MTS & STP ZERO-EMISSION BUS TRANSITION PLAN

METROPOLITAN COUNCIL

April 2023

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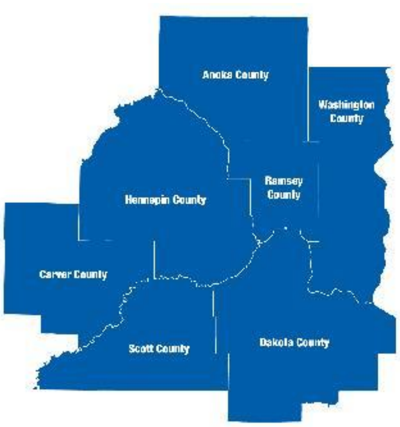

The Metropolitan Council is the regional planning organization for the seven-county Twin Cities area. The Council operates the regional bus and rail system, collects and treats wastewater, coordinates regional water resources, plans and helps fund regional parks, and administers federal funds that provide housing opportunities for low- and moderate-income individuals and families. The 17-member Council board is appointed by and serves at the pleasure of the governor.

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TABLE OF CONTENTS

Executive Summary

The *MTS & STP Zero-Emission Bus Transition Plan* lays out a roadmap for how five public transit providers in the Minneapolis-Saint Paul region—Metropolitan Transportation Services (MTS), Maple Grove Transit, Minnesota Valley Transit Authority, Plymouth Metrolink, and SouthWest Transit (collectively, the Suburban Transit Providers, or STPs)—could manage the shift from conventional gas- or diesel-powered vehicles to zero-emission vehicles.

This plan comes at a moment when transit agencies across the country are studying the same issues and working on the same questions. The technology behind zero-emission vehicles is rapidly improving and it promises to provide public benefits like cleaner air and lower greenhouse gas emissions. At the same time, there are still many challenges to public transit operations that such a shift could bring. It is thus more important than ever to understand the full picture of the technology, the market, and their implications, so that agencies can prepare on their own terms for this oncoming change to the industry.

Background

Pursuant to Minnesota state law, the Metropolitan Council completed a zero-emission bus (ZEB) transition plan for Metro Transit in February 2022. This plan, accessible at metrotransit.org/electric-buses, laid out a roadmap for how the largest transit provider in the Twin Cities' region could begin its transition from gas/diesel powered to zero-emission buses.

In November 2021 as the Metro Transit plan was being drafted, President Biden signed legislation that mandated that applicant agencies complete a zero-emission bus plan in order to be eligible for FTA's Buses and Bus Facilities and Low or No Emission (Low-No) grant programs. In December 2021, the FTA released guidance for the structure of a qualifying plan.

This report builds off the federal guidance and the example of the Metro Transit plan by applying the same research and analytical methods to the needs and unique situations of Minneapolis-Saint Paul region's remaining transit providers. To align with the Transition Plan's updates every five years, short-term for the purposes of this report, is defined as a five-year time horizon.

State of the Technology

There are several types of zero-emission bus technologies. The most popular are battery-electric buses (BEBs). BEB technology has improved substantially in recent years. Most major bus manufacturers are now creating BEB models and many American transit agencies are operating limited numbers of these buses to gain experience with their operation.

The critical consideration for BEBs is the capacity of the bus battery, which determines the range for which a bus can travel on a single charge. Buses over 30 feet in length currently boast longer ranges because they have space to hold larger batteries compared to smaller vehicles. Due to degradation of battery life over time and capacity reserved for operational flexibility, about 70% of the advertised capacity of a battery is considered to be useable. The assumptions about the capability of BEBs contained in the plan are based upon this 70% usable capacity threshold.

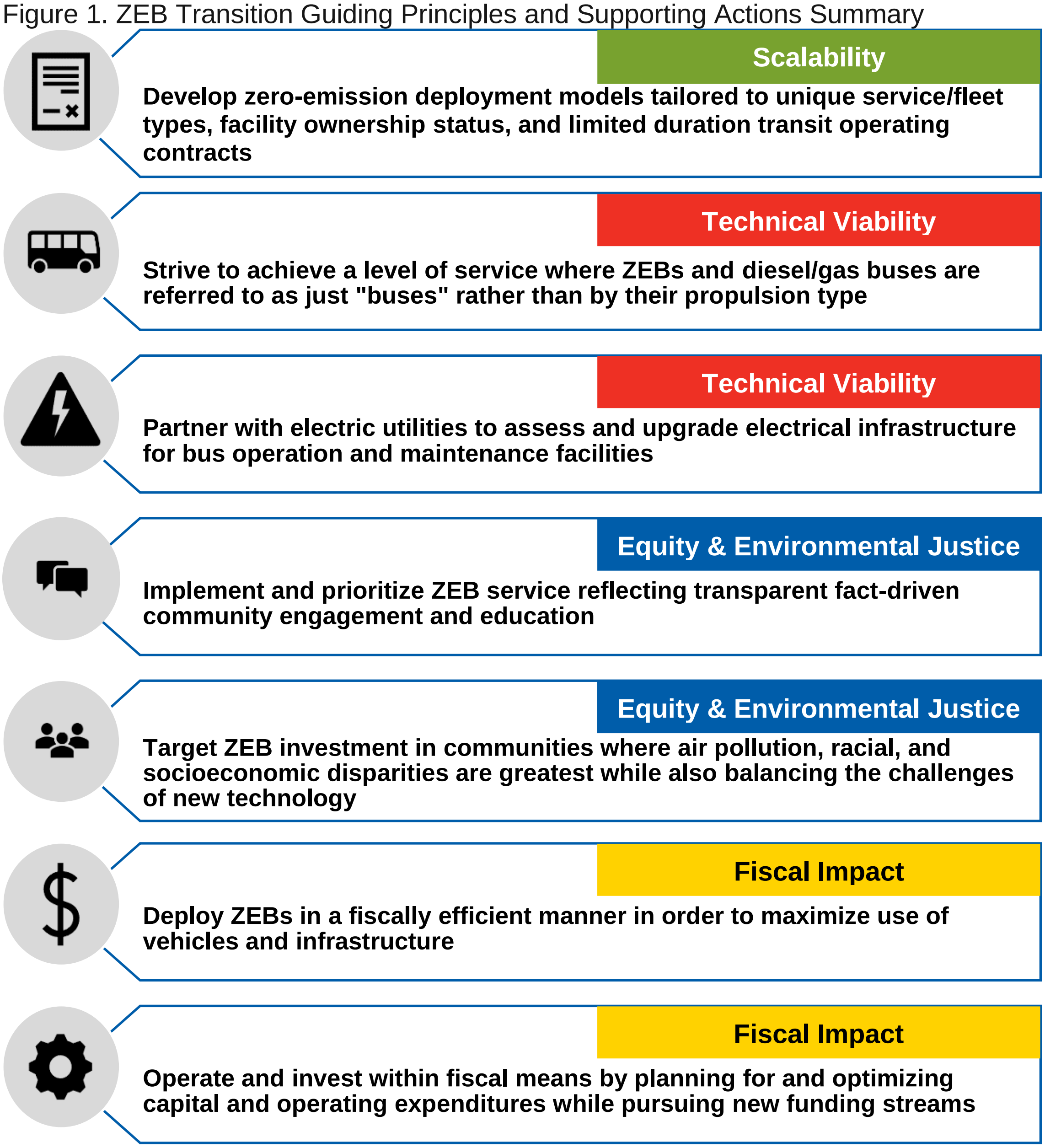
The adoption of BEB fleets also triggers other considerations. BEBs require different types of maintenance and have different specifications than conventionally powered buses. These changes may lead to renovations of existing, or construction of new maintenance facilities. BEBs require places to charge and the equipment to charge them. This equipment may be built in garages and also at special locations on key routes. Because BEBs currently have lower ranges than gas-powered buses, transit agencies may need to increase their fleet sizes to offer the same amount of service, consequently increasing demand for storage.

Given the proven public and private demand for zero-emission vehicles, it appears likely that research and development into the technology will continue to increase and continue to produce more efficient and powerful models in coming years. The capabilities of these models will, in turn, alter the considerations that transit agencies will make towards ancillary considerations.

Transition Plan Guiding Principles

To guide the goals and action steps that result from this plan, MTS, in partnership with the STPs, developed a set of four guiding principles and seven supporting actions to inform the development of zero-emission program goals, milestones, assessment criteria, and a prioritization framework for the zero-emission transition (
Figure 1).

Figure 1. ZEB Transition Guiding Principles and Supporting Actions Summary



These guiding principles are intended to be applied sequentially. The first step in planning for a transition to ZEBs is to ensure that the framework is scalable and tailored to the unique contractual and operational characteristics of MTS and the STPs. Second, the principle of technical viability must be applied to ensure that ZEBs are able to provide an excellent, safe, and reliable service and that the facilities can viably support ZEBs. Third, the equity and environmental justice and fiscal impact principles will be used to prioritize ZEB investment in underserved and underinvested areas that have borne a disproportionate share of negative environmental consequences. Finally, these recommendations will be evaluated for the maximum benefit and usage that can be gleaned from these significant investments.

Industry Case Studies and Best Practices

This plan contains five case studies from North American transit agencies working with ZEBs on fixed route service. Fixed route service operates along a set route at a set timetable every day. The agencies studied are Metro Transit, Foothill Transit in the Los Angeles region, King County Metro in the Seattle region, the Chicago Transit Authority, and the Toronto Transit Commission.

The broad lessons learned from these case studies emphasize the value of planning as early as possible, close coordination with the electric utility, being patient with the technology, training, and acquisition, and always expecting the unexpected.

Figure 2. Bus Charging Stations

This plan also contains four abbreviated case studies from American transit agencies applying ZEBs to demand response or microtransit service. Demand response service provides flexible point-to-point travel that is reserved ahead of time and operates within certain areas. The agencies listed are Orange County Transportation Authority in the Los Angeles region, Houston METROLift, King County Metro Access ADA Paratransit in the Seattle region, and Sacramento SmaRT Ride. Because all of the efforts of these agencies are so new, there are no major lessons to take away from their experience at the time of this plan, but they will be among the pilot programs worth watching in coming years.

ZEB Implementation and Guidance

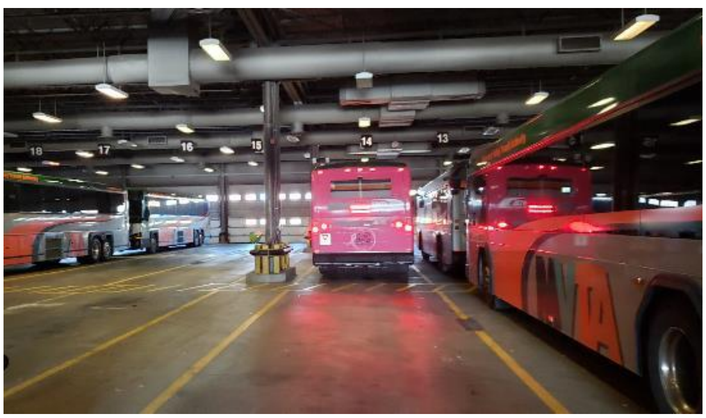
MTS and the STPs have selected BEBs as the short-term ZEB propulsion technology for implementation and deployment. As ZEB technologies evolve, MTS and the STPs will continually reassess this decision.

This plan analyzes fixed route service for each agency and evaluates their suitability for ZEB operation with a framework derived from the plan's guiding principles. MTS and the STPs divide their bus routes into service blocks, defined as series of transit trips that are linked together and assigned to a single vehicle for operation. This analysis found that just 41% of total blocks and 24% of total annual bus miles can be feasibly replaced at a 1:1 ratio by currently available BEBs with a worst-case range established by Minnesota winter conditions. Of these technically viable blocks 48% also meet criteria for having a high equity and environmental justice impact while 39% of technically viable blocks meet criteria for having a high fiscal efficiency. The combination of these factors yields a first priority recommendation for 25 blocks and a second priority recommendation for a further 63 blocks distributed between the agencies. The number of suitable blocks for ZEB operation will likely increase as technology improves and longer ranges become possible. The STPs could also increase the number of viable blocks by reorganizing service patterns so that blocks are shorter or involve less stopping and starting.

This plan also analyzes demand response service for MTS and STPs using a simpler framework. The total average daily miles for each agency's demand response service was calculated for each type of demand response vehicle, and then multiplied by a contingency to reflect fluctuation in daily demand. This aggregate was then divided by a standard "Minnesota Winter" range for each type of vehicle to produce an estimate for the number of battery-electric vehicles needed to provide existing amounts of service. This analysis found that both MTS and the STPs would need to acquire, operate, maintain, and store larger fleets than they currently use, due to the lesser range of battery-electric vehicles compared to their gas-powered counterparts.

MTS and the STPs rely on a variety of different locations to store and maintain buses. Many of these locations are owned or leased by the independent companies that are contracted to provide transit services. This plan presents recommendations for the existing facilities that are publicly owned and suitable for electrification. These facilities include Eagan Bus Garage (MVTA), Burnsville Bus Garage (MVTA), Eden Prairie Bus Garage (SWT), and SouthWest Station (SWT).

Figure 3: Enclosed bus parking / Future Charging



In the future, it may become necessary to construct new storage and maintenance facilities for battery-electric buses to handle increased fleet sizes and to perform new kinds of maintenance and upkeep (including charging). This plan contains the results of a screening exercise to identify suitable sites for such a facility. That exercise identified eleven sites that met criteria for public ownership, adequate size, proximity to an electrical substation, proximity to a major roadway, and not in a residential or environmentally sensitive area.

Regardless of the specific facilities and the scope of work required, MTS and the STPs will need to ensure long-term control over the sites during the duration of the ZEB transition. This can be accomplished either through ownership of the facilities or a lease of 25 years or longer. Long-term control is required to provide electrical providers such as Xcel Energy with assurance that electrical upgrades made for a given site will be used long enough to recoup the investment. Additionally, long-term control allows investments in new technology to be used for the complete lifecycle.

Milestones and Performance Measures

Each of the five separate agencies involved in the development of this plan will need to take their own path to the ZEB transition based on their circumstances. This plan lays out separate milestones for each of MTS and the STPs. This plan also includes specific performance measures against which progress can be judged.

Workforce Development and Other Barriers, Constraints, and Risks

At the time of this plan's production, MTS, the STPs, Metro Transit, and other transit agencies across the country are navigating a tight labor market for staff. The transition to ZEBs will impose additional demands on existing and future transit workforces that must be accounted for. Mechanics and technicians will need to learn new skills and there may be a need for additional operators.

This plan provides recommendations for how MTS and the STPs can identify the abilities of a ZEB workforce and recruit, train, and retain that workforce in the coming years. Those recommendations include establishing a detailed curriculum for working with ZEBs, conducting a skills assessment of the workforce, identifying skills gaps, and then collaborating with the existing workforce and other agencies to disseminate that curriculum and build a skilled ZEB workforce within the region and within each individual agency.

The ZEB transition will also create new challenges for transit agencies. Some of these challenges will simply build upon existing issues such as the operator shortage and the lingering impacts of the COVID-19 pandemic. Others are new but foreseeable, such as production and supply chain constraints as manufacturers make the ZEB transition at the same time as their clients. High demand and low supply for ZEBs, spare parts, and associated infrastructure is to be expected for a time. Permitting delays are also to be expected for new designs that are constantly being iterated.

Still other challenges are likely to be unexpected and unpredictable. The speed of innovation in ZEB technology is a major variable that will govern the ability of transit agencies to make this transition in propulsion. While the current trend is one of rapid improvement, new technological barriers may arise and slow the pace of progress. Electrical grid capacity is another challenge that will likely impact the ZEB transition. Transit agencies will be competing locally for power, as other industries electrify their operations and large numbers of private car owners electrify their personal transportation. That these competing interests will intensify is not in question, but their pace is unknown.

All these constraints and uncertainties make evident that the rate of progress of the ZEB industry is likely to be uneven. Technologies may not advance in concert. Advances for various types of vehicles or chargers may not be easily replicated for other types. As a result, it may make sense to electrify some parts of an agency fleet before others (for example fixed route buses over demand response cutaways) and only those that are a good fit for certain charging or operations strategies.

To best prepare themselves to meet future challenges of all kinds, MTS and the STPs must prioritize close collaboration with Xcel Energy, continuously evaluate and reevaluate plans based on changing circumstances, rigorously evaluate their own experiences and set up experiments in advance to learn lessons, invest in a well-trained and flexible workforce, stay abreast with the latest technological developments, pair ZEB projects with the pace of workforce and technological advancement, and stay patient with the pace of progress.

1.0 Introduction

This section outlines the purpose and motivation for the Metropolitan Transportation Services (MTS) and Suburban Transit Provider (STP) Zero-Emission Bus Transition Plan and places the Transition Plan in a broader political and environmental context. Specifically, this section defines the requirements and components of a transition plan and highlights the impact that transportation and public transit sectors have on the environment, the global trend towards zero-emission buses, and existing studies and initiatives with zero-emissions implications.

1.1 Zero-Emission Bus (ZEB) Transition Plan Overview

1.1.1 Federal Infrastructure Investment and Jobs Act (IIJA)

Signed into law by President Biden on November 15, 2021, the Infrastructure Investment and Jobs Act (IIJA), also known as the "Bipartisan Infrastructure Law," amended the statutory provisions for FTA's Buses and Bus Facilities and Low or No Emission (Low-No) grant programs to include the requirement that any application related to zero-emission vehicles must include a zero-emission transition plan (ZEBTP) and that five percent of the requested Federal award for these projects must be used for workforce development activities, unless the applicant certifies that less is needed to carry out their zero-emission transition plan.[1] Additionally, the IIJA includes funding authorized for the Low-No grant program at around 1.1 billion dollars annually from 2022 through 2026, a 20-fold increase from the approximately $55 million annually authorized under the FAST Act, 2016-2021.[2]

1.1.2 Federal Transit Administration (FTA) Dear Colleague Letter (December 2021)

On December 1, 2021, the Federal Transit Administration (FTA) published a Dear Colleague letter entitled Fleet Transition Plan for Zero Emission Competitive Applications, which clarified the six minimum requirements of a zero-emission transition plan. Namely, a transition plan must include documentation of at least the following elements:

- Long-Term Fleet Management Plan
- Availability of Current and Future Resources to Meet Transition and Implementation Costs
- Policy and Legislation Impacting Relevant Technologies
- An Evaluation of Existing and Future Facilities and Their Relationship to The Technology Transition
- Description of Utility Partnership(s)
- An Examination of Workforce Development Impacts.

1.1.3 State Statute Requirement

Under state statute, the Metropolitan Council is responsible for developing a ZEB and electric vehicle transition plan and revising it at least once every five years.[3] In February 2022, the Metro Transit Zero-Emission Bus Transition Plan was submitted to the Minnesota Legislature. The MTS and STP Zero-Emission Bus Transition Plan is intended to build upon and complement the Metro Transit plan by detailing zero-emission considerations and plans related to Suburban Transit Providers as well as Metro Mobility, Transit Link, and MTS-contracted fixed route services.

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[1] Source: *Fact Sheet: Buses and Bus Facilities Program*, Federal Transit Administration, December 9, 2021
[2] Source: *Bipartisan Infrastructure Law*, FTA, June 7, 2022
[3] Source: *State of Minnesota Statute 473.3927*, Minnesota Legislature Office of the Revisor of Statutes

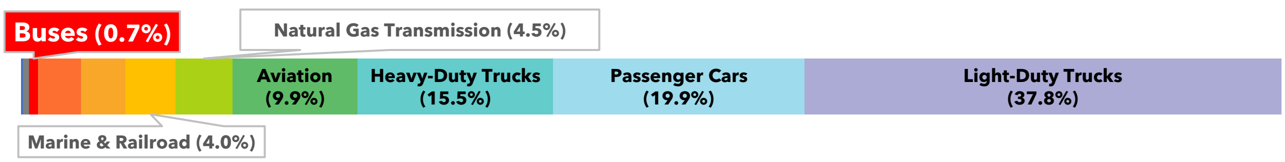
1.2 ZEB Transition Plan Context

1.2.1 Transportation and the Environment

According to data from the Minnesota Pollution Control Agency (MPCA) and the U.S. Environmental Protection Agency (EPA), the transportation sector is the state and country's largest source of greenhouse gases (GHG) accounting for about a quarter of all GHG emissions.[4,5] Although GHG from the transportation sector in Minnesota declined by about seven percent between 2005 and 2018, these reductions have leveled off since 2016.[5] Nearly three quarters (73%) of transportation related GHG emissions in Minnesota come from light duty trucks and SUVs, passenger vehicles, and heavy-duty trucks. Less than one percent of these statewide emissions are emitted by buses (Figure 4). Although buses represent a proportionately small share of GHG emissions in Minnesota, the Metropolitan Council and the Suburban Transit Providers are committed to reducing these emissions, adapting to climate impacts, and building resilience to potential environmental changes.

Less than one percent of statewide transportation emissions are emitted by buses

Figure 4. Minnesota Transportation Sector GHG Emissions by Source[6]



1.2.2 Existing Policies, Studies, and Initiatives with Zero-Emission Implications

In addition to federal and state legislation, a variety of existing studies and initiatives have implications for zero-emission goals. These studies and initiatives include Thrive MSP 2040, the Council's Green Energy Partnership with Xcel Energy and Electric Vehicle Study, and existing Zero-Emission Transition and Sustainability Plans.

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. These outcomes include:

- Stewardship
- Prosperity
- Equity
- Livability
- Sustainability

[4] Source: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019*, United States Environmental Protection Agency, 2021
[5] Source: *Greenhouse Gas Emissions Inventory: 2005 to 2018*, Minnesota Pollution Control Agency, 2021
[6] Source*: Climate change in Minnesota: Greenhouse gas emissions data*, Minnesota Pollution Control Agency, 2018

Xcel Energy Green Energy Partnership & Clean Energy Transition

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.[7] This partnership creates a framework with established 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.[8]

In December 2018, Xcel Energy, the primary electrical utility provider for most MTS and STP garages, became the first major U.S. utility to signal it would move to 100 percent carbon-free electricity by 2050.[9] Approved in February 2022, Xcel Energy's Upper Midwest Energy Plan will make significant strides towards this goal by reducing carbon emissions by 85% by 2030 compared to 2005 levels.[10,11]

Xcel Energy Fleet Electrification Advisory Services Pilot Program

Xcel Energy's Fleet Electrification Advisory Services pilot program provides data-driven fleet assessment services to enable agencies to make data-driven fleet-electrification decisions using real-time telematic vehicle analytics. Currently, SouthWest transit is participating in this pilot program.

Xcel Energy Fleet Electric Vehicle Supply Infrastructure (EVSI) Pilot Program

Xcel Energy's EVSI pilot program is open to any public, non-profit, or government customer and includes infrastructure construction services including line extension and electric vehicle supply infrastructure installation and maintenance. The current iteration of this pilot program is set to expire in January 2024. As of November 2022, SouthWest transit is participating in this pilot program.

Metropolitan Council Climate Action Work Plan

The Metropolitan Council's Climate Action Work Plan, adopted in December 2022, is a three- to five-year plan which will unify efforts across Metropolitan Council divisions, including MTS, to reduce greenhouse gas emissions, adapt to climate impacts, and build resilience to potential changes. The Climate Action Plan defines 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 includes current efforts as well as commitments to future actions.

Metropolitan Council Electric Vehicle Study

The Metropolitan Council's Electric Vehicle Planning Study, published in May 2022, provides the technical background around the rapidly changing technology and landscape of transportation electrification. It also summarizes the greenhouse gas reduction potential of this technology, charging infrastructure status and needs, vehicle availability, and equity impacts and opportunities. The project evaluates and prioritizes 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.

