, October 2020.

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.[74] 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.[74]

As the CTA continues to electrify their bus fleet, the agency intends to pursue a primarily garage-based charging approach.[74] 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.

5.4.4. **Training Modules**

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 operations and maintenance of the BEBs.[74] 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.

5.4.5. **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 is conducting 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.[76]

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.[74] Based on the results of its analyses, the CTA plans to prioritize the Chicago Avenue Garage on the city's West Side and the 103rd Street Garage on the city's South Side as the first two garages to be electrified. Bus routes/blocks operating from these garages serve areas with among the highest concentration of minority and low-income populations.[75] Going forward, the CTA plans to continue prioritizing the equitable deployment and implementation of BEBs.

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[76] Source: *City of Chicago Air Quality and Health Report*, City of Chicago, 2020.

5.4.6. **Lessons Learned**

Lessons learned from CTA's implementation of BEBs include:

- Start 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 operators and maintenance staff across all garages to be ready for BEB service
- Recognize the importance of modeling operational parameters including route characteristics, charging times, and vehicle/battery limitations in advance of deployment

5.5. Toronto Transit Commission (Toronto, Ontario)

5.5.1. **ZEB Program History**

In July 2017, the Toronto City Council approved Toronto's ambitious climate action strategy, TransformTO, which included a goal of reducing greenhouse gas emissions by 80 percent from 1990 levels by 2050.[77] To align with this framework, the Toronto Transit Commission (TTC) developed a Green Bus Technology Plan that targeted a zero-emission fleet by 2040, including procurements of only ZEBs starting in 2025.[78]

Figure 23: Toronto Transit Commission 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 23). This procurement included 10 extended-range BEBs from each of 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 *Green Bus Technology 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.[79] 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.[79] The TTC is currently developing a BEB procurement of 300 electric buses planned for delivery between 2023 and 2025.

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 a fraction of this nominal capacity, only allowing agencies to use a portion of the

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[77] Source: *Transform TO: Climate Action for a Healthy, Equitable & Prosperous Toronto*, City of Toronto, July 2017.
[78] Source: *Green Bus Technology Plan*, TTC, November 2017.
[79] Source: Interview and email with TTC staff, October 2021.

nominal capacity 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).[79]

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

5.5.2. BEB Operational Experience

The TTC 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 AC charging infrastructure.

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.[79] Doors were cycled at each stop to simulate typical TTC in-service conditions and performance data was captured using an onboard telematics system.[79] Preliminary results from this evaluation were shared with the TTC Board in April 2021 focused on the performance of each bus across four key domains:

- System Compatibility
- Accessibility
- Vehicle Performance
- Vendor Performance

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 24).

Figure 24: TTC preliminary results for primary evaluation domains[80]

	Battery-Electric Buses			Baseline
	BYD K9M	NFI XE40	Proterra E2	Nova HEV
System Compatibility	Needs Improvement	Very Good	Needs Improvement	Very Good
Accessibility	Very Good	Very Good	Very Good	Very Good
Vehicle Performance	Needs Improvement	Satisfactory	Needs Improvement	Very Good
Vendor Performance	Needs Improvement	Satisfactory	Satisfactory	Very Good

Legend: Very Good; Satisfactory; Needs Improvement

5.5.2.1. 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.[80]

Additionally, while the New Flyer and Proterra buses had interoperable charging technology meeting charging system standards set from the Society of Automotive Engineers (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 *Green Bus Technology Plan*,his 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 require DC charging capacity using SAE standards to allow for interoperability between all buses and chargers.[80]

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

5.5.2.2. Accessibility

All three bus manufacturers were found to be compliant with 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.

5.5.2.3. 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 met or surpassed the TTC's reliability target threshold of a 30,000 km (approximately 18,700 mile) mean distance between failures.[81] 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.[80] As of April 2021, the New Flyer buses were achieving 89 percent availability with an upward trend, while Proterra and BYD were performing at 62 percent and 52 percent respectively, both with downward trends.[80] 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.[79]

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.[80] 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

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[81] 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 bus.

diesel usage. As such, diesel heaters are only allowed when the temperature is below five degrees Celsius (41° F).[79]

5.5.2.4. Vendor Performance

The TTC used the vendor performance domain to monitor the performance of vendors' quality and contractual requirements.[80] 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 one to two months behind schedule whereas BYD was over six months (186 days) behind schedule.[80]

5.5.3. **Power Generation and Charging Configuration**

In Ontario, generation of electricity for overnight charging is 100 percent nuclear and completely free of GHG emissions.[78] The TTC has partnered with Ontario Power Generation (OPG) 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, four of the original 10 BEBs at each garage were stored and charged solely outdoors to assess environmental impacts.[82] To-date, the TTC has observed no difference between storing and charging buses outdoors compared with indoor storage and charging.[79] 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.[79]

5.5.4. **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).[80] 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[79]

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

5.5.5. **Prioritization Method**

In deploying their initial BEBs, the TTC set a goal of operating BEBs on the maximum possible number of technically viable blocks. To accomplish this goal, the 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

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[82] Source: Green Bus Technology Plan Update, TTC, June 2018.

BEB service covered the largest possible area of the TTC bus network while also ensuring that historically underinvested areas received BEB service.[79]

5.5.6. 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.
- Include 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.

5.6. Key Considerations and Best Practices Summary

Although each of the transit agencies included in the case studies have had unique ZEB experiences (Table 19), 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;
- Meet early and often with your electric utility;
- Consistent range allows for reliable operation through all seasons. Plan for bad weather days;
- Develop strong contractual language including performance metrics;
- 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.

Table 19: Case studies summary (Data as of December 2021)

	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*
Total Bus Fleet	910	347		1,391		1,854	2,096
Type of ZEB	**BEB**	**BEB**	**FCEB**	**Electric Trolleybus**	**BEB**	**BEB**	**BEB**
Year of First In-Service ZEB	2019	2010	2022/2023	1940	2015	2014	2019
ZEBs in Service (Dec. 2021)	8	34	0	174	51	8	60
ZEBs on Order or Programmed	100	0	33	0	250	93	300
Programmed Time Horizon	2022-2027	2021-2024		2025-2028		2020-2027	2023-2025
Total ZEBs Identified	**108** (12% of bus fleet)	**67** (19% of bus fleet)		**475** (34% of bus fleet)		**101** (5.4% of bus fleet)	**360** (17% of bus fleet)
Current ZEB Transition Goal	20% of 40-foot bus replacement procurements from 2022-2027 will be BEB	100% zero-emissions by 2040 Set by CARB		100% zero-emissions powered by renewable energy by 2035 Set by King County Metro		100% zero-emissions by 2040 Set by City of Chicago	100% zero-emissions by 2040 Set by TTC
Year Goal Established	2022	2019		2020		2019	2017

	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*
Best Practices	• Emphasize and build partnerships and relationships with electrical specialists and utility providers • Create contingency plans to manage potential challenges	• Proactively identify energy necessary to electrify each service block	• Stakeholder involvement in planning and implementation • Planning focused on service and fleet needs, BEB costs, infrastructure needs, environmental impacts, and financing	• Design-build contracts are critical to deliver BEB charging infrastructure on a quicker schedule • Hold frequent recurring calls with bus manufacturers to discuss BEB performance	• Anyone who parks a BEB by a charger plugs it in rather than specific staff • Garages with prior diesel-electric hybrid bus experience selected as the home garages for initial BEBs
Lessons Learned	• Clearly define successful ZEB implementation and deployment • Transparently set and manage expectations • Start ZEB process early; implementation takes much longer than a diesel bus • Be an early adopter but not a first adopter; avoid low serial number equipment	• Expect the unexpected • True ZEB lifecycle costs are unknown until a transit agency has run a ZEB to the end of its life • ZEB transition plans should be flexible and dynamic to respond to technology advancements • Plan for longer ZEB/charger repair times	• Focus on KPI clarity and comprehension rather than quantity • Transparently set and manage expectations • When conducting an equity analysis, consider impacts to service reliability with emerging technologies • Pilot programs with ZEBs from multiple manufacturers allow stakeholders to identify positive and negative aspects of each ZEB for use in improving the procurement/ operation of future ZEBs	• Start ZEB process early; implementation takes much longer than a diesel bus • Develop and implement BEB and charger training modules for bus operators and maintenance staff at all garages • Recognize the importance of modeling operational parameters including route characteristics, charging times, and vehicle/battery limitations in advance of deployment	• Providing a less detailed bus specification procurement document, necessitated multiple change orders to address unintended consequences including confusion regarding different operating procedures and features between buses • Predictable and reliable range is more important than achieving the lowest energy consumption. • Develop strong contractual language including performance metrics

6. Metro Transit Bus System and Facilities

As Metro Transit begins its own large-scale transition towards ZEBs, several questions must be answered including:

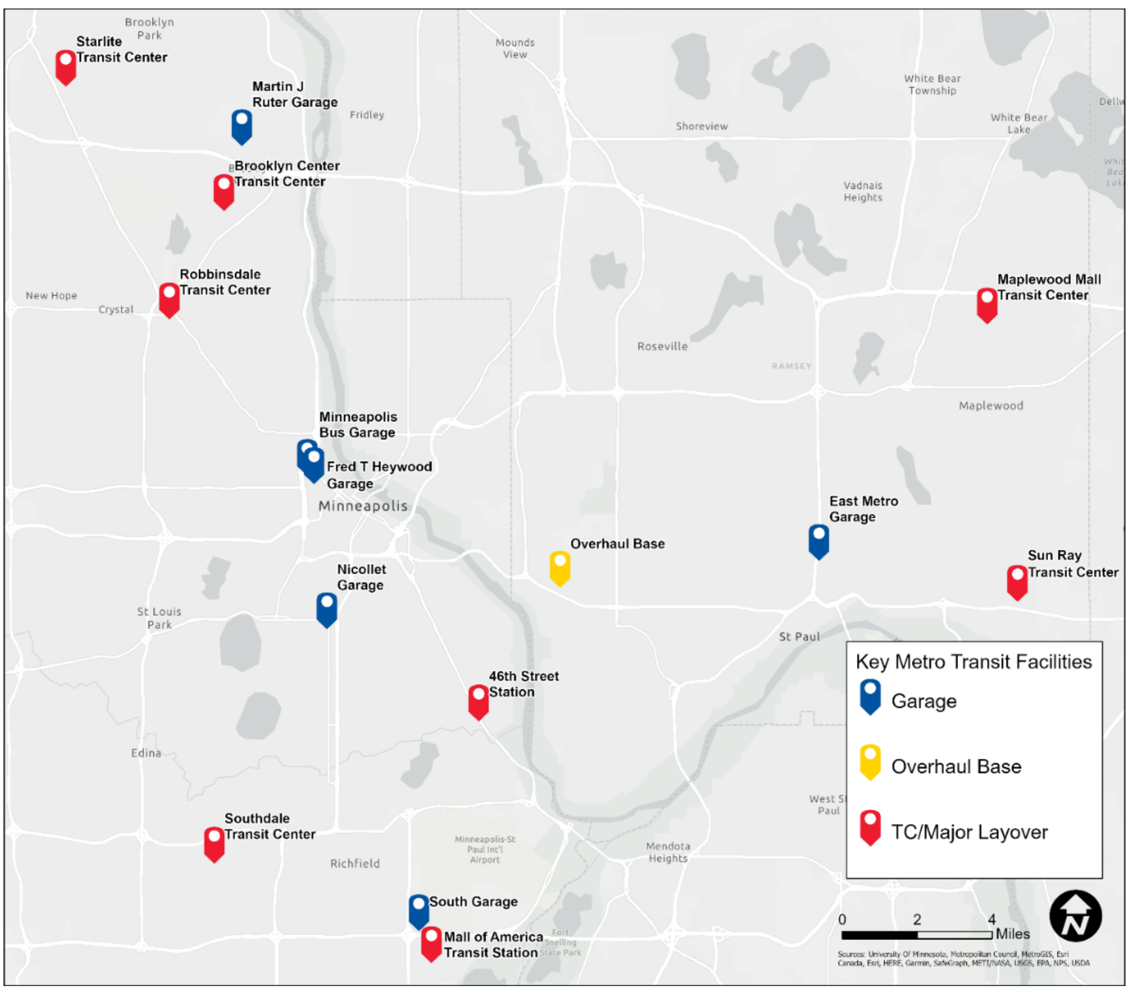
- Are any layover facilities currently suitable for ZEB infrastructure?
- Which garages should be the first to store ZEBs?
- Which bus service is most promising for the short-term transition to ZEBs?

Prior to answering these questions, this section summarizes an inventory and overview of Metro Transit's existing bus system, garages, and select layover facilities in order to establish the existing conditions framework necessary to answer the aforementioned questions.

6.1. Asset Inventory

This sub-section provides an inventory of Metro Transit facilities including the Overhaul Base heavy maintenance facility, garages, and major transit centers and layover locations that are candidates for ZEB infrastructure (Figure 25). This information establishes a current infrastructure and facility baseline from which ZEB infrastructure requirements can be estimated and compared.

Figure 25: Select Metro Transit facilities considered for ZEB infrastructure



Note: C Line BEB pilot charging infrastructure located at the Brooklyn Center Transit Center and Heywood Garage.

6.1.1. **Overhaul Base**

While minor maintenance work can be performed at any Metro Transit garage, all major bus maintenance and repairs occur at Metro Transit's Overhaul Base (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.

Currently there is no charging infrastructure at the OHB. As a result, when one of the current eight electric buses needs to travel to the OHB, Metro Transit carefully orchestrates its movements to ensure buses are fully charged when leaving the Heywood Garage while also monitoring the batteries' charge while at the OHB.

6.1.2. **Garage Inventory**

Metro Transit currently operates bus service from five garages with a sixth garage under construction. The existing garages were originally designed for diesel buses; however, Metro Transit has worked with Xcel Energy to accommodate BEBs at the Heywood Garage, northwest of downtown Minneapolis. Metro Transit is currently building a new garage, the MBG, located across the street from the existing Heywood garage. The MBG is designed to support both diesel buses and BEBs.

6.1.3. **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 20, Metro Transit is currently accommodating 86 more buses than its five existing bus garages were designed to accommodate. This has forced Metro Transit to evaluate each of its facilities to determine a maximum capacity for each garage, recognizing that this can result in suboptimal operations within a garage. When the MBG comes online in early 2023, it will increase Metro Transit's design capacity to store and maintain buses by about 26 percent, from 824 buses to 1,040 buses. This will provide Metro Transit with greater flexibility as to which garage buses are based and operated out of while allowing for future growth of the fleet allowing more efficient operations within the garage.

Table 20: Metro Transit garage inventory and characteristics

Garage	Address	Estimated Sq. Ft.	2020 Pre-COVID Utilization (Fleet)	Design Capacity (Fleet)	In Excess of Total Design Capacity	Adjacent Power Utility Provisions
Fred T. Heywood (Heywood) Garage	570 6th Ave. N., Minneapolis	290,000	**236** • 40': 154 • 60': 75 • Coach: 7	**214** • Storage: 194 • Maintenance: 20	22	• Overhead Mainline • 2.5MW Transformer Available • 1500 kVa Transformer in place
East Metro Garage	800 Mississippi St., Saint Paul	350,000	**216** • 40': 144 • 60': 45 • Coach: 27	**198** • Storage: 174 • Maintenance: 24	18	• Overhead Mainline • 2.5MW Transformer Available
Nicollet Garage	10 W. 32nd St., Minneapolis	190,000	**171** • 40': 171	**162** • Storage: 146 • Maintenance: 16	9	• Overhead Mainline • 2.5MW Transformer Available
Martin J. Ruter (Ruter) Garage	6845 Shingle Creek Pkwy., Minneapolis	170,000	**129** • 40': 62 • 60': 47 • Coach: 20	**127** • Storage: 119 • Maintenance: 8	2	• Underground • 2.5MW Transformer Available
South Garage	2100 MTC Rd., Minneapolis	210,000	**158** • 40': 127 • 60': 20 • Coach: 11	**123** • Storage: 107 • Maintenance: 16	35	• Underground • 2.5MW Transformer Available
Existing Total	--	1,210,000	**910** • 40': 658 • 60': 187 • Coach: 65	**824** • Storage: 740 • Maintenance: 84	86	
Minneapolis Bus Garage	812 N 7th St., Minneapolis	350,000	n/a	**216** • Storage: 192 • Maintenance: 24	TBD	• Overhead Mainline • 8MW ATO in place
Total with MBG	--	1,560,000	n/a	**1,040** • Storage: 932 • Maintenance: 108	-130	

Source: Metro Transit Electrification Considerations & Assumptions Memo and email with Metro Transit staff, December 2021.

6.1.4. Transit Centers and Layover Facilities

Metro Transit operates 24 transit centers throughout the metropolitan region.[83] Metro Transit defines transit centers as facilities that have the following characteristics:

- Two or more routes connect to transfer passengers
- Buses connect off street (or in clearly designated on-street spaces)
- There are marked 'gates' for different routes and directions
- The location serves a major activity center
- There is a standing facility, or in some cases, a collection of bus shelters[83]

In addition to transit centers, Metro Transit also owns property at the termini/layover locations of many routes. Based on the criteria outlined below, several of these transit centers and layover facilities are candidates for ZEB infrastructure. In particular, if additional BEBs are implemented as part of the Metro Transit's transition to ZEBs, these buses could be charged with overhead conductive chargers located at an on-route transit center or layover facility. As these overhead conductive chargers represent a substantial investment and add significant complexity to infrastructure design and construction as well as operations and scheduling, Metro Transit must be strategic about where, how, and if on-route chargers are used for range extension versus other available strategies. In consideration of these factors, Metro Transit identified potential locations for ZEB infrastructure based on:

- Ownership/longer term lease of the facility
- Size of the property
- Number and type of routes laying over at each location

The major layover facilities and transit centers identified as candidates for ZEB infrastructure are listed below in Table 21 and depicted above in Figure 25.

[83] Source: *Park & Rides and Transit Centers*, Metropolitan Council, 2021.