Metro Transit ZEB Transition Plan

Metro Transit's Zero-Emission Bus Transition Plan (February 2022)[12] is a living document that identifies short- (2022-2027), medium (2028-2032), and long- (beyond 2033) term opportunities, risks, and

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[7] Source: *Met Council, Xcel Energy Work to Get Council to 100% Renewable Energy By 2040*, June 8, 2018.
[8] Source*: Xcel Energy – Green Energy Partnership Update*, Presentation to the Metropolitan Council, September 16, 2020
[9] Source: *Xcel Energy Commits to 100% Clean Energy by 2050,* State of Minnesota
[10] Source: *Clean Energy Transition Highlights*, Xcel Energy, 2022
[11] Source: *Upper Midwest Energy Plan,* Xcel Energy, 2022
[12] Source: *Metro Transit Zero-Emission Bus Transition Plan,* Metro Transit, February 2022

implementation strategies to transition Metro Transit's bus fleet to zero-emission technology. In the short-term, between 2022 and 2027, the Transition Plan establishes a target that at least 20 percent of Metro Transit's 40-foot bus replacement procurements will be electric. In support of this milestone, the Transition Plan outlines sequential packages of projects to guide Metro Transit's deployment of battery-electric buses (BEBs) in the short-term.

Minnesota Valley Transit Authority (MVTA) Phase 1 ZEB Transition Plan
Developed in accordance with the statutory provisions for the Buses and Bus Facilities and Low or No Emission competitive grant programs (as amended by the IIJA and clarified in a FTA Dear Colleague letter), Minnesota Valley Transit Authority (MVTA)'s initial Phase 1 Zero-Emission Bus Transition Plan (May 2022) includes a summary of policy and legislation impacts, workforce development impacts, a long-term fleet management plan, an evaluation of existing and future facilities and service and their relation to zero-emission technologies, and an evaluation of resource availability.

Minnesota Valley Transit Authority (MVTA) Sustainability Plan
The MVTA Sustainability Plan (Spring 2023) was created as a living document to gather data and information about the agency's current sustainability practices, measure progress towards its desired sustainability goals, and set new policies and goals for the future. The plan sets goals like reducing the greenhouse gas emissions of the fleet, supporting the transition of both buses and private vehicles to electric propulsion through the installation of charging stations at MVTA facilities, and supporting a statewide goal for 20% VMT reduction.

SouthWest Transit (SWT) FTA Zero-Emission Fleet Transition Plan
Developed in accordance with the statutory provisions for the Buses and Bus Facilities and Low or No Emission competitive grant programs (as amended by the IIJA and clarified in an FTA Dear Colleague letter), SWT's FTA Zero-Emission Fleet Transition Plan (May 2022) established an initial transition baseline for the agency. Like MVTA's initial Phase 1 ZEB Transition Plan, SWT's plan also includes a summary of policy and legislation impacts, workforce development impacts, a long-term fleet management plan, an evaluation of existing and future facilities and service and their relation to zero-emission technologies, and an evaluation of resource availability.

SouthWest Transit (SWT) Sustainability Plan
The SWT Sustainability Plan (March 2022) is a living document that serves as the agency's roadmap to becoming more energy efficient. The report summarizes the results of a baseline GHG emissions inventory for the years 2015-2020, establishes goals for reducing fleet/facility energy use and GHG emissions, and establishes a roadmap of tangible action items to achieve these sustainability goals by 2050. Specific goals established in the plan include achieving net-zero GHG emissions by 2050, decreasing building energy use intensity by 25% by 2030 from 2015 levels, using 100% renewable electricity by 2030, and transitioning to a zero-emission vehicle fleet and equipment by 2050.[13]

1.2.3 National Trend Towards ZEBs

Over the past decade, transit agencies across the country have begun to integrate and transition towards zero-emission buses (ZEBs). As ZEB technology matures and increased funding sources become more readily available, the adoption of ZEBs is anticipated to rapidly increase. For example, between 2020 and 2021, the number of active fleet

Between 2020 and 2021 the number of active fleet ZEBs in the United States grew by approximately 20%

[13] Source: *SouthWest Transit Commission Meeting Packet*, SouthWest Transit, March 24, 2022

ZEBs[14] in the United States grew by approximately 20 percent to a total of about 1,600 buses.[15] On August 16, 2022, the Federal Transit Administration (FTA) announced over $1.6 Billion IIJA Funding—also known Bipartisan Infrastructure Law Funding—funding more than 1,100 ZEBs which would nearly double the number of ZEBs on America's roads.[16]

The adoption of small electric transit vehicles (< 30' long) lags the integration of full-size zero-emission transit vehicles. More than 100 of these small electric vehicles are currently part of active transit fleets nationwide as of 2021, an increase of approximately 27% compared to 2020. But this is driven by electric automobile and van growth which increased from 21 to 56 vehicles. During the same period, the number of active fleet electric buses less than 30 feet in length nationwide actually decreased from 41 to 32.

1.3 ZEB Transition Plan Organization

The remainder of the MTS and STP ZEB Transition Plan is organized as follows:

- Section 1.0 – Introduction
- Section 2.0 – Metropolitan Transportation Services (MTS) and Suburban Transit Provider (STP) Overview
- Section 3.0 – ZEB Technology—State of the Industry
- Section 4.0 – Transition Plan Guiding Principles
- Section 5.0 – Industry Case Studies and Best Practices
- Section 6.0 – ZEB Implementation Policies and Guidance
- Section 7.0 – Long-Term Fleet Management Plan
- Section 8.0 – Milestones and Performance Measures
- Section 9.0 – Opinion of Probable Fixed Route Implementation Costs
- Section 10.0 – Workforce Development
- Section 11.0 – Barriers, Constraints, and Risks
- Section 12.0 – Updates to the Transition Plan

[14] Note: The National Transit Database (NTD) defines active fleet vehicles as vehicles that are available to operate in revenue service at the end of an agency's fiscal year, including: spares, vehicles temporarily out of service for routine maintenance and minor repairs, and operational vehicles.
[15] Source: 2020 and 2021 Annual Database Revenue Vehicle Inventory Data, National Transit Database
[16] Source: *Biden-Harris Administration Announces Over $1.6 Billion in Bipartisan Infrastructure Law Funding to Nearly Double the Number of Clean Transit Buses on America's Roads*, FTA, August 16, 2022

2.0 Metropolitan Transportation Services (MTS) and Suburban Transit Provider (STP) Overview

2.1 Metropolitan Transportation Services (MTS)

The Metropolitan Council's duties as the seven-county Twin Cities region's Metropolitan Planning Organization (MPO) are performed by three primary organizational divisions: community development, environmental services, and transportation. Support is provided from administrative and service units.[17] The Council's Transportation Division includes both Metro Transit and Metropolitan Transportation Services (MTS).

MTS' responsibilities include both regional Transportation Planning and Transit Operations functions, several of which are outlined in Figure 5.[18] Key transit operations functions include overseeing multiple transit programs such as door through door Metro Mobility service, Transit Link Dial-A-Ride, and Contracted Fixed Route service are described below in Sections 2.1.1 to 2.1.3.

Figure 5. Key MTS Functions and Responsibilities

Transportation Operations

- Provide, contract for, and coordinate metropolitan transit operations
- Provide financial assistance and administer transportation grants to local agencies and transit operators
- Purchase STP fleet & regional technology

Transportation Planning

- Serves as the region's federally required Metropolitan Planning Organization (MPO)
- Performs long-range transportation system planning for all modes
- Shorter term federal transportation funds programming

In addition to the above functions, the Metropolitan Council (MTS) also owns most of the transit fleet operated by the four Suburban Transit Providers (STPs). As of July 2022, the MTS owned revenue fleet includes:

- 37 automobiles/vans used for Demand Response/Dial-A-Ride service; and
- 752 small (cutaway) buses less than 30 feet in length; and
- 354 heavy-duty diesel buses (30', 35', 40', 45' coach, and 60' articulated) about 75% operated by the STPs.[19]

In addition to these Council-owned vehicles, STPs can also purchase additional fleet vehicles for specific needs using agency funds.

There are currently no electric buses or vehicles in the revenue fleet owned by MTS as of summer 2022. Recently, however, SouthWest Transit independently purchased three electric vehicles (two SUVs and one van) for their SouthWest Prime on-demand fleet and in August 2022, SouthWest Transit was awarded over $8.1 million in Federal grants to purchase electric vehicles including four fully electric coach buses and six new electric SouthWest Prime vehicles expected to be in service by 2026.

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[17] Source: *Divisions & Departments*, Metropolitan Council
[18] Source: *Metropolitan Transportation Services (MTS) Division Overview*, Blue Ribbon Commission, September 14, 2020
[19] Source: MTS Fleet List Spreadsheet, Provided July 6, 2022

The Council-owned fleet of vehicles is housed across a total of 15 garage/maintenance facilities, none of which are directly owned by MTS—one is owned by Metro Transit, three are owned by STPs, and the other 11 facilities are leased or owned by MTS contractors.[19]

All MTS transit service is contracted from public or private transportation providers; this model is referred to as purchased transportation (PT). As shown in Table 1, MTS has 14 active contracts for transit service. Nine of these contracts are for Metro Mobility and Transit Link service and five are for MTS contracted fixed route service. The expiration dates of these contracts span from March 2023 to August 2027. When these contracts expire, new contractors and facility locations with unique characteristics may be selected for future service. This is unlike other transit agencies such as Metro Transit which owns its fleet and facilities and directly operates its service. As such, MTS faces many complexities and challenges when transitioning towards ZEBs that are unique to purchased transportation and limited duration operating contracts. See Section 11.1 for more detail on these unique challenges.

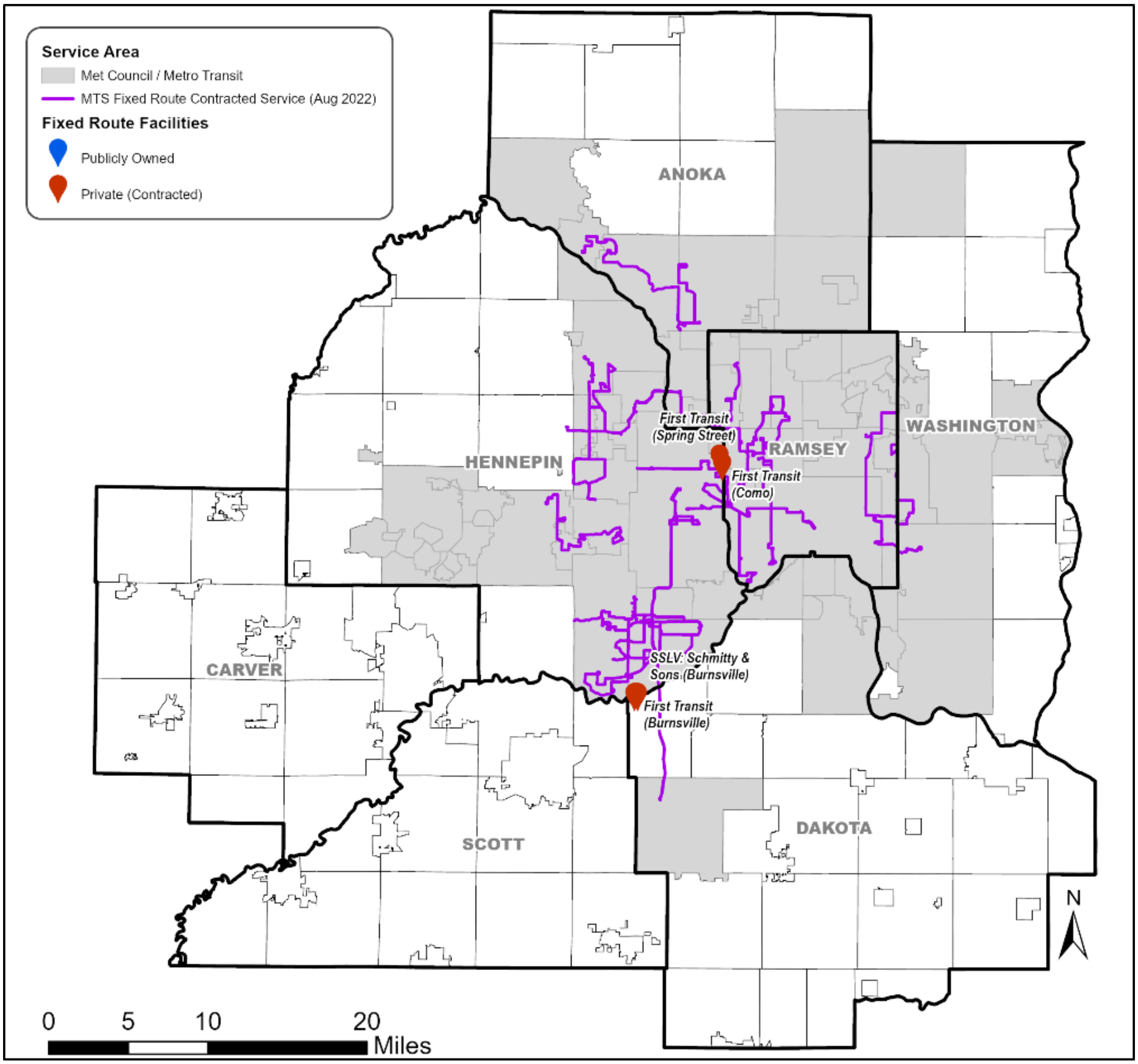
Table 1. MTS Contracted Service Overview

Contractor	Contract Expiration Date	Service Provided
First Transit	March 2023	Fixed Route Operation & Maintenance
First Transit	May 2023	Fixed Route Operation & Maintenance
Transit Team	September 2023	Metro Mobility Agency Operation & Maintenance
Scott County	January 2024	Scott/Carver County Transit Link Operation & Maintenance
First Transit	June 2025	Fixed Route Operation & Maintenance
Transit Team	July 2025	Metro Mobility South Zone Operation & Maintenance
First Transit	August 2025	Dakota County Transit Link Operation & Maintenance
First Transit	August 2025	Washington County Transit Link Operation & Maintenance
First Transit	November 2025	Fixed Route Operation & Maintenance
Transit Team	April 2026	Anoka County Transit Link Operation & Maintenance
Transit Team	April 2026	Hennepin County Transit Link Operation & Maintenance
Transit Team	June 2026	Metro Mobility West Zone Operation & Maintenance
First Transit	August 2026	Metro Mobility East Zone Operation & Maintenance
Schmitty and Sons	July 2027	Fixed Route Operation & Maintenance

2.1.1 Contracted Fixed Route

Although Metro Transit branded buses operate on approximately one hundred 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 MTS to private providers (Figure 6). As of August 2022, MTS contracts out a total of 28 routes split between First Transit and Schmitty and Sons. These routes utilize nearly 110 Council-owned vehicles operating out of four privately owned garage facilities. The contractor leases two of the three First Transit facilities while Schmitty and Sons own their SSLV Burnsville facility. Approximately three quarters of these nearly 110 vehicles are 30-foot or 40-foot buses while the remainder are small (cutaway) buses less than 30 feet in length.

Figure 6. MTS Fixed Route Contracted Service and Facilities (August 2022)

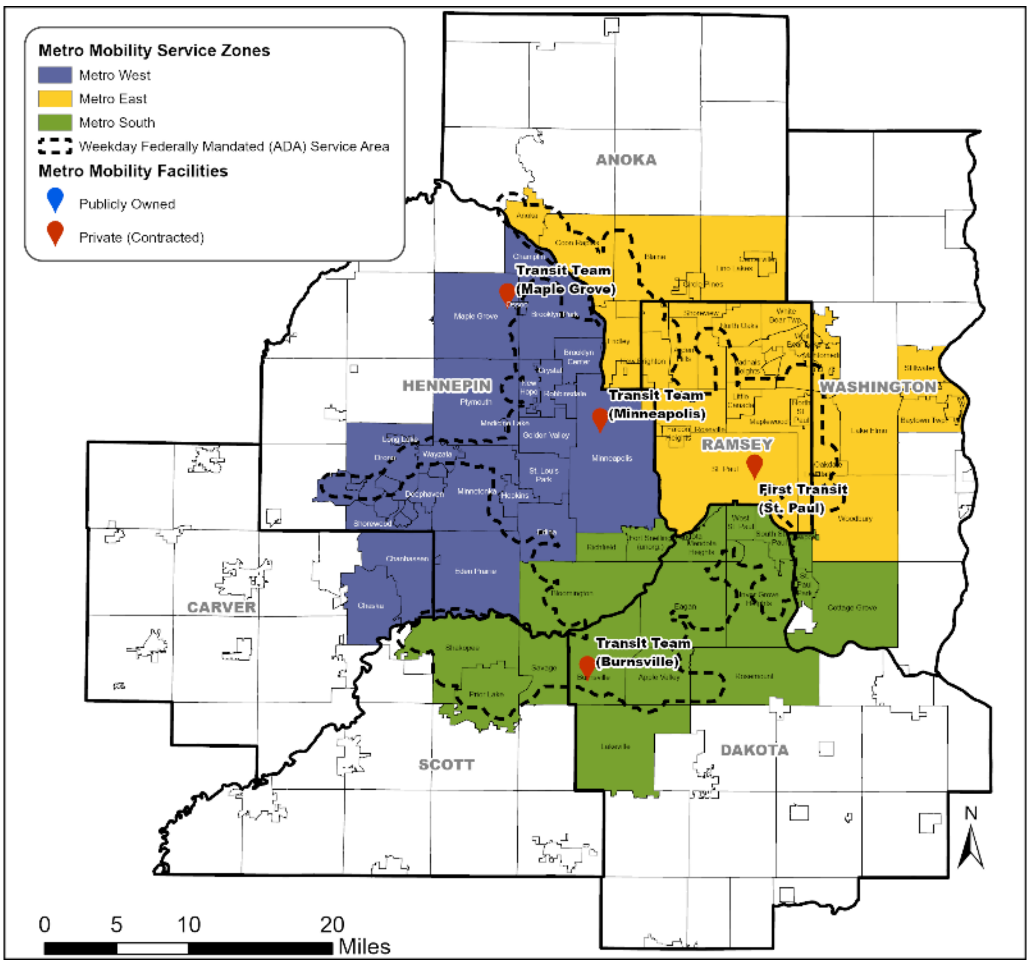


2.1.2 Metro Mobility

Metro Mobility is "a shared ride public transportation service for certified riders who are unable to use regular bus or train routes because of a disability or health conditions. The service is on-demand and is mandated under the Americans with Disabilities Act (ADA), as well as state law."[20] Metro Mobility trips are provided for any purpose. Figure 7 depicts Metro Mobility's three demand Service Zones that encompass 93 communities.[20] Guaranteed ADA trips are provided within a ¾ mile radius of regular fixed route service. "Trips that begin or end outside of the ADA service area, but within the Metro Mobility service area, are placed on standby. This means that the trip is scheduled and confirmed only if it fits with other already scheduled trips."[20]

As of Fall 2022, the MTS Metro Mobility fleet is comprised of 630 vehicles. Approximately 95% of these vehicles are small (cutaway) buses less than 30 feet in length while the remainder of the fleet are sports utility vehicles (SUVs). Two private contractors provide Metro Mobility service—First Transit and Transit Team—operating from a total of four garage facilities, all of which are privately owned. The First Transit St. Paul facility is leased by the contractor while Transit Team owns their facilities.

Figure 7. Metro Mobility Service Zones and Facilities (Fall 2022)



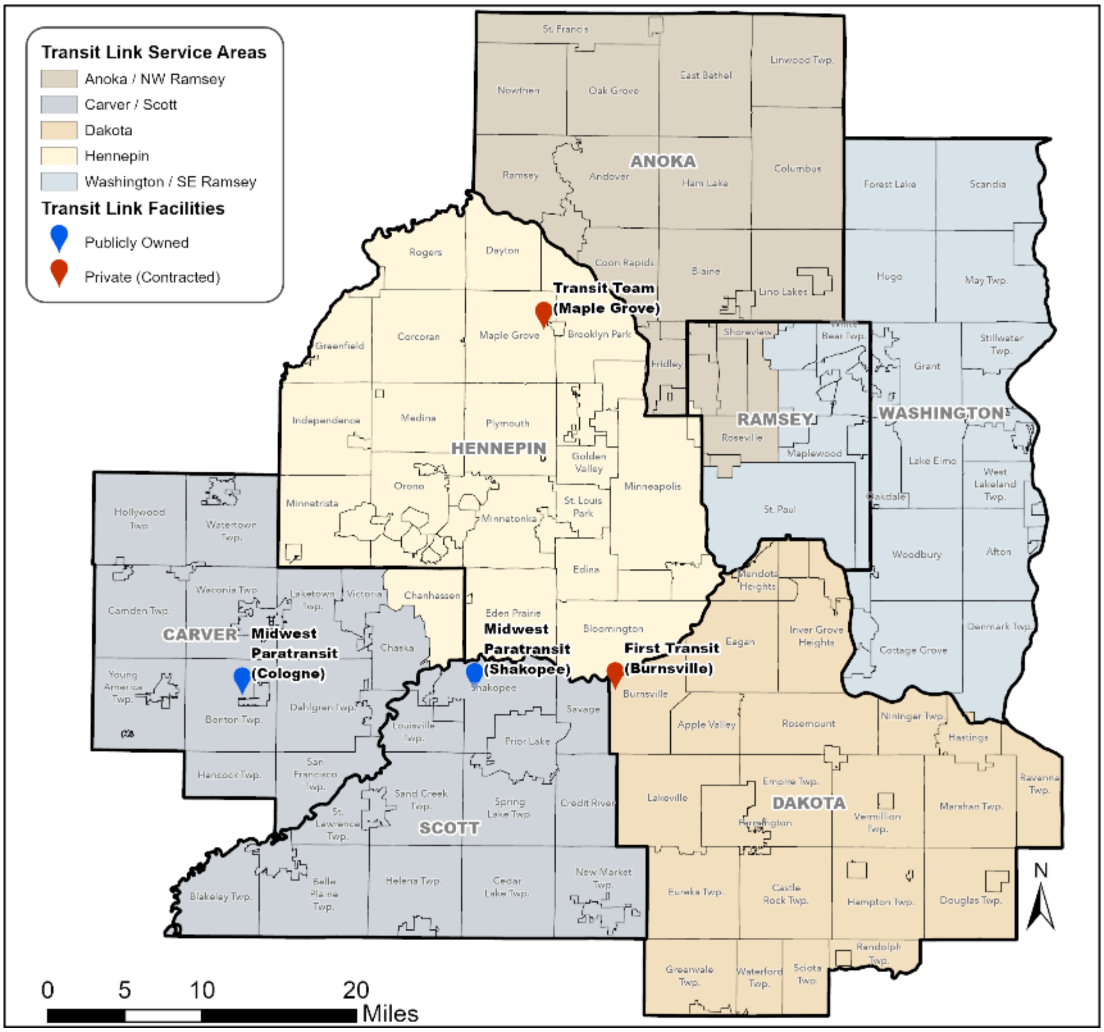
[20] Source: *Metro Mobility: Our Regional Commitment*, Metropolitan Council

2.1.3 Transit Link

Transit Link is a “shared-ride public transportation [service] for the Twin Cities metro area where regular route transit service is infrequent or unavailable. It’s for trips that can’t be accomplished on regular transit routes alone.”[21] Transit Link trips may “begin on Transit Link and connect to regular route buses at a convenient transit hub OR begin on regular route transit and transfer to Transit Link.”[22] Transit Link service is divided into five service areas primarily along county lines (Figure 8). Standard service hours are weekdays, Monday through Friday, from 6 a.m. to 7 p.m.

As of Fall 2022, the MTS Transit Link fleet is comprised of seventy-nine vehicles all of which are small (cutaway) buses less than 30 feet in length. Two private contractors provide Transit Link service—First Transit and Midwest Paratransit—operating from a total of four garage facilities. The two facilities used by Midwest Paratransit are publicly owned while the Transit Team facilities are privately owned.

Figure 8. Transit Link Service Areas and Facilities (Fall 2022)



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21 Source: [Transit Link](), Metropolitan Council

22 Source: [Transit Link Service Areas and Hours](), Metropolitan Council

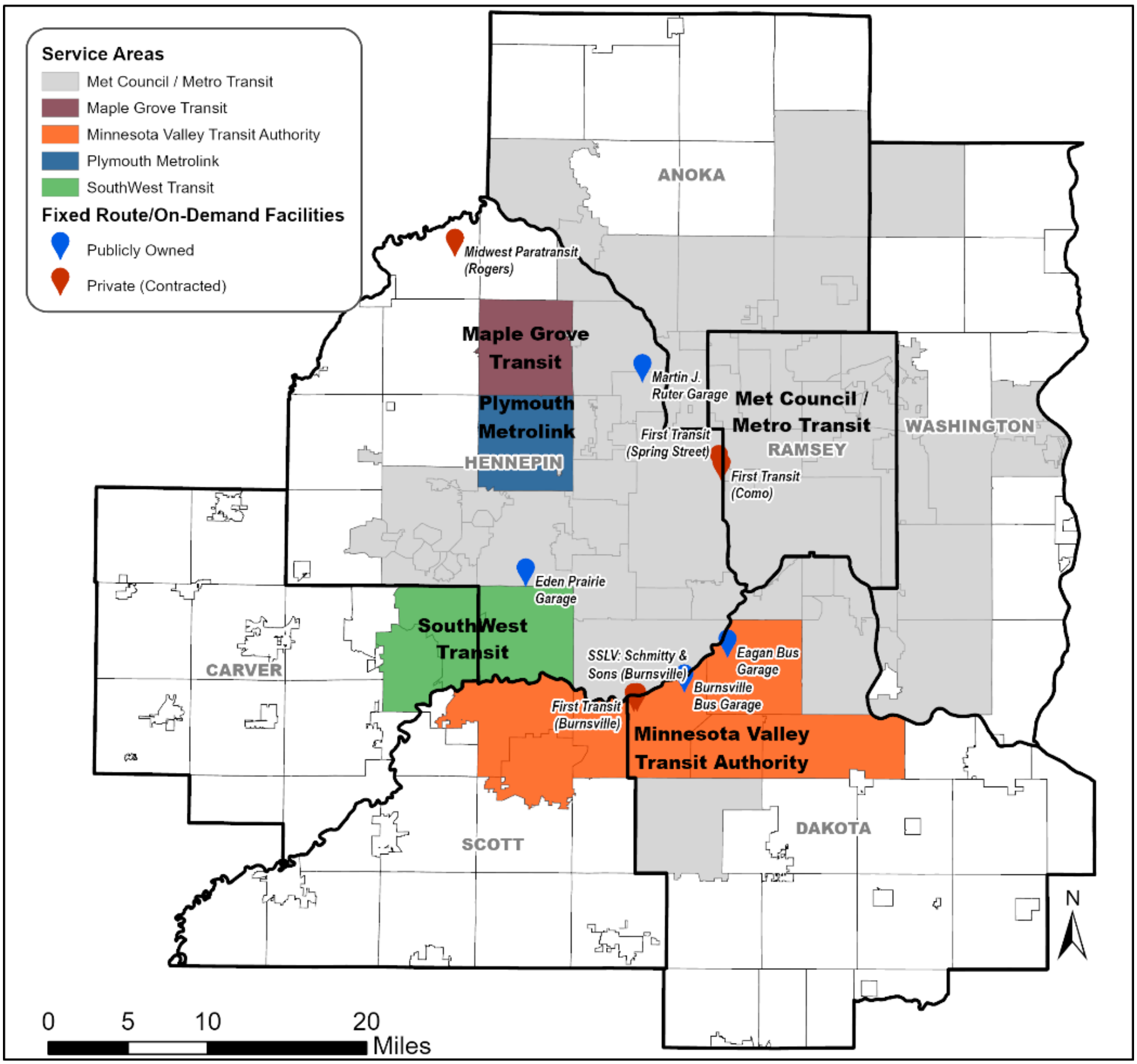
2.2 Suburban Transit Providers (STPs)

Along with the services provided through the Metropolitan Council, other providers operate transit service in the region (Figure 9). These Suburban Transit Providers (STPs) include:

- Maple Grove Transit
- Minnesota Valley Transit Authority (MVTA)
- Plymouth Metrolink
- SouthWest Transit (SWT).

The following sub-sections provide an overview of the size, geographic service area, and service types of these STPs.

Figure 9. MTS and STP Service Areas (Fall 2022)

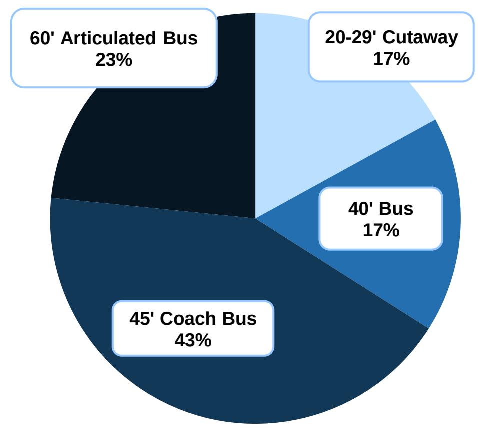


2.2.1 Maple Grove Transit

Maple Grove Transit is a public transit agency operated by the City of Maple Grove. As of November 2022, Maple Grove Transit operates four fixed ***Commuter Express*** routes, three of which travel to downtown Minneapolis and one that travels to the University of Minnesota. Maple Grove Transit also offers My Ride, an on-demand "microtransit" service within Maple Grove and adjacent municipalities. Maple Grove Transit's service area spans 36 square miles and is home to over 75,000 people. In 2019, prior to the COVID-19 pandemic, Maple Grove Transit provided nearly 810,874 trips, with an average weekday ridership of 3,100.

As of July 2022, 47 vehicles, or about 4% of the Council-owned fleet is used by Maple Grove Transit. A total of thirty-nine of these vehicles (83%) are used to provide fixed route service and ten are used for on-demand service. Maple Grove Transit's fixed route service is operated by Metro Transit and on-demand service is operated by Midwest Paratransit Services (MPS); a local transportation company headquartered in Maple Grove (Table 2). As shown in Figure 10, Maple Grove Transit uses a variety of different vehicle lengths to provide service. A plurality (43%) are 45-foot coaches, however almost a quarter (23%) are 60-foot articulated buses. Notably, Maple Grove Transit is the only STP that operates 60-foot articulated buses. The rest of the Maple Grove Transit fleet is made up of 40-foot buses or smaller 20–29-foot cutaway vehicles (Figure 10).

Figure 10. Maple Grove Transit Fleet by Vehicle Length (July 2022)



Maple Grove Transit buses are housed and operated from two garages. As of Fall 2022, on-demand buses operate out of the privately owned Midwest Paratransit Services– Rogers Garage, located at 21601 John Deere Lane, Rogers, MN 55374.[23] As of Fall 2022, fixed route buses operate out of Metro Transit's Martin J. Ruter Garage located at 6845 Shingle Creek Parkway, Brooklyn Center, MN 55430. In 2023, Maple Grove Transit's fixed route fleet will move to Metro Transit's electrification ready Heywood Campus[24] in Minneapolis' North Loop neighborhood. This move advantageously positions Maple Grove Transit for future fixed route electrification projects.

Table 2. Maple Grove Transit Contracted Service Overview

Contractor	Contract Expiration Date	Service Provided
Metro Transit	December 2024	Fixed Route Operation & Maintenance
Midwest Paratransit Services	December 2024	Demand Response (My Ride) Operation & Maintenance

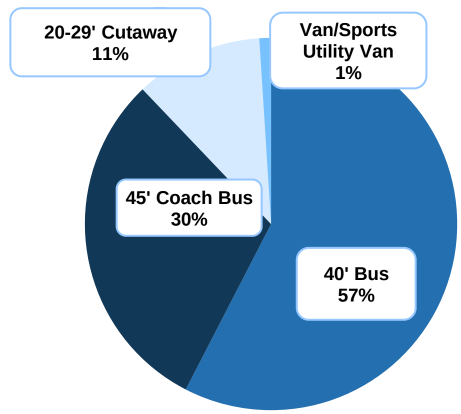
[23] Note: The location of Maple Grove Transit's on-demand buses has changed several times throughout the writing of this plan. Fall 2022 is used as a consistent benchmark with other MTS and STA data.
[24] Note: Metro Transit's Heywood Campus is comprised of the Heywood Garage and North Loop Garage which are located across the street from one another.

2.2.2 Minnesota Valley Transit Authority (MVTA)

The Minnesota Valley Transit Authority (MVTA) is the public transportation agency for seven suburbs located south of the Minnesota River including Apple Valley, Burnsville, Eagan, and Rosemount in Dakota County as well as Savage, Prior Lake, and Shakopee in Scott County.[25] As of November 2022, MVTA operates a total of 25 fixed routes including both ***Suburban Local*** *and* ***Commuter Express*** service across a nearly 140 square mile service area encompassing a total population of about 282,250 people.[26] In addition to fixed route service, MVTA also operates MVTA Connect, an on-demand "microtransit" service available in Apple Valley, Burnsville, Eagan, Rosemount, and Savage.[27] In 2019, prior to the COVID-19 pandemic, MVTA provided over 2.5 million trips with an average weekday ridership of more than 9,200.[26]

As of July 2022, MVTA has 174 vehicles in its fleet, 155 of which are part of the Council-owned fleet. Approximately 88 percent of MVTA's fleet is used to provide fixed route service while the remaining 12 percent are used for demand response service. MVTA's entire fleet is operated and maintained by Schmitty and Sons, a local transportation company headquartered in Lakeville, Minnesota (Table 3). As shown in Figure 11, MVTA uses a variety of different vehicle lengths to provide service. A majority (57%) are 40-foot buses while just under a third (30%) are 45-foot coach buses. The remainder of the fleet is made up of smaller 20–29-foot cutaway vehicles or SUVs/vans (Figure 11).

Figure 11. MVTA Fleet by Vehicle Length (July 2022)



MVTA buses are housed and operated from two garages both of which are owned by MVTA: Eagan Bus Garage (EBG) located at 3600 Blackhawk Road, Eagan MN, 55122 and the Burnsville Bus Garage (BBG) 11550 Rupp Drive, Burnsville, MN 55337.

Table 3. MVTA Contracted Service Overview

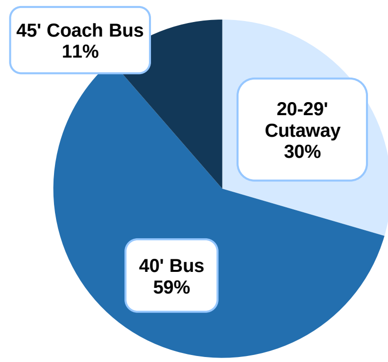
Contractor	Contract Expiration Date	Service Provided
Schmitty & Sons	December 2024	Fixed Route & Demand Response Operation & Maintenance

[25] Source: *Other Regional Transit Providers*, Metropolitan Council
[26] Source: *Minnesota Valley Transit Authority 2019 Annual Agency Profile*, National Transit Database
[27] Source: *MVTA Connect*, MVTA, 2021

2.2.3 Plymouth Metrolink

Plymouth Metrolink is a public transit agency operated by the City of Plymouth. As of November 2022, Plymouth Metrolink operates six fixed ***Commuter Express*** routes to downtown Minneapolis and the University of Minnesota. In addition, Plymouth Metrolink offers Click-and-Ride, an on-demand "microtransit" service within Plymouth and to select locations nearby. Plymouth Metrolink's service area spans 35 square miles and includes a population of over 80,000 people. In 2019, prior to the COVID-19 pandemic, Plymouth Metrolink provided nearly 522,750 trips, with an average weekday ridership of 2,050.

Figure 12. Plymouth Metrolink Fleet by Vehicle Length (July 2022)



As of July 2022, 44 vehicles, or about 4% of the Council-owned fleet is used by Plymouth Metrolink. A total of 31 (70%) of these vehicles are used exclusively for fixed route service and 13 are used for both fixed route and on-demand service. Plymouth Metrolink's fleet is operated and maintained by First Transit, a national transportation company headquartered in Cincinnati, Ohio (Table 4). As shown in Figure 12, Plymouth Metrolink uses a variety of different vehicle lengths to provide service. A majority (59%) are 40-foot buses and just under a third (30%) are 20-29-foot cutaway vehicles. The remainder are 45-foot coaches (Figure 12).

Plymouth Metrolink's buses are housed and operated from two garages, one leased by First Transit: First Transit – Como Garage at 3204 Como Ave SE, Minneapolis, MN 55414, and one owned by First Transit: First Transit – Spring Street Garage at 3400 Spring Street NE, Minneapolis, MN 55413.

Table 4. Plymouth Metrolink Contracted Service Overview

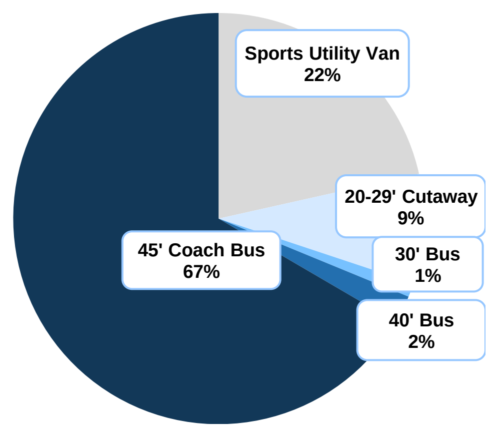
Contractor	Contract Expiration Date	Service Provided
First Transit	December 2024	Fixed Route & Demand Response Operation & Maintenance

2.2.4 SouthWest Transit (SWT)

SouthWest Transit (SWT) is a public transit agency for three southwestern suburbs located north of the Minnesota River including Carver, Chaska, Chanhassen in Carver County and Eden Prairie in Hennepin County. As of November 2022, SWT operates three fixed ***Commuter Express*** routes to downtown Minneapolis and the University of Minnesota. For major events like the Minnesota State Fair, Vikings games, and others, SWT offers special service. Further, SWT runs SW Prime, an on-demand "microtransit" service for Eden Prairie, Chaska, Chanhassen, Carver, Victoria and Normandale Community College with access to other major close-by destinations. SWT operates across eighty-five square miles and is home to a population of nearly 120,000 people. In 2019, prior to the COVID-19 pandemic, SWT provided nearly 1,107,500 trips, with an average weekday ridership of 3,754.

As of July 2022, SWT has ninety-three vehicles in its fleet, eighty of which are part of the Council-owned fleet. Approximately 68 percent of SWT's fleet is used to provide fixed route service while the remaining 32 percent are used for demand response service. SWT's fleet is operated by First Transit and maintained by SWT staff (Table 5). As shown in Figure 13, SWT uses a variety of different vehicle lengths to provide service. Approximately two thirds (67%) are 45-foot coach buses, the greatest share for any of the STPs. SWT also has several vans and sedans, 20-29-foot cutaway vehicles, 40-foot buses, and a single 30-foot bus (Figure 13).

Figure 13. SWT Fleet by Vehicle Length (July 2022)



SouthWest Transit's buses are housed and operated from a single garage which is owned by SWT: the SouthWest Transit Garage at 11405 62nd St W, Eden Prairie, MN 55346.

Table 5. SouthWest Transit Contracted Service Overview

Contractor	Contract Expiration Date	Service Provided
First Transit	December 2023	Fixed Route & Demand Response Operation

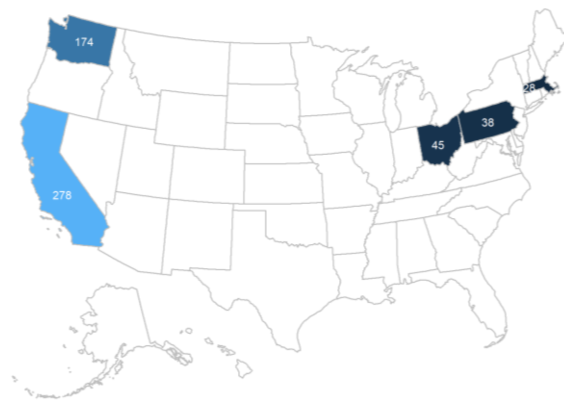
3.0 ZEB Technology—State of the Industry

Currently, three zero-emission bus technologies are commercially available: electric trolleybuses, fuel cell electric buses (FCEBs), and battery electric buses (BEBs). The following section outlines and discusses the pros and cons of each ZEB technology.

3.1 Electric Trolleybus Technology Overview

The first zero-emission transit vehicle to 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 via two trolley poles on the top rear of the bus. Operators typically raise and lower the trolley poles manually via a rope at the back of the bus.

Figure 14. Electric Trolleybus Distribution (Active Fleet[14])



Source: 2021 NTD Revenue Vehicle Inventory

The first commercial trolleybus system in the United States began operation in September 1910 in Laurel Canyon, CA in the Hollywood Hills region.[28] During the 1930s, the number of transit systems operating trolleybuses quickly grew, reaching a peak of approximately 60 systems in the 1940s and early 1950s.[29] Despite being in use for over a century, electric trolleybuses are now far less common than they once were. Today, only five U.S. transit agencies currently operate this type of ZEB (Figure 14). These agencies are:

- San Francisco Municipal Transportation Agency (San Francisco, CA)
- King County Metro (King County, WA)
- Greater Dayton Regional Transit Authority (Dayton, OH)
- Southeastern Pennsylvania Transportation Authority (SEPTA) (Philadelphia, PA)
- Massachusetts Bay Transportation Authority (MBTA) (Boston, MA).[30]

As other ZEB technology matures, continued usage of electric trolleybuses will vary by agency. King County Metro is planning to purchase thirty trolleybuses in 2027[31] while MBTA expects to begin transitioning their remaining trolleybus fleet to battery electric buses (BEBs) starting in spring 2024.[32]

Key strengths and weaknesses of electric trolleybuses are summarized below in Figure 15.

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[28] Source: *The Trackless Trolleys of Laurel Canyon,* Los Angeles Magazine, Nathan Masters, April 2013
[29] Source: *Trolleybus History* excerpt from *Urban Transportation Systems,* by Sigurd Grava, 2003
[30] Source: *2021 Annual Database Revenue Vehicle Inventory*, National Transit Database (NTD), 2021
[31] Source: *Metro 2022 Outlook and New Revenue: Electrification,* King County Metro, Accessed August 2, 2022
[32] Source: *Beginning March 2022, MBTA Routes 71 and 73 Trolley Buses to Be Replaced with Diesel -Hybrid Buses…*,MBTA, January 27, 2022, Accessed August 2, 2022

Figure 15. Electric Trolleybus Strengths and Weaknesses

Trolleybus Strengths

- Unlimited range on overhead catenary wire
- No recharging/refueling required for operations
- Lighter weight vehicles impact roadways less

Trolleybus Weaknesses

- Limited off-wire range of about 15-20 miles
- Significant visual impact and initial capital costs as overhead wires are required throughout the corridor for power supply
- Less maneuverable than a bus and not suited for high-speed operations due to overhead wires
- Limited manufacturers to provide vehicles and supporting infrastructure

3.2 Hydrogen Fuel Cell Electric Bus (FCEB) Technology Overview

As the name suggests, an 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 combined with oxygen to produce electric energy, leaving only water and heat as by-products.[33] FCEBs are currently the least-utilized ZEB technology, representing approximately three percent of the total transit ZEBs based on the latest 2021 National Transit Database (NTD) revenue vehicle inventory released in November 2022.[30] Based on 2021 NTD data, the only FCEBs available to operate in revenue service in the United States are 40-foot FCEBs.

Figure 16. Hydrogen FCEB Distribution (Active Fleet[14])

Source: 2021 NTD Revenue Vehicle Inventory

Although the total number of active FCEBs nearly doubled between 2019 and 2021, only California had more than 10 active FCEBs based on the most recent 2021 NTD data (Figure 16).[30] 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.

Approximately 95 percent of the hydrogen produced in the United States is created through a process known as reforming where natural gas or other fossil fuel (*e.g.,* oil or coal), is exposed to pressurized high temperature steam (700 – 1,000° C) creating a chemical reaction that produces carbon monoxide and hydrogen.[34] This hydrogen can then be delivered in either a gaseous or liquid form.[35] For use in buses, hydrogen is typically transported and stored in liquid form, as it allows for higher storage capacity.

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[33] Source: *About Fuel Cell Electric Buses*, Fuel Cell Electric Buses Knowledge Base
[34] Source: *Hydrogen Production: Natural Gas Reforming*, Hydrogen and Fuel Cell Technologies Office, U.S. Department of Energy
[35] Source: *Hydrogen Costs and Financing*, California Fuel Cell Partnership

Hydrogen fuel is often expensive and difficult to access.[36] While it is possible to produce hydrogen on-site, this requires high electricity consumption and significant capital investment. Currently, the majority of U.S. transit agencies operating FCEBs 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 three hundred miles from Sarnia, Ontario.[37] Although FCEBs have zero-tailpipe emissions, FCEBs typically have significant upstream carbon emissions due to the hydrogen extraction process and the need to transport this fuel to the transit facility. As of this writing, there is no commercial source of hydrogen in Minnesota.

Hydrogen fuel cells have a higher energy density. This feature enables FCEBs to have a proven range of 250 to 370+ miles per day,[38,39] large enough that FCEBs can be introduced 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. In addition to a proven range significantly greater than battery electric buses, FCEBs can be fully refueled in less than 10 minutes—much faster than an electric bus.[33]

Key strengths and weaknesses of FCEBs are summarized below in Figure 17.

Figure 17. Fuel Cell Electric Bus Strengths and Weaknesses

FCEB Strengths

- Proven range of 250 – 300 miles per day
- Refueling takes less than 10 minutes

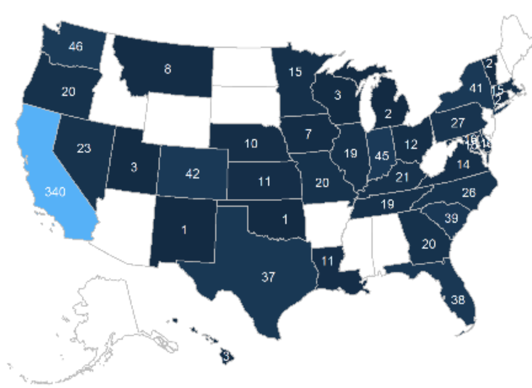
FCEB Weaknesses

- Significant upstream carbon emissions to extract and transport hydrogen
-
- Hydrogen fuel is often expensive and difficult to access
- FCEBs are more expensive than other bus types

3.3 Battery Electric Bus (BEB) Technology Overview

Battery Electric Buses (BEBs) are the third and most widely adopted ZEB technology. Based on the most recent NTD Data (2021), approximately 990 transit BEBs—including Bus, Articulated Bus, Double Decker, and Motorcoach—were available to operate in revenue service in the United States, an increase of about 35 percent since 2020 (Figure 18).[30] Approximately one third of these BEBs are located in California. BEBs use onboard battery packs to propel and power the vehicle. BEBs are charged either at operations/maintenance facilities and garages or on-route during operation. Transit agencies located in colder climates often include an auxiliary diesel heater on their BEBs for supplemental heat to avoid excess energy load which would otherwise reduce bus range.