Table 21: Transit Centers and major layover facilities considered for ZEB infrastructure

Transit Center	Location	Metro Transit Operated Bus Routes	Adjacent Power Utility Provisions
46th Street Station	3660 E 46th St, Minneapolis	A Line, Blue Line, and Routes 7, 9, 46, 74	• Overhead Mainline • 2.5MW Transformer Available
Mall of America Transit Station	8240 24th Ave S, Bloomington	Blue Line, Red Line, Future D Line, and Routes 5, 54, 515	• Underground • 2.5MW Transformer Available
Maplewood Mall Transit Center	1793 Beam Ave., Maplewood	Routes 54, 64, 270	• Underground • 2.5MW Transformer Available
Robbinsdale Transit Center	4151 Hubbard Ave. N, Robbinsdale	Routes 14, 32	• Underground • 2.5MW Transformer Available
Southdale Transit Center	6704 York Ave. S, Edina	Future E Line and Routes 6, 515, 538, 578, 589	• No 3-phase service available
Starlite Transit Center	8081 Brooklyn Blvd, Brooklyn Park	Routes 723, 724, 764	• Underground • 2.5MW Transformer Available
Sun Ray Transit Center	463 Pedersen St., Saint Paul	Future H Line, Routes 63, 70, 74,	• Overhead Mainline • 2.5MW Transformer Available

Note: As Brooklyn Center Transit Center already has charging infrastructure installed, no further upgrades are being considered for the purpose of this analysis

6.2. Bus Service Overview

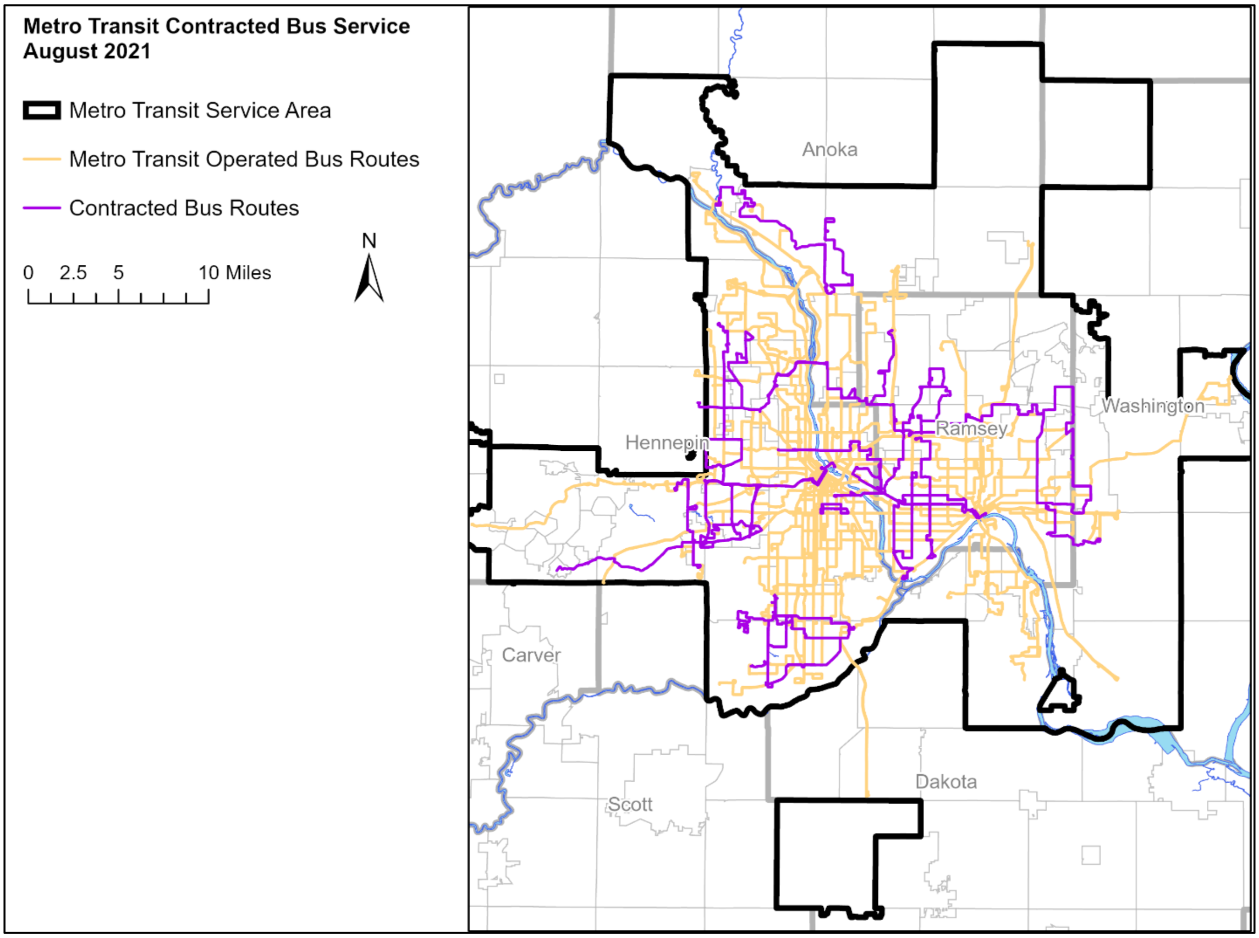
Metro Transit's bus fleet is composed of buses of varying lengths and propulsion types operating from a variety of home garages to provide a range of service types. This section provides an overview of these various components that influence the way in which Metro Transit operates its bus fleet of over 900 buses. Similar to the asset inventory baseline outlined in Section 6.1, the information contained in this section establishes a current service baseline from which ZEB bus service can be estimated and compared.

6.2.1. Bus Service Provider

Although Metro Transit branded buses operate on over 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 26). Together these contracted routes represent approximately five percent of the regular-route bus service in the metro area.[84] For the purposes of this Transition Plan, only the bus service and routes operated by Metro Transit are considered and analyzed.

[84] Source: *What We Do: Transportation Department*, Metropolitan Council

Figure 26: Metro Transit contracted bus service (August 2021)



6.2.2. **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.[85]

6.2.2.1. 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.

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[85] Source: *2040 Transportation Policy Plan, Appendix G: Transit Design Guidelines*, Metropolitan Council, January 2015.

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.

6.2.2.2. 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.

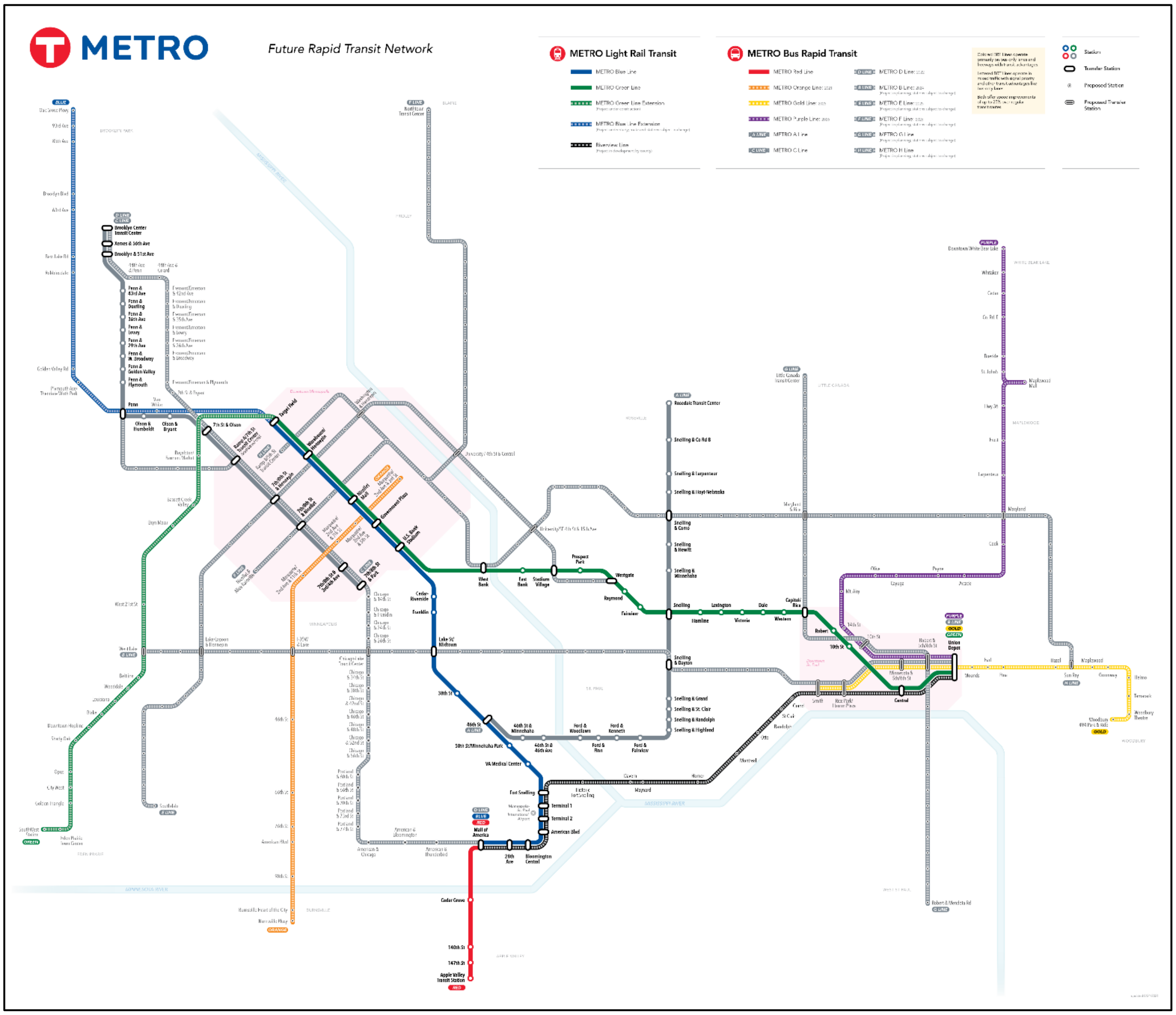
6.2.2.3. BRT

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 27 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. Arterial BRT lines currently operated by Metro Transit include the A Line, operating along the Snelling Avenue corridor in Saint Paul, and the C Line which serves north Minneapolis neighborhoods. As shown in Figure 27, six future arterial BRT lines (D, B, E, F, G, and H Lines) are currently planned as part of the future Rapid Transit Network.

Highway BRT lines operate in high demand highway or dedicated 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 (opened December 2021) Lines, as well as future Gold and Purple Lines.

Figure 27: Metro Transit future rapid transit network



6.2.3. **Bus Fleet**

Metro Transit's bus fleet at the beginning of 2020 included 910 buses. The fleet was comprised of:

- 544 40-foot diesel buses,
- 179 articulated 60-foot diesel buses,
- 114 40-foot hybrid-electric buses,
- 65 diesel coach buses,
- 8 articulated 60-foot electric buses.[86]

Metro Transit currently has a BEB pilot program with eight 60-foot New Flyer Xcelsior Charge electric buses operating exclusively on the METRO C Line. In addition, Metro Transit is preparing for a second BEB pilot program which will utilize eight 40-foot Proterra BEBs, funded in part

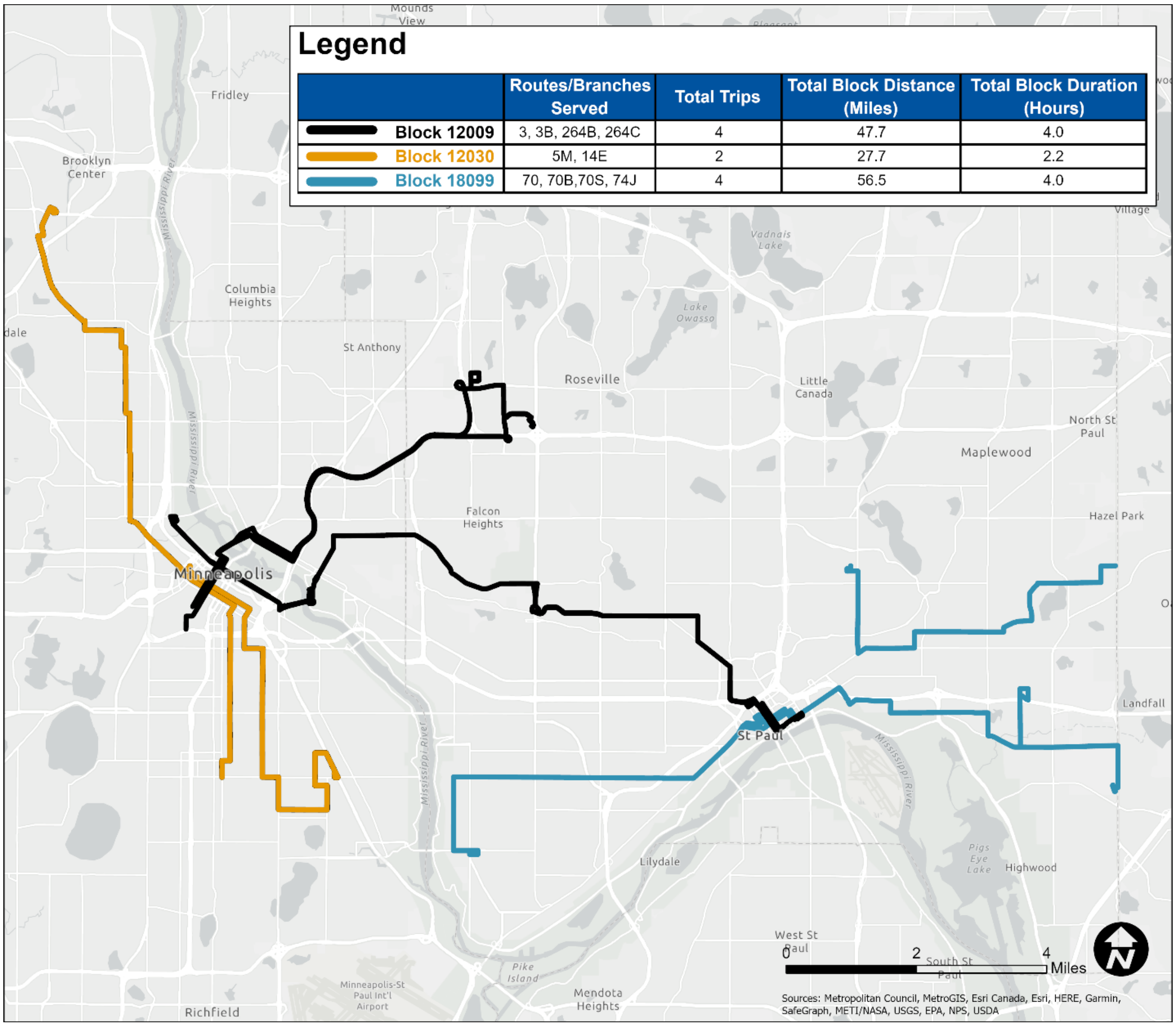
[86] Source: *Electric Buses*, Metro Transit

through a 2021 FTA Low-No grant. Metro Transit is actively pursuing additional funding opportunities to fund additional BEBs.

6.2.4. 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 28 depicts three example blocks, each of which are made up of two routes.

Figure 28: Overview map of three example service blocks



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. Internally the word “pick” is used as each schedule change coincides with when operators pick their work from what is scheduled for the next quarter. 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. As ZEB transition plans proceed, Metro Transit will review available scheduling tools and practices to incorporate electric vehicles while maintaining service efficiency and operability. In the future, new scheduling techniques may also be used to create additional BEB-compatible blocks while adhering to standards of efficiency and operability.

6.2.5. **Service Blocks by Garage**

As discussed in Section 6.2.4, block length and characteristics can vary between service schedules which are updated four times a year. For the August 2021 schedule, Metro Transit built its schedule from 1,189 blocks in their original, long form (672 weekday, 293 Saturday, and 224 Sunday blocks). These blocks ranged in length from 10 miles to over 300 miles long. The average service block operated by Metro Transit in this August 2021 service schedule was approximately 133 miles long and was composed of approximately 10 trips distributed across one to two routes.

As shown in Table 22 and Table 23, each garage stores buses assigned to blocks of differing lengths. For example, based on the August 2021 service schedule, the majority of 40-foot bus blocks at Heywood Garage are less than 88 miles long, while the East Metro Garage has the greatest number of blocks operated by 40-foot buses that are longer than 131 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 timeframe of BEBs.

Table 22: August 2021 blocks using 40-foot buses by facility

Block Length*	Heywood	East Metro	Ruter	Nicollet	South	Total
< 88 miles	80	50	20	55	36	241
88-131 miles	11	28	9	55	49	152
> 131 miles	72	126	52	123	88	461
Total	163	204	81	233	173	854

**Block length thresholds correspond with anticipated BEB battery technology ranges in Minnesota winters as outlined in Section 8.3.1.2. Blocks greater than 131 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 23: August 2021 blocks using 60-foot buses by facility

Block Length*	Heywood	East Metro	Ruter	South	Total
< 79 miles	26	16	16	14	72
> 79 miles	115	36	26	34	211
Total	141	52	42	48	283

**Block length thresholds correspond with anticipated BEB battery technology ranges in Minnesota winters as outlined in Section 8.3.1.2. Blocks greater than 79 miles are assumed to require on-route charging, significant 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.*

6.2.6. **COVID-19 Pandemic Service Impacts**

In 2020, with the onset of COVID-19, Metro Transit experienced unprecedented changes to its service delivery. Ridership demand patterns were disrupted by the pandemic response and new operational requirements (such as enhanced cleaning protocols) were introduced. In response, service levels were adjusted several times throughout 2020 and 2021 to keep pace including operating fewer routes and trips. Bus assignment practices were also changed to provide additional capacity by operating 60-foot buses on high-ridership local routes to support social distancing.

As shown in Table 24, as of August 2021, Metro Transit's local service levels were similar to pre-pandemic levels with just seven percent fewer revenue hours and six percent fewer trips being operated than in March 2020. However, much of the Commuter Express and Suburban Local network service operated by Metro Transit remains suspended or significantly reduced from pre-pandemic service. In particular, only a third of the March 2020 Commuter Express trips are in operation as of August 2021. Future service levels and strategies for these networks are dependent on evolving market conditions and operator availability.

Table 24: Metro Transit weekday bus service summary change from Pre-COVID (March 2020) to August 2021

Service Type	Unique Routes Decrease	Weekday Trips Decrease	Revenue Hours Decrease
Core Local	5 (17%)	217 (6%)	227 (7%)
Supporting Local	2 (20%)	111 (17%)	64 (14%)
Suburban Local	1 (13%)	42 (8%)	43 (15%)
BRT	--	2 (1%)	2 (1%)
Commuter Express	32 (50%)	667 (65%)	488 (66%)

Source: March 14, 2020 GTFS data with weekday-01 service_id's used for Pre-COVID numbers and August 21, 2021 GTFS data using weekday-01 service_id's data

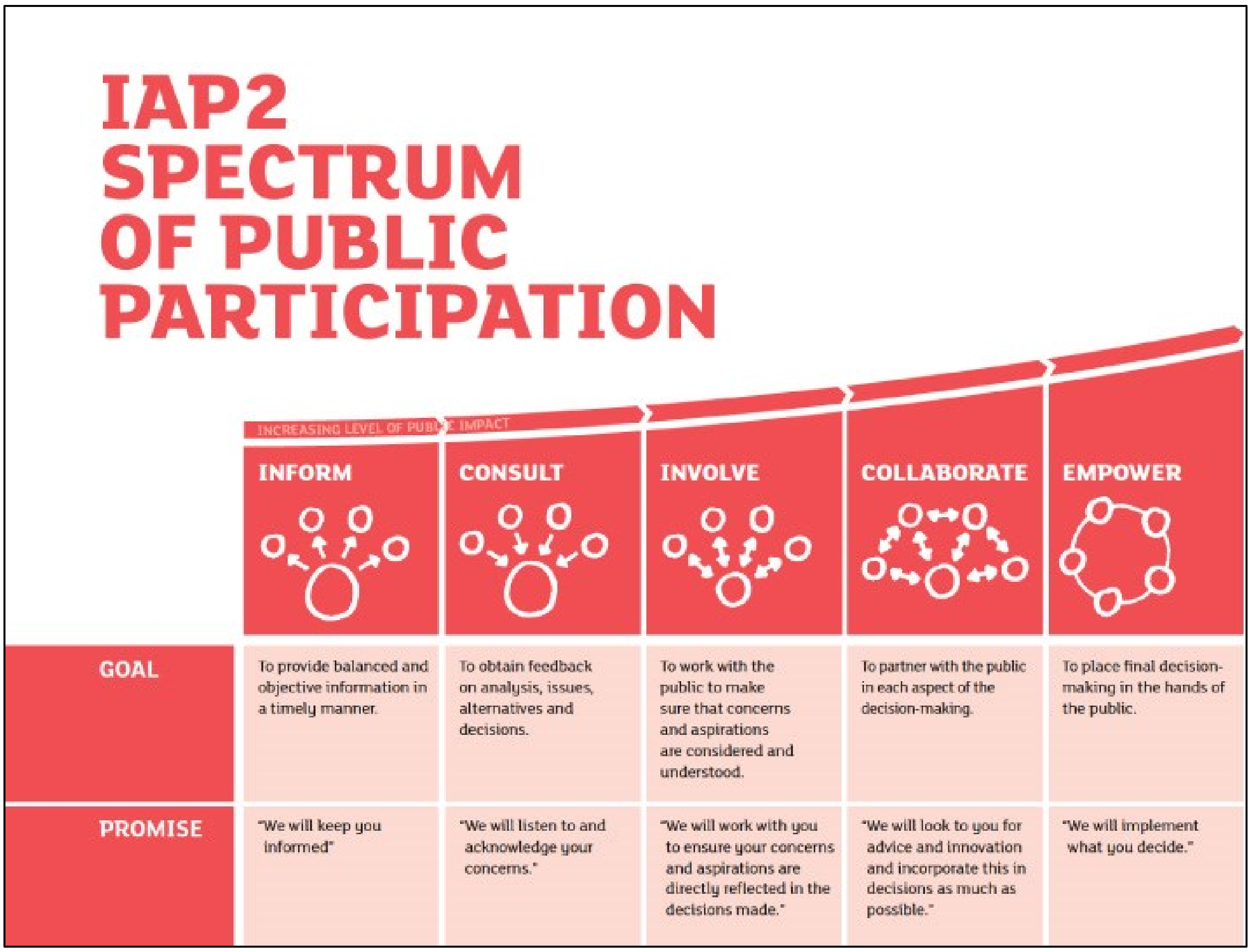
7. Outreach and Engagement

7.1. Engagement Goals

The overall purpose of engagement for this Transition Plan 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 Transition Plan. As a regularly updated plan, continued engagement is anticipated in future ZEB planning and implementation stages.