Figure 18. BEB Distribution (Active Fleet[14])



Source: 2021 NTD Revenue Vehicle Inventory.

[36] Source: *Fuel Cell Electric Buses in the USA*, NREL, June 25, 2019
[37] Source: *Zero-Emission Bus Evaluation Results: Stark Area Regional Transit Authority Fuel Cell Electric Buses*, NREL 2019.
[38] Source: *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2020*, NREL, March 2021
[39] Source: *NFI Unveils Next Generation Hydrogen Fuel Cell-Electric Bus, The Xcelsior Charge FC*, Mass Transit, September 9, 2022

3.3.1 BEB Range

The amount of energy provided by a BEB's battery is described as its energy capacity and is 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. Unlike conventional diesel buses which typically have 100+ gallon fuel tanks that allow a bus to travel more than 300 miles before refueling, BEBs currently have a reliable range in transit service of 150 miles or less on a single charge.[40] Two characteristics largely influence a BEB's range: (1) battery capacity and (2) energy usage.

Battery Capacity

Battery capacity is directly proportional to BEB range. Greater capacities allow for greater range on a single charge. As of Spring 2022, BEB manufacturers offer on-board BEB batteries with capacities typically ranging from approximately 113 kWh to 686 kWh for buses 30 feet or longer.[41,42,43] Improving on these capacities, Proterra has announced that starting in 2023, they will offer a 40-foot BEB that can be equipped with up to 738 kWh of onboard energy.[44] These advertised capacities, also referred to as nameplate or nominal battery capacities, indicate the capacity of a new battery pack. For smaller BEBs less than 30 feet in length, battery capacities are much less, ranging from 43 kWh to 157 kWh, primarily due to the limited weight and space reserved for batteries on board these vehicles.[45,46,47,48]

Usable Battery Capacity

Unfortunately, not all nominal battery capacity can be reliably used for BEB operation. Due to the combination of battery degradation as well as the need to reserve a portion of the capacity to preserve battery life and allow for operational flexibility, only about 70 percent of a BEB's nominal battery capacity is typically usable as detailed below (Figure 19).[49]

Only about 70% of nominal battery capacity can be reliably used for BEB operation due to battery degradation and the need to preserve battery life and allow for operational flexibility

Just as smartphones and other electronics require more frequent charging to reach a "full charge" as they grow older, BEB batteries wear down and become less efficient over time. Based on manufacturer warranties, it is estimated that a BEB's battery capacity degrades by as much as 2.4 percent per year.[50] Furthermore, charging a BEB to full capacity or charging it from a zero state of charge (SOC) puts additional strain on batteries' physical and chemical components further accelerating degradation. To preserve hardware longevity, manufacturers reserve a portion of the total battery capacity—typically 10-30 percent—only allowing agencies to use a portion of the nominal capacity in day-to-day use. Additionally, just as operators avoid driving a conventional bus 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

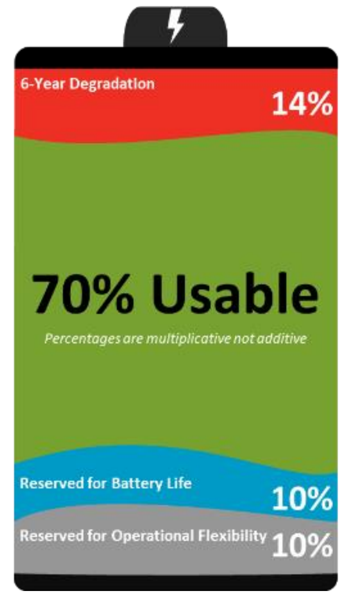
[40] Source: *Guidebook for Deploying Zero-Emission Transit Buses*, The National Academies Press, 2021
[41] Source: *Electrifying Transit: A Guidebook for Implementing Battery Electric Buses*, National Renewable Energy Laboratory, April 2021
[42] Source: *GILLIG's next-generation battery to provide 32 percent increase in onboard energy*, Gillig, November 2021
[43] Source: *Zero Emissions Buses: A Market Report for Canada and the US 2022-Second Release*, Evenergi, 2022
[44] Source: *Proterra Introduces ZX5 Electric Bus With 738 Kilowatt Hours of Energy*, Proterra, April 14, 2022
[45] Source: *Lightning Electric E-450 Shuttle, Cutaway & Stripped Chassis*, Lightning Electric, 2021
[46] Source: *EVSTAR+,* GreenPower Motor Company, 2022
[47] Source: *Lightning ZEV4 Zero Emission Class 4 Shuttle Bus*, Lightning eMotors, 2022
[48] Source: *PG&E EV Fleet Program*, PG&E, July 2021
[49] Note: Battery capacity degradation calculated for bus mid-life (6 years). Six years is used as bus mid-life based on regional policy which currently defines usable life for non-coach buses as 12 years. In 2023 the Metropolitan Council plans to revisit this definition of usable life.
[50] Source: *Battery Electric Bus and Facilities Analysis Final Report*, Milwaukee County Transit System, January 2020

event of an unforeseen delay or other unexpected event requiring a BEB to remain in service longer than originally planned.

Energy Usage

A BEB's **energy usage** (kWh/mile) also impacts 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 increased time idling and accelerating from rest, thereby also requiring greater energy usage. Efficient operation of the vehicle through gentle accelerations and decelerations can reduce energy usage by not only requiring less energy to accelerate from rest, but also maximizing the bus's ability to regenerate energy. When the bus is rolling forward, BEBs are capable of recapturing some of that energy and improving overall energy usage. From this combination of factors, energy usage on the same bus can vary widely within a single transit agency's operation and therefore lead to different functional ranges.

Figure 19. Example of usable battery capacity calculations (percentages are rounded up)



3.3.2 Vehicle Length

Fixed route transit service, defined as "services provided on a repetitive fixed schedule along a specific route,"[51] is traditionally operated with vehicles 30 feet or greater in length. Demand response service, defined as "any non-fixed route system of transporting individuals that requires advanced scheduling by the customer,"[52] typically utilizes passenger cars, vans, or small buses.

Approximately two thirds of the current MTS revenue fleet is comprised of small cutaway buses (< 30' in length and typically built in a two-stage process), while sports utility vehicles and vans make up an additional three percent of the fleet. As of July 2022, over 90 percent of the cutaway vehicles owned by MTS are utilized for Metro Mobility paratransit and Transit Link Dial-A-Ride demand response services while the remainder are used for fixed route service. While modeling energy use for fixed route transit can help to identify fleet transition opportunities, risks, and challenges in a straightforward way, identifying these items for the more fluid daily service profiles of demand response (Transit Link, Metro Mobility and STP on-demand) vehicles can present unique challenges.

Significant complications associated with transitioning towards electric cutaway and demand response vehicles include: (1) limited existing BEB applications and market for these vehicles, and (2) reduced battery capacity and range on a single charge. For example electric paratransit and shuttle vehicles battery capacities currently range from 100 to 160 kWh compared to transit bus capacities of 168 kWh to nearly 700 kWh.[42,53] Additionally, as of 2022, only seven paratransit and shuttle electric vehicle types

[51] Source: *NTD Glossary*, NTD
[52] Source: 49 C.F.R Section 604.3(g), 2022
[53] Source: *Zero Emissions Buses: A Market Report for Canada and the US 2022-Second Release*, Evenergi, 2022

currently exist in the North American market compared to 25 types of electric transit buses.[53,54] Notable electric paratransit and shuttle manufacturers include GreenPower, Vicinity, Lightning eMotors and Ideanomics. Should larger orders be placed for these electric vehicles in the future or if multiple agencies seek to expand their small bus zero-emission fleets concurrently, these smaller companies could struggle to keep pace with demand. Larger manufacturing companies, such as Rivian, are rapidly scaling up their production to meet private sector demand for companies such as Amazon and UPS, but this will also result in much of their capacity being allocated for the foreseeable future.

To identify existing applications of electric cutaway and demand response vehicle operations, NTD's most recent (2021) revenue vehicle inventory was reviewed including an analysis of demand response vans and both cutaway vehicles as defined by the NTD as well as small buses (less than 30' in length) to account for varying definitions of cutaway vehicles. Based on this data, only ten transit agencies nationwide operated electric small buses, cutaway, or vans. Together, these agencies had a total of 32 small BEBs, 1 cutaway BEB, and 40 electric vans available for revenue service (Table 6).

Table 6. Total Small Bus (<30'), Cutaway, and Electric Van Revenue Vehicle Inventory (2021 NTD)

Agency	Bus Type	Active Vehicle Count
Chattanooga Area Regional Transportation Authority (CARTA) *[Chattanooga, TN]*	**Small Bus** *(< 30' in Length)*	**14**
Sacramento Regional Transit District (SacRt) *[Sacramento, CA]*	**Small Bus** *(< 30' in Length)*	**9**
Central Contra Costa Transit Authority (County Connection) *[Concord, CA]*	**Small Bus** *(< 30' in Length)*	**8**
Denver Regional Transportation District (RTD) *[Denver, CO]*	**Small Bus** *(< 30' in Length)*	**1**
City of South Pasadena *[South Pasadena, CA]*	**Cutaway**	**1**
L.A. Metro *[Los Angeles, CA]*	**Van**	**15**
City of Porterville *[Porterville, CA]*	**Van**	**12**
Antelope Valley Transit Authority *[Northern Los Angeles County, CA]*	**Van**	**8**
San Diego Association of Governments *[San Diego, CA]*	**Van**	**4**
JAUNT, Inc. *[Charlottesville, VA]*	**Van**	**1**

With a less-restrictive use case, cutaway vehicles are a growing area of interest for BEB fleet conversion studies. However, smaller buses come up against multiple challenges that impact both the range and affordability of these vehicles.

The first of these challenges is the limited available on-board space for storing the large batteries required to supply sufficient energy for a full day's worth of service. Whereas full-size transit buses typically have available space for battery storage in their floorboards and on their roof, cutaway vehicles have less spare space. The weight of the batteries on board these smaller transit vehicles is also more significant relative to the rest of the vehicle than is the case with full-size transit buses. This leads to concerns about weight distribution and the structure of the vehicle frame should the battery be placed on the roof. While cutaway vehicles require less energy per mile due to their smaller size, the combined difficulties of space and weight restrictions still result in very limited vehicle ranges compared to conventionally fueled vehicles. Energy use profiles can be modeled for both cutaway and paratransit

[54] Note: This includes BEBs that are not eligible for purchase in the United States with federal funding

vehicles, but due to the nature of these operations which vary drastically from day to day, modeling won't be as precise as it will often involve more variability than fixed route energy use modeling.

The costs of cutaway vehicles, from both the manufacturing and the implementation perspective, are another challenge associated with transitioning towards electric cutaway vehicles. While there are manufacturers producing electric cutaways for sale, the current manufacturing process relies upon components of the unfinished vehicle to be produced and assembled in separate facilities. This sometimes means that the vehicle must be transported between different locations as it is built, which can be further complicated by the unique components associated with electrification.

While an electric cutaway bus fleet presents challenges, they are not unsurmountable. Many strategies can be considered to overcome the range limitations, such as increasing the fleet size to reduce the energy required onboard each individual cutaway vehicle or implementing midday charging to take advantage of the time between peak service periods to replenish the energy onboard the vehicle. These approaches, however, come with their own costs and risks which must be weighed by MTS and each of the STPs. Increasing fleet size can present both capital and operational cost increases, as well as a need for increased staffing. Midday charging can also increase the overall cost of energy by bringing the impacts of time of use rate structures into an energy bill for agencies with applicable utility rate structures, especially as the power demand increases proportionate to an increase in the rate of charging.

City of South Pasadena Case Study Example (South Pasadena, CA)

As introduced in Table 6 above, the only electric vehicle classified as a cutaway available for revenue service in the United States is the City of South Pasadena's electric cutaway vehicle according to the most recent (2021) NTD data. This cutaway vehicle entered revenue service in July 2017 and has been consistently used by South Pasadena's Dial-A-Ride program ever since.[55] The vehicle is equipped with a wheelchair lift and ramp and offers a range of up to 100 miles on a full charge. Notably, four years after the introduction of this electric cutaway shuttle, it remains the only electric cutaway vehicle in the NTD's Revenue Vehicle Inventory.

3.3.3 Charging Strategies

BEB chargers are necessary to support BEB operation. Currently, two primary charging strategies govern where and when BEBs can be charged: (1) garage charging and (2) opportunity charging. Many agencies also use a combination of both strategies based on their unique operational characteristics and needs.[56]

Garage charging, also referred to as depot charging, occurs while the BEB is at a garage. Typically, garage charging occurs overnight when agencies can take advantage of longer parking windows and lower utility rates to reduce costs. Garage charging, however, can also occur during the day or utilize fast chargers.

Opportunity charging, also referred to as on-route charging, refers to charging while the BEB is in-service at layover points or general bus stops. To sufficiently charge a BEB in just 5-15 minutes, opportunity charging requires fast chargers with greater power than garage charging. Although opportunity charging typically provides greater flexibility in service design with fewer changes to block configurations, opportunity charging is typically more expensive and logistically challenging compared to garage charging. Specific challenges include:

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[55] Source: *All Electric Shuttle!*, South Pasadenan, January 28, 2018.
[56] Source: *Deploying Charging Infrastructure for Electric Transit Buses*, Atlas Public Policy, June 2022

- Daytime electricity premiums
- Lower maintenance cost-effectiveness compared to garage charging
- Potential need to acquire land or right-of-way for charger installation along a route

3.3.4 Charging Infrastructure Systems

BEB charging infrastructure typically includes transformers, switchgear, chargers (charger "bases / cabinets" where the majority of charging equipment is housed including Alternating Current (AC) – Direct Current (DC) rectifiers, charge controls and communication) and dispensers. Three primary types of BEB charging dispenser types are currently available in the United States: (1) plug-in dispensers, (2) overhead conductive dispensers, and (3) in-ground wireless inductive pads (Figure 20). Plug-in dispensers are most often used for garage charging whereas overhead conductive dispensers and wireless inductive pads are used for both garage and opportunity charging. As charging technology advances, a number of charging original equipment manufacturers (OEMs) have recently begun to offer charger cabinets that support a mix of connected dispensers (*i.e.,* plug-in cords and overhead conductors connected to the same cabinet).

Figure 20. BEB Charging Infrastructure

Plug-In **Overhead Conductive** **Wireless Inductive[57]**

Plug-in charging systems either utilize an 'All-in-one' unit with dispensing plug-in cords attached directly to the charger cabinet, or a charging cabinet connected to remote plug-in dispensers (Figure 21). Typically, a plug-in all-in-one unit has one or two dispensers while a remote dispenser cabinet can support up to twenty dispensers.[58] Charge power for plug-in dispensers ranges from 50 to 200 kW per dispenser. Due to this relatively low power, plug-in chargers typically take several hours to fully charge a bus and are therefore often used for overnight garage charging. Overhead suspended dispenser plug-in cords mounted over parked buses energized by remote charging cabinets located away from bus parking can be used where ground mounted plug-in cord equipment is impractical or not desired.

Figure 21. Plug-In Charger Detail

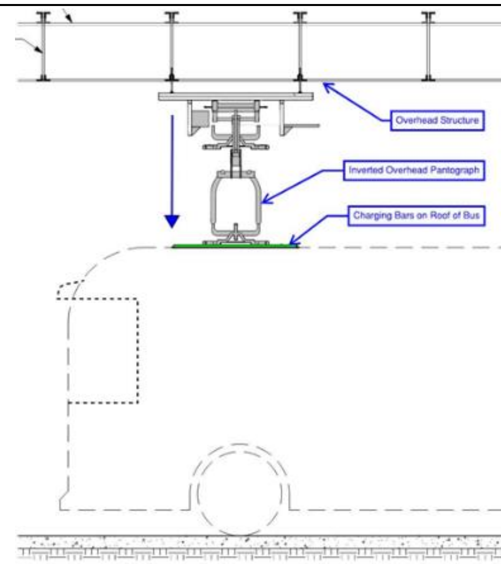
[57] Source: *Electric Wireless Charging System for Electric Buses extended 5-years*, Link Transit and eVehicle Technology, January 23, 2020
[58] Source: *Proterra Specification Sheet: 1.5MW Charing Systems*, Proterra, September 2021

BEBs typically have charging ports located in similar locations to conventional internal combustion engine fuel ports – curb side, rear quarter of bus. BEBs can be specified to have plug-in ports on both sides of the vehicle or only one at the center rear to the bus to increase flexibility in parking positions especially at ground mounted charger islands and curbs. 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.

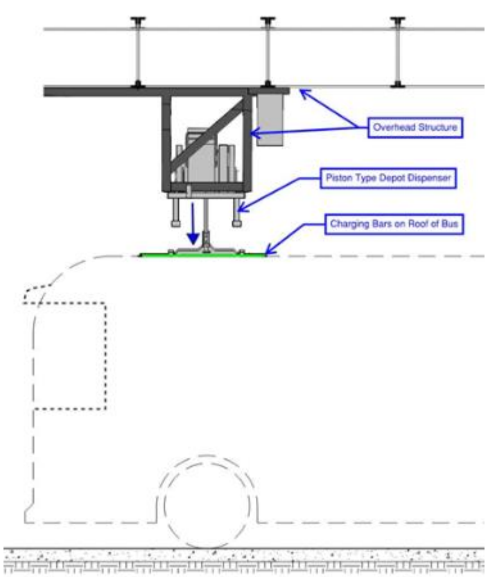
Overhead conductive charging systems use either a movable pantograph or piston[59] dispensers that lower down from a structure above the bus to connect to charge rails mounted on a BEB's roof (Figure 22). As of Fall 2022, overhead conductive roof mounted charging rails are only available for heavy-duty buses (30', 45', 40', 45' coach, and 60' articulated), and not smaller vehicles (also known as cutaway vehicles), to ensure that the charge rails are sufficiently out of reach from the ground to prevent safety issues. Compared to overhead conductive pantograph dispensers, piston dispensers are less expensive and more space efficient. At the time of writing, however, piston dispensers are only manufactured by a single source but can and are able to be utilized by many charger OEMs. Currently, charge power for overhead conductive charging systems ranges from 150 to 720kW (125A – 1,500A) depending on the overhead conductive charging dispensing model.[40]

Overhead conductive chargers have historically been reserved for off-site opportunity charging. Recently, however, a growing number of agencies have begun implementing overhead conductive chargers for garage / depot charging as their BEB fleets grow due to the ease with which these chargers can initiate and end a charging session (set / release parking brake) compared to the need to manually plug and unplug all plug-in BEBs.[56] In these cases, lower capacity overhead conductive charging units are typically used for garage charging similar to where plug-in dispensers would be used but with the benefit of not requiring ground space or reducing the already narrow people circulation aisle around sides and ends of the bus. Higher capacity units (300+ kW) are most often used at shared garage charging positions or for opportunity charging.

Figure 22. Example Overhead Conductive Dispensers



Inverted Overhead Pantograph Dispenser



Piston Dispenser

[59] Source: [Depot Charger](), Schunk Transit Systems

Due to their ability to distribute more power than a traditional plug-in cord, overhead conductive chargers can be flexibly used to “top-up” a BEB’s charge for 5 to 20+ minutes at higher power. Because of this higher power output and reduced charging infrastructure footprint, a lower ratio of overhead conductive chargers to buses is required. However, a single charging station malfunction may then have a larger impact on service. Compared to plug-in chargers, overhead conductive chargers have higher capital and maintenance costs.

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.

Wireless inductive charging systems 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. An above ground charging cabinet, like a plug-in or overhead conductor cabinet, is still needed to convert AC to DC power and energize the charging pad dispenser (Figure 23). Inductive chargers eliminate overhead clearance issues. However, there may be significant costs and operational disruptions to install, repair, or replace the charger and wireless pad. Retrofitting multiple induction pads and their above ground chargers in existing garages would require significant trenching and cutting of the floor slabs. Inductive charging can be operationally challenging because 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 less than a dozen U.S. agencies have implemented inductive chargers as of summer 2022.[61,62]

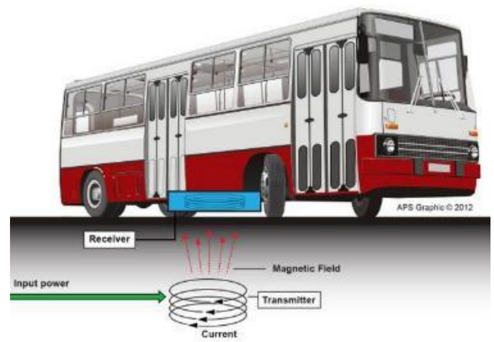


Figure 23. Inductive Charging Schematic[60]

Currently, there is no national standard for inductive charging. As a result, 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 smartphones from other versions.

Key strengths and weaknesses of BEBs are summarized below in Figure 24.

Figure 24. Battery Electric Bus Strengths and Weaknesses

BEB Strengths

- Increased budget predictability due to multi-year utility rates
- Less expensive than FCEBs
- Charging infrastructure can be flexibly installed at a variety of locations either along a bus route or at a garage

BEB Weaknesses

- Limited usable range (likely < 150 miles on a single charge) influenced by battery capacities, challenging climates, and topographies
- Up to multi-hour charging times
- Major facility and operational changes often required

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[60] Source: *Wirelessly Charged Electric Buses*, Physics Central
[61] Source: *One of America’s Largest Electric Bus Fleets Reveals Operating Costs of EV Buses Using Wireless Chargers From Momentum Dynamics is Half of A Diesel-Fueled Bus*, PR Newswire, June 18, 2022
[62] Source: *WAVE Bringing Wireless Depot Charging to Oregon with Expanded Order from Josephine Community Transit*, PR Newswire, June 22, 2022

4.0 Transition Plan Guiding Principles

MTS, in partnership with the STPs, has developed a set of four guiding principles and seven supporting actions to inform the development of zero-emission program goals, milestones, assessment criteria, and a prioritization framework for the zero-emission transition (Figure 25). Recognizing the importance of consistency between Council divisions, MTS has adopted the three guiding principles established in Metro Transit's Zero-Emission Bus Transition Plan (Technical Viability, Equity & Environmental Justice, and Fiscal Impact)[12] in addition to adding the guiding principle of Scalability in recognition of the distinct type of service that MTS and the STPs manage and oversee. To align with the Transition Plan's updates every five years, short-term, for the purposes of this report, is defined as a five-year time horizon.

Figure 25. ZEB Transition Guiding Principles and Supporting Actions Summary

Scalability

Develop zero-emission deployment models tailored to unique service/fleet types, facility ownership status, and limited duration transit operating contracts

Technical Viability

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

Technical Viability

Partner with electric utilities 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

4.1 Principle 1: Scalability

MTS' transition towards ZEBs must be scalable and responsive to the unique service types, facility ownership characteristics, and limited duration transit operating contracts MTS and the STPs manage and oversee. Unique aspects of MTS service due to the governance structure with contractors and STP providers include:

- MTS does not own any garage facilities as the existing contractors either own their own facilities or lease them
- MTS transit operating contracts are limited in duration with the potential of new contractors and facility locations and fleet characteristics to change every five to six years
- Metro Mobility is a federal civil right for all eligible riders, defined in the Americans with Disabilities Act, with an uninterrupted service requirement necessitating particularly smooth service transitions

Beyond these key aspects of MTS service, each STP also has a distinct set of characteristics further underscoring the need for a scalable transition plan with the flexibility to meet the unique needs of MTS as well as each STP. For example, whereas MTS, Plymouth Metro Link, and Maple Grove Transit do not own any of their garage facilities, MVTA and SWT both own their garages and may therefore have a different ZEB infrastructure installation and investment strategy. See Section 2.0 for more details regarding the unique characteristics and ZEB considerations associated with each of the four STPs.