Engagement efforts focused on each of the Transition Plan's three guiding principles outlined in Section 3. To help define the public's role in the Transition Plan, an engagement goal (defined by the IAP2 Spectrum of Public Participation in Figure 29) was established for each guiding principle.

Figure 29: IAP2 spectrum of public participation[87]



IAP2 SPECTRUM OF PUBLIC PARTICIPATION

INCREASING LEVEL OF PUBLIC IMPACT

	INFORM	CONSULT	INVOLVE	COLLABORATE	EMPOWER
GOAL	To provide balanced and objective information in a timely manner.	To obtain feedback on analysis, issues, alternatives and decisions.	To work with the public to make sure that concerns and aspirations are considered and understood.	To partner with the public in each aspect of the decision-making.	To place final decision-making in the hands of the public.
PROMISE	"We will keep you informed"	"We will listen to and acknowledge your concerns."	"We will work with you to ensure your concerns and aspirations are directly reflected in the decisions made."	"We will look to you for advice and innovation and incorporate this in decisions as much as possible."	"We will implement what you decide."

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

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.*

Equity and Environmental Justice Engagement Goal

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

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.*

7.2. 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 Transition Plan, community is defined as a group of individuals that share common geography or characteristic. Examples of community could be a classroom, an apartment building, the disability community, or the Latino community.

Under-represented community- within every community there are members whose voices are under-represented 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.

7.3. Engagement Strategies

Acknowledging the compressed engagement timeframe, engagement opportunities primarily targeted interested stakeholders with an outreach strategy (overviewed below) that was designed to inform the wider community. The ZEB Transition Plan 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 30: Transition Plan overview video screenshot

7.3.1. Engagement and Outreach Opportunities

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

7.3.1.1. Internal Engagement

Internal engagement targeted frontline staff, bus operators, and mechanics. This engagement included pop-ups at all five garage facilities, an informational slide show on operator dayroom video screens, manager-direct report briefings (train-the-trainer model), and internal communications newsletters (Figure 31).

Figure 31 Bus operator outreach

7.3.1.2. External Engagement

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

Stakeholder Workshops

Two stakeholder virtual summit workshops were held in November 2021. Over sixty 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 (EV) or environmental sustainability projects as well as Twin Cities organizations with a known focus on EV or environmental sustainability. The workshops were also publicized on Metro Transit's social media pages and website.

Neighborhood Organization Updates

Thirty-two Minneapolis and St. 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.

Online and Paper Survey

A twelve-question public survey was publicized on Metro Transit's website, social media, and external newsletters. Three hundred two 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.

7.4. What We Learned

A majority of the 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.

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 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 vehicle miles traveled (VMT). As noted in Section 1, 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.

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.

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.[88] 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 (Table 25).

Table 25: 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

[88] 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 Black, Indigenous, or a person of color, portion of households lacking a vehicle, the number of five-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

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

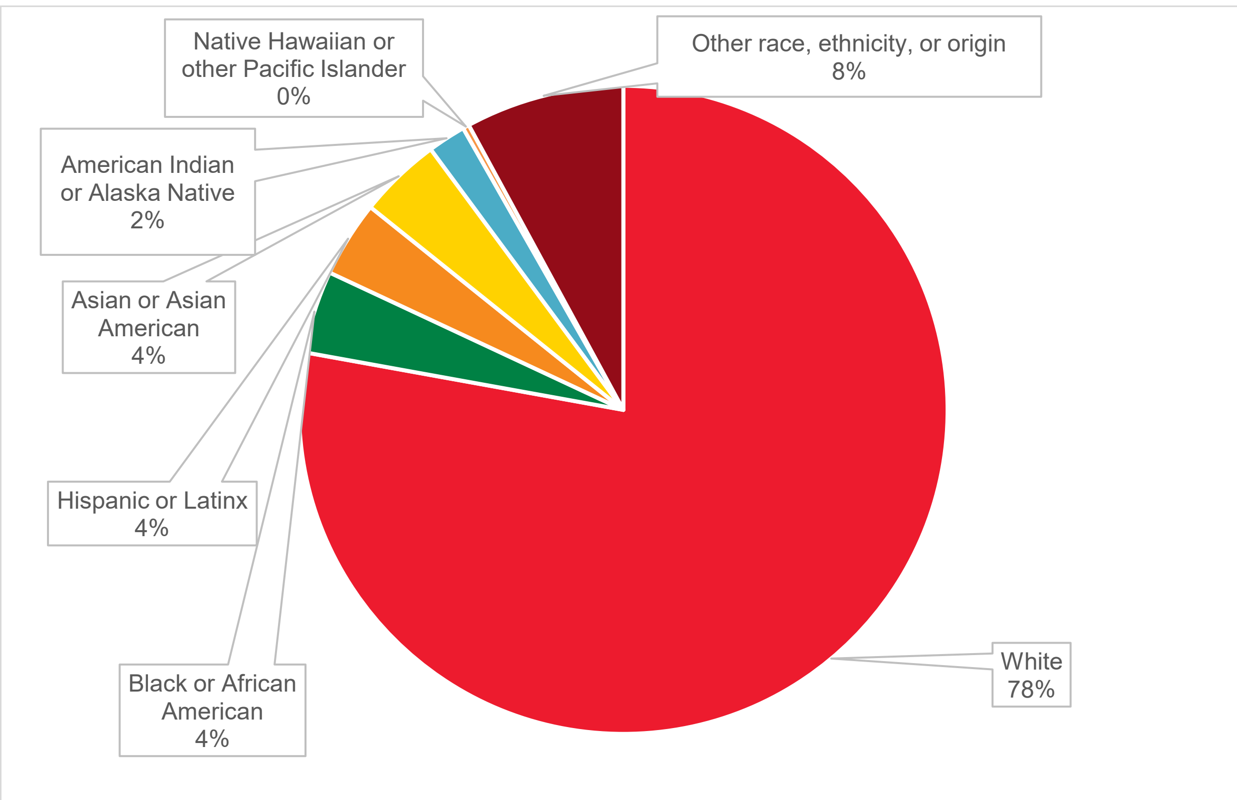
Respondents identified several characteristics and factors such as access to alternative transportation, as well as access to essential services (e.g., grocery stores, hospitals, libraries), and health care that Metro Transit should consider when measuring equity and environmental justice. Several respondents 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 equity and environmental justice, 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 Transition Plan.

7.5. 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 25-34 (32 percent) or 35-44 (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 32).

Figure 32: Race/ethnicity of survey respondents



8. ZEB Policies and Guidance

This section describes the development of assessment criteria and a 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 future.

8.1. Short-Term ZEB Propulsion Technology

As outlined in Section 4, there are three primary types of ZEBs currently operating in the United States: 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.

Additionally, Metro Transit has also 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.

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

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 sub-sections 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/routes are supportive of BEB range limitations.

8.2. Facility Guidance

The first of the two core elements required for successful BEB integration is suitable facilities. For the purposes of this analysis, three types of facilities were considered, the Overhaul Base, garages, and select transit centers/layover facilities. 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 three 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.

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

8.2.1. Overhaul Base

As Mentioned in Section 6.1.1, the Overhaul Base 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 transitions to a larger number of BEBs, this detailed orchestration will become less practical and technically viable. Therefore, moving forward, it is recommended that, in the short-term, a minimum of two plug-in style chargers should be installed at the overhaul base to provide operational flexibility for maintenance activities. Currently, the OHB has approximately 1MW of electrical capacity available for use and could support a maximum of seven 150-kW charging stations prior to needing additional electrical upgrades.

In the short-term, a minimum of 2 plug-in style chargers should be installed at the Overhaul Base

8.2.2. Garage Modeling

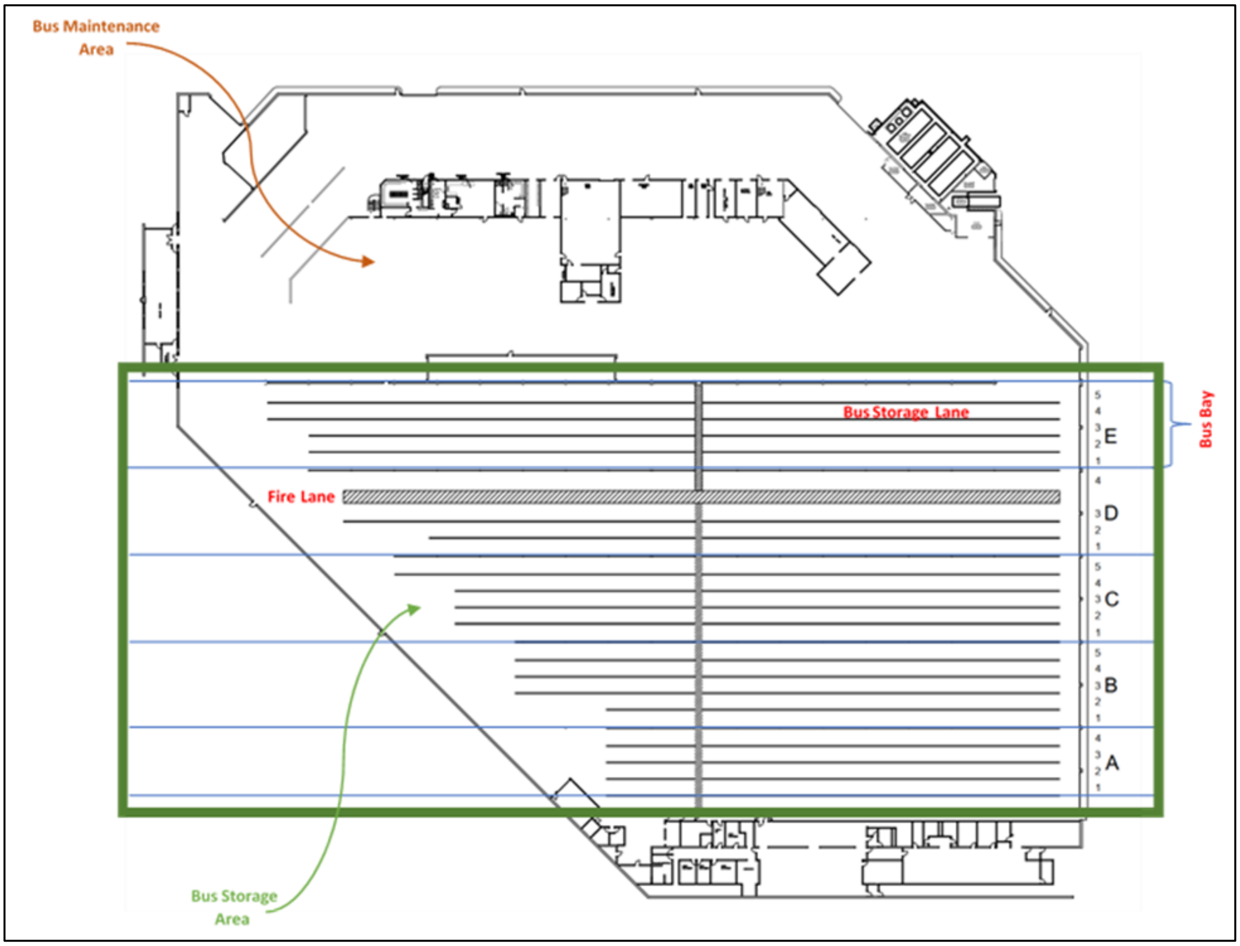
To assess garage suitability for BEB service, the electrical and spatial constraints of each of Metro Transit's six garages were analyzed. Based on the results of this analysis, each garage was placed into one of three ranked suitability tiers indicating their electrification priority. In a parallel effort, Metro Transit is currently developing a Support Facilities Strategic Plan (SFSP) in coordination with this Transition Plan. Long-term recommendations for Metro Transit's facilities will be included in the SFSP.

8.2.2.1. 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.

Functionally, Metro Transit's garages are divided into two primary areas: one for bus storage and a second for bus maintenance (Figure 33). 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 33: Example garage layout with bus storage and maintenance areas



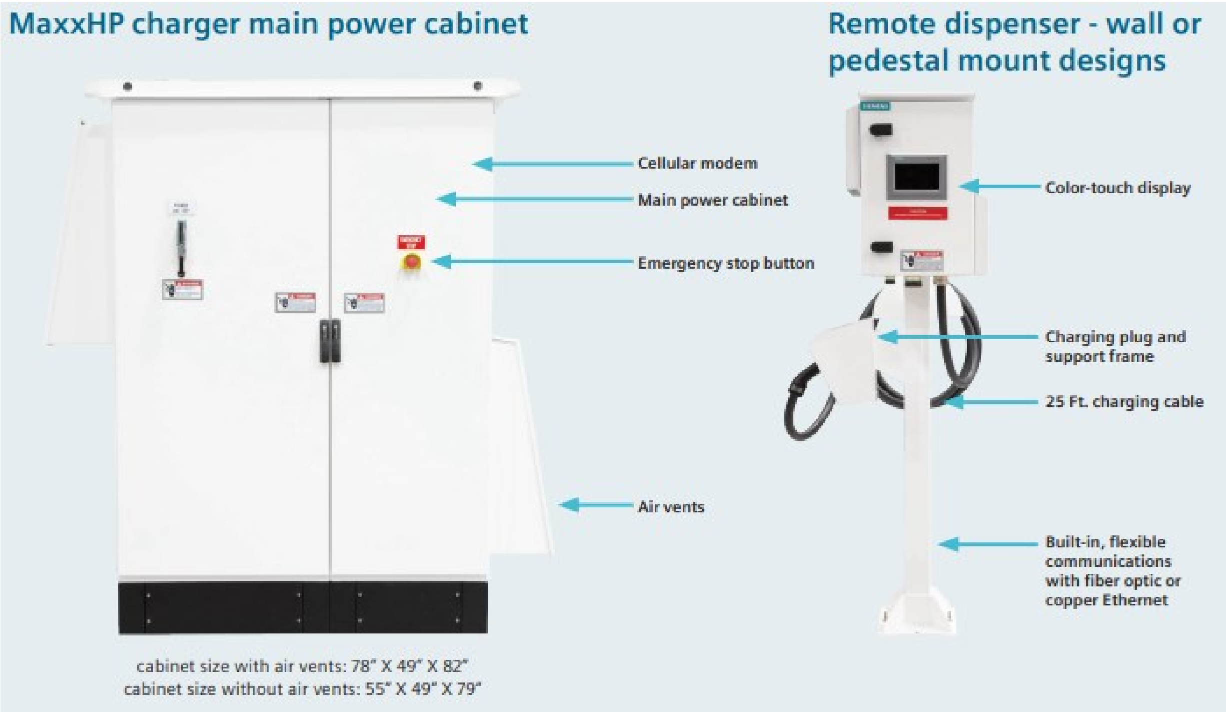
As BEBs are typically the same length as conventional buses, impacts to bus storage capacity associated with electrifying a garage are primarily due to the spatial requirements of the chargers themselves. To model these spatial impacts on bus parking capacity at each garage, two factors must be considered:

- Charger Dimensions; and
- Charger Quantity.

None of Metro Transit's existing five garages currently have 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. Instead, 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 is the space required for the charger bases/power cabinets. The new Minneapolis Bus Garage, currently under construction, 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, the largest 150 kW charger currently on the market (Siemens Versicharge MaxxHP) was used 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 34).

Figure 34: Siemens MaxxHP charger dimensions[89]



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

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; it is assumed this temporary practice will end with the opening of the Minneapolis Bus Garage when adequate bus storage capacity is returned to the system

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

- 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.

Charger Quantity and Power Assumptions

- One 150kW charger is required per two bus parking spaces
- One 150kW charger is required per four bus maintenance bays
- Sufficient space exists to house maintenance bay chargers without capacity losses
- In addition to 150kW chargers, each electrified garage will include two 300kW chargers

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 the optimal 2:1 bus-to-charger ratio. 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.[90]

If all five existing garages were to be fully electrified, it is estimated that 56 parking spaces would be lost compared with existing storage capacity (Table 26). 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).

Table 26: Fully electrified garage: bus storage capacity impacts

Garage	Design Capacity	Maintenance Capacity	Storage Capacity (Current)	Difference from Current Storage Capacity	Storage Capacity** (BEBs)
East Metro	198	24	174	-4 (-2%)	170
Nicollet	162	16	146	-16 (-11%)	130
Heywood	214	20	194	-17 (-9%)	177
Ruter	127	8	119	-9 (-8%)	110
South	123	16	107	-10 (-9%)	97
Subtotal:	**824**	**84**	**740**	**-56 (-8%)**	**684**
MBG	216	24	0	+192	192
Total:	**1,040**	**108**	**740**	**+136**	**876**

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)*

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[90] 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)

When the MBG comes online in early 2023, its 192 additional bus storage parking spaces can help mitigate garage capacity constraints by:

- Accommodating buses currently stored above a garages' design capacity;
- Accommodating buses that can no longer be stored at an electrified garage due to a reduced BEB storage capacity; and
- Temporarily accommodating buses relocated to the MBG as other garages undergo electrical upgrades necessary to support BEBs.

With the introduction of the MBG, no net bus parking spaces will be lost systemwide

After accommodating the 86 buses that are currently stored at garages over their design capacity (as detailed in Section 6.1.3), and the estimated 56 parking spaces lost if all five existing garages were fully electrified, the opening of MBG would introduce an anticipated surplus of 50 bus storage area parking spaces in the garage system. Therefore, with the introduction of the MBG, no net bus parking spaces will be lost systemwide. In fact, given that there is a surplus of bus parking spaces, these additional parking spaces in the system will allow for operational flexibility as buses could be temporarily relocated to a different garage as their home garage undergoes electrical upgrades necessary to support an electrified bus fleet.

8.2.2.2. 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 six 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 new MBG garage, which Xcel Energy upgraded specifically to accommodate BEBs at the site. Therefore, aside from the initial 6MW at the MBG, 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

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

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 MBG, multi-year electrical upgrades by Xcel Energy will be needed at all garages to support future BEB charging infrastructure. These upgrades are estimated to take Xcel Energy between two to five 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.

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, that every four maintenance bays will require one 150kW charger, and that each garage will also include two 300kW chargers, 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. 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), five maintenance area chargers (totaling 750kW) and the two additional 300kW chargers (totaling 600kW) assumed at each garage. Together, this would require a future electrical capacity of approximately 9MW (8,850 kW). Combined, the quantity and timeframe to complete these upgrades greatly influence the suitability of a garage for short-term BEB service.

Overall, each of Metro Transit's six garages can accommodate a unique number of BEBs and chargers resulting in a range of electrical impacts (Table 27). 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 required less time to retrofit.

Table 27: Fully electrified garage: electrical impacts

Garage	Storage Capacity** (BEBs)	150kW Storage Area Chargers	150kW Maintenance Area Chargers	300kW Chargers	MW Needed to Support Full Electrification
East Metro	170	85	6	2	15
Nicollet	130	65	4	2	11
Heywood	177	89	5	2	15
Ruter	110	55	2	2	10
South	97	49	4	2	9
Subtotal:	**684**	**343**	**21**	**10**	**60**
MBG	192	96	6	2	16
Total:	**876**	**439**	**27**	**12**	**76**

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)*

If, in the long-term, Metro Transit were to fully electrify the bus fleet, a total of 76MW of electrical capacity would be needed, approximately the same electrical capacity used to power the entire light rail system including the Blue Line (29MW), Green Line (21MW), and Southwest Light Rail Green Line Extension (30MW).[91]

Table 28: Fully electrified garage facility electricity needs compared with the light rail system

Garage Facility		LRT System	
Existing Garages*	60 MW	**Existing LRT System** *(Blue & Green Line)*	50 MW
MBG	16 MW	**Green Line Extension** *(Southwest LRT)*	30 MW
Total:	**76 MW**	**Total:**	**80 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*

Approximately the same electrical capacity used to power the entire 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 (DERs) 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 installation of the DERs would also lead to an increase in Metro Transit's capital costs.

8.2.2.3. Individual Garage Guidance

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

Minneapolis Bus Garage (MBG)

As discussed in Section 2.4.6, Metro Transit is currently constructing a second bus garage on the Heywood Campus, known as the **MBG** (Figure 35). The MBG is anticipated to open in early 2023 and was designed to accommodate both diesel and electric buses. The MBG is located on the western edge of downtown Minneapolis with close access to expressways and numerous routes.

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

The MBG has a current bus storage capacity of 192 diesel and electric buses. Each bus storage lane at the MBG 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 MBG without losing any parking spaces.

Figure 35: Minneapolis Bus Garage

As currently designed, the MBG has 6MW of electrical capacity to support an initial implementation of 80 BEBs. To electrify the remainder of the bus fleet stored at the MBG, 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 MBG, 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 two years to complete this work. It is recommended that Metro Transit review charging configurations and onsite energy generation before reaching capacity limits that would require substation upgrades, as this would be a costly and time intensive endeavor. Metro Transit has 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 to gain experience with distributed energy resources.

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 36). 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 and that 5MW of capacity could be provided to the facility by 2024. In partnership with Xcel Energy, preliminary scoping is underway for electrical upgrades at the garage which will occur in coordination with the Gold Line and Purple Line BRT projects between 2022 and 2024. Up to 22 BEBs are planned to be based out of the East Metro Garage as part of these BRT Projects.[92]

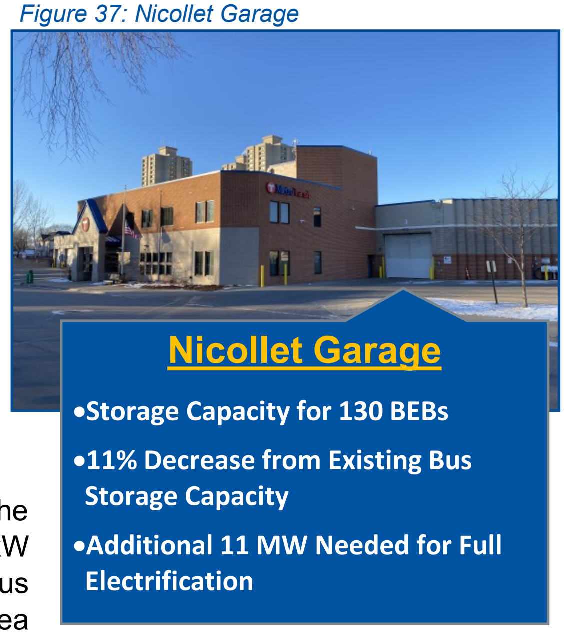
Figure 36: East Metro Garage

To support a fully electrified fleet of 170 BEBs at the East Metro Garage, the facility would require 85 150kW chargers and two 300kW chargers in the general bus storage area as well as six 150kW maintenance area chargers. Together, these chargers would require a total electrical capacity of 15MW. Overall, it is estimated that one row (four buses) of existing bus storage space would be lost to provide space for the chargers.

Nicollet Garage

The **Nicollet Garage** is located in south Minneapolis and only operates 40-foot buses (Figure 37). It is a very long and narrow facility with bus lanes storing ten to twelve 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 two years to complete.

Figure 37: Nicollet Garage



To support a fully electrified fleet of 130 BEBs at the Nicollet Garage, the facility would require 65 150kW chargers and two 300kW chargers in the general bus storage area as well as four 150kW maintenance area chargers. Together, these chargers would require a total electrical capacity of 11MW. 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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[92] Source: *Metropolitan Council Transportation Division Proposed 2022-2027 Transit Capital Program*, Metropolitan Council, September 27, 2021

Heywood Garage

The **Heywood Garage** is centrally located on the western edge of downtown Minneapolis adjacent to the new MBG with close access to expressways and numerous routes (Figure 38). It is Metro Transit's busiest garage and the 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.

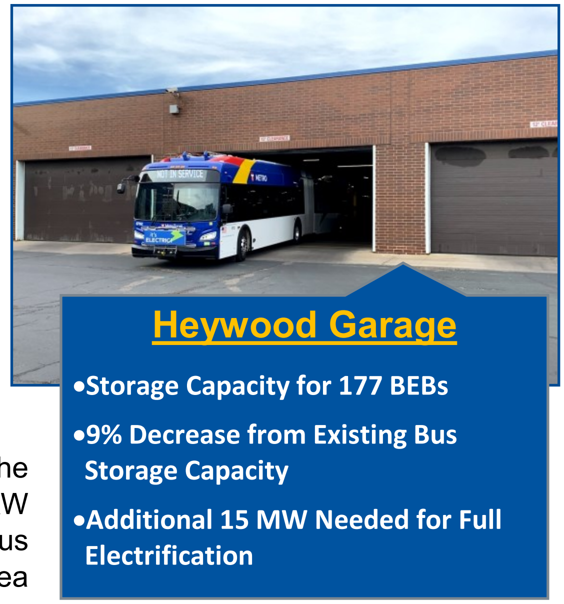

Figure 38: Heywood Garage

To support a fully electrified fleet of 177 BEBs at the Heywood Garage, the facility would require 89 150kW chargers and two 300kW chargers in the general bus storage area as well as five 150kW maintenance area chargers. Together, these chargers would require a total electrical capacity of 15MW. 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 MBG, 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 Minneapolis Bus Garage.

Ruter Garage

The **Ruter Garage** is located in Brooklyn Center in the north metro area (Figure 39). It was originally an industrial warehouse which was converted into a bus garage. It is a very long and narrow facility with bus lanes storing up to 13 buses. 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. An additional 5MW of capacity could be provided to the garage through an underground line. Due to the added complexity of connecting to underground lines, Xcel Energy estimates that bringing additional power to the Ruter Garage would take approximately five years to complete.

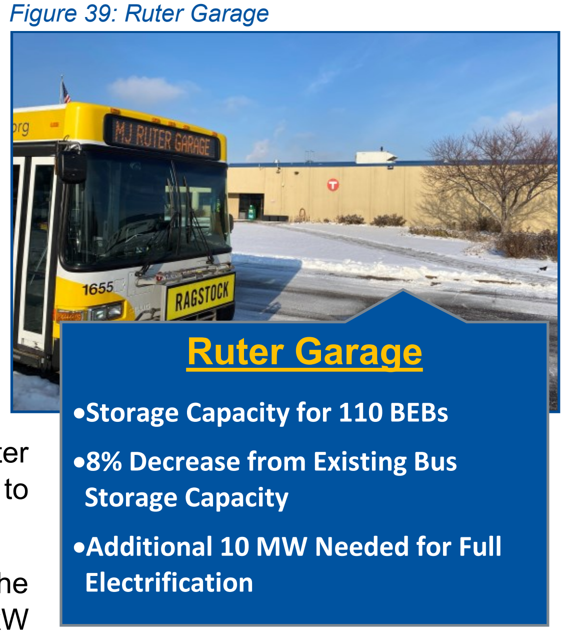

Figure 39: Ruter Garage

To support a fully electrified fleet of 110 BEBs at the Ruter Garage, the facility would require 55 150kW chargers and two 300kW chargers in the general bus storage area as well as 2 maintenance area chargers. Together, these chargers would require a total electrical capacity of 10MW. Overall, it is estimated that one row (nine buses) of existing bus storage space would be lost to provide space for the chargers.

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 40). The land the garage is built upon is leased from the Metropolitan Airports Commission (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).

Figure 40: South Garage

South Garage

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

Due to the electrical complexities associated with upgrading the electrical feeders into the site, Xcel Energy anticipates that it may take up to five 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 two 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 2028 or 2029 if starting at the beginning of 2022. 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 the South Garage at this time. As a result, the bus storage capacity at South Garage would remain consistent with the garage's current bus storage capacity.

8.2.2.4. BEB Suitability Tiers

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

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. Absent 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 one-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.

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 new MBG and East Metro Garage 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 three electrification priority tiers (Table 29). 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 three priority tiers shown in Table 29, it is recommended that the new MBG and East Metro Garage 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 Minneapolis Bus 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 needed 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. 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 four and seven 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 29: Metro Transit garage electrification priority tiers

Tier	Garage Facility	Xcel Energy Timeline Horizon	Construction & Installation Timeline Horizon*	Total Time to Electrify	Total MW Needed to Support Full Electrification
Tier 1 (Start in 2022)	Minneapolis Bus Garage (MBG)	First 40% Ready	1-1.5 Years	1 – 1.5 Years	16 MW
	East Metro	1.5 – 2 Years	1.5 – 2 Years	3 – 3.5 Years	15 MW
Tier 2 (Start TBD)	Nicollet	2 Years	1.5 – 2 Years	3.5 – 4 Years	11 MW
	Heywood				15 MW
Tier 3 (Start TBD)	Ruter	5 Years	1.5 – 2 Years	6.5 – 7 Years	10 MW
	South	No upgrades recommended without long-term lease			

**Note: 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.

8.2.3. **Transit Center and Layover Facility Suitability**

To supplement garage-based charging, Metro Transit is also considering the use of on-route chargers to extend BEB bus range throughout the day. However, as these overhead conductive chargers represent a substantial investment and add significant complexity to bus operations and scheduling, Metro Transit wants to be strategic about where, how, and if on-route overhead conductive chargers are utilized.

To assess the feasibility of this charging scheme, the electrical suitability and readiness of each of the seven key transit centers and layover facilities outlined in Section 6.1.4 were studied. Given that on-route charging takes place outside the confines of a garage, no bus storage impacts are associated with on-route charging. Therefore, only the electrical constraints were analyzed for each of these facilities.

Similar to the assessment of the electrical constraints at Metro Transit's garages, existing electrical infrastructure and capacity limitations at each of the seven key transit centers and layover facilities were identified in collaboration with Xcel Energy. Based on these conversations, it was identified that the electrical transformers at each of these facilities have limited available electrical capacity. As a result, multi-year electrical upgrades will be needed at all seven facilities to support future BEB charging infrastructure. Whereas the majority of Metro Transit's garages are serviced by overhead electrical lines, most of the transit center and layover facilities are serviced by underground lines. Electrical upgrades at most of these sites would therefore take at least five years for Xcel Energy to complete. Additionally, as Southdale Transit Center lacks the three-phase and 480-volt service needed for electrification, no upgrades are recommended at this location.

From these electrical constraints, the seven transit center and layover facilities were divided into tiers based on the total time necessary to electrify each facility (Table 30). Unlike with the garages, however, none of the transit centers or layover sites fell into a short-term priority tier as even the most suitable facilities, 46th Street Station and Sun Ray Transit Center, would require at least three and a half years to become electrified. In addition, as further discussed in Section 8.3.1, below, nearly half of Metro Transit's bus blocks have a short enough distance that they could be served by the 675 kWh BEBs Metro Transit is purchasing in 2022 without range-extending on-route chargers.

On-route charging strategies will not be pursued in the short-term

Based on these suitability factors as well as the inherent challenges of on-route charging outlined in Section 4.3.2, Metro Transit has determined that the agency will not pursue on-route charging in the short-term[93] due to:

- Increased number of operators and vehicles required to allow for longer layovers
- Longer electrification timelines
- Nearly half of existing bus service could be covered without on-route chargers
- Outdoor maintenance challenges, particularly in Minnesota winters
- Higher operational costs due to daytime electricity premium
- Capital costs are four times greater than garage chargers
- Maintenance is less cost effective than for garage chargers due to distributed outdoor assets around the region

In future updates to the ZEB Transition Plan, Metro Transit will continually reassess this decision as on-route charging technologies, vehicle battery capacities, and garage charger power outputs improve.

[93] Due to the unique aspects of projects funded through the FTA Capital Investment Grant (CIG) Program, on-route charging may receive further considerations in future CIG projects.

Table 30: Transit center and layover facility electrification priority tiers

Tier	Transit Center/Layover Facility	Xcel Energy Timeline Horizon	Construction & Installation Timeline Horizon*	Total Time to Electrify
Tier 2	46th Street Station	2+ Years	1.5 – 2 Years	3.5 – 4+ Years
	Sun Ray Transit Center			
Tier 3	Mall of America Transit Station	5+ Years	1.5 – 2 Years	6.5 – 7+ Years
	Maplewood Mall Transit Center			
	Robbinsdale Transit Center			
	Starlite Transit Center			
	Southdale Transit Center	***No 3-phase service available***		No Upgrades Recommended

**Note: Charger construction and installation timeline horizon assumes two on-route chargers; more time needed for larger quantities*

8.2.4. **Xcel Energy Memo**

Section 8.2.4 was provided by Xcel Energy as a summary of the analysis Xcel Energy completed and discussions with Metro Transit to analyze garages and transit centers for electrical capacity readiness (Figure 41).

Figure 41: Xcel Energy memo

Xcel Energy®

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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. While there may be adequate capacity forecasted now, 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. We anticipate the East Metro bus garage in St. Paul will require an additional 5 MW of capacity by 2024. 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 is committed to continuing to work with Metro Transit as they provide regular updates to their ZEBTP. This partnership team will schedule regular check ins to ensure capacity requirements are met along with continuing long term planning exercises to meet future capacity needs.

8.3. Service Prioritization Methodology and Implementation Guidance

This sub-section 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.

As mentioned in Section 6.2.4, a block represents a series of transit trips that are linked together and assigned to a single vehicle for operation. The characteristics of these blocks 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 2021 service schedule to provide an example and illustrate how this methodology can be used to inform transition policies and the prioritized deployment of ZEBs.

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 Transition Plan's three guiding principles of technical viability, equity and environmental justice, and fiscal impact as introduced in Section 3 (Figure 42). 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 42: Block-level BEB prioritization methodology

8.3.1. Technical Viability Modeling

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 worst-case 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 4.3.1.2, the distance (range) that a BEB can travel is a function of two primary characteristics:

- Battery capacity; and
- Energy usage.

8.3.1.1. Assumptions

Battery Capacity Impacts on BEB 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 kilowatt-hours (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 2021, BEB manufacturers offer on-board BEB batteries with capacities typically ranging from approximately 215 kWh to 686 kWh.[94,95] 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 of 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.

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.[96] This equates to a capacity loss of up to approximately 16 percent after seven years (bus mid-life), and up to about 30 percent after 14 years (bus end-life).

Battery Life Capacity Reservations

In addition to general battery degradation, 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. 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

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[94] Source: *Electrifying Transit: A Guidebook for Implementing Battery Electric Buses*, National Renewable Energy Laboratory, April 2021

[95] Source: *GILLIG's next-generation battery to provide 32 percent increase in onboard energy*, Gillig, November 2021

[96] Source: *Battery Electric Bus and Facilities Analysis Final Report*, Milwaukee County Transit System, January 2020

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.[97]

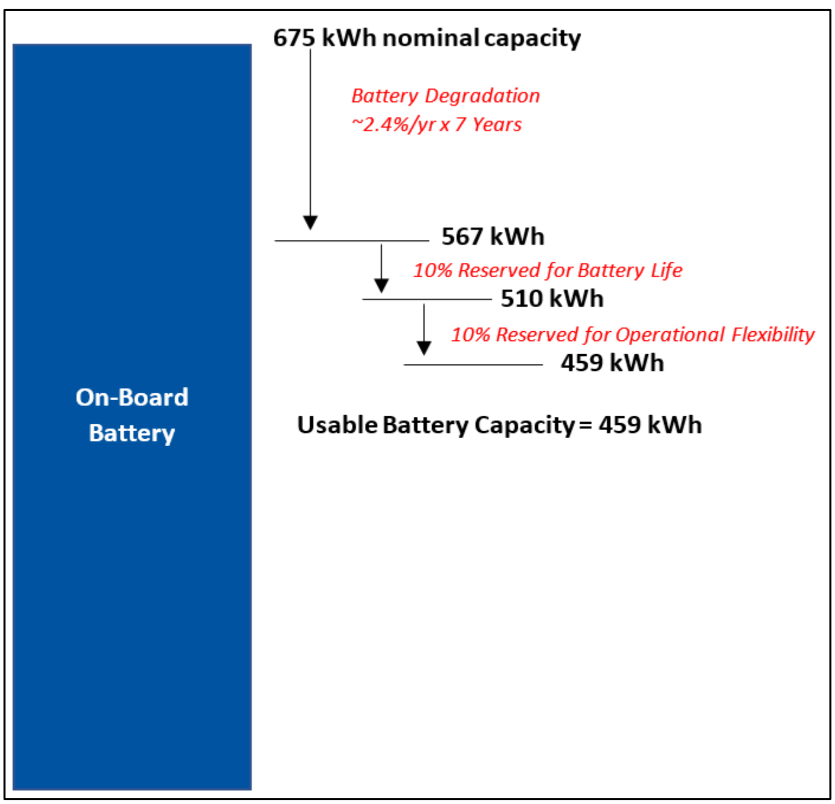
Operational Flexibility Capacity Reservations

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.[94] 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.

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 43 for a nominal battery capacity of 675 kWh, the nominal battery capacity of the BEBs Metro Transit is purchasing in 2022.

Figure 43 Calculation of usable battery capacity at bus mid-life



[97] Source: Interview with TTC staff, October 2021

Energy Usage Impacts on BEB 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 5.1.2.4, in the Twin Cities region, average monthly temperatures have historically been below freezing (32 F) between three to five months out of the year.[98] 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. [99] Additionally, the region experiences sub-freezing air temperatures on an average of 151 days per year with 24-25 days of sub-zero air temperatures.[99] For example, in February 2021 the region experienced 13 days of below zero air temperature including one day reaching negative 19 degrees Fahrenheit.[100] 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 around worst-case range estimates based on winter temperatures to ensure reliable service can be maintained through all seasons.