Supporting Action: Develop zero-emission deployment models tailored to unique service/fleet types, facility ownership status, and limited duration transit operating contracts

MTS and the STPs manage and oversee the operation of a wide variety of vehicle and transit service types as described in the Section 2.1 above. Many vehicles and services are operated from and maintained at facilities not owned by the Council or the STPs. Complicating the situation even further is the fact that transit operating contracts for MTS as well as the STPs are limited in duration, typically less than the useful life of ZEB supporting infrastructure. As such, the fleet and facilities used to provide service today may not be the fleet and facilities used in the future.

To address these challenges, the transition towards ZEBs will be scalable and tailored to these unique aspects of service. From a fleet perspective, compared to traditional full-size transit buses (30'+ in length), small buses (< 30' in length and typically built in a two-stage process) have unique operating characteristics such as limited weight reserved for battery capacity. As a result of these battery capacity restrictions, vehicle range is reduced, and rapid charging strategies are infeasible as rapid charging utilizes higher voltages than these vehicles can currently handle. As such, unique deployment models are necessary for these vehicles.

In addition to vehicles of varying type and length, MTS also manages and oversees a variety of unique service types including traditional fixed route service, Metro Mobility (ADA complementary service), and Transit Link dial-a-ride. Unlike fixed route service that has regular service patterns, Metro Mobility and Transit Link service is much more variable and may therefore require unique analyses and deployment models. For example, Metro Mobility is a federal civil right for all eligible riders defined in the Americans with Disabilities Act and must be provided with uninterrupted and high-quality service. As such, additional ZEBs, each with shorter operating hours than fixed route ZEBs, would be necessary to ensure that each vehicle has sufficient range to reliably complete its work.

Underlying the need to scale the ZEB transition framework to each of these unique service/fleet types is the fact that MTS and STP service is provided through limited duration operating contracts and many of the garage facilities are not owned by MTS or the STPs. Installing ZEB supporting infrastructure is a significant investment. Although these long-term infrastructure investments may be suitable for facilities owned by STPs, alternative infrastructure investment strategies will need to be considered for facilities not owned by MTS or the STPs, particularly given the limited duration operating contracts and potential complications that may arise when applying for federal funding to support such projects at contracted facilities.

4.2 Principle 2: Technical Viability

Technical Viability is one of the three guiding principles MTS and the STPs have adopted from the Metro Transit ZEBTP. To manage and oversee a strong and reliable ZEB transit system, buses, facilities, and service must all be technically viable. To attain technical viability, MTS and the STPs will strive to achieve a level of service where ZEBs and conventional diesel/gas 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 electric providers to assess and upgrade electrical infrastructure and bus facilities, where applicable, 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.

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

ZEBs and conventional diesel/gas buses have many different characteristics including, but not limited to, the equipment needed to maintain the vehicles and charging/fueling infrastructure, standard operating procedures regarding the recharging/refueling of the buses, and the range the buses can operate between recharging/refueling. Although operating requirements and procedures will need to be tailored to take advantage of the unique operating characteristics associated with ZEBs in the short-term, in the long-term, a successful transition to ZEBs would be one in which MTS and the STPs will not need separate use cases for buses of different propulsion types. Reaching this long-term goal where buses are equally utilized regardless of propulsion type will require changes to how MTS and the STPs manage and oversee bus service. It will also require additional staff training so that the existing workforce can continue to operate and maintain the system.

Supporting Action: Partner with electric utilities 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/gas buses. For example, whereas diesel/gas 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 to recharge. To ensure that future ZEBs will have the support infrastructure necessary to operate consistently and reliably, MTS and the STPs will partner and closely collaborate with electric utilities to assess the existing electrical infrastructure and capacity limitations at 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.

4.3 Principle 3: Equity and Environmental Justice (EEJ)

Adopted from the Metro Transit ZEBTP, 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.[63]

In alignment with the above definitions and to maximize equity and environmental justice, MTS and STP ZEB implementation and prioritization will reflect the results of transparent fact-driven community engagement and education conducted through public meetings, seminars, surveys, and staff engagement as part of Metro Transit's ZEBTP process. Based on this engagement and education, MTS, in collaboration with STPs and transit contractors, 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.

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.[64] In recognition of these wide disparities, MTS and the STPs are 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 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, MTS and the STPs are committed to prioritizing and implementing ZEB service that reflects transparent fact-driven community engagement and education.

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 increase. Therefore, to deliver the greatest possible benefits to the communities where air pollution, racial, and socioeconomic disparities are greatest, MTS and the STPs will focus 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, MTS and the STPs will work to mitigate the many risks of deploying emerging technologies so as to minimize adverse impacts to these same communities.

As part of the community education and outreach process associated with Metro Transit's ZEBTP, participants were asked to evaluate and rank the relative importance of seven unique population and environmental variables in identifying equitable and environmentally just areas with 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.[65] Reflecting this

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[63] Source: [Learn About Environmental Justice,]() EPA
[64] Source: [Environmental justice and air,]() Minnesota Pollution Control Agency
[65] 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

feedback, a regional equity and environmental justice priority level for ZEB service was identified for all census tracts in the seven-county Twin Cities area based on the relative percentage of first choice votes engagement participants assigned to each of the aforementioned equity and environmental justice variables. To align with other Metropolitan Council ZEB initiatives such as the Metro Transit ZEBTP, MTS and the STPs will utilize the regional equity and environmental justice priority designations to target ZEB investments to make a difference in communities where air pollution, racial, and socioeconomic disparities are greatest.

4.4 Principle 4: Fiscal Impact

Adopted from the Metro Transit ZEBTP, the principle of fiscal impact means that MTS and the STPs 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.

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

Locally, Metro Transit has found that the current capital cost of putting a ZEB on the road is at least 2.5 times as expensive as a diesel bus.[66] As ZEBs represent such a significant financial investment, MTS is focused on extracting the most benefit and usage from these vehicles. To maximize the return on investment these ZEBs can provide, MTS will work with STPs and contractors to 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.

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

As an increasing emphasis is placed on environmentally sustainable solutions, it is anticipated that funding opportunities for ZEB systems will need to grow to remain fiscally sustainable. Beyond the capital costs associated with ZEBs, MTS and the STPs 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/gas buses due, in part, to the challenges of working with emerging technology resulting in excess costs attributed to less reliable chargers and vehicles. However, utility rates are typically locked in and often require a multi-year process to adjust and as such, MTS and the STPs will likely see increased budget predictability rather than being subject to diesel market volatility which has seen the average price of a gallon of diesel in Minnesota increase by nearly 75 percent from July 2021 to July 2022.[67] As MTS and STPs gain ZEB experience and develop a more complete understanding of the practical operating and maintenance costs associated with ZEBs, MTS will collaborate with regional partners to continue studies and identify actions to control and reduce these costs. Specific steps to manage the O&M costs of the ZEB system are likely to include modifying service delivery methods and working with electric utilities to optimize specific utility rate selections and metering systems.

4.5 Application of Guiding Principles

In developing zero-emission program goals, milestones, assessment criteria, and a prioritization framework for the zero-emission transition, our four guiding principles of ***Scalability*, *Technical***

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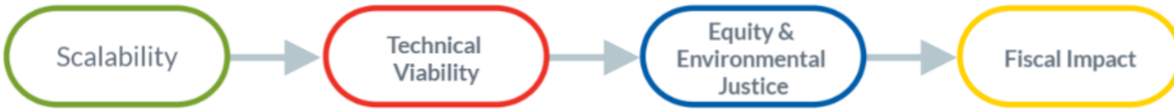
lacking a vehicle, the number of years in which the census tract was designated as an area of concentrated poverty, the portion of households that are housing cost-burdened (housing costs are 30 percent of household income), and the average land surface temperature on a hot summer day (proxy for urban heat island effect).

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

[67] Source: *Minnesota Average Gas and Diesel Prices*, AAA, Accessed August 5, 2022

Viability, ***Equity & Environmental Justice***, and ***Fiscal Impact*** will be sequentially applied as shown in Figure 26.

Figure 26. ZEB Guiding Principles Flow Chart



In recognition of the unique contractual and operational characteristics of MTS and STP transit service, the first step in establishing program goals and milestones as well as a prioritization framework for the zero-emission transition will be to ensure that our approach to developing these frameworks is scalable and tailored to our limited duration transit operating contracts as well as our unique service/fleet types and facility ownership status. Having sufficiently scaled and tailored these frameworks we then apply the principle of technical viability to ensure that ZEBs are able to provide an excellent, safe, and reliable service to our customers similar to vehicles of all other propulsion types and that the facilities can viably support ZEBs. For technically viable instances, our equity and environmental justice and fiscal impact principles are then applied to prioritize ZEB investment in underserved and underinvested areas that have borne a disproportionate share of negative environmental consequences where the maximum benefit and usage can be gleaned from these significant investments.

5.0 Industry Case Studies and Best Practices

This section summarizes the state of practice for ZEB implementation and operation in North America. This summary includes a review of key lessons learned, best practices, and words of caution to consider when transitioning to ZEBs. In recognition of the unique service types, facility ownership characteristics, and limited duration transit operating contracts that MTS and the Suburban Transit Providers (STP) manage and oversee, this section:

- Summarizes full-size fixed route ZEB case studies,
- Reviews the state of practice for smaller cutaway buses and demand response vehicles, and
- Outlines considerations and lessons learned for transitioning contracted services to ZEBs.

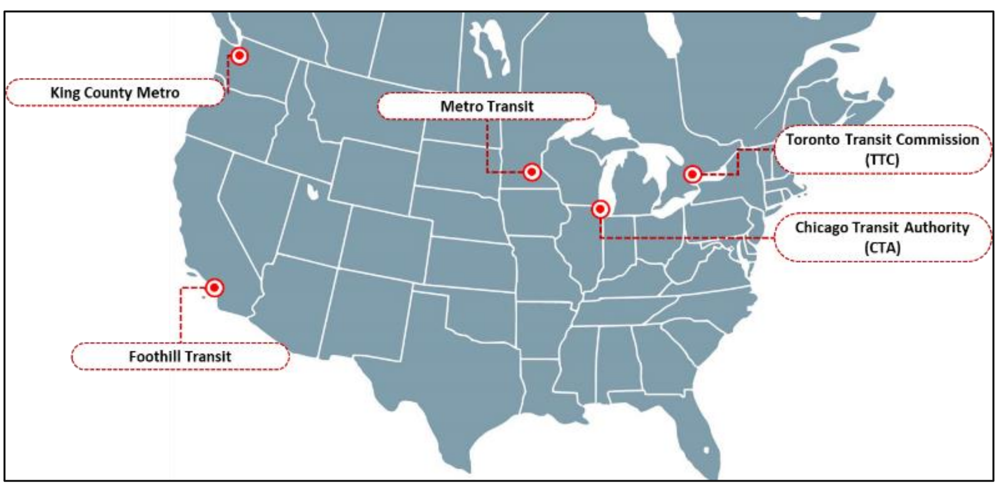
5.1 Fixed Route Bus Service

Approximately one third of the Council-owned revenue fleet is comprised of full-size heavy-duty buses

Approximately one third of the Council-owned revenue fleet is comprised of full-size heavy-duty buses (30', 35', 40', 45' coach, and 60' articulated) providing fixed route service throughout the region. To identify best practices for transitioning this type of service to ZEBs, MTS has reviewed and updated the five fixed route ZEB case studies previously developed for Metro Transit's ZEB Transition Plan.[68] These case studies encompass a variety of fleet sizes, climates, and operating characteristics (urban, suburban, local service, express service). They include agencies with the longest track record of operating ZEBs and place heavy emphasis on northern agencies (located between 40- and 50-degrees latitude) (Figure 27). Updates to these case studies since fall 2021 are based on publicly available information. The five 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 27. Geographic Distribution of Fixed Route Full-Size Service



[68] Source: *Metro Transit Zero-Emission Bus Transition Plan*, Metro Transit, February 2022

5.1.1 Metro Transit (Minneapolis – Saint Paul, Minnesota)

ZEB Program History

As part of Metro Transit's long-standing efforts to move toward greener operations, in 2017 Metro Transit established a BEB pilot program on the METRO C Line, an arterial BRT route traveling from downtown Minneapolis to Brooklyn Center. (Figure 28) This pilot program included the purchase of eight New Flyer 60-foot Xcelsior Charge BEBs with 466 kilowatt-hour (kWh) batteries. To serve these BEBs, two overhead conductive chargers were installed at the Brooklyn Center Transit Center, the route's northern terminus, and eight plug-in garage chargers were installed at the Fred T. Heywood Garage. The selection of the C Line was driven partly due to an emphasis on targeting ZEBs in a heavily utilized transit corridor serving historically underinvested communities with historically higher rates of asthma. Service on the METRO C Line BEB pilot began in June 2019.

BEB Operation	Directly Operated
Facility Ownership	Public Agency

Source: 2021 NTD Data

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.

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 is beginning a second BEB pilot program with the purchase of eight 40-foot Proterra BEBs in early 2023 planned to enter revenue service in 2024. The deployment of these 40-foot BEBs will be based on the three-step service prioritization methodology encompassing technical viability, equity and environmental justice, and fiscal impact as outlined in Metro Transit's ZEB Transition Plan.[68]

Figure 28. Metro Transit C Line 60-foot Articulated BEB Pilot

Metro Transit's ZEB Transition Plan established a target that at least 20% of 40-foot bus replacement procurements between 2022 and 2027 will be electric.[68] To accomplish this target, Metro Transit has developed several sequential packages of projects to be initiated by 2027. Metro Transit also plans to track eight key performance indicators (KPIs) including bus and charging infrastructure availability and reliability, as well as other fiscal, environmental, and equity and environmental justice metrics to assess the performance of the ZEBs and drive procurement targets.

Operational Experience, Best Practices, and Lessons Learned

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

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 opportunity 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.[69] Additionally, between December 2021 and May 2022, average C Line BEB availability[70] has exceeded average C Line diesel bus availability demonstrating a significant BEB performance improvement compared to earlier in the pilot program.

Best Practice: Partnerships and Relationship Building

Further areas of success for Metro Transit's C Line BEB pilot program include partnership and relationship building and the creation and implementation of contingency plans.

- Establishing and building interagency relationships with electrical specialists and Xcel Energy has allowed Metro Transit to create innovative technical and financial partnerships that will be vital for managing costs and providing dependable 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 that connect the transformer to the base of each charging cabinet.
- Metro Transit's proactive development of contingency plans has meant that Metro Transit has not missed service for the C Line due to vehicle unavailability or charger issues. Technical difficulties with various aspects of the charging equipment and BEBs have included blown fuses, blank charging interface screens, chargers not restarting in extreme cold, transformer failures, and longer than expected charging infrastructure construction and installation times. One contingency plan included the development of an alternative C Line service plan that does not require the use of range extending on-route overhead conductive chargers. Another contingency plan branded five additional 60-foot diesel buses as C Line BRT buses for deployment if a BEB could not make service.

Lesson Learned: Climate Challenges

In addition to these aforementioned areas of success and best practices, Metro Transit has been able to use the C Line pilot program to identify and correct shortcomings and other challenges. Through this experience, the agency has increased its in-house knowledge and understanding of BEB technology and has improved service for Metro Transit's riders.

One of the biggest continued challenges that Metro Transit faces in implementing BEBs is the Minnesota climate. Based on 30-year average temperatures, Minneapolis (and the greater Twin Cities Region) averages the coldest winters of any major U.S. city.[71] When the energy used to heat the bus cabin is the same energy that would be used for the propulsion of the bus, BEB range can be substantially reduced in cold weather. For example, based on data from the first year of C Line service, theoretical maximum average daily range[72] was reduced by about 33 percent in February compared to September when very little electricity was needed for heating or cooling the BEBs.

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[69] Source: Interview and email with Metro Transit staff, October-November 2021
[70] Note: Availability is defined as the percent of time a bus is ready for service
[71] Source: *America's 20 Coldest Major Cities*, NOAA, 2014
[72] 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.

In addition to range impacts, these extreme low temperatures are also 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. To address this challenge and to restart chargers in these particularly 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 be turned on (Figure 29).

Lesson Learned: Early Adopter Challenges

As an early adopter of these BEB technologies, Metro Transit experienced unique operational challenges due to the technological novelty of the C Line pilot program.

Figure 29. Temporary Charger Heating Structure

Following the delivery and acceptance of the BEBs, Metro Transit identified lingering challenges with the BEBs and their associated charging infrastructure including both software and mechanical issues. Between March 2019 and November 2021, 25 updates—nearly one update every month—were made to the C Line's BEB software.[69] Although each update improved BEB operation, Metro Transit had to relearn the intricacies of the BEB software with each update. 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.[69]

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. In 2021, all garage chargers were replaced under warranty due to insufficient structural support of transformer windings leading to premature transformer degradation. On-route overhead conductive chargers have had dozens of blown fuses, plus a premature transformer failure that led to the chargers being out of service for an extended period of time. Due to extreme cold temperatures, some outdoor chargers required shelters and temporary heating. To minimize charger related issues and reliance on contingency plans, Metro Transit intends to avoid widespread usage of the low serial number equipment in the future, while still striving to be an early adopter of BEB technology.

Best Practice: Metro Transit ZEB Transition Plan Recommendations

In recognition of the successes and challenges associated with implementing BEBs on the C Line (as summarized above) conversations with Xcel Energy, and a ZEB service suitability and readiness assessment, Metro Transit's ZEB Transition Plan includes a variety of additional implementation policies, recommendations, and strategies including:

- Each electrified garage will include two (2) high-capacity overhead conductive chargers and at least one (1) plug-in charger for every two bus parking spaces.
- It is recommended that ideally one but no more than two garages are electrified at the same time to mitigate operational impacts associated with garage renovations and avoid exceeding storage capacities.
- Opportunity (on-route) charging is not recommended as a short-term charging strategy due to outdoor maintenance challenges (particularly in Minnesota winters), higher operational costs due to daytime electricity premiums, and that nearly half of existing bus service could be covered without on-route chargers.

Summary of Metro Transit Lessons Learned & Best Practices

Key lessons learned and best practices to consider when transitioning to ZEBs based on the first three years of the C Line BEB pilot program and the technical analysis contained in the Metro Transit ZEB Transition Plan include:

- In cold climates, plan BEB service around worst-case bus range estimates based on winter temperatures.
- 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.
- Clearly define successful ZEB implementation and deployment.
- Be an early adopter but not the first adopter; avoid low serial number equipment.

5.1.2 Foothill Transit (Greater Los Angeles, California)

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. These fast-charge BEBs have shorter range than other BEBs and typically charge several times per day for 5-20 minutes at high power. Since then, Foothill Transit's BEB fleet has driven about two million miles and grown to include a total of 34 electric buses in revenue service, including both fast-charge and extended-range BEBs as well as the first two double-decker BEBs purchased by a United States public transit agency (Figure 30).[73]

BEB Operation	Purchased Transportation
Facility Ownership	Public Agency

Source: 2021 NTD Data

As Foothill Transit's BEBs have demonstrated range limitations and demanding charging requirements, between August 2022 and January 2023, Foothill Transit will replace older CNG coaches and their oldest BEBs with 33 FCEBs that can be "refueled in 6-20 minutes and…can travel up to 350 miles on a single refueling."[74,75,76] This procurement will establish Foothill Transit as North America's largest fleet of hydrogen FCEBs.[77] Buildout of the fuel cell supporting infrastructure began in late spring of 2022 with completion scheduled for late December 2022. In each of 2023 and 2024, "Foothill Transit will need to retire 30 buses…that have reached the end of their useful life."[76] To support these replacements, Foothill Transit plans to apply for Low or No Emission competitive grants to purchase ZEBs to replace these retiring buses.[76] The ZEB fleet composition at both of Foothill Transit's garages as of April 2022 is nine percent.[78]

Figure 30. Foothill Transit Enviro500EV Double Decker BEB

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.[79] To continue their ongoing commitment to sustainability, Foothill Transit's goal is to meet the California Air Resources Board (CARB)'s Innovative Clean Transportation Rule by transitioning to a 100 percent ZEB fleet by 2040.[78]

Operational Experience, Best Practices, and Lessons Learned

As a pioneer in deploying BEBs in fixed route transit service for over a decade, Foothill Transit has identified challenges associated with deploying BEBs as well as numerous lessons learned and best practices to consider when implementing fixed route (express and local) BEB service.

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[73] Source: *Foothill Transit Sustainability*, Foothill Transit
[74] Source: *Agenda Packet – Governing Board Meeting*, Foothill Transit, June 24, 2022
[75] Source: *Go Greener*, Foothill Transit, January 19, 2022
[76] Source: *Agenda Packet – Executive Board Meeting*, Foothill Transit, May 27, 2022
[77] Source: *California's Foothill Transit Adds 13 Hydrogen Fuel Cell-Electric Buses from NFI subsidiary New Flyer*, GlobeNewswire, November 8, 2021
[78] Source: *Foothill Transit Zero-Emission Bus Rollout Plan*, Foothill Transit, April 2022
[79] Source: *Foothill Transit Announces All Electric Bus Fleet By 2030*, Foothill Transit, May 2016.

Lesson Learned: BEB Availability
Foothill Transit is working with manufacturers to resolve the availability and overall "fit-and-finish" quality of the BEBs (and in particular the fast-charge BEBs) has been steadily degrading over the past six years.

In the first few years of Foothill Transit's fast-charge BEB evaluation, from 2014 to 2017, when Proterra technicians were permanently on-site to handle warranty work, the fast-charge BEBs consistently met Foothill Transit's 85 percent availability target, fluctuating between an average monthly availability of 80 to 100 percent (Figure 31). Since then, however, BEB availability has steadily declined from approximately 85 percent in 2017 to about 60 percent in December 2020.[80] In particular, in 2019 and 2021 the BEBs were 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.[81] As a result, CNG buses have had to be deployed on Line 291 to compensate for the lack of BEBs available for service.[81] Compared to the older fast-charge BEBs, Foothill Transit's newer extended-range BEBs have achieved an 82 percent availability rate based on 2020 data. However, this availability still falls below the 85 percent availability target.

Figure 31. Foothill Transit Overhead Charger and Proterra BEB

Lesson Learned: Replacement Part Availability & Speed of ZEB Innovation
One challenge and risk Foothill Transit has noted associated with being an early adopter of BEBs is the availability of replacement parts. 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 now obsolete and no longer preferred by manufacturers or compliant with adopted industry standards.[81] 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.[81] 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.

To best adapt and grow with the rapid speed of ZEB technology innovation, Foothill Transit recommends that ZEB transition plans should be flexible and dynamic to respond to technological advancements.

Lesson Learned: Significant BEB Lifecycle Cost Impacts and Operational Changes
Based on over six years of data, Foothill Transit's fuel costs by distance across its entire fleet are approximately $0.45/mile for BEBs and $0.28/mile for the CNG buses.[81] 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.[82] This estimation is based on Foothill Transit's experience over the last 11 years as they approach

[80] Source: *Foothill Transit Battery Electric Bus Evaluation: Final Report,* NREL, June 2021
[81] Source: *Executive Board Meeting*, Foothill Transit, July 23, 2021

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.

Additionally, due to the range limitations and other technological and operational challenges associated with BEBs, Foothill Transit has found that BEBs require significant 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 Foothill Transit's CNG buses. Instead, to deliver this same level of service, Foothill Transit would need a significantly larger fleet of BEBs. The agency has calculated that BEBs are a 1.5-to-one replacement of existing CNG buses.[82] 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 instead of BEBs, because 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.