Metro Transit must plan BEB service around worst-case range estimates based on winter temperatures

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.

8.3.1.2. Technical Viability Methodology

Using the impacts to BEB range described above, a BEB's worst-case range can be calculated against block length to determine whether the block is technically viable for BEB service. Table 31 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 both 450 kWh and 675 kWh nominal battery capacities in addition to 60-foot buses with 525 kWh nominal battery capacities. These values were selected based on average battery capacities available on the market for extended-range BEBs. For reference, 60-foot buses with 466 kWh nominal battery capacities are currently being used for the C Line pilot. Metro Transit's next procurement of BEBs will be 40-foot BEBs with 675 kWh nominal battery capacities. All calculations assume supplemental cabin heating via auxiliary

98 Source: *Climate Saint Paul – Minnesota*, U.S. Climate Data
99 Source: *America's 20 Coldest Major Cities*, NOAA, 2014
100 Source: *Twin Cities Weather - February 2021*, Weather.gov, 2014

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 in the short-term as detailed in Section 8.2.3.

Table 31: Assumptions for BEB route and block analysis

Item	450 kWh 40-foot buses with auxiliary diesel heater	675 kWh 40-foot buses with auxiliary diesel heater	525 kWh 60-foot buses with auxiliary diesel heater
Battery size, nominal capacity	450 kWh	675 kWh	525 kWh
Battery size, useable capacity (68% of nominal) *	306 kWh	459 kWh	357 kWh
Average kWh per mile	2.2	2.2	3.5
Average range in miles	139	209	102
Worst-case kWh per mile	3.5	3.5	4.5
Worst-case (winter in Minnesota) range in miles	88	131	79
Minimum Average Speed	8 mph	8 mph	8 mph

** Usable battery capacity defined as the bus mid-life battery capacity defined as 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.*

In the short-term, Metro Transit plans to implement additional 60-foot BEBs on the Gold and Purple Line services. As both the Gold and Purple Line are BRT services, they are required, regardless of propulsion type, by the FTA to have a dedicated bus fleet with separate branding to distinguish the service from other bus service.[101] Similar to the service planning for the C Line, Gold and Purple Line blocks will therefore be specifically tailored to support the range requirement thresholds necessary to operate 60-foot BEBs. Aside from these two services, Metro Transit is focused on the implementation of 40-foot, rather than 60-foot, BEBs in the short-term to gain experience on other service types. As a result, the following service analysis will consider block suitability based only on 40-foot BEB characteristics.

Using this methodology and the criteria presented in Table 31, each block within a given service schedule change is analyzed to assess BEB suitability. This analysis is performed twice for each block, once for 40-foot BEBs using a 450 kWh nominal battery capacity and once for 40-foot BEBs using a 675 kWh battery. As the length of buses operated on any given block is subject to change in the future, this analysis was applied to all blocks regardless of the length of buses currently operating on the block. In both cases, a block was determined to be technically viable if:

- The total block distance was less than the BEBs worst-case range; and
- The bus's average speed along the block was at least eight miles per hour.

Based on this analysis, the technical viability of the given service schedule for BEB service is summarized in three ways:

[101] Source: *Final Interim Policy Guidance Federal Transit Administration Capital Investment Grant Program*, FTA, June 2016

- Count (and percent) of total blocks that are technically viable;
- Percent of total annual bus hours that are technically viable;[102]
- Percent of total annual bus miles that are technically viable.[103]

8.3.1.3. Technical Viability (August 2021 Service Schedule)

To provide an example of how the technical viability portion of this methodology could influence service decisions, this methodology was applied to Metro Transit's August 2021 service schedule change. These analysis results are subject to change up to four times a year due to changes in block length and composition as a result of Metro Transit's service schedule changes four times a year.

About a third of Metro Transit's annual bus hours and miles could be served by a 675 kWh 40-foot BEB, like those being ordered in 2022

Overall, approximately half of Metro Transit's August 2021 blocks representing nearly a third of the agency's total annual bus hours and miles were technically viable for 40-foot BEB service assuming a 675 kWh nominal battery capacity like the batteries on board the BEBs Metro Transit is purchasing in 2022 (Table 32).

Table 32: Technically viable block summary for 40-Foot BEBs for August 2021 schedule

	450 kWh 40-foot buses with auxiliary diesel heater	675 kWh 40-foot buses with auxiliary diesel heater
Number of Technically Viable Blocks	343	558
% of Total Blocks	29%	47%
% of Total Annual Bus Hours*	13%	31%
% of Total Annual Bus Miles	16%	32%

**Note: Bus Hours defined as the time between when a bus pulls out of a garage to when it pulls back into the garage.*

As described in Section 6.2.5, block characteristics vary by garage. To gain a greater understanding of this variability, technical viability summary metrics were calculated for the August 2021 bus service operating from each of the existing garages (Figure 44). Overall, when increasing the nominal battery capacity from 450 kWh to 675 kWh, all three technical viability metrics (percent of total blocks, bus hours, and bus miles) increase by an average of approximately 17 percent across all garages.

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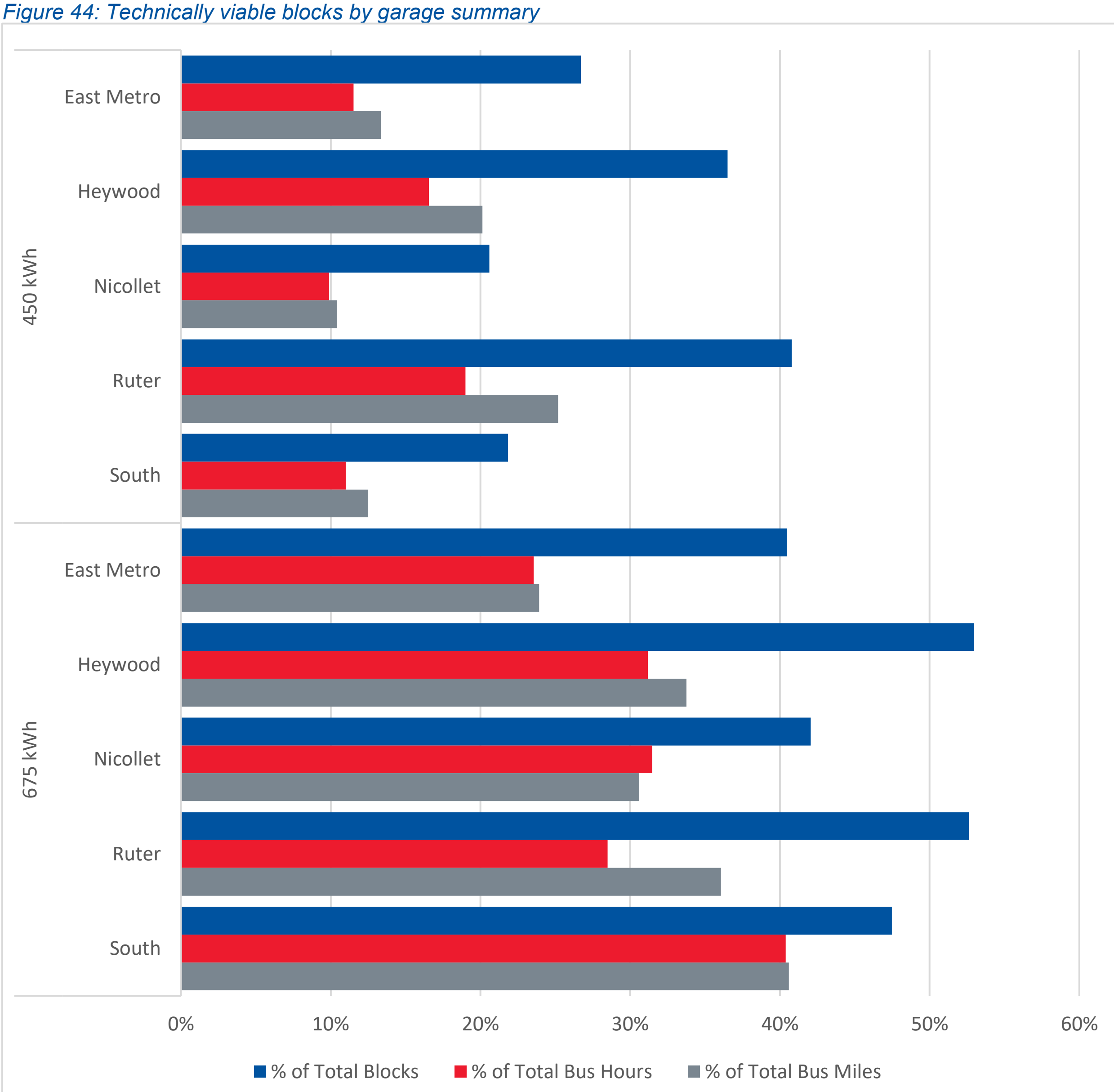
[102] Note: Bus hours defined as the time between when a bus pulls out of a garage to when it pulls back into the garage

[103] Note: To calculate the portion of technically viable annual bus hours or miles for a given service schedule, the number of service days of each schedule type (Weekday, Saturday, and Sunday) were multiplied by their respective share of technically viable bus hours or miles compared to all bus hours and miles in the schedule and then added together. Note that each quarterly service schedule change may have a unique number of Weekday, Saturday, and Sunday service days for that year. For the August 2021 schedule change, for example, it was assumed that there were 257 days of Weekday service, 51 days of Saturday service, and 57 days of Sunday/Holiday service across the entire year including New Year's Day, Memorial Day, Independence Day, Labor Day, Thanksgiving Day, and Christmas Day.

For a 450 kWh 40-foot BEB, the garages with the highest prevalence of technically viable blocks (blue bars) are the Heywood and Ruter Garages. At these two garages, over a third of the blocks are technically viable, representing 20 percent or more of the total annual bus miles operated from each garage. All of the blocks that are technically viable at the Heywood Garage could shift to the Minneapolis Bus Garage in the future. Conversely, although the East Metro Garage has a relatively high percentage of technically viable blocks (27 percent), the share of the total bus hours and miles from the garage that are technically viable for BEB service is much lower (12 and 13 percent respectively) and is comparable to the other two garages (Nicollet and South) that have a lower prevalence of technically viable blocks. These results will be considered when service is redistributed across the system with the opening of the Minneapolis Bus Garage in early 2023 to determine which blocks could efficiently operate out of the new facility or East Metro garage and be contenders for BEB operations in the short-term.

Figure 44: Technically viable blocks by garage summary



For 40-foot BEBs with an expanded nominal battery capacity of 675 kWh, the garage-level trends are largely the same as the Heywood and Ruter Garages have the highest prevalence of technically viable blocks. Unlike with the 450 kWh analysis, however, both Nicollet and South Garages have a similarly high proportion of technically viable bus hours and miles. In fact, although the electrification of South Garage is not recommended due to the electrical complexities and property-lease status discussed in Section 8.2.2.3, this garage actually has the highest proportion of technically viable bus hours and miles when compared to all other garages. These blocks will be assessed to determine if any can efficiently operate out of Tier 1 garages in the short-term as part of service redistribution with the opening of the new garage. Additionally, although the Nicollet Garage, has a lower total prevalence of technically viable blocks, the relative share of technically viable bus hours and miles within the garage is comparable to both the Heywood and Ruter Garages. As Metro Transit adjusts block characteristics quarterly as well as the garage that blocks are assigned to annually, Metro Transit has the flexibility to move some blocks between garages to concentrate technically viable blocks at garages with Tier 1 electrification priority as identified in Section 8.2.2.4.

Overall, this analysis illustrates that nearly half (47 percent) of Metro Transit's August 2021 bus blocks representing just under a third of all bus miles (32 percent) and hours (31 percent), can be served by the 675 kWh BEBs Metro Transit is purchasing in 2022 without altering existing block structures or using on-route charging. As these results are specific to the August 2021 service schedules, the results are subject to change up to four times a year due to changes in block length and composition as a result of Metro Transit's service changes.

In the short-term, Metro Transit plans to substantially replace the existing Routes 5, 6, and 21 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 60-foot buses operating on redesigned blocks that are longer in length due to the nature of the arterial BRT service. Therefore, although most of the blocks currently serving these routes are technically viable, it is anticipated that many may not be technically viable when this dynamic prioritization methodology is applied to future service schedules.

Overall, however, due to the rapid advancement of BEB technology and battery capacities, it is anticipated that an increasing number of blocks will become technically viable in the coming years. Given that such a significant percentage of Metro Transit's existing (August 2021) bus network is technically viable for BEB service, the primary limiting factors to large scale BEB deployment are the lengthy timeframes necessary to electrify the bus garages, the need for expanded workforce development, the limited production capacity of BEBs, batteries, and chargers and the amount of available funding for bus operation and maintenance. As such, Metro Transit will focus their efforts on partnering with Xcel Energy for facility improvements and workforce development in the short-term while monitoring manufacturing and supply chain capacity in the coming years to meet the demands of increasing BEB and infrastructure purchases across the transit industry.

8.3.2. Equity and Environmental Justice (EEJ) 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 are assigned an EEJ priority score to guide block-level implementation in the short-, medium-, 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 was conducted as well as an inspection and evaluation of the nearly 300 variables related to equity and environmental justice from the Metropolitan Council's *Equity Considerations for Place-Based Advocacy and Decisions in the Twin Cities Region* dataset. 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 Black, Indigenous, People of Color (BIPOC)
- Percent of census tract households lacking a vehicle
- Number of five-year American Community Survey (ACS) datasets (2006-2010 through 2015-2019) in which the census tract was designated as an Area of Concentrated Poverty (ACP).[104]
- 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

8.3.2.1. EEJ Methodology

Census Tract EEJ 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, 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 7.4, 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, then 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 33 below.

[104] 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 33: 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 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:

$$\boldsymbol{Census\ Tract\ EEJ\ Weighted\ Average} = 0.34 * (Cancer\ Risk\ Percentile)$$

$$+0.21 * (Population\ Density\ Percentile)$$

$$+0.17 * (BIPOC\ Percentile)$$

$$+0.11 * (Zero\ Car\ Household\ Percentile)$$

$$+0.10 * (Number\ of\ Years\ ACP\ Percentile)$$

$$+0.04 * (Average\ Land\ Temperature\ Percentile)$$

$$+0.03 * (Housing\ Cost\ Burdened\ Percentile)$$

To simplify the interpretation of these weighted averages, these values are then scaled from zero 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 34).

Table 34: EEJ priority tier thresholds

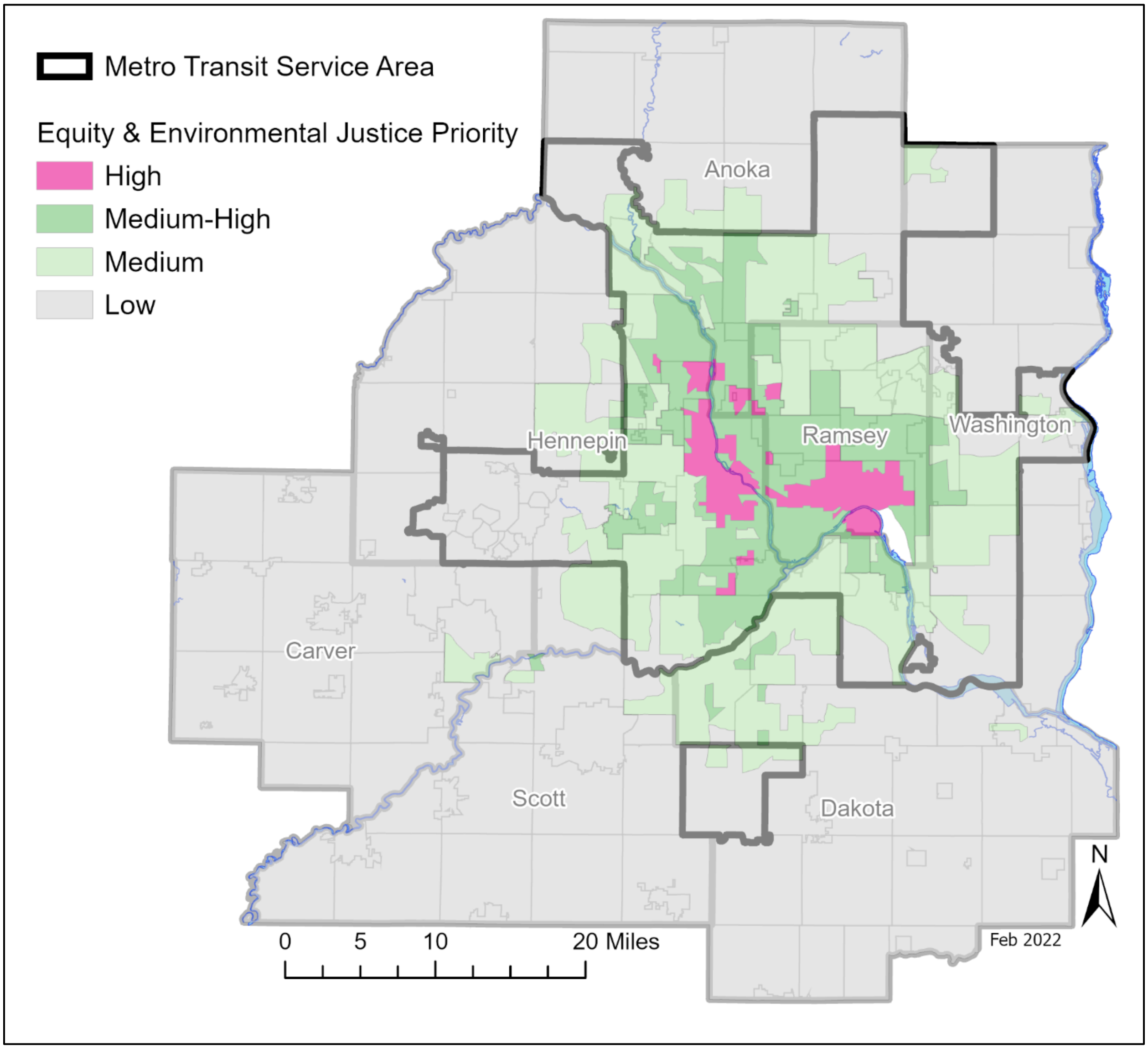
Census Tract EEJ Priority Tier	Census Tract EEJ Priority Score Range
High	>75
Medium-High	50-75
Medium	25-50
Low	< 25

As shown in Figure 45, 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. For context, based on the August 2021 service schedule, approximately 36 percent of all Metro Transit bus miles are located in an area of high EEJ priority.

Figure 45: Census-Tract Equity and Environmental Justice (EEJ) priority areas



Bus Service Block EEJ Methodology

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 average of the relative number of block miles in each EEJ priority area shown in Figure 45. The weighted average for each block is calculated as follows:

$$\textbf{\textit{Bus Block EEJ Score}} = (4 * (Miles\ in\ \text{“}High\text{”}\ Priority\ EEJ\ Area)$$

$$+3 * (Miles\ in\ \text{“}Medium - High\text{”}\ Priority\ EEJ\ Area)$$

$$+2 * (Miles\ in\ \text{“}Medium\text{”}\ Priority\ EEJ\ Area)$$

$$+1 * (Miles\ in\ \text{“}Low\text{”}\ Priority\ EEJ\ Area))\ /\ Total\ Block\ Miles$$

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 35).

Table 35: EEJ block-level priority tier thresholds

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

8.3.2.2. EEJ Priority (August 2021 Service Schedule)

To provide an example of how the EEJ Priority portion of this methodology could influence BEB prioritization and deployment decisions, this methodology was applied to Metro Transit's August 2021 service schedule. These analysis results are subject to change up to four times a year due to changes in block length and composition as a result of Metro Transit's service changes.

Based on the EEJ categories outlined in the methodology above, approximately one third of the technically viable August 20201 blocks for both the 450 kWh and 675 kWh 40-foot BEBs are designated as a high EEJ priority for BEB implementation. Overall, more than a tenth of the total annual bus hours and miles traveled across the entire Metro Transit bus network could be performed by operating a 675 kWh 40-foot BEBs (like those Metro Transit is purchasing in 2022) on just high EEJ priority blocks (Table 36).

Table 36: Technically viable and high EEJ priority block summary for 40-Foot BEBs

	450 kWh 40-foot buses with auxiliary diesel heater	675 kWh 40-foot buses with auxiliary diesel heater
Number of Technically Viable & High EEJ Priority Blocks	106	199
% of Technically Viable Blocks	31%	36%
% of Total Blocks	9%	17%
% of Total Annual Bus Hours*	5%	13%
% of Total Annual Bus Miles	5%	11%

**Note: Bus Hours defined as the time between when a bus pulls out of a garage to when it pulls back into the garage.*

8.3.3. **Fiscal Impact Modeling**

Currently, the capital cost of putting a BEB on the road for Metro Transit is about 2.5 times as expensive as a diesel

Metro Transit is focused on deploying BEBs in a fiscally efficient manner to maximize vehicle and infrastructure usage

bus.[105] 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.

8.3.3.1. Fiscal Impact Methodology

To achieve a fiscally efficient deployment of BEBs, Metro Transit plans to prioritize BEB deployment on the longest technically viable blocks. As such, the technically viable blocks for each battery capacity are categorized into four fiscal priority tiers based on the naturally occurring groups and breakpoints in total block distance (Table 37). 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 blocks. Alternatively, a grouping of blocks in lower tiers could be assembled into one longer block to reach high fiscal efficiency. For example, if a 30-mile and a 45-mile block are grouped together for a 450kWh BEB, together this would yield 75 miles driven for that vehicle in a resulting in high efficiency. For this analysis, only individual blocks were reviewed, however in the future block groupings could be reviewed for additional deployment opportunities.

Table 37: Fiscal efficiency categories by technically viable block distance

Block-Level Fiscal Efficiency	450 kWh 40-foot buses with auxiliary diesel heater	675 kWh 40-foot buses with auxiliary diesel heater
High	> 75 Miles	> 105 Miles
Medium-High	60-75 Miles	80-105 Miles
Medium	45-60 Miles	55-80 Miles
Low	< 45 Miles	< 55 Miles

8.3.3.2. Fiscal Impact Priority (August 2021 Service Schedule)

To provide an example of how the fiscal impact portion of this methodology could influence BEB deployments, this methodology was applied to Metro Transit's August 2021 service schedule. These analysis results are subject to change up to four times a year due to changes in block length and composition as a result of Metro Transit's service changes.

As shown in Table 38, based on the August 2021 service schedule, 48 (14 percent) of the technically viable blocks for the 450 kWh 40-foot BEBs and 142 (25 percent) of the technically viable blocks for the 675 kWh 40-foot BEBs are designated as having a high fiscal efficiency. Overall, compared to the total annual bus hours and miles traveled across the entire Metro Transit bus network, approximately 12 percent of the total bus blocks, hours, and miles could be performed by operating 675 kWh 40-foot BEBs on just the technically feasible blocks with high fiscal efficiency (Table 36).

[105] Source: Metro Transit Statement, C. Desmond, September 2021

Table 38: August 2021 technically viable and high fiscal efficiency block summary for 40-Foot BEBs

	450 kWh 40-foot buses with auxiliary diesel heater	675 kWh 40-foot buses with auxiliary diesel heater
Number of Technically Viable & High Fiscal Efficiency Blocks	48	142
% of Technically Viable Blocks	14%	25%
% of Total Blocks	4%	12%
% of Total Annual Bus Hours*	3%	12%
% of Total Annual Bus Miles	3%	12%

**Note: Bus Hours defined as the time between when a bus pulls out of a garage to when it pulls back into the garage.*

8.3.4. Service Prioritization Summary

By combining the three guiding principles of technical viability, equity and environmental justice, and fiscal impact, the most promising blocks suitable for short-term BEB deployment can easily 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 while the other principle has a “medium-high” rating.

As shown in Table 39, by applying the full methodology to the illustrative example of the August 2021 service schedule, 51 blocks from the August 2021 schedule were identified as the most-promising blocks to consider when selecting the first eight blocks to operate the new 675 kWh 40-foot BEBs Metro Transit will be purchasing in 2022. Although an aggregate top priority tier of only 51 blocks may initially appear limiting, it is important to remember that this prioritization is representative of how Metro Transit will deploy the next eight BEBs in 2023. This methodology was intended to identify block priority rather than the total potential opportunity to electrify Metro Transit’s bus service. Therefore, a limited number of top priority blocks is most beneficial towards establishing implementation policies and guidance as this allows for a more in-depth and detailed consideration of the top blocks when ultimately determining which blocks will receive BEB service next. This methodology also establishes a prioritization scheme that can be used for future service schedules, each time additional BEBs are deployed.

Table 39: Count of top priority most viable blocks for BEB service in the short-term

Aggregate Priority	450 kWh 40-foot buses with auxiliary diesel heater	675 kWh 40-foot buses with auxiliary diesel heater
Top Priority • Technically Viable • High EEJ Priority • High Fiscal Efficiency	15 Blocks	52 Blocks
Secondary Priority • Technically Viable • High EEJ Priority • Medium-High Fiscal Efficiency OR • Technically Viable • Medium-High EEJ Priority • High Fiscal Efficiency	32 Blocks	52 Blocks
TOTAL:	47 Blocks	104 Blocks

Note: Block count does not include blocks serving current BRT service (A Line, C Line, Red Line, Orange Line) as these services already have existing fleets. Although several local routes will be substantially replaced by arterial BRT service with longer blocks and dedicated fleets in the future, they may be top candidates for BEB service currently. As such, blocks on all future BRT routes remain included in the above short-term priority table with the recognition that in the future, these blocks will likely be less suitable for short-term BEB service.

Metro Transit will continually evaluate ZEB prioritization methodology to ensure consistency with the Transition Plan's guiding principles while meeting ridership and available workforce levels

Overall, this section has established a service prioritization methodology informed by the experiences of peer transit agencies, community engagement, and based upon the guiding principles of technical viability, equity and environmental justice, and fiscal impact. Based on the illustrative application of this methodology to the August 2021 service schedule, it was determined that nearly half of all bus blocks are technically suitable for BEB service based on a conservative worst-case winter BEB range of 131 miles and that 51 (nine percent) of these technically viable blocks had a high EEJ prioritization and high fiscal efficiency for implementation. 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.

9. 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 ZEB Transition Plan, Metro Transit is required to establish milestones and/or performance measures for the plan. The milestones and performance measures outlined throughout this section will 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.

9.1. 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 are set in five-year increments to be consistent with legislative plan updates. The first update to the Transition Plan will be submitted in 2027. The short-term aligns with the first Transition Plan update and extends from 2022 through 2027. The medium-term aligns with the second Transition Plan update and extends from 2028-2032. The long-term time horizon begins in 2033 and extends beyond this year into the future. Using these time increments, this plan establishes targets and projections for vehicle procurement as well as annual communications and performance reporting milestones. 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 medium-term. Unlike targets, projections do not define specific numbers or metrics. Experience in the short-term will inform projections for future Transition Plan updates.

9.1.1. 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 horizon. For the short-term target, Metro Transit is aiming for at least 20 percent of 40-foot bus replacement procurements to be electric, from 2022-2027. This target was set based on the maximum amount of charging infrastructure that could be installed within the short-term timeframe. This could be accomplished by purchasing between 100 to 130 ZEBs which would account for 12 to 15 percent of Metro Transit's total 2021 fleet, defined as the total number of buses owned and operated by Metro Transit, and 20 to 24 percent of Metro Transit's active 2021 fleet, defined as the number of buses in use in 2021 due to service reductions from the operator shortage and COVID-19 pandemic.

For the medium-term projection, the percentage of Metro Transit bus procurements that are ZEBs will be driven by key performance indicators and available budgetary resources. Metro Transit is committed to continuing to transition its fleet to ZEBs in the medium- and long-term. An official target will be set for these timeframes during future updates of this plan based on realized experience in the short-term as well as industry advancements.

9.2. Performance Measures

Performance measures will be used to analyze progress against the milestones, inform plan updates, and drive decision making for future procurements. The performance measures will 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 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 (miles between roadcalls), 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. As an additional example, AC Transit in Oakland, CA, uses five main performance measures to assess its ZEBs: Fleet Mileage, Cost/Mile, Emissions, Fleet Availability, and Reliability. AC Transit is conducting a performance study of five different propulsion types with five vehicles each. Table 40 compares the performance of each propulsion type for AC Transit after six months of revenue service.

Table 40: AC Transit ZEB performance measures January 2021-June 2021

FLEET	DIESEL (BASELINE)	DIESEL HYBRID	FUEL CELL ELECTRIC (FCEB)	BATTERY ELECTRIC (BEB)	LEGACY Fuel Cell
Series Grouping	1600	1550	7000	8000	FC
Technology Type	Diesel	Hybrid	Fuel Cell	Battery	Fuel Cell
Bus Qty	5	5	5	5	5
Manufacturer	Gillig	Gillig	New Flyer	New Flyer	Van Hool
Year	2018	2016	2019	2019	2010
Length	40’	40’	40’	40’	40’
Data Summary (January – June 2021)					
Fleet Mileage	120,749	98,189	88,389	54,275	70,859
Cost/Mile	$1.41	$1.80	$1.97	$2.02	$4.07
Cost/Mile (w/ credits)	$1.37	$1.78	$1.97	$2.02	$4.07
Emissions (CO_2 Metric Tons)	298	182	0	0	0
Fleet Availability	96%	75%	69%	47%	68%
Reliability (MBCRC)	12,075	4,091	6,314	3,618	2,531

To follow industry best practices, Metro Transit will use similar performance measures to evaluate ZEBs and supporting infrastructure within its system. In the short-term, Metro Transit’s ZEB Transition Plan is to utilize BEBs. The following sections summarize the performance measures that Metro Transit will use to assess the BEBs and infrastructure.

- **Fleet Mileage**: How many miles vehicles are driven annually
- **Bus Availability**: % of calendar year ready for service
- **Infrastructure Availability:** % of calendar year infrastructure available for use
- **Bus Reliability:** Mean distance between road calls
- **Charger Reliability:** Warranty ticket volume
- **Cost/mile:** Energy cost per mile driven
- **Environmental Impact:** Emissions or cost of carbon
- **Equity and Environmental Justice:** Miles driven through high priority EEJ areas

9.2.1. Fleet Mileage

Fleet mileage is a useful metric for assessing Metro Transit’s progress towards transitioning its fleet to ZEBs. Fleet mileage measures the number of miles the vehicles within a fleet drive annually. This metric will help Metro Transit compare the number of miles that are driven with different propulsion types and manufacturers. As Metro Transit makes progress towards transitioning its fleet to ZEBs, the total number of fleet miles driven by ZEBs will increase and the total number of fleet miles driven by diesel vehicles will decrease.

9.2.2. Bus Availability

Bus availability measures the percent of the calendar year that a vehicle is ready for service. This metric will help Metro Transit determine the level of redundancy that is needed to consistently provide service. For example, if the average ZEB is only available for service 50 percent of the time, Metro Transit will need to consistently have another vehicle that can provide service in the event the scheduled ZEB is out of service. On the other hand, if the average ZEB is available for service 90 percent of the time, there would be a lesser need for spare ZEBs. This metric can also help Metro Transit evaluate different ZEB vendors. ZEBs from different vendors may have higher or lower bus availability. By tracking this metric, Metro Transit will be able to make informed decisions on the availability of buses from different vendors and proceed with greater confidence on larger scale procurements in the future.

9.2.3. Infrastructure Availability

Infrastructure availability measures the percent of the calendar year that infrastructure is available for use. Similar to bus availability, this metric will help Metro Transit determine the level of infrastructure redundancy that is needed to consistently provide service. For example, the availability of chargers can influence the bus availability of BEBs. In the event that a charger is out of service for a prolonged amount of time, certain BEBs may not be able to get charged unless there are backup chargers available. As a result, a high percentage of infrastructure availability is critical to the operation of ZEBs. This metric can also help Metro Transit evaluate different ZEB vendors. Chargers from different vendors may have higher or lower infrastructure availability. By tracking this metric, Metro Transit will be able to make informed decisions on the availability of chargers from different vendors and proceed with greater confidence on larger scale procurements in the future.

9.2.4. Bus Reliability

Bus reliability measures the mean distance between road calls. This metric will help Metro Transit evaluate how often a bus breaks down while it is in service. Generally, the more miles a bus can travel without a road call, the more reliable service the bus can deliver. As a result, this metric is important for assessing the impact ZEBs have on service reliability and customer experience. This metric can also help Metro Transit evaluate different ZEB vendors. ZEBs from different vendors may have higher or lower bus reliability. By tracking this metric, Metro Transit will be able to make informed decisions on the reliability of buses from different vendors and proceed with greater confidence on larger scale procurements in the future.

9.2.5. Charger Reliability

In the short-term, Metro Transit’s ZEB plan is to utilize BEBs. For BEBs, charger reliability measures the amount of times Metro Transit needs to temporarily take a charger out of service for unplanned maintenance. This metric will help Metro Transit understand how many times a charger needs to be repaired due to technical issues. Since BEBs need to be charged to be ready for service, chargers need to be reliable for BEBs to consistently deliver service. If chargers are constantly malfunctioning and need repairs, it will impact the reliability of service that BEBs can deliver. This metric can also help Metro Transit evaluate different ZEB vendors. Chargers from different vendors may have higher or lower charger reliability. By tracking this metric, Metro Transit will be able to make informed decisions on the reliability of chargers from different vendors and proceed with greater confidence on larger scale procurements in the future.

9.2.6. Cost/Mile

Cost per mile measures the energy cost per mile driven. This metric will help Metro Transit understand the ongoing costs of operating ZEBs. The cost of energy per mile will influence the amount that Metro Transit needs to budget for operating and maintenance costs. Additionally, this metric will help Metro Transit evaluate ZEB vendors. ZEBs from different vendors may have higher or lower energy costs per mile. By tracking this metric, Metro Transit will be able to make informed decisions on the operating costs of buses from different vendors and proceed with greater confidence on larger scale procurements in the future.

9.2.7. Environmental Impact

Environmental impact measures various emissions from vehicles. This can be measured based on tons of emissions of different types per vehicle and/or by assigning a cost of carbon to monetize carbon emissions. This metric will help Metro Transit understand the impact the transition to ZEBs will have on reducing emissions from transit vehicles. Tracking the impact ZEBs have on emissions can help Metro Transit demonstrate the community benefits that ZEBs deliver to the region. This information can be used in future grant applications to secure funding for procuring additional ZEBs.

9.2.8. Equity and Environmental Justice

Equity and environmental justice measures vehicles operating in equity priority areas based on the methodology described in Section 8.3.2. This can be measured based on miles driven through high priority equity areas when compared to total miles driven. This metric will help Metro Transit understand the impact the prioritization of ZEB deployment is having in the community based on environmental, racial, and socioeconomic considerations.

10. 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 initiate the transition to ZEBs, Metro Transit developed several packages of projects. These packages of projects were created based on Metro Transit's 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 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.

10.1. Package A: C Line BRT 60-Foot Pilot

Package A began revenue service in June 2019. Package A consists of piloting BEBs on the C Line BRT service. Package A included the procurement of eight 60-foot buses, eight plug-in chargers at Heywood, and two overhead conductive chargers at Brooklyn Center Transit Center. This project was done on an expedited schedule and significant equipment failures in first generation charging equipment resulted in an agreement with the vendor to replace all charging equipment under warranty. This pilot program is giving Metro Transit valuable insights into how BEBs perform on BRT routes. Piloting the BEBs on the C Line BRT allows Metro Transit to do a head-to-head comparison of diesel vehicles versus BEBs since both types of vehicles were purchased new to operate on the BRT route. Additionally, since this pilot program includes both plug-in and overhead conductive chargers, this project is providing information on how a range extension (garage and on-route) charging strategy could work within Metro Transit's system. Table 41 summarizes Package A.

Table 41: Package A summary table

Package	Description	Learning Objectives
A *C Line BRT 60' pilot* *(began service in June 2019)*	(8) 60' 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

10.2. Package B: 40-Foot Extended Range Local Service Pilot and Distributed Energy Resources Pilot

Metro Transit has already begun to implement Package B. Package B involves piloting Proterra 40-foot BEBs with extended range on local transit routes. This pilot project includes the procurement of eight 40-foot buses, eight plug-in chargers and 2 high-capacity overhead conductive chargers for rapid charging at MBG. In addition to buses and chargers, Package B also includes the installation of an approximately 2 MW solar array on the roof of MBG, an approximately 2 MWh/800 kW battery storage system at MBG, and enhanced telematics. Package B will give Metro Transit the opportunity to test both lower power and higher power chargers at a garage. It will also provide information on how a garage-only charging strategy could work within Metro Transit's system. This package will also provide Metro Transit with experience in distributed energy resources for power generation and power storage. Additionally, Package B includes enhanced telematics software which will allow Metro Transit to test how advanced software can assist Metro Transit with asset management, operations, and maintenance diagnostics. Table 42 summarizes Package B.

Table 42: Package B summary table

Package	Description	Learning Objectives
B *40' local service pilot and distributed energy resources*	(8) 40' buses (8) plug-in chargers at MBG Up to 2MW solar array at MBG Up to 2MWh/800 kW battery storage system at MBG (2) high-capacity overhead conductive chargers at MBG Enhanced telematics Workforce Development	**Pilot long range local service BEB and distributed energy resources** • Pilot local service BEBs with garage only charging strategy • Mix of lower power plug-in chargers & higher power overhead conductive chargers • Study distributed energy resources • Pilot enhanced telematics software

10.3. Package C: BRT Moderate Expansion

Package C would complete moderate BRT BEB expansion on the Gold and Purple Line routes. Package C would procure up to 22 buses and up to 22 plug-in chargers. This package would also include enhanced software tools. Package C will allow Metro Transit to expand the use of BEBs on BRT routes. As part of this package, Metro Transit will install its first chargers at the East Metro Garage. Additionally, this package will allow Metro Transit to test new software tools that includes capabilities to track demand, assist with scheduling, monitor vehicles, and provide telematics data. Package C is also anticipated to include two high-capacity overhead conductive chargers at the East Metro Garage, up to six lower power chargers in the maintenance shop at the East Metro Garage and at least two chargers at the Overhaul Base heavy maintenance facility. Table 43 summarizes Package C.

Table 43: Package C summary table[93]

Package	Description	Learning Objectives
C *BRT Moderate Expansion*	Up to (22) BRT buses Up to (22) plug-in chargers at East Metro garage Up to (2) high-capacity overhead conductive chargers at East Metro Garage Up to (2) high-capacity overhead conductive chargers on route Up to (6) plug-in maintenance chargers at East Metro Garage (2) plug-in chargers at the Overhaul Base Enhanced software tools Workforce Development	• Assess the benefits of multiple garages with charging infrastructure • Scale up BRT BEB use • Expand to East Metro Garage • Pilot software tools to enable scaling up (demand, schedule, monitor, telematics)

10.4. Package D: 40-Foot Bus Moderate Transition

Package D would increase the deployment of 40-foot BEBs. Package D would procure up to 30 40-foot buses and up to 30 plug-in chargers. This package would also include software updates. As part of Package D, Metro Transit will install chargers at the MBG and East Metro garage. Additionally, this package will allow Metro Transit to develop more of its workforce and educate more of its staff on operating and maintaining BEBs. Package D would also include the installation of up to six chargers in the MBG maintenance shop. Table 44 summarizes Package D.