Summary of Foothill Transit Lessons Learned & Best Practices

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.
- ZEB transition plans should be flexible and dynamic to respond to technological advancements.
- Repair times for BEBs can be longer than traditional CNG and diesel buses due to software complexity.

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

5.1.3 King County Metro (King County, Washington)

BEB Operation	Directly Operated
Facility Ownership	Public Agency

Source: 2021 NTD Data

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.[83] In 2017, Metro committed to transitioning to a 100 percent ZEB fleet powered by renewable energy by no later than 2040.[83] 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.[84] Metro plans to meet this goal "through a combination of BEBs and zero-emission trolleybuses."[85]

Since its initial ZEB commitment in 2017, Metro has steadily been transitioning to a ZEB fleet. As of May 2022, approximately 14 percent of Metro's current fixed route bus fleet is comprised of ZEBs including 174 electric trolleybuses and 21 BEBs (11 short-range (<25 mile) Proterra BEBs and 10 extended-range New Flyer BEBs) with the remainder of the fleet being diesel-electric hybrids.[85] To move towards a 100 percent ZEB fleet by 2035, Metro plans to expand their BEB fleet while retaining their electric trolleybuses.[85] Between 2025 and 2035 Metro plans to purchase 1,334 BEBs and 30 electric trolleybuses. Additionally, Metro plans to upgrade their trolleybus battery systems to improve off-wire capabilities as the current batteries reach the end of their useful life.[85] Key upcoming transition milestones include:

- Delivery of forty new extended-range New Flyer BEBs in service by Q3 2022 (10 of which have arrived as of May 2022).
- Opening of a Test Charging Facility in 2022 which can charge 9 buses simultaneously with chargers from three different vendors.
- All bus purchases from 2024 onward will be zero-emission.
- Five layover charging projects between 2026 and 2028.[85]

Operational Experience, Best Practices, and Lessons Learned

Based on over six years of experience operating fast-charge BEBs as well as a head-to-head comparison of extended-range BEBs from three manufacturers in 2019, Metro has developed a wealth of BEB knowledge including best practices and lessons learned.

Best Practice: Phased Transition and ZEB Technology Testing

Metro has used a phased approach for acquiring BEBs; building the necessary supporting infrastructure and IT systems, converting transit operations, and training and recruiting the workforce.[85] Using this phased approach, Metro is able to develop best practices and incrementally build upon lessons learned with smaller test and pilot projects before advancing to larger BEB procurements and infrastructure projects.

For example, BEB technology has significantly evolved since Metro's initial investment over six years ago. To help inform future purchase and further develop their understanding of BEB technology, in 2019, Metro conducted a head-to-head comparison of 10 BEBs and associated charging infrastructure

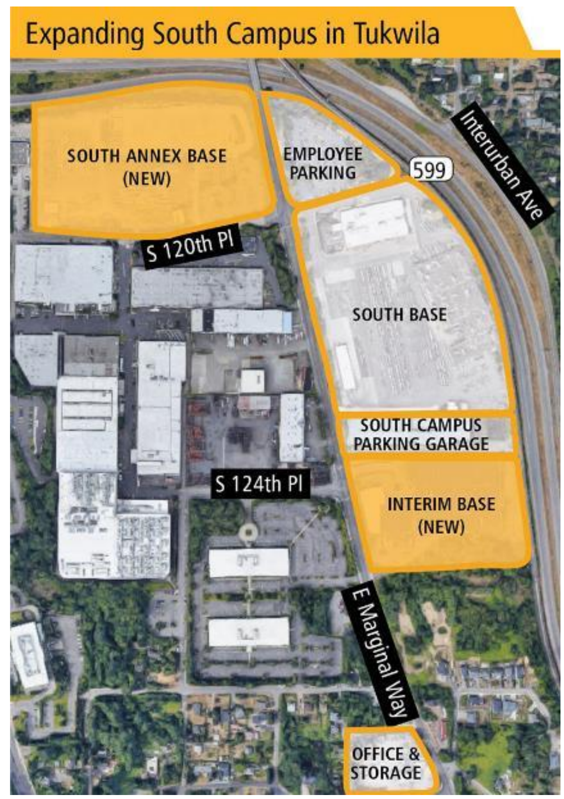
[83] Source: *Metro is transitioning to a zero-emissions bus fleet*, King County Metro, August 2019.
[84] Source: *Council Approves Plan to Accelerate Conversion of Metro Fleet to All-Electric*, February 4, 2020.
[85] Source: *Moving to A Zero-Emission Bus Fleet: Transition Plan*, May 2022, King County Metro

from three manufacturers (Proterra, New Flyer, and BYD) including both 40-foot and 60-foot buses. Following the culmination of the head-to-head analysis period, the buses, batteries, and charging facilities were returned to the manufacturers. To verify BEB range and performance specifications, testing was conducted with various loads in all types of weather and on all route types ranging from freeway service to local service with hills.[86] Overall, testing ZEB technology in this manner helped Metro staff complete updates and revisions to training requirements and documentation, informed purchasing and procurement specifications, and 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.

In addition to conducting a phased implementation and testing of zero-emission bus and charger technology, Metro is also taking an innovative approach to renovating and developing garage and maintenance facilities to support a large-scale transition to BEBs. Metro owns and operates seven existing bus garages across King County. Recognizing that converting these existing facilities to support BEBs will have significant operational impacts, Metro plans to convert its garages sequentially with each garage expected to take between 18 to 24 months depending on size and complexity.[85] Based on an equity and social justice prioritization methodology (described below), Metro selected the South Campus as the first location to be converted to support BEBs (Figure 32).

A key feature of the South Campus (and Metro's larger phased strategy of testing and implementing ZEB technology) is the recently commissioned South Base Test Facility (SBTF), located on the western side of the existing South Base. The SBTF can support 40 BEBs and was "designed to enable testing of equipment from multiple vendors in multiple configurations to inform design of future infrastructure…test interoperability…[and provide] training opportunities."[85] In the next decade as charger software develops, Metro can deploy this updated software in a controlled environment and use the lessons learned from this facility to inform charging infrastructure planning at future facilities.

Figure 32. King County Metro South Campus Overview



Source: Bus Base Expansion, King County Metro

As each of Metro's bases are closed for conversion, the overall system capacity will be impacted temporarily. Metro's base conversion strategy seeks to balance construction efficiency with operational efficiency. When all bases are converted, Metro estimates that there will be a permanent reduction in storage capacity of 10-15 percent due to the installation of charging infrastructure within the yards.[85]

Best Practice: Simple & Easy to Understand Key Performance Indicators (KPIs)

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

[86] Source: *Zero-Emission Battery Bus Preliminary Implementation Plan*, King County Metro, September 30, 2020

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 of 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.[87]

Best Practice: Equity and Social Justice Prioritization

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.[85] 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.[88] Based on this analysis, for the initial transition to ZEB service Metro has prioritized service out of their South Campus, which includes the South Base Test Facility (SBTF) and Interim Base (garage). By prioritizing ZEB service from the South Campus, Metro can provide the greatest benefit to communities that have historically been disproportionately affected by air pollution.

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 dependable 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.

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[87] Source: Interview and email with King County Metro staff, October 2021
[88] Source: *Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet*, King County Metro, March 2017

Best Practice: Charging Strategies

Metro's internal testing has shown that if the agency were to only utilize its garage-based chargers, 60-foot extended-range BEBs travel 140 miles and support 70 percent of the existing service without route structure changes or the use of opportunity charging. For routes longer than 140-miles in length, Metro plans to strategically build opportunity (on-route) charging stations throughout the county. This mixed charging strategy of garage and opportunity charging (1) increases system resiliency by distributing the electrical load over a larger area, (2) increases flexibility by supporting BEB route operation from different garages, and (3) allows the agency to purchase the smallest battery packs needed to support blocks of work, thereby reducing the weight and cost of the BEB.[85]

Figure 33. King County Metro Gantry Charging System

Source: [King County Metro Blog](), Al Sanders, November 18, 2021

Based on the results of ZEB technology tests described above, Metro has selected overhead conductive charging systems with pantographs affixed to an overhead bridge-like structure (gantry) as their preferred charging method. This system provided the most efficient and safest power transfer and (unlike plug-in charging) there are no cords to manage (Figure 33). However, Metro plans to include plug-in charging ports on its BEBs increase maintenance flexibility and in the event an on-road recovery is necessary.[85]

Summary of King County Metro Lessons Learned & Best Practices

Best practices and lessons learned from King County Metro's transition to ZEBs include:

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

5.1.4 Chicago Transit Authority (Chicago, Illinois)

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.[89] Following the pilot program, the vehicles were returned to the manufacturer. CTA's first electric buses (two 40-foot New Flyer BEBs with a range of 80-120 miles) entered service in 2014, making CTA one of the first U.S. transit agencies to use BEBs as part of regular service.[90] Expanding upon these initial BEBs, in 2018 CTA executed a contract for 20 Proterra 40-foot BEBs, later expanded to include a total of 23 BEBs all of which have entered service as of fall 2022 (Figure 34).[91,92] Combined, CTA has a total of 25 BEBs in its fleet representing just over one percent of their fleet of over 1,800 buses.[91]

BEB Operation	Directly Operated
Facility Ownership	Public Agency

Source: 2021 NTD Data

In April 2019, the City of Chicago made a commitment for all CTA buses to be electric by 2040.[93] Following a multi-year analysis, in February 2022, CTA published its first-ever roadmap to achieving this commitment to full-electrification of their bus fleet, facilities, and supporting infrastructure by the year 2040.[94] The plan, entitled *Charging Forward: CTA Bus Electrification Planning Report*, gives important guidance on "which [ZEB] technologies to invest in, where to install charging infrastructure, how to sequence the electrification of garages and routes, and how to ensure the related upgrades are coordinated with other modernization needs to maximize cost effectiveness and overall system reliability."

Figure 34. CTA Proterra BEB with Overhead Charger

[89] Source: Chicago Transit Authority Concludes Fuel Cell Bus Demonstration Program, CTA, March 2000
[90] Source: CTA Announces First Electric-Powered Buses Added to its Fleet, CTA, October 2014
[91] Source: CTA Expands Electric Bus Fleet, CTA, June 2018.
[92] Source: CTA Unveils New Electric Buses as Part of City's Green Initiatives, CTA, April 2021.
[93] Source: Electric Buses, CTA
[94] Source: Charging Forward: CTA Bus Electrification Planning Report, CTA, February 2022

In August 2022, CTA received nearly $29 million in Buses and Bus Facilities grant funds from the FTA to purchase ten additional BEBs and modernize electrical, communications, and safety systems at CTA's Chicago Avenue Garage.[95,96]

Operational Experience, Best Practices, and Lessons Learned

Combined, CTA's newly published roadmap for transitioning to a fully electric fleet and experience operating 25 BEBs provide insight into several best practices and lessons learned that MTS could incorporate when transitioning fixed route bus service towards ZEBs.

Best Practice: Anticipate Long Lead Times for Utility Coordination and Planning

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 now 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 experiences with their first 25 BEBs, 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 programs 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.

Best Practice: Hands-On Training Strategies

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 rotated 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.[97] 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. As part of the Buses and Bus Facilities grant funds awarded by the FTA in August 2022, the CTA will receive approximately $1.1 million to help "further train CTA employees on how to maintain and operate the agency's growing electric fleet."[96]

Best Practice: Equity Analysis & BEB Deployment Prioritization Strategy

As the CTA transitions to a fully electric bus fleet, the agency must decide how to prioritize the deployment of these buses across the region. Although CTA buses contribute a relatively small amount to overall local air pollution, CTA has estimated that electrifying their bus fleet will reduce local health-impacting emissions from buses by 98% or more.[94] As such, CTA plans to prioritize the deployment of BEBs in areas disproportionately affected by air pollution and associated health issues to help address existing inequities. To inform this prioritization CTA analyzed the presence of minority and low-income populations supplemented with information from the Chicago Air Quality and Health Index which combines pollution burden with population vulnerability/sensitivity.

CTA's BEBs are currently deployed on #66 Chicago [Avenue]. This route was selected for electric bus service because it serves low-income and minority communities that experience some of the highest

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[95] Source: *FY22 FTA Bus and Low- and No-Emission Grant Awards*, FTA, August 31, 2022
[96] Source: *CTA Receives Nearly $29 Million to Advance its Bus Fleet Electrification Plans*, CTA, August 16, 2022
[97] Source: Interview and email with CTA staff, October 2021

rates of asthma and other respiratory and chronic illnesses throughout Chicago in addition to being one of the highest ridership bus routes in the CTA system.

Best Practices: Charging Forward Report Conclusions
As the framework for CTA's BEB transition, *Charging Forward,* contains best practices for consideration when electrifying fixed route bus service. These strategies and best practices include:

- Centralized charging at garages with a limited network of on-route chargers yields simpler operations.
- Monitor technology performance and refine plans accordingly.
- Consider alternative strategies to increase BEB compatibility such as modifying fixed route schedules to better align with current BEB technology constraints.
- State of good repair projects should be coordinated with the installation of new infrastructure at bus facilities, whenever feasible, to avoid duplication of effort, construction disruption, and associated cost increases.
- Pursuing a balanced charging strategy using both fast and slow chargers balances technology-related risks and cost savings.
- Plan for risk and resiliency by ensuring back-up power sources are available for charging infrastructure.

Summary of CTA Lessons Learned & Best Practices
Based on the *Charging Forward* report and CTA's operational experience with BEBs, key best practices and lessons learned include:

- Start transition 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 shared importance of equity analyses as well as modeling operational parameters including route characteristics, charging times, and vehicle/battery limitations in advance of deployment.
- Consider alternative strategies to increase BEB compatibility such as modifying fixed route schedules to better align with current BEB technology constraints.

5.1.5 Toronto Transit Commission (Toronto, Ontario)

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.[98] 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.[99] In working toward this goal, TTC has committed to being 50 percent zero-emissions by 2028-2032.[100]

BEB Operation	Directly Operated
Facility Ownership	Public Agency

Source: TTC Bus Maintenance and Warranty Administration

The *Green Bus Technology Plan* was approved by the TTC Board in November 2017 and included a head-to-head evaluation pilot program with 30 40-foot BEBs from each of New Flyer, Proterra, and BYD. In June 2018, this pilot program was expanded to include an additional 30 BEBs evenly distributed between New Flyer and Proterra. The first of TTC's 60 BEBs entered service in June 2019 and approximately one year later (October 2020), TTC initiated its head-to-head evaluation of these BEBs. The objectives of the head-to-head evaluation were to:

- Evaluate all three BEB types in TTC's operating environment and leverage lessons learned to inform BEB technical and commercial specifications for future procurements; and
- Share the findings with the broader transit community through an open exchange of best practices to assist with BEB planning and adoption.

As route characteristics and topography vary from route to route, TTC operated the BEBs in both revenue service and simulated service to directly compare the buses against each other while minimizing other variables unrelated to the BEBs themselves. For this simulated service, the three BEBs (one from each manufacturer) operated back-to-back along TTC routes through winter and summer, loaded with ballast to represent the passenger weight of a fully loaded bus.[101] Doors were cycled at each stop to simulate the typical TTC in-service conditions and performance data was captured using an onboard telematics system.[101]

In TTC Board meetings held on April 14 2022[102] and July 14, 2022,[103] staff shared several updates associated with the Green Bus Program including:

- Accelerating the procurement of only ZEBs from 2025 to 2023.
- Accelerating the transition to a ZEB fleet from 2040 to 2037.

98 Source: *Transform TO: Climate Action for a Healthy, Equitable & Prosperous Toronto*, City of Toronto, July 2017.
99 Source: *Green Bus Technology Plan*, TTC, November 2017.
100 Source: *TTC Green Initiatives*, TTC
101 Source: *TTC's Green Bus Program: Final Results of TTC's Head-to-Head eBus Evaluation*, TTC, April 14, 2022
102 Source: *Green Bus Program Update Presentation*, Bem Case (TTC Executive Director, Innovation and Sustainability), April 14, 2022
103 Source: *Green Bus Program Update Presentation*, TTC, July 14, 2022

- Initiating procurement in April 2022 for 240 BEBs with the intent of increasing to four hundred with increased funding reflecting the lessons learned from the head-to-head evaluation and representing the largest ZEB procurement in Canada to date.[101]

Operational Experience, Best Practices, and Lessons Learned

Despite operating BEBs for just over three years, TTC's first of its kind multi-year head-to-head BEB evaluation program provides an invaluable comparison of full-size BEBs from three different manufactures providing a range of lessons learned and "must have" requirements for large-scale BEB procurements.[101] TTC's BEB evaluation monitored and analyzed dozens of metrics across nine evaluation domains including:

- System Compatibility
- Accessibility
- Customer Experience
- Operator and Maintainer Experience
- Maintainability
- Vendor Performance
- Charging System Performance
- Vehicle Performance
- Total Lifecycle Cost

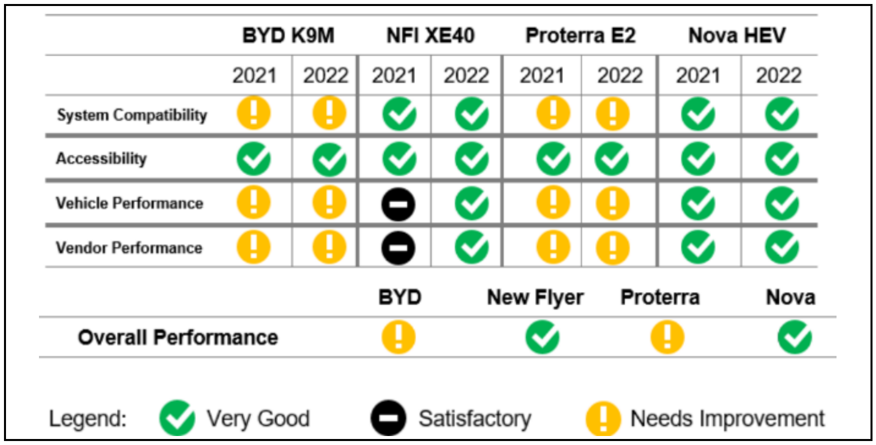
As a baseline for comparison, TTC's results from the three BEB types were compared to TTC's NOVA Hybrid-Electric Vehicle/Bus (HEV) which is of similar age and propulsion technology to the BEBs and was "introduced as a transition technology through the TTC's Green Bus Program in 2018" (Figure 35).[101]

Figure 35. TTC BEB Head-to-Head Evaluation Bus Types[102]

Lessons Learned: Head-to-Head Evaluation Results

Results and lessons learned from the head-to-head evaluation are summarized below. Across these four primary evaluation domains, the only BEB to deliver service at or above the performance required by TTC, and the only BEB to receive a higher performance rating in 2022 than in 2021, was New Flyer's XE40 (Figure 36).

Figure 36: TTC BEB Head-to-Head Evaluation Results by BEB Type[99]



Key findings and lessons learned from this head-to-head evaluation include:

- To preserve bus storage density at existing maintenance facilities and avoid capacity losses, going forward, TTC will require a maximum bus length specification of 42 feet (including bike rack).
- To allow for maximum charge rates, competitive procurement, and interoperability between buses and chargers across different manufacturers, future bus specifications will require DC charging capability using SAE interface and communication standards.
- Stainless steel frame structure negates the need for, and associated risks of, annual rust-proofing maintenance programs.
- To incentivize greater BEB reliability, TTC will include availability metrics to be achieved by the BEB OEM in future procurement contracts. Failure to meet the availability targets will result in liquidated damages.
- To motivate vendors to improve quality and responsiveness during the acceptance process, TTC will restructure milestone payments to move away from a high milestone payment percentage due upon delivery (75%). Two key facets of TTC's restructured milestone payments for future procurements include (1) increasing the percentage due upon achievement of the consecutive 30-day reliability requirement from 5 percent to 20 percent and (2) a higher payment percentage (20-50%) due at final acceptance certificate (FAC) when the bus is deemed ready for service.
- To ensure new BEB procurement deliveries can be charged and dispatched into service without delay, implementation of charging infrastructure at each garage is typically completed three to six months ahead of BEB deliveries.
- Predictable and reliable range throughout all seasons is more important than achieving the lowest energy consumption.
- To minimize battery consumption and preserve BEB range TTC will continue to specify a diesel-fired auxiliary heater and avoid pure-electric defroster units.
- To avoid negatively impacting bus service, avoid dispatching BEBs to their upper range limits due to high variation in efficiency.
- To more accurately characterize BEB range, future procurement specifications will specify minimum usable battery capacity target and not advertised battery capacity.

Best Practice: Procurement Must Haves

Informed by the head-to-head evaluation and reflecting the key lessons learned summarized above, TTC has developed a list of “must have” requirements for future procurements. These requirements focus on ensuring the longevity of the BEB structure and high system reliability through a proven bus platform.

- Altoona and shaker table testing have been successfully completed.
- A full stainless-steel structure with a minimum of six years in service experience.
- A minimum usable battery capacity of 400 kWh.
- A maximum overall bus length of 12.8 m (42 ft.) including a stowed bike rack.
- A maximum overall height of 340 cm (134 in.) including any roof-mounted equipment;
- Ability to charge via roof mounted pantograph charging interface, capable of accepting a minimum charge rate of 300kW (400 ADC) at 750 VDC or greater via SAE J3105/1; and
- Two rear-mounted charging ports capable of accepting a minimum charging rate of 150 kW (200 ADC) at 750 VDC or greater via the SAE J1772 standard published by the Society of Automotive Engineers that allows for interoperability of plug-in chargers with different types of buses from multiple manufacturers=.[101]

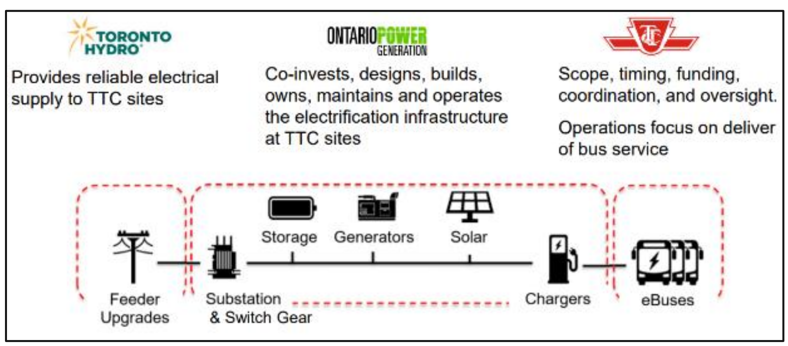
Best Practice: Hybrid-Electric Buses as a Steppingstone to BEBs

Due to the complexity of ZEBs and the extent to which they differ from conventional diesel buses, transitioning towards a ZEB fleet involves substantial changes to bus operation and maintenance. To flatten this learning curve, TTC is using hybrid-electric buses as a transition technology between conventional diesel buses and BEBs. For example, TTC recently awarded their last hybrid-electric contract for 336 hybrid-electric buses in February 2022[103] to “provide an opportunity for maintainers and operators to familiarize themselves with electric technology without impacting service” as these hybrids also have a more familiar diesel engine to assist with battery recharging.[104]

Best Practice: Charging Infrastructure Deployment Plan

On February 10, 2022, the TTC Board of Commissioners approved a 20-year agreement with PowerON, a subsidiary of Ontario Power Generation, for the co-investment, ownership, design, build, operation, and maintenance of TTC charging and related electrical infrastructure.[105,106,107] This agreement represents a “first-of-its-kind partnership between public agencies and corporations working together to deliver full-fleet electrification” and allows TTC to focus more exclusively on the delivery

Figure 37: Electrification Infrastructure Roles and Responsibilities[107]



[104] Source: *Public Transit Authorities are Taking Action to Electrify City Bus Fleets Across Canada*, Electric Autonomy Canada, May 10, 202

[105] Source: *TTC Signs Agreement with PowerON for Zero-Emission Charging Infrastructure*, Mass Transit, February 14, 2022

[106] Source: *Principal Agreement with PowerON Energy Solutions LP (OPG) to Decarbonize TTC Operations, Fleet, and Facilities*, TTC, February 10, 2022

[107] Source: *TTC-OPG-THESL Framework for Agreement Presentation*, Bem Case (TTC Executive Director, Innovation and Sustainability), April 14, 2021

of BEB service rather than the operation and maintenance of the electrification infrastructure (Figure 37).[105,107]

Summary of TTC Lessons Learned & Best Practices

Lessons learned and best practices from TTC's implementation and transition to ZEBs include:

- To incentivize greater BEB reliability, TTC will include availability metrics to be achieved by the BEB OEM in future procurement contracts. Failure to meet the availability targets will result in liquidated damages.
- To allow for maximum charge rates, competitive procurement, and interoperability between buses and chargers across all manufacturers, future bus specifications should require DC charging capability using SAE interface and communication standards.
- Predictable range allowing BEBs to reliably operate through all seasons is more important than achieving the lowest energy consumption.
- To avoid negatively impacting bus service, avoid dispatching BEBs to their upper range limits due to high variation in efficiency.
- Hybrid-electric buses can be used as a transition technology to flatten the operating and maintenance learning curve between diesel buses and BEBs.