Table 44: Package D summary table

Package	Description	Learning Objectives
D *40' Bus Moderate Transition*	Up to (30) 40' buses Up to (30) plug-in chargers Up to (6) plug-in maintenance chargers at MBG MBG & East Metro Garage Upgrades Software suite upgrades Workforce Development	• Assess optimization of BEB deployment with upgraded software suite • Scale up 40' BEB use • Scale up MBG & East Metro Garage • Workforce development focus

10.5. Package E: 40-Foot Bus Larger Transition

Package E would increase the deployment of 40-foot BEBs with the first larger scale transition. Package E would procure up to 70 40-foot buses and up to 35 plug-in chargers. This package would also include software updates allowing Metro Transit to expand the use of BEBs within its system and gain experience with BEBs being a significant proportion of the fleet mix at two garages. As part of this package, Metro Transit will install more chargers at the MBG and East Metro garage. Table 45 summarizes Package E.

Table 45: Package E summary table

Package	Description	Learning Objectives
E *40' Bus Larger Transition*	Up to (70) 40' buses Up to (35) plug-in chargers Software suite expansion	• Evaluate experience with BEBs as a significant portion of the fleet mix at 2 garages • Larger procurement of BEBs and chargers • Operating BEBs at larger scale

10.6. 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 operational energy cost forecasts 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 recently passed IIJA renewed several existing funding programs for procuring ZEBs and supporting infrastructure, at significantly higher funding levels. 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 identify a sustainable source of funding as well as means to stabilize and reduce energy costs per mile. To accomplish this, operational cost estimates will need to be further studied and optimized to understand the long-term recurring costs that will be associated with the transition to ZEBs. Currently, electricity is more than double the cost per mile compared to diesel.[23] Moving forward, electricity costs are projected to increase approximately 32 percent between 2021 and 2027.[106] Within the same time period, Metro Transit forecasts an approximately 20 percent increase in diesel costs for budgetary purposes.[107] As a result, BEB operating costs may become a barrier to the larger scale adoption of BEBs. Establishing a close partnership with Xcel Energy with the shared commitment to further study

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[106] Source: *A87 Calculations Dataset*, Energy Tariff Experts, January 2022.
[107] Source: Metro Transit, Finance Department, January 2022.

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 10 as well as a discussion of energy costs per mile and other operational cost considerations.

10.6.1. Capital Cost Estimating Assumptions

Several assumptions were made to develop capital cost estimates for the packages of projects. The following list summarizes the assumptions that were used to calculate the capital cost estimates that are in Section 10.6.2:

- Cost estimates are based on the maximum number of identified vehicles and infrastructure the package could implement.
- Both a 3.5 percent per year escalation rate and a 7 percent per year escalation rate were applied to the cost estimates to estimate the range of capital costs for future packages of projects.
- For Packages A-D, it is assumed that one charger per bus will be installed in the bus storage facility. Each charger will have two dispensers. For Package E, it assumed that one charger per 2 buses will be installed in the bus storage facilities. Each charger will have two dispensers.
- Infrastructure will be built conservatively in the early years of the transition to ZEBs to provide redundancy while allowing for the addition of more ZEBs in later years without having to construct as much infrastructure.
- There will be one charger for every four maintenance bays.
- Each garage will have two high-capacity overhead conductive chargers.[108]
- There will be two chargers at the Overhaul Base.
- The cost estimates do not include a contingency.

10.6.2. Estimate of Capital Costs by Package

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. Capital costs can be volatile, and above average year over year price increases are currently being seen with multiple manufacturers due to manufacturing, supply chain, and shipping constraints that are largely attributed to impacts of the COVID-19 pandemic. In particular, multiple manufacturers are reporting average annual cost escalations from 2020 to 2021 in the six to seven percent range. To capture the potential volatility of capital costs, a capital cost range was calculated by applying two average annual cost escalation rates (3.5 percent and 7 percent) to vehicle and infrastructure costs year over year for each package. 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 46 shows an overview of the anticipated capital costs for each package.

[108] Note: Electrification of the South Garage is not recommended for implementation at this time.

Table 46: Capital cost estimates by package

Package	Total Estimated Capital Cost in Year of Expenditure
A: C Line BRT 60' pilot	$14.7M
B: 40' local pilot and distributed energy resources	$19.5M - $19.8M
C: BRT Moderate Expansion	$49.9M - $56.1M
D: 40' Bus Moderate Transition	$47.0M - $50.8M
E: 40' Bus Larger Scale Transition	$105.8M - $121.9M
TOTAL 2022-2027	**$236.8M - $263.4M**

Notes: Package A lists the actual cost for the C Line.

10.6.3. 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.

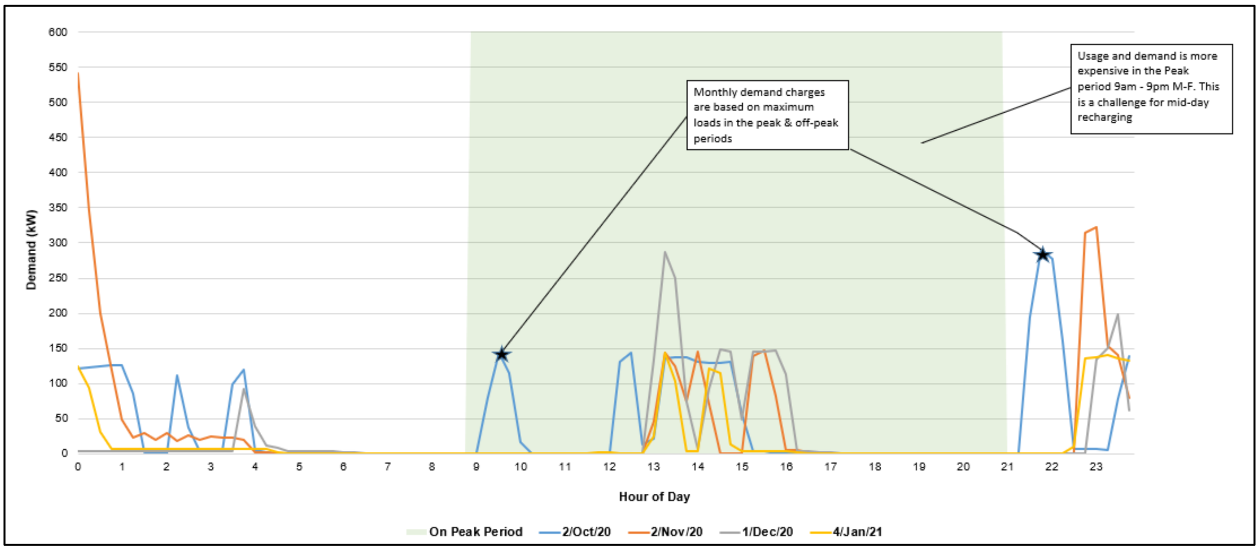
No agency in the United States has operated an electric bus for its full FTA required 12-year or 500,000-mile (whichever comes first) vehicle life. Therefore, a meaningful estimate of lifecycle operating cost cannot be calculated. However, this is something Metro Transit intends to monitor closely as we gain more experience and as the first electric buses in the United States reach their end of life.

10.6.4. Energy Cost Per Mile

As part of Package A (C Line BRT 60' Pilot), Metro Transit has calculated energy costs per mile for the 60-foot electric and diesel buses operating on the route. For the period between June 2019, when the C Line began revenue service, and February 2021, the average energy cost per mile for the electric buses was $1.00/mile while the average energy cost per mile for the diesel buses was $0.46/mile.[23] 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. Additionally, the calculations exclude the month of October 2019 as the electric buses were not in revenue service during this month.

When Metro Transit prepares its annual operating budget, increases to energy costs are forecasted for future years. Metro Transit forecasts a 3.15 percent annual diesel cost increase for budgetary purposes. While some years may have higher or lower cost increases, a consistent rate of inflation is used for budgeting diesel costs. 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 46, below, illustrates an electric bus charging load and how it is billed under Xcel Energy's Electric Vehicle Fleet pilot.

Figure 46: BEB charging load by time of day



As Figure 46 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.

Xcel Energy presently has a rate case before the MPUC in its Multi Year Rate Plan (MYRP) (Docket 21-630)[109],[110]. This MYRP includes an interim rate adjustment factor for commercial rates of 13.52 percent applied to the Basic Service Charge, Energy Charge, and Demand Charge in

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109 Source: *Northern States Power Company Before the Minnesota Public Utilities Commission: Application for Authority to Increase Electric Rates in Minnesota Docket No. E002/GR-21-630*, Xcel Energy, October 2021

110 Source: *Order Accepting Filing, Suspending Rates, and Extending Timeline*, December 2021

2022 while the case is pending, and then subsequent annual step-wise increases in 2023 and 2024 that will be determined by the MPUC in their final Order expected in late 2022.

In its MYRP filing, Xcel Energy has proposed Electric Vehicle Fleet Pilot rate schedules for 2022 through 2024. The Metropolitan Council prepared a cost forecast of expected bus charging costs per mile based on the proposed rates pending before the MPUC as well as historic bus charging loads at the Heywood Garage for the C Line from June 2019 through February 2021. This load data was used in this analysis to be representative of the garage charging plan recommend in the short-term. It should be noted, however, that the MPUC may authorize rates which are different from those proposed by Xcel Energy.

Since Xcel Energy has proposed changes to each component of its Base Rates, modeling the proposed tariff changes was required for budgetary forecasting instead of applying a simple escalation factor as demand, usage, and charges by season all change by varying percentages.

Table 47, below, shows the actual energy cost per mile experienced for the C Line buses between 2019-2021 and forecasted increases for 2022-2027. Note that the electricity rate escalation factors are dependent not only on the MPUC adopting Xcel Energy's rates as proposed, but also on Metro Transit having similar charging habits in the future. Absent improvements to energy efficiency of vehicles and/or electricity rates that align with the operating characteristics of BEBs, a new source of operating funds will be necessary to address this increased energy cost per mile.

Table 47: Operating cost assumptions by year[106]

		Escalation Calculation		Energy Cost Per Mile		
Year	**Electricity Comments**	**Electricity**	**Diesel**	**Electric Bus**	**Diesel Bus**	**Ratio of Electric to Diesel Cost***
2019-2021	--	100%	100%	$ 1.00	$ 0.46	2.17
2022	Interim	11.0%	3.15%	$ 1.11	$ 0.47	2.34
2023	Proposed	3.7%	3.15%	$ 1.15	$ 0.49	2.35
2024	Proposed	3.5%	3.15%	$ 1.19	$ 0.50	2.36
2025	Forecasted	3.5%	3.15%	$ 1.23	$ 0.52	2.37
2026	Forecasted	3.5%	3.15%	$ 1.28	$ 0.54	2.38
2027	Forecasted	3.5%	3.15%	$ 1.32	$ 0.55	2.38

Note: Energy costs per mile rounded to the nearest cent while the ratio of costs per mile has been rounded to the nearest hundredth

10.6.5. **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 recently passed 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 FTA on a project-by-project basis.

The FTA also requires that all projects contain a non-federal match.[111] Metro Transit's non-federal funds come from a variety of sources including Regional Transit Capital (RTC), county sales taxes, Regional Railroad Authority (RRA) 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 and Purple Line BRT projects in Package C.

In addition to Metro Transit's traditional capital funding sources, there may be additional funding opportunities specific to BEBs through Xcel Energy. The MPUC is currently reviewing Docket No. E002/M-20-745, which is an electric vehicle rebate program. If approved, the rebate program could assist Metro Transit, or other Minnesota Xcel Energy customers, with an additional source of funding for the purchase of BEBs and associated charging equipment. Metro Transit will continue to investigate and seek all available capital funding sources.

10.6.6. Sources of Operating and Maintenance Costs

More than 60 percent of Metro Transit's operating funds are provided by the state of Minnesota, primarily through the Minnesota Vehicle Sales Tax and the state general funds (Table 48). While the long-term operating costs related to BEBs are still unknown, based on Metro Transit's experience on the C Line, the BEBs were 2.2 times more expensive to operate compared to diesel buses as measured by energy costs per mile.[23]

Table 48: Sources of Metro Transit operating and maintenance costs

	Fare Revenue, Other, Directly Generated Funds	Local Funds	State Funds	Federal Assistance
2015	26.9%	8.1%	61.0%	4.0%
2016	26.3%	7.2%	62.6%	3.9%
2017	26.4%	7.6%	60.5%	5.5%
2018	26.5%	6.8%	61.4%	5.2%
2019	25.9%	9.3%	60.4%	4.3%
Average:	**26.4%**	**7.8%**	**61.2%**	**4.6%**

Source: National Transit Database https://www.transit.dot.gov/ntd/transit-agency-profiles/metro-transit

[111] Note: Non-federal matching requirements were waived for projects funded by individual COVID-19 relief funds.

11. 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 greenhouse gas 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: long-term level of service changes driven by the COVID-19 pandemic and a nationwide shortage of bus operators; 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.

11.1. Long Term Level of Service Changes

11.1.1. COVID-19 Pandemic

The outbreak of the COVID-19 pandemic has greatly impacted transit ridership, altered travel behavior, and created additional challenges for transit operations across the country. According to a recent study, U.S. transit ridership declined an average of 73 percent during the first full month of the pandemic (April 2020).[112] During this same timeframe, Metro Transit experienced a 75 percent decrease in ridership.[113] Lockdowns, business closures, remote-learning, and telecommuting were largely responsible for the ridership decrease, along with fear among the public that social distancing would not be possible on transit. During this time, when trips were made, many people began traveling by car and active transportation modes rather than by transit as transit agencies encouraged riders to use other modes of transportation when possible and to limit use of transit to essential trips only.

As of this writing, the COVID-19 pandemic has been ongoing for nearly two years. As lockdowns have been lifted and an increasing portion of the public has become vaccinated, transit ridership has begun to rebound. For example, in October 2021, Metro Transit's ridership was up 103 percent compared to April 2020 levels. However, overall transit ridership was still down 48 percent in 2021 compared to pre-pandemic levels.[113,114] Looking into the future, it remains to be seen whether ridership will rise back to pre-pandemic levels. In response to these ridership changes, transit agencies nationwide, including Metro Transit, are preparing for an increase in demand for neighborhood-to-neighborhood trips, as well as non-peak period trips, while peak period trips to

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[112] *Impacts of COVID-19 on public transit ridership*, International Journal of Transportation Science and Technology, November 22, 2021.

[113] Source: *Monthly Bus Rides, Revenue, and Expenses for Service Development*, Monthly Ridership History by Route Spreadsheet, Metro Transit

[114] Note: October 2019 and October 2021 ridership data used to compare ridership to pre-pandemic levels

and from downtown areas are expected to remain at reduced levels as telecommuting at least a portion of the time becomes the norm for those who are able.[115]

11.1.2. **Operator Shortages**

> **Metro Transit has taken efforts to expand and retain its existing workforce including providing paid training to operators and mechanics**

Metro Transit has put out a call for more personnel, as the agency is about 80 drivers short of what they need to operate regularly scheduled transit service.[116] As a result of the current operator shortage, Metro Transit was forced to make a five percent cut in bus service hours in December 2021, with some routes being temporarily suspended or operating less frequently.[117] This reduction in service came despite the fact that Metro Transit's ridership was starting to rebound from the lows experienced due to the COVID-19 pandemic. Metro Transit, however, is not alone in this problem. Agencies throughout the country that would like to fully return to pre-COVID service levels are facing canceled trips which reduce service reliability due to a shortage of bus drivers.[118] While the pandemic has exacerbated the operator shortage, it existed prior to the pandemic. To address this constraint, Metro Transit has taken efforts to expand and retain its existing workforce including providing paid training to operators and mechanics. In addition, Metro Transit has reduced layover charging times for the C Line at Brooklyn Center Transit Center to allow the service to be provided with less operators. Moving forward, the lack of operators may have negative impacts on Metro Transit's ability to transition to ZEBs.

11.2. BEB 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 anticipated increasing demand.

The IIJA reflects the Biden Administration's commitment to green technology by increasing the annual authorization for the Low-No program from $55k to $1.1B, for the next 5 years.[119] With this sudden increase in funding, it will take time for BEB manufactures to build the capacity to produce the supply of ZEBs and supporting infrastructure necessary to meet the anticipated demand.

For example, currently, there are only four large BEB manufacturers, which are approved to sell BEBs to U.S. transit agencies: New Flyer, Proterra, Gillig, and Novabus/Volvo.[120] Although many

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[115] Source: *After Massive Transit Losses during the Pandemic, Agencies Are Planning a Comeback*, Urban Institute, December 2021.

[116] Source: *Sometimes providing a reliable service requires difficult choices*, Metro Transit, November 2021.

[117] Source: *Metro Transit suspending routes, cutting service amid 'unprecedented' driver shortage*, Bring Me The News, November 2021.

[118] Source: *Bus driver shortage hurts D.C. region's ability to return to pre-pandemic transit service levels*, Washington Post, November 2021.

[119] Source: , Federal Transit Administration, January 2022.

[120] Note: In Dec. 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*).

other manufacturers are considering entering the U.S. BEB market, including BEB manufacturers with operations in other countries (Green Power Motor company, Van Hool, and Arrival) as well as makers of light- and medium-duty electric vehicles (e.g., vans and cutaways) such as Ford, Chevrolet, and Rivian, each of these manufactures will 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 to limit the BEB manufacturing capacities in the U.S. for the next several years.

Makers of BEB chargers such as ABB, ChargePoint, Heliox, Proterra, 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 of 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.

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.[121] 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.

Transportation economists are predicting that the electric bus market will grow by 31% between 2021 and 2026

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. When compounded by the complications to global supply chains as a result of the COVID-19 pandemic, it is clear that BEB production and supply chain constraints could limit Metro Transit's ability to transition to BEBs in the short-term.

11.3. 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

[121] *U.S. Electric Bus Market Research Report: Industry Revenue Estimation and Demand Forecast to 2026*, Prescient and Strategic Intelligence, November 2021

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.

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. It is reasonable to expect that this upward trend will continue, and with it, the range of BEBs. Similarly, while first generation Buy America compliant charging equipment was available for purchase as recently as two years ago for some manufacturers, many manufacturers are selling third generation equipment in 2021 and 2022.

Metro Transit plans to evaluate multiple ZEB and supporting infrastructure manufacturers in smaller orders before proceeding to larger orders

Metro Transit is planning to allow for approximately two years between procurements of ZEBS and supporting infrastructure to evaluate their performance and to understand how the industry is changing

Charging scenarios and equipment are typically determined based on an analysis of routes and blocks in a transit agency's network. If Metro Transit invests in too many on-route chargers, for example, there is a risk that the agency could be stuck with redundant and unnecessary chargers as increased battery capacities or wireless inductive technology becomes available and make the purchased products obsolete before the end of their lifespan. To address this barrier, Metro Transit is planning to start with smaller ZEB and supporting infrastructure procurements before gradually increasing procurement size. Metro Transit is planning to evaluate multiple manufacturers in these smaller orders before proceeding to larger orders. In addition, Metro Transit intends to allow approximately two years between procurements of ZEBs and supporting infrastructure to evaluate the performance of the equipment and to 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 operators and maintenance 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.