5.1.6 Fixed Route BEB Best Practices and Lessons Learned Summary

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

- Expect the unexpected.
- Start the ZEB process early as implementation takes much longer than for a diesel bus.
- Plan for longer ZEB and supporting infrastructure repair times.
- Meet early and often with your electric utility.
- Use a phased approach for acquiring and testing ZEB technology, building the necessary supporting infrastructure and IT systems, converting transit operations, and training and recruiting the workforce.
- Consistent range allows for reliable operation through all seasons. Plan for severe weather days.
- Utilize charging strategies with SAE interface and communication standards to allow for interoperability between buses and chargers from different manufacturers.
- Avoid dispatching BEBs to their upper range limits.
- Develop strong contractual language including performance metrics.
- When conducting an equity analysis, consider the impacts to service reliability with emerging technologies.
- Transparently set and manage expectations using a broad communication strategy with frequent stakeholder communication.

5.2 Demand Response Service

As defined in law, Demand Response service is "any non-fixed route system of transporting individuals that requires advanced scheduling by the customer."[52] Demand Response service is typically provided by "passenger cars, vans, or small buses."[51] These types of vehicles provide daily, point-to-point, shared-ride travel for individuals who may not be able to use fixed routes, or for trips that may not be served by fixed routes. Demand response vehicles "may be dispatched to pick up several passengers at different pick-up points before taking them to their respective destinations and may even be interrupted in route to these destinations to pick up other passengers."[108]

About two thirds of the current MTS-owned revenue fleet is comprised of small cutaway buses, sport utility vehicles and vans providing demand response service throughout the region.

5.2.1 Americans with Disabilities Act (ADA) Complementary Paratransit Services

ADA Complementary Paratransit Service[109] is a transportation service required by the ADA for individuals with disabilities who are unable to use fixed route transportation systems.[110] ADA Complementary service poses unique difficulties compared to other zero-emission transit applications.

The daily service profiles for these vehicles include substantial amounts of idling time while waiting for passengers during pickups, along with the more frequent use of lift equipment and other on-board electronics which can increase the energy required of an electric vehicle. As with other small vehicle applications for ZEB transit technologies, the challenges of storing an adequate amount of energy on board for the duty cycle demanded can present issues when converting a fleet. Although there are limited ZEB paratransit technology applications in service due to these challenges, three case studies are presented below.

Orange County Transportation Authority Case Study Example (Orange County, California)

As part of the FY22 Low- or No-Emission Grant Program, the Orange County Transportation Authority has been awarded $2.5 million to support the purchase of 10 BEBs to replace 10 gasoline vehicles in use in its OC ACCESS paratransit program.[111] This is a pilot project to help expand OCTA's zero emission fleet transition into its smaller bus fleet. The California Air Resources Board's Innovative Clean Transit (ICT) rule sets the goal for all public transit agencies in the state to have a plan in place to transition their fleets to 100% zero-emission by 2040. As this funding was announced in August 2022, no best practices or lessons learned are currently available from this case study.

Houston METROLift (Houston, TX)

To support the agency's aim to "establish a more sustainable fleet and shift to [the] procurement of only zero emissions [vehicles] by FY2030," in January 2022, Houston METRO authorized "the purchase of 10 electric paratransit vehicles and chargers."[112] These electric wheelchair accessible vehicles are planned for use in METRO's curb2curb microtransit service and METROLift paratransit service.[113] As this electric paratransit purchase was approved less than one year ago, no best practices or lessons learned are currently available from this case study.

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[108] Source: FTA Circular 2710.2A, FTA, 1988
[109] Note: Several peer agencies refer to ADA Complementary Paratransit Service as 'Paratransit'
[110] Source: Transportation Services for Individuals with Disabilities (ADA) Definitions, 49 CFR Section 37.3
[111] Source: *News - FTA Awards OCTA $2.5 Million Toward Zero-Emission Paratransit Buses*, OCTA, August 16, 2022
[112] Source: *METRO Approves Purchase of 10 Electric Paratransit Vans as Part of Sustainability Initiative,* Community Impact, January 27, 2022
[113] Source: *Houston METRO Climate Action Plan,* METRO, January 2022

King County Metro Access ADA Paratransit (King County, WA)
In May 2021, King County adopted their 2020 Strategic Climate Action Plan which establishes the goal that at least two-thirds of Metro's Access Transportation paratransit fleet (over 250 vehicles) be electrified by 2030.[114,115] In fall 2022 Metro will begin a four-vehicle pilot of the first battery-electric Access paratransit vehicles. The selection of these electric vehicles will be informed by Access rider survey results from spring 2022.[115] Towards the conclusion of the pilot program in 2023, Metro plans to again survey Access riders to receive feedback on their experiences with the pilot electric vehicles.[115] These results as well as other community engagement feedback will be used in tandem to help determine Access's final electric fleet.

5.2.2 On-Demand/Microtransit Service
On-demand/microtransit is a technology-enabled service that typically uses shuttles or vans to provide pooled on-demand transportation with dynamic routing. Unlike traditional demand response service, which typically requires riders to reserve trips further in advance and to place these reservations by calling the transit agency, on-demand/microtransit riders use a mobile application or website to book trips 15+ minutes in advance, more akin to how rideshare services such as Uber and Lyft operate. Examples of on-demand/microtransit service in the Twin Cities include Maple Grove Transit My Ride, MVTA Connect, Plymouth Metrolink Click-and-Ride, SW Prime, as well as Metro Transit Micro[116] a pilot service contracted by MTS which began operating in September 2022.

On-demand/microtransit vehicles are a growing area of interest for fleet conversion studies, especially as the surge in popularity for ride sharing apps continues to show no signs of stopping. Like cutaways, these fleets introduce their own set of uncertainties resulting from finding a way to balance the amount of energy available on board with the amount of energy required in service. However, these vehicles do present the benefit of requiring less energy on board due to the more compact size of the vehicles. This still does not address the issue of energy on board, though it does reduce the amount of energy used in operation.

Sacramento SmaRT Ride Case Study Example (Sacramento, CA)
Sacramento's SmART on-demand microtransit shuttle service is "the largest microtransit provider in the country, operating with 45 shuttles, nine of which are zero emission electric vehicles."[117] The first three of these GreenPower EV Start shuttles entered service in June 2020 and all of the electric shuttles have a "unique side door configuration" to facilitate wheelchair lifts and other ADA features.[118]

5.3 Contracted Service/Facilities
For MTS and the STPs, contracting transit service and facilities offers many benefits including the ability to reduce overhead costs by leveraging contractors' staffing, experience, and facilities to serve multiple contracts and reducing risk by assigning the second party claims liability or budget control responsibilities.

The two primary contracting types are "fixed costs" or "cost-plus-fixed-fee." With a fixed costs contract, the contractor assumes all risks and agrees to provide the service for a set price. For the costs-plus-fixed fee model, the transit agency pays all expenses to provide the service and compensates the contractor with an agreed-upon fee for delivering the service. MTS and the STPs primarily utilize the fixed-cost model although in addition to providing fleet, MTS also supplies software and technology

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[114] Source: *King County 2020 Strategic Climate Action Plan*, King County, May 2021
[115] Source: *Access Electric Vehicles*, King County Metro, April 8, 2022
[116] Source: Metro Transit Micro Metro Transit, 2022
[117] Source: *Sacramento's SmaRT Ride Microtransit Service Among Most Successful in the US*, September 9, 2020
[118] Source: *Electric Shuttles to Start Service in South Sacramento*, Green Car Congress, June 12, 2020

equipment, provides incentives for meeting performance standards, and provides cost adjustments to mitigate the risk to contractors of fluctuating fuel expenses.

The introduction of ZEB technology inserts some complications into the contracting model. ZEBs may require unique infrastructure for fueling/charging, which can be problematic for contracts leasing a facility or who are unable to afford such upgrades. A contractor may also object to being held to punitive performance standards with such new technologies. While larger contractors may have the resources and experience to absorb such requirements, smaller contractors may be precluded from these opportunities due to the increased risk it introduces. For MTS and the STPs, this is of particular importance since more than half of MTS and the STPs' current service contracts are with smaller entities based in Minnesota and that have a history of service to the agencies.

Ultimately, MTS and the STPs want to encourage as many contractors as possible to bid on a contract, as competition typically leads to lower prices. To help ensure a robust contracting process, several elements are outlined below for consideration when preparing to operate ZEBs with contracted services and facilities.

5.3.1 Contracted Service

A transition to zero emission vehicles will require modifications to the standard contracts with vehicle operators; these changes will have significant financial impacts. Proactive communication with contractors and perspective vendors will be necessary to get in front of these future issues. Some of the elements discussed below will empower MTS and the STPs to hold operators to performance standards and help control costs as vehicle fleets transition to cleaner technologies.

Performance Credits

Most transit operating contracts have performance standards (such as on-time performance or timely vehicle inspections) that a contractor must achieve to receive the full fee for the service provided. Failure to meet these expectations results in a reduction in the contractor's fee, while surpassing some of these standards can result in bonuses that incentivize superior performance. A contractor's success in business depends on their ability to meet or exceed these standards. The relatively new operating characteristics of ZEBs create a risk of non-compliance that can damage a contractor's financial health as they learn how to optimize the vehicle's performance. Almost all transit operating contracts allow the contractor to seek relief from these penalties due to situations that are beyond their control. For example, contractors would be held harmless for poor on-time performance or missed trips on bad weather days or for technology disruptions.

In preparation for a transition towards ZEBs, MTS and the STPs will explore similar relief for issues with ZEB technology. This has the dual benefit of relieving some of the risks a contractor may experience while also helping MTS and the STPs further understand these challenges. MTS and the STPs can then collaborate with contractors on ways to overcome these issues, which will help to ensure that performance standards are met or even exceeded.

Workforce Development

Except for national/multinational transit operating contractors, many small, regional transit operators have likely never maintained or operated a ZEB. Almost all ZEB manufacturers provide maintenance and operator training resources with the purchase of their vehicles. It is essential that contractors not only have access to this training but are required to incorporate it into the training programs for any employee who interacts with the vehicle.

As many transit agencies are transitioning their fleets to ZEBs at the same time, it is advantageous for agencies to learn from each other during this evolution. Regions with multiple agencies, like

Minneapolis-Saint Paul, are well positioned to conduct joint training sessions to reduce the costs of additional training programs and learn best practices from each other's experiences. By paying for additional training programs, and coordinating shared knowledge resources, all contractors are empowered to develop the skills necessary to operate this new fleet regardless of company size.

It will also be important to include first responders in the training of any ZEB operating within their jurisdiction. Knowing how to identify ZEBs and take the necessary safety protocols will be essential in responding to incidents involving ZEBs.

Energy Costs

BEBs require a substantial amount of power to energize the vehicle for service delivery. Depending on which electrical utility a contractor's facility is served by the price of power and its related fees may vary significantly. This disparity could prohibit a contractor from bidding on work with BEBs unless the Public Utilities Commission creates regulations to keep costs for charging battery electric buses low.

While electric rates are typically predictable and tend to have less dramatic price swings than diesel or gasoline, utility companies levy additional fees on large power consumers to help control the amount and time electricity is utilized by the consumer. When there is a typically a high demand for power during the day, utilities may charge "on-peak" rates at a higher price than during "off peak" hours, when the demand is lower, to entice consumer to reduce their power draw during the times the electrical grid is most challenged. Another fee, known as "demand charges", places a high penalty on consumers that draw too much power off the grid at one time (typically measured in 15-minute increments). The intent of the fee is to entice their customers to keep the facilities' power draw low so as to not strain the utility grid. These demand charges and on-peak rates can cause dramatic increases to utility bills, even if the power use doesn't change, based solely on when and how much power is used during a certain time period.

A large portion of an operating contractor's budget is energy costs. The introduction of BEBs introduces a lot of variability into how much electricity the contractor might need. Buses may need a lot of power depending on how many miles they are expected to travel and what the energy efficiency of the vehicle is. If the bus has larger batteries, it may need to charge for longer periods of time. This may require the bus to be charged during on-peak hours. If most of the bus fleet needs to be charged around the same times, the contractor may need to pay for extreme demand chargers to ensure the vehicles have enough power for service the next day.

While contractors may have some control over when a BEB is charged, there are a lot of unknowns about the capabilities of BEBs in the Minnesota operating environment and how that impacts vehicle charging schemes. To combat this risk, contractors may bid their anticipated energy costs at high rates to protect themselves from cost overages.

Due to the variability of fossil fuel costs, many existing operating contracts have fuel cost credits/surpluses to help contractors and agencies mitigate the risks of changing fuel prices in the middle of the contract. For this arrangement, an average cost for fuel is pre-determined in the contract and the contractor is compensated by the agency, such as MTS or the STPs, for the amount their fuel costs are higher than the average and the contractor will pay the agency the difference if their costs are lower than the average. As a result, agencies, such as MTS and the STP have limited ability to predict energy cost and the total cost of the operating contract.

To help reduce the risks surrounding charging BEBs, agencies can insert electrical credits and surpluses, similar to what is currently done with fossil fuels, into operating contracts to help control these costs. As agencies' and contractors' knowledge of BEB energy needs increases, the need for contract clauses sharing this risk should decrease. For BEBs, these types of clauses will become less important as the contractor controls when and how much the BEBs are charged. Since utility rates are more stable, these energy costs would be something the contractor can control and predict.

Equipment

ZEBs are specialized pieces of equipment representing a small percentage of the total number of vehicles on the road today. While some contractors have expertise in this technology, most contractors will have a learning curve to overcome.

Transit agencies have found that when transitioning to a new technology purchasing extended and comprehensive warranties with every ZEB acquisition will relieve the contractor from trying to predict the frequency or cost of ZEB part failures when preparing their budgets, in early years allowing both the contractor and MTS and the STPs to gather first-hand experience regarding the maintenance needs of ZEBs. This is particularly important as many ZEB components are expensive and can be difficult to source. Additionally, many ZEB manufacturers offer on-site support to maintain the vehicles with these warranties. This maintenance service should not only increase the vehicle's availability for service but also provides the contractor's maintenance team the opportunity to have hands-on experience fixing the vehicle alongside an ZEB manufacturers vehicle maintenance staff.

Many ZEBs and their ancillary equipment require special tools for maintenance that may not be needed for internal combustion engine vehicles. By providing this equipment to the maintenance contractor, MTS and the STPs could relieve them of the need, and likely the passthrough cost, of purchasing it independently. The tool would then become an asset owned by MTS or the STPs that could be transferred to another contractor at the end of the operating contract.

Traditional transit operating contractors are proficient in maintaining vehicles, and the transition to successfully maintaining ZEBs is generally a matter of training and time with the vehicles. However, maintenance staff tend to have less experience maintaining the battery charging equipment required to charge BEBs. This equipment is vital to the success of BEBs. To keep this equipment in a state of good repair, some agencies contract their maintenance to an electrical contractor instead of the transit operating contractor. The rising popularity of electric vehicles, not just BEBs, is increasing electrical contractors' aptitude with the technology. These electrical contractors generally have the skill and access to parts required to keep the equipment functioning effectively.

5.3.2 Contracted Facilities

As discussed in Section 3.3.4 *Charging Infrastructure Systems*, BEBs require a significant amount of infrastructure to power the vehicle. For garage charging, this equipment would need to be installed in the contractor's facility. When selecting a charging technology, consideration should be given to how it will be integrated into the garage. Recognizing that many operating contractors lease their facilities, ideally the charging equipment could be removed and reinstalled at another location should the operator need to relocate or if the operating contract is awarded to another contractor in the future. However, this is not financially feasible at the current maturity level of ZEB technology.

In addition to charging equipment, operating a fleet of BEBs can require substantial increases in the amount of electricity being provided to a bus garage. Providing the additional infrastructure requires transit providers, such as MTS and the STPs, to work with their local utility to program, plan, design, permit, and construct additional electrical service/infrastructure for the garage. Working with Xcel Energy, this process can take 3 to 5 years before the charging equipment is installed depending on a variety of factors including: where the additional electrical power is coming from, and whether the power can be provided overhead or underground. This long lead time to have the appropriate power provided to a leased facility creates challenges for both the contractor and utility provider.

For the contractor, transit operating contracts are typically awarded through a competitive bid process. Transit operating contracts are generally 3-7 year contracts, depending on numerous factors. As a result, this would require the contractor to coordinate with the utility, without confidence that they will be awarded the future competitively bid project. This discourages contractors from investing resources into a facility they are leasing, without assurances they will benefit from the infrastructure improvements. It could also limit competition or provide an unfair advantage for future competitive procurements if some potential proposers don't have a facility with the appropriate electrical infrastructure

Most electrical utilities, including those in Minnesota, are regulated utilities. As a result, the utilities have an obligation to the rate payers to recoup the capital cost of electrical infrastructure through future charges for electrical service. The utility company may have a difficult time justifying investing resources into providing additional electrical service to a facility knowing that the future need for the additional electric infrastructure would be dependent upon both terms of the lease and the awarding of a future contract through a future competitive bid process.

MTS and the STPs also have limitations regarding how different public funding sources can be utilized. These restrictions are explained through the following guidelines:

- State Bonds can only be used for public purposes.
- The capital investment and the lease length need to be aligned. For example, a 5-year lease with a 15–20-year capital investment life would not be aligned. The bond life and the lease term should be the same or the lease term greater than the bond (most bonds are set at 10 years)
- Although the IRS allows minimal private use (10%) of the Council's GO bonds, the Council has chosen to limit use to public purposes. The Council issues bonds for cash flow needs, not for specific projects. The model to track multiple projects with multiple bond issues would not be cost effective nor administratively feasible for the Council.

The only viable way to use public money to equip garages with the necessary charging infrastructure for contracted services is for the Council to provide contractors with a facility that the Council either owns or has leased for 20 years or more.

Between 2015 and 2021 the share of agencies owning their own facility for purchased transportation (contracted) service increased by six percentage points while the share of facilities owned or leased by contractors decreased by four percentage points (Table 7).This trend toward agency-owned facilities allows agencies to prepare for future ZEB fleets by significantly investing in the facility equipment and infrastructure with a high degree of confidence it will be utilized for the life cycle of the equipment and infrastructure.

Table 7. Facility Ownership Trends for Purchase Transportation (Contracted) Service

Facility Ownership Type	2015	2021	Change (2015-2021) *(Percentage Point)*
Owned or Leased by Purchase Transportation (PT) Provider	69%	65%	-4%
Owned by Public Agency	26%	32%	6%
Leased by Public Agency	5%	3%	-2%

Source: NTD 2020 and 2015 Maintenance Facilities Data for Commuter Bus (CB), Demand Response (DR), Rapid Bus (RB), Motor Bus (MB), Trolley Bus (TB), and Vanpool (VP) Modes

CapMetro Case Study Example (Austin, TX)

The Capital Metropolitan Transportation Authority (CapMetro) provides public transportation services, including bus, rail, and paratransit service for residents throughout the Austin metropolitan area. For its demand response services, including the storage of its paratransit and on-demand (microtransit) vehicles, CapMetro leases a repurposed privately-owned facility. Due to the terms of the lease and general size of the existing site, CapMetro faces challenges for potential future expansion or modernization including the integration of renewable energy systems or modern energy efficiency technology. CapMetro cannot transition its bus fleet to electric nor repair and maintain the existing vehicles at the leased facility. The facility was not originally constructed for transit operations and significant renovations would be required to accommodate vehicle repair equipment and electric fleets. As such, vehicle repairs are outsourced, adding maintenance costs and other inefficiencies.

In alignment with the agency's Strategic Plan, Long Range Facility Plan and Facility Master Plan, and regional sustainability plans, CapMetro decided it would terminate its facility lease and construct a new facility. By applying to the Federal Transit Administration's Grants for Buses and Bus Facilities Program, CapMetro was able to secure $20 million in Federal funding to use for the construction of the facility. The new state-of-the-art operations and maintenance facility will support operational and maintenance efficiencies, include electrical vehicle (EV) infrastructure to support the agency's transition to clean energy and lowered emissions, and prioritize community connectivity in Austin.

6.0 ZEB Implementation Policies and Guidance

6.1 Short-Term ZEB Technology

As outlined in Section 3.0, there are three primary types of ZEBs currently operating in the United States: electric trolleybuses, BEBs, and FCEBs. Each has meaningfully different characteristics. One of the key decisions that transit agencies face when transitioning to ZEBs is determining what type of technology to use.

In the short-term, MTS and the STPs do 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 throughout the region.
- Extensive costs associated with building and maintaining a network of overhead wires.
- 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, MTS and the STPs do not intend to pursue using FCEBs in the short-term due to the significant upstream carbon emissions to extract and transport hydrogen, the high cost and difficulty to access hydrogen fuel, and the high cost of FCEBs.

Instead, MTS and the STPs have selected BEBs as the short-term ZEB propulsion technology for implementation and deployment. As ZEB technologies evolve, MTS and the STPs will continually reassess this decision. Based on this selection of BEBs for implementation and deployment in at least the short-term, the following sub-sections and analysis focus only on the unique operational characteristics associated with BEBs.