11.4. 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 a large amount of electrical capacity from the grid roughly equivalent to the entire 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 a 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 also would require large amounts of electricity and could utilize the existing grid capacity. Therefore, although Metro Transit has collaborated with Xcel Energy to analyze available power connections to 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. For this reason, it will be essential that Metro Transit and Xcel Energy review project plans on an annual basis and stay in close coordination with each other's capital plans.

11.5. Strategies and Objectives to Address ZEB Barriers, Constraints, and Risks

Throughout this Transition Plan, Metro Transit has identified several objectives and strategies to address and mitigate the aforementioned barriers, constraints, and risks associated with transitioning to ZEBs (Table 49). As Metro Transit's experience and knowledge of ZEBs grows, these strategies and objectives will be continuously updated to reflect current best practices and lessons learned as additional experience is gained.

Table 49: Strategies and objectives to address ZEB barriers, constraints, and risks

Barrier, Constraint, or Risk Addressed	Mitigating Strategy or Objective	Discussed in Section
Electrical Grid Capacity	**Metro Transit will collaborate with Xcel Energy to develop project timelines that coordinate with Xcel Energy timelines for planning, engineering, construction**	Section 8.2.2.2
Level of Service Changes	**Continually evaluate ZEB service implementation prioritization methodology to tailor service to ridership and available workforce levels**	Section 8.3.4
Speed of Innovation Level of Service Changes	**Identify learning objectives for each package of projects up front and pair ZEB projects with the development of other areas of the business including software tools and workforce development**	Section 10
Level of Service Changes	**Provide paid training to operators and mechanics**	Section 11.1.2
Speed of Innovation Supply Chain Constraints	**Evaluate multiple ZEB and supporting infrastructure manufacturers in smaller orders before proceeding to larger orders**	Section 11.3
Speed of Innovation Supply Chain Constraints	**Allow for approximately two years between procurements of ZEBs and supporting infrastructure to evaluate their performance and to understand how the industry is changing**	Section 11.3

12. Updates to the Transition Plan

Metro Transit envisions the Transition Plan 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 Transition Plan every five years for submittal to the Minnesota State Legislature. With each update to the Transition Plan, 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 five 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 Capital Improvement Plan and operating budgets. The key performance measures that will be tracked, as outlined in Section 9.2, include:

- **Fleet Mileage**: How many miles vehicles are driven annually
- **Bus Availability**: % of calendar year ready for service
- **Infrastructure Availability:** % of calendar year infrastructure available for use
- **Bus Reliability:** Mean distance between road calls
- **Charger Reliability:** Warranty ticket volume
- **Cost/mile:** Energy cost per mile driven
- **Environmental Impact:** Emissions or cost of carbon
- **Equity and Environmental Justice:** Miles driven through high priority EEJ areas

In addition, Metro Transit will provide 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 2022 and 2027, at least 20% of Metro Transit's 40-foot bus replacement procurements will be electric.
    - Potentially accomplished by the purchase of 100-130 electric buses
    - Anticipated to represent 12-15% of 2021 total fleet
    - Anticipated to represent 20-24% of 2021 active fleet
    - Equates to maximum charging infrastructure achievable
  - **Projection**: Between 2028 and 2032, the percentage of Metro Transit bus procurements that are zero emission will be driven by key performance indicators and available budgetary resources.

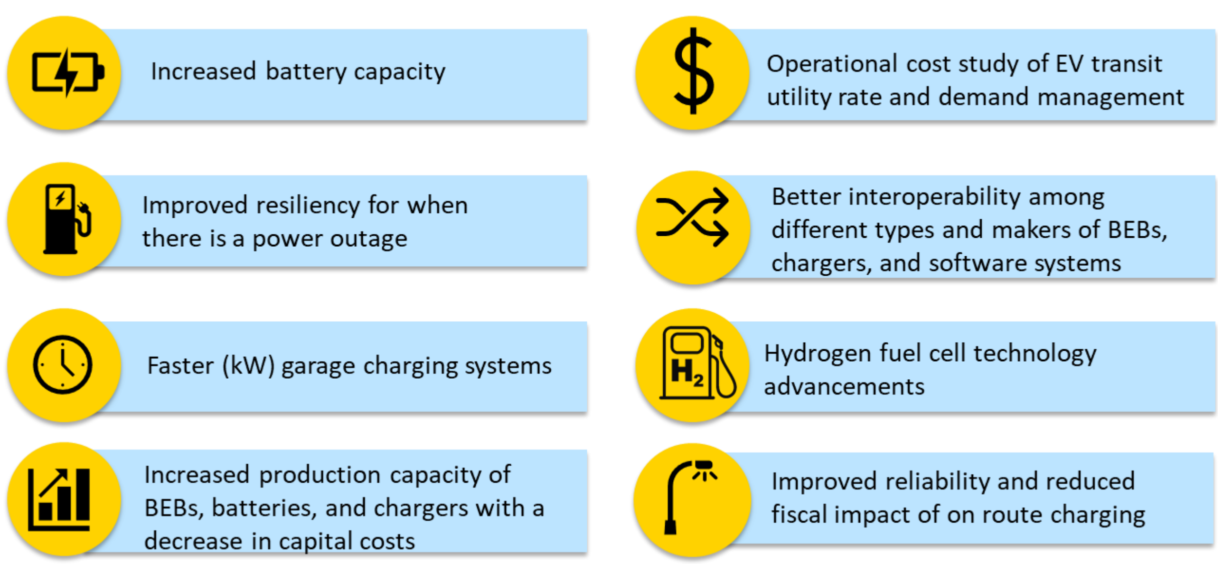
12.2. Future Transition Plans

While the current Transition Plan is primarily focused on setting a path toward fleet transition, identifying the suitability of Metro Transit's facilities and service for ZEBs, and developing pilot programs to guide the larger scale transition of the Metro Transit's fleet to ZEBs, future updates to this plan will focus more on the large-scale transition of Metro Transit's fleet and facilities.

12.2.1. Changing Technology

ZEBs are still a new and evolving technology. Future Transition Plans updates will assess the then current state of technology and in particular address the areas shown in Figure 47.

Figure 47: Areas anticipated to change in the next five years



12.2.1.1. Increased battery capacity.

In recent years, there have been significant improvements and advancements in battery technology. These advancements have led to batteries that are lighter, less expensive, and can be charged at a faster rate per kW. As batteries are stored on board BEBs, carrying a lighter-weight battery means that a bus can go further on a single charge.

12.2.1.2. Improved resiliency for when there is a power outage.

As the percentage of BEBs in Metro Transit's fleet increases, the need for resiliency when there is a power outage will also increase. If Metro Transit is unable to recharge its buses due to a power outage, the agency will not be able to deliver BEB transit service. Metro Transit is currently exploring multiple ways to improve resiliency during a power outage as listed below.

- MBG was designed to have power brought in from two separate circuits on Xcel Energy's grid with an automatic throwover switch between them. As a result, if Xcel Energy is experiencing a power outage on one circuit, Xcel Energy will still be able to provide electricity to MBG by pulling electricity from the other circuit if it is not impacted by the outage.
- Metro Transit will be installing a 2MW solar array on the roof of the MBG allowing Metro Transit to generate clean electricity that can be used to charge the BEBs.
- The MBG will also include 2MWh/800kW of battery storage capacity that Metro Transit can use to charge buses from during a power outage as well as during peak demand periods.
- Distributing charging capabilities throughout the region. Power outages tend to be confided to limited geographic areas. As a result, having charging capabilities in different locations decreases the chance that all of Metro Transit's charging capabilities would be affected by a power outage at the same time. Metro Transit currently has chargers at the Heywood Garage and Brooklyn Center Transit Center and plans to install them at MBG and East Garage in the next few years.

12.2.1.3. Faster (kW) garage charging systems.

Similar to the advancements in battery technology, Metro Transit anticipates charger technology will continue to improve. Faster garage charging time may mean that Metro Transit will need fewer chargers to charge the same number of buses. In addition to plug-in chargers, Metro Transit is planning to install two overhead conductive chargers at MBG to allow for fast charging in the garage. This will provide Metro Transit with the opportunity to compare the potential operational benefits associated with fast-charging with the known operating characteristics of plug-in charging.

12.2.1.4. Increased production capacity of BEBs, batteries, and chargers with a decrease in capital costs.

Metro Transit anticipates that as the production capacity for BEBs, batteries, and chargers increases over the next several years, manufacturers will be able to take advantage of economies of scale and increased competition. Metro Transit will continue to monitor pricing to determine if these economies of scale result in decreases to the capital costs of BEBs, batteries, and chargers. Additionally, Metro Transit will monitor how increased demand and increased production capacity impacts lead times for vehicle and equipment purchases.

12.2.1.5. Operational cost study, including study of EV transit utility rate.

Metro Transit plans to monitor and study the cost of operating BEBs under several different operating scenarios. A key component of managing the operating cost for BEBs will be to gain a better understanding of how different charging scenarios affect the operating costs. The solar array and battery storage planned at MBG will give Metro Transit the opportunity to determine the impact of on-site power generation and storage on operating costs as the battery storage can be used for charging during the peak period and excess energy could be sold to Xcel Energy.

In order to cost effectively implement a large-scale transition to an electric fleet, Metro Transit will work with Xcel Energy to study ways to stabilize and reduce electricity operational costs. This may include studying charging profiles, smart charging software, and existing tariffs as well as the possible creation of a transit vehicle or heavy-duty vehicle charging tariff (utility rate).

Figure 48, below, shows the charging profiles associated with the C Line Pilot Program for four representative weekdays between October 2020 and January 2021 at both the Heywood Garage and at the Brooklyn Center Transit Center. The on-peak period is highlighted in green. The profile demonstrates the peaked nature of charging as well as operational needs to charge during peak demand hours. By comparing the charging profile at the Heywood Garage with the charging profile at Brooklyn Center Transit Center, it is apparent that by nature, on-route charging (at Brooklyn Center Transit Center) leads to more expensive electricity bills as the majority of charging occurs during peak hours (9AM – 9PM) on layovers.

Figure 48: C Line pilot program charging profiles

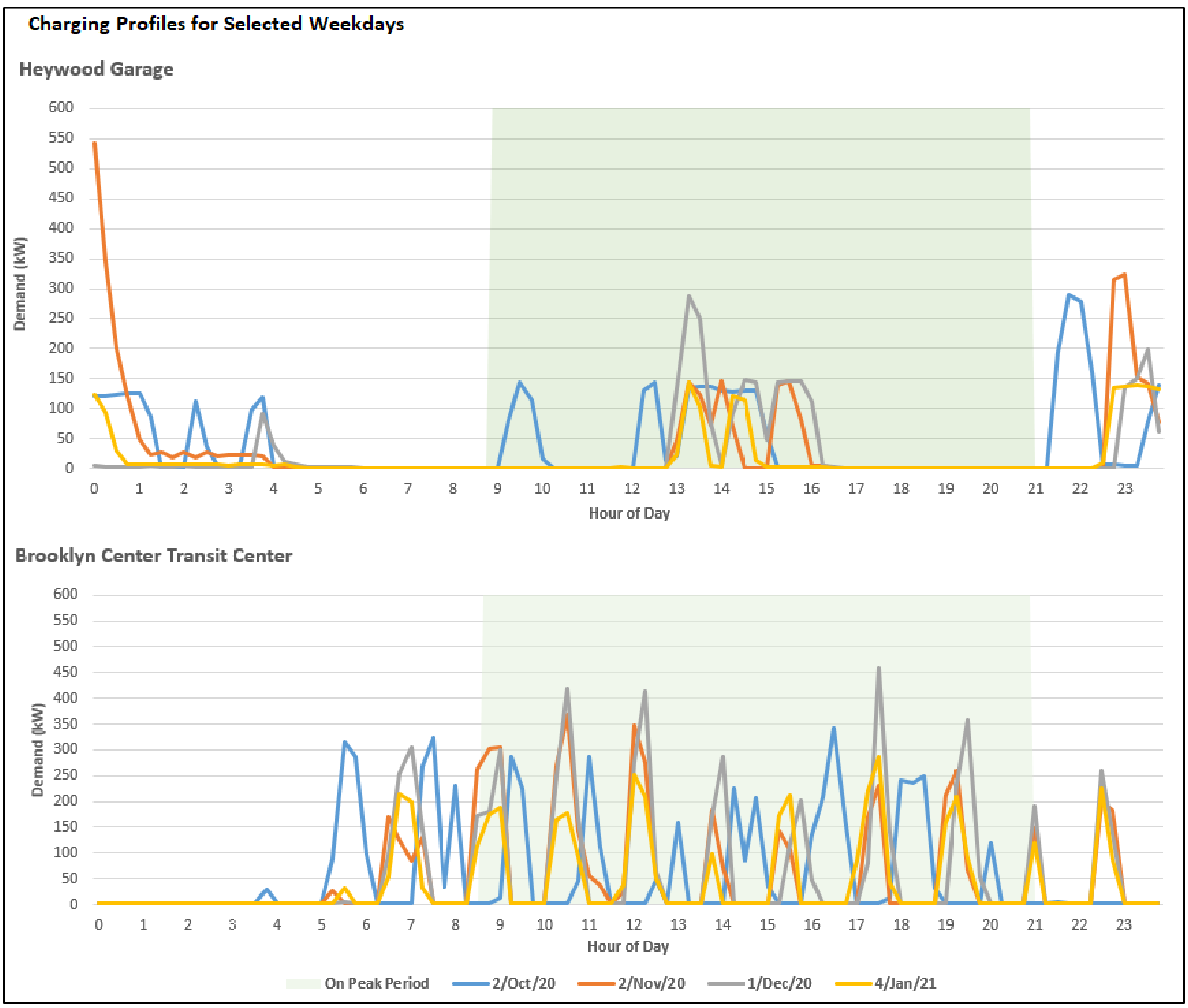
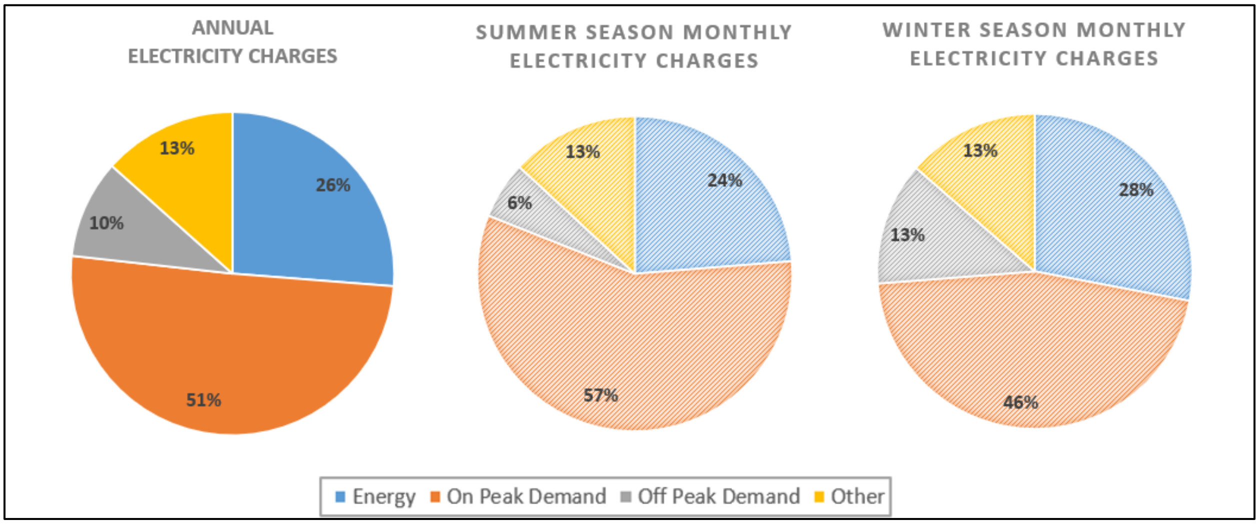


Figure 49, below, shows the proportion of historic electricity bill costs for the various cost drivers for Heywood Garage on an annual basis as well as broken out by seasonal summer and winter monthly electricity charges. Notably, as shown in the aggregate (leftmost) pie-chart, 51 percent of the annual electricity bill costs were due to on-peak demand charges. The 13 percent of costs labeled as other are various fees and taxes outside of Xcel Energy's control. When breaking these costs out by season, it is apparent that charges are further skewed towards paying on-peak demand charges in the summer months (center pie-chart) when electricity demand charges are higher compared to in the winter months (rightmost pie-chart) when on-peak demand charges are lower.

Figure 49: Heywood Garage electricity charges by type



The above analysis is based on Metro Transit's historical utility bills for charging at the Heywood Garage between June 2019 and February 2021, excluding October 2019. Transit bus charging loads translate to a low load factor and have unique operational needs when compared with a more traditional high load factor Commercial and Industrial customer. After optimizing charge times of day to shift as much load off-peak as possible, Metro Transit will still require charging some amount during on-peak hours to sustain operations.

12.2.1.6. Better interoperability among different types and makers of BEBs, chargers, and software systems.

With any new or rapidly changing technology, problems can sometimes occur when at the interface between different systems and equipment. Metro Transit intends to observe how well equipment and systems provided by different manufactures/vendors interact with each other. Metro Transit intends to focus on purchases which meet specified interoperability industry standards.

12.2.1.7. Hydrogen fuel cell technology advancements.

Metro Transit will continually reassess the suitability for FCEBs as upstream carbon emissions associated with Hydrogen production are reduced, and as hydrogen production sources and stations are built in the region.

12.2.1.8. On-route charging advancement.

The C Line Pilot Program demonstrated that on-route charging is more expensive than charging at the garage. When functioning properly, on-route charging can extend the range of the vehicles. However, during times when on-route chargers have issues, immediate impacts to operations occur as the vehicles do not have sufficient charge to finish their trip. Metro Transit will continue to monitor all of the factors above as well as advancements in on-route charging to determine which strategies are advisable for future transition steps to accommodate longer blocks of work that cannot currently be accommodated with today's technology.

12.2.2. **Well-to-Wheel Analysis**

Although ZEBs have zero tailpipe emissions, emissions may be produced when generating the electricity or creating the fuel necessary to propel the ZEB. To quantify the overall environmental impact associated with both transitional buses and ZEBs, a well-to-wheel analysis can be conducted that explores both the amount of GHG emissions associated with electricity/fuel production and use. Overall, well-to-wheel analyses compare the life-cycle emissions associated with having a bus move a mile. For diesel buses, this would include everything from the extraction and refining of crude oil to the burning of this fuel to propel the bus. For BEBs, this would include quantifying the emissions associated with the energy source used to generate the electricity necessary to refuel the BEBs. As the sources of electricity become greener over the next several decades and energy/fuel economy (miles per kWh) improves, Metro Transit anticipates the well-to-wheel emissions will improve.

12.2.3. **Mutual Aid**

A key function that Metro Transit provides to the community, which many are not aware of, is the agency's Mutual Aid function. Mutual Aid is when one governmental entity comes to the aid of another governmental entity, typically in an emergency situation. Examples of Metro Transit utilizing its buses for Mutual Aid include the delivery of COVID-19 vaccines to rural areas throughout Minnesota as well as providing temporary warming shelters for large apartment, condominium, hotel and/or office fires in the winter. Since Metro Transit envisions maintaining a portion of its fleet as diesel buses in the short-term, the agency is confident that it will be able to meet its Mutual Aid obligations in the short-term. Mutual Aid agreements will be studied further in future updates to the Transition Plan to assess how Metro Transit can continue to provide these essential services to the community as the fleet evolves.

12.3. Conclusion

As ZEB technology improves, this Transition Plan 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.