MTS and the STPs have selected BEBs as the short-term ZEB propulsion technology for implementation and deployment

6.2 Service Guidance

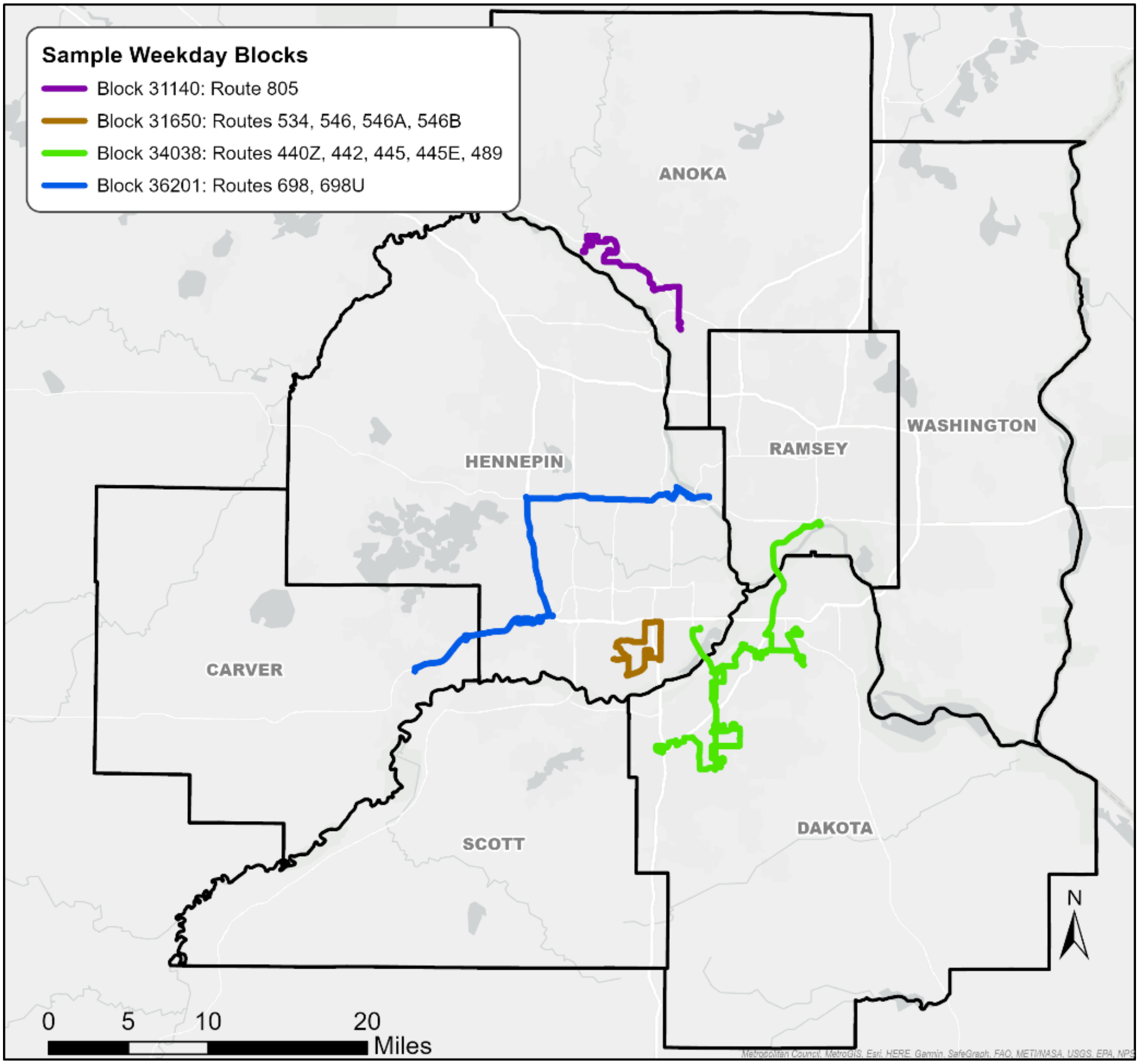
This sub-section develops and presents methodologies to analyze existing MTS and STP transit service for BEB and electric vehicle suitability. Given the unique characteristics of Fixed Route and Demand Response service, these two types of service were analyzed separately using distinct methodologies.

6.2.1 Fixed Route Service

Fixed Route Scheduling Practices

MTS and the STPs use advanced transit vehicle and operator scheduling practices to maximize efficiency and tailor service to ridership and available workforce levels. MTS and STP fixed route service is divided 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 38 depicts four example blocks, ranging in composition from one to five routes. Vehicle blocks and operator assignments are reconfigured quarterly to maximize efficiency and tailor service to ridership and the available workforce even when service levels are stable. Each update or reconfiguration is referred to in this document as a service schedule change.

Figure 38. Overview Map of Four Example Service Blocks



Fixed Route Service Prioritization Methodology and Implementation Guidance

In recognition of the quarterly service adjustments and potential impacts on block characteristics, 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 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 MTS and STP August 2022 service schedules to 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 guiding principles of technical viability, equity and environmental justice, and fiscal impact as introduced in Section 0. To ensure that this methodology aligns with the guiding principle of scalability and reflects the unique characteristics of each agency, results are specific to each agency and vehicle/service type. Drawing upon the words of caution and lessons learned from the peer transit agencies identified in Section 5.0, 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, MTS and the STPs can confidently deploy BEBs on top priority blocks while maintaining reliable service for transit customers.

Figure 39: Block-level BEB prioritization methodology

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 this Transition Plan's guiding principles. BEBs must be able to provide a 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.

TECHNICAL VIABILITY MODELING ASSUMPTIONS AND CONSIDERATIONS

Key technical viability modeling assumptions and considerations are shown below in Table 8. Given the pace with which battery technology and capacity is advancing, "current" battery sizes for the purposes of modeling were selected as the largest non-Proterra battery capacity currently on the market and eligible for FTA funds as of November 2022. Proterra capacities were excluded as Proterra BEBs have a unique lighter weight composite body which allows these vehicles to carry larger/heavier than average batteries. For enhanced accuracy, modeling is performed for each service block based on the vehicle type and length currently assigned to the block as of August 2022. All calculations assume cabin heating via auxiliary diesel heater and the use of garage charging without range-extending opportunity charging as MTS and the STPs do not plan to pursue opportunity charging in the short-term as detailed in Section 6.1.

All modeling calculations assume cabin heating via auxiliary diesel heater and the use of garage charging without range-extending opportunity charging

Unfortunately, not all nominal battery capacity can be reliably used for BEB operation due to the combination of battery degradation as well as the need to reserve a portion of the capacity to preserve battery life and allow for operational flexibility. As introduced in Section 3.3.1, usable battery capacity is assumed to be 70% of nominal battery capacity based on a 2.4% annual degradation rate calculated at bus mid-life (6-years), 10% reserved for battery life, and 10% reserved for operational flexibility.

In addition to battery capacity, 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 5.1.1, the Twin Cities has the coldest winters, on average, of any major U.S. metropolitan area with an average temperature of 18.7 degrees Fahrenheit between December and

February.[119] 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.[119] Therefore, while many transit agencies across the county can largely plan BEB service assuming relatively warm average ambient temperatures, MTS and the STPs must plan BEB service around worst-case range estimates based on winter temperatures to ensure reliable service can be maintained throughout all seasons. Drawing upon Metro Transit's experience operating BEBs in Minnesota winters, this Transition Plan utilizes the same worst-case energy efficiencies for 40-foot and 60-foot buses outlined in Metro Transit's ZEB Transition Plan.

The speed at which a BEB operates influences energy usage and therefore BEB range. Typically, slower speeds are a result of either busy or congested environments. As discussed in Section 3.3.1, in busy environments, buses often see greater energy use due to more need for climate control inside the bus and more stop/start driving. Due to these considerations, blocks with an average speed of eight 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.

Table 8. Key Technical Viability Modeling Assumptions and Considerations

Item	20-29' Cutaway	30' Bus	40' Bus	45' Coach	60' Articulated Bus
Nominal Battery Capacity	122 kWh	350 kWh	686 kWh	544 kWh	525 kWh
Usable Battery Capacity *(70% of nominal)*	85 kWh	245 kWh	480 kWh	381 kWh	368 kWh
Average kWh per mile	0.9 kWh/mi	1.7 kWh/mi	2.2 kWh/mi	2.7 kWh/mi	3.5 kWh/mi
Average Range	95 mi	145 mi	220 mi	140 mi	105 mi
Worst Case kWh per mile	1.4 kWh/mi	2.7 kWh/mi	3.5 kWh/mi	4.3 kWh/mi	4.5 kWh/mi
Worst Case (MN Winter) Range *(Max. Technically Viable Range)*	60 mi	90 mi	135 mi	90 mi	80 mi

Note: All modeling calculations assume cabin heating via auxiliary diesel heater and the use of garage charging without range-extending opportunity charging. Nominal battery capacities are informed by EVEnergi's North America ZEB Report and a review of OEMs current BEBs that are eligible for FTA funds. Average and worst-case range thresholds are rounded to the nearest five miles and battery capacities are rounded to the nearest integer.

TECHNICAL VIABILITY METHODOLOGY

Using the criteria presented in Table 8, each block within a given service schedule is analyzed to assess BEB suitability. This analysis is performed using each block's vehicle type and length as assigned by the given service schedule. All calculations assume cabin heating via auxiliary diesel heater and the use of garage charging without range-extending opportunity charging. In all cases, a block is determined to be technically viable if:

For the purposes of this analysis, worst case (MN winter) range by vehicle length is used as the vehicle's maximum technically viable range

- The total block distance is less than the worst-case range[120] of a BEB with corresponding length; and
- The bus's average speed along the block is at least eight miles per hour.

[119] Source: *America's 20 Coldest Major Cities*, NOAA, 2014

[120] Note: For the purposes of this analysis, worst case range by vehicle length is used as the vehicle's maximum technically viable range

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

- Count (and percent) of total blocks that are technically viable.
- Percent of total annual bus hours that are technically viable.[121]
- Percent of total annual bus miles that are technically viable.[122]

TECHNICAL VIABILITY RESULTS (AUGUST 2022 SCHEDULE)

To provide an example of how the technical viability portion of this methodology could influence service decisions, this methodology was applied to MTS and the STP's August 2022 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 MTS and STP service schedule changes four times a year.

About 27 percent of annual MTS & STP bus hours and 29 percent of annual miles are technically viable with current BEB technology

Overall, approximately 46 percent of the MTS and STP August 2022 blocks, representing 27 percent of the total annual bus hours and 29 percent of total annual bus miles were technically viable with current BEB technology (Table 9).

Table 9. Technically Viable Block Summary for (August 2022 Schedule)

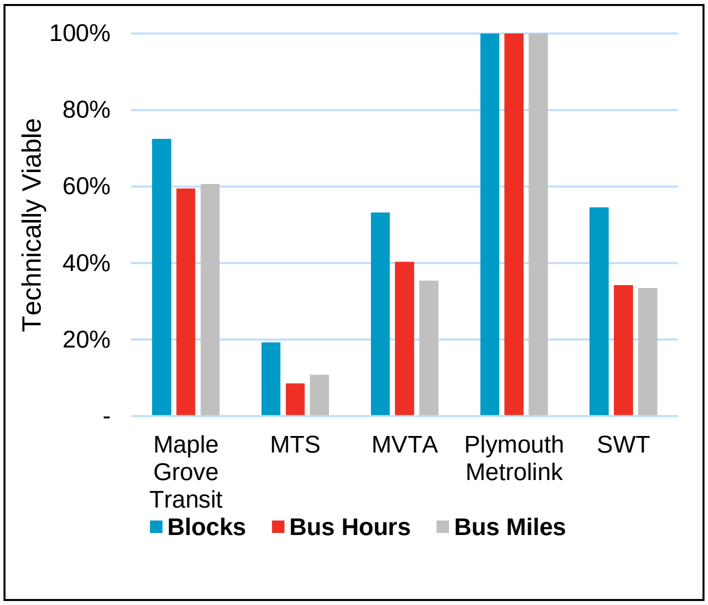
Item	TOTAL	20-29' Cutaway	30' Bus	40' Bus	45' Coach	60' Articulated Bus
Number of Technically Viable Blocks	**206**	**2**	**17**	**104**	**76**	**7**
% of Total Blocks	46%	6%	20%	53%	65%	50%
% of Total Annual Bus Hours	27%	2%	9%	42%	45%	36%
% of Total Annual Bus Miles	29%	1%	10%	40%	47%	36%

Note: All modeling calculations assume cabin heating via auxiliary diesel heater and the use of garage charging without range-extending opportunity charging.

[121] Note: Bus hours defined as the time between when a bus pulls out of a garage to when it pulls back into the garage
[122] Note: To calculate an agency's 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 the respective share of technically viable bus hours or miles of a given vehicle type compared to all bus hours and miles of that vehicle type 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 2022 schedule change, for example, it was assumed that there were 256 days of Weekday service, 52 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.

Given the unique characteristics associated with each of the MTS and STP service areas and to highlight the variability in technical viability by agency, summary metrics were calculated for the August 2022 bus service for each agency (Figure 40). MTS contracted fixed route service has the longest block lengths at an average of 163 miles followed by MVTA at 120 miles. Plymouth Metrolink and SouthWest Transit (SWT) had similar average block lengths of 92 and 91 miles, respectively, while Maple Grove Transit had the shortest blocks with an average length of just 74 miles. Due to this variability in block length, technical viability by agency varies considerably with MTS contracted fixed route service having the lowest percentage of technically viable blocks at 19 percent.

Figure 40. Technically Viable Blocks by Agency (August 2022 Schedule)



Although a minority of blocks are technically viable given current technology, current block structure and characteristics are designed for the operating requirements of diesel buses rather than BEBs. To increase the share of blocks that are technically viable, MTS and the STPs can either alter scheduling procedures and shorten block length or allow BEB technology and range to improve. The following sub-sections present a brief summary of technical viability for each agency.

Maple Grove Transit:

Nearly three quarters (72 percent) of Maple Grove Transit's August 2022 blocks representing approximately 60 percent of annual hours and miles are technically viable with current BEB technology, including all blocks using 40-foot buses (Table 10). Although blocks using 60-foot articulated buses are only about 15 miles longer, on average, than the 40-foot bus and 45-coach blocks, articulated buses have a substantially shorter technically viable range, as defined in Table 8. As such, 60-foot bus technical viability is much lower compared to Maple Grove Transit's other blocks. Starting in Spring 2023, Maple Grove Transit's vehicles will begin operating out of Metro Transit's electric-bus ready Heywood Campus. Although this move may advantageously position Maple Grove Transit to transition their fixed route service toward BEBs and build upon Metro Transit's institutional knowledge, existing electrical capacity at the Heywood Campus is programed for use with projects identified in Metro Transit's short-term transition plan. It is anticipated that adding electrification demands, such as any potential Maple Grove Transit electric buses, would require coordination and advance planning in order to add sufficient additional electrical capacity.

Table 10. Maple Grove Transit Technical Viability Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
40' Bus	3 (100%)	100%	100%
45' Coach	11 (92%)	86%	87%
60' Articulated Bus	7 (50%)	36%	36%
TOTAL:	**21 (72%)**	**59%**	**61%**

MTS:

Table 11. MTS Technical Viability Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
20-29' Cutaway	2 (6%)	2%	1%
30' Bus	17 (20%)	9%	10%
40' Bus	2 (13%)	5%	5%
45' Coach	6 (100%)	100%	100%
TOTAL:	**27 (19%)**	**9%**	**11%**

** Percentages expressed relative to agency's total blocks*

Less than 20 percent of MTS' August 2022 blocks, representing about 10 percent of annual hours and miles, are technically viable with current BEB technology (Table 11). More than half of MTS blocks utilize 30-foot buses. These 30-foot bus blocks include some of the longest MTS blocks with lengths of nearly 300 miles. The average 30-foot bus block length is 172 miles, nearly double a 30-foot BEB's maximum technically viable range (90 miles). As such, only 20 percent of 30-foot bus blocks and an even smaller share of cutaway and 40-foot bus blocks are technically viable with current BEB technology. Since only about a quarter of MTS' existing August 2022 blocks could be operated with current BEB technology, if MTS were to fully convert its fleet to BEBs, MTS would need to change how service is designed and delivered because this service is currently designed for the operating requirements of diesel buses rather than BEBs. This could mean breaking long blocks into smaller blocks.

MVTA:

Over half (53 percent) of MVTA's August 2022 blocks representing more than a third of annual hours and miles are technically viable with current BEB technology (Table 12). As MVTA operates the most fixed route blocks of MTS and the other STPs, MVTA has the greatest number of technically viable blocks. Based on current technology, a larger percentage of MVTA's coach buses are technically viable for electrification compared to the 40-foot bus blocks.

Table 12. MVTA Technical Viability Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
40' Bus	75 (49%)	41%	35%
45' Coach	41 (62%)	42%	44%
TOTAL:	**116 (53%)**	**40%**	**35%**

** Percentages expressed relative to agency's total blocks*

Plymouth Metrolink:

As all of Plymouth Metrolink's blocks utilize 40-foot buses and all blocks are under 135 miles long, 100 percent of Plymouth Metrolink's August 2022 blocks and annual hours and miles are technically viable with current BEB technology (Table 13). This is the largest share of technically viable blocks for any of the STPs.

Table 13. Plymouth Metrolink Technical Viability Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
40' Bus	24 (100%)	100%	100%
TOTAL:	**24 (100%)**	**100%**	**100%**

** Percentages expressed relative to agency's total blocks*

SWT:

Over half (55 percent) of SWT's August 2022 blocks representing a third of annual hours and miles are technically viable with current BEB technology (Table 14).

Table 14. SWT Technical Viability Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
45' Coach	18 (55%)	34%	33%
TOTAL:	**18 (55%)**	**34%**	**33%**

** Percentages expressed relative to agency's total blocks*

Equity and Environmental Justice (EEJ) Modeling

To understand the interaction between MTS and STP bus service and areas of high Equity and Environmental Justice (EEJ) priority, 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 defined in Metro Transit's ZEB Transition Plan (2022)[12] and shown in Figure 41.[123] The weighted average for each block is calculated as follows:

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

Using this equation, the lowest EEJ score a block could receive is 1 (if the entire block were in a low priority EEJ Area) while the highest value is a 4 (if the entire block were in a high priority EEJ Area). Bus Block EEJ scores are then categorized into one of four EEJ priority tiers (High, Medium-High, Medium, Low). As service area characteristics differ between MTS and each of the STPs, EEJ Priority categories are individually calculated for each agency based on their unique range of EEJ scores, not across agencies. For example, Plymouth Metrolink blocks are only compared to other Plymouth Metrolink blocks, not Maple Grove, MTS, MVTA, and SouthWest Transit, blocks as their characteristics and service areas differ greatly from an EEJ standpoint.

As service area characteristics differ between MTS and each of the STPs, EEJ Priority categories are individually calculated for each agency based on their unique range of EEJ scores, not across agencies

Agency-specific EEJ priority tiers are based on the ratio of blocks' EEJ score to the maximum EEJ score for the given agency as outlined in Table 15. For example, if the block with the highest EEJ priority score for Maple Grove Transit had a value of 3.0 the EEJ Priority categories for Maple Grove Transit would be as follows: High [≥ 2.40], Medium-High [1.95 – 2.39], Medium [1.5 – 1.94 miles], Low [< 1.5].

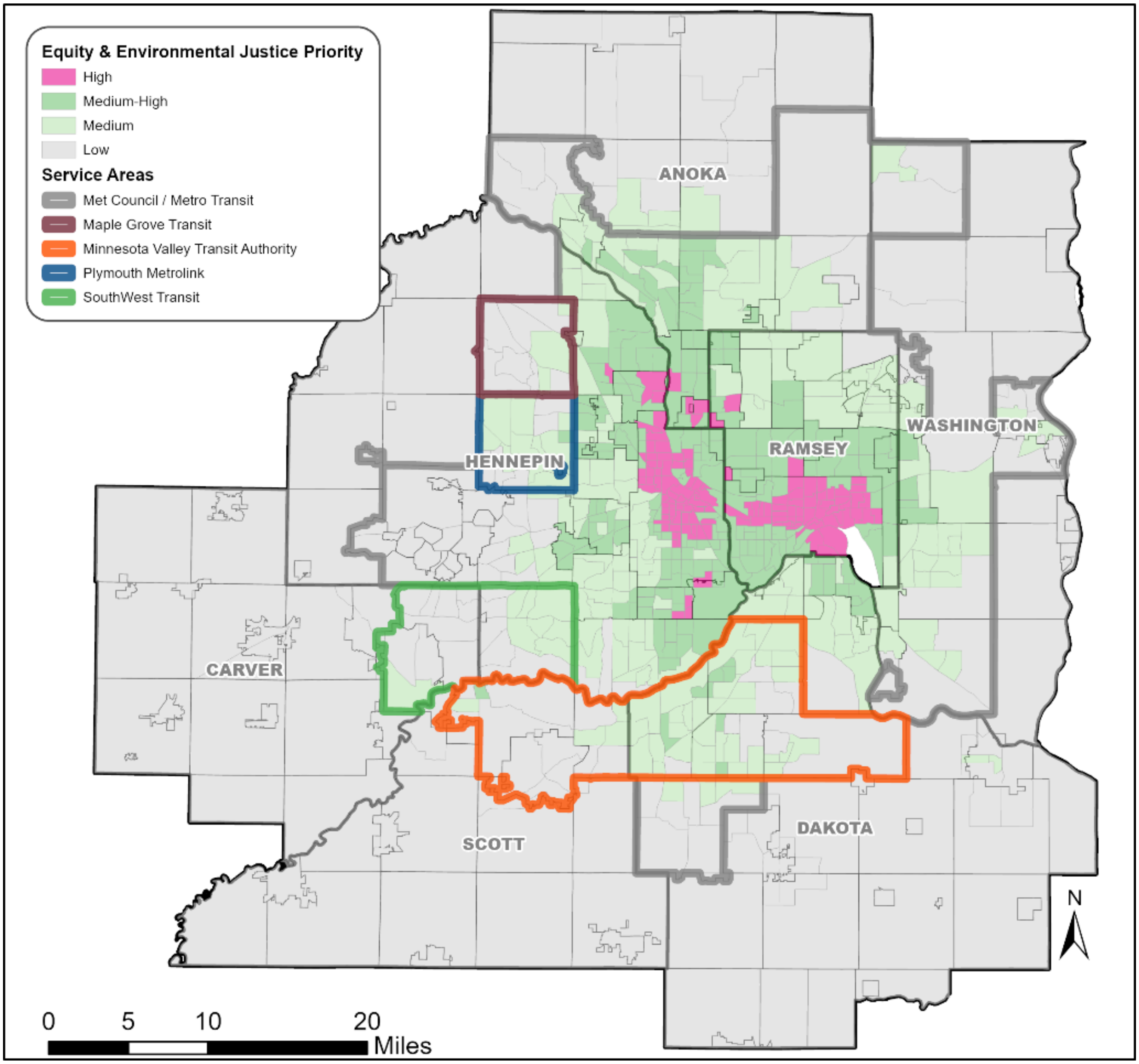
Table 15. EEJ Block-Level Priority Tier Threshold Ranges

Block-Level EEJ Priority Tier	% of Agency's Maximum EEJ Score
High	≥ 80%
Medium-High	65% – 79.9%
Medium	50% – 64.9%
Low	< 50%

Note: As service area characteristics differ between MTS and each of the STPs, EEJ Priority categories are individually calculated for each agency based on their unique range of EEJ scores, not across agencies.

[123] As part of Metro Transit's ZEB Transition Plan, EEJ priority areas were defined using more than 300 survey respondents' evaluation and ranking of the relative importance of seven unique population and environmental variables from the Metropolitan Council's *Equity Considerations for Place-Based Advocacy and Decisions in the Twin Cities Region* dataset. These seven census-tract level variables 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).

Figure 41. Census Tract Equity and Environmental Justice (EEJ) Priority Areas



EEJ PRIORITY RESULTS (AUGUST 2022 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 the MTS and STP August 2022 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 quarterly service changes.

20 percent of the technically viable MTS and STP August 2022 blocks are a high EEJ priority for BEB implementation

Based on the EEJ categories outlined in the methodology above, 46 percent of the technically viable MTS and STP August 2022 blocks are a high EEJ priority for BEB implementation. Overall, just over a tenth of the total annual bus hours and miles traveled across the entire MTS and STP fixed route network could be performed by operating comparable size BEBs on just High EEJ priority blocks (Table 16). No technically viable articulated bus blocks are designated High EEJ priority. Just 18 percent of technically viable 30’ bus blocks are High EEJ priority. However, more than half of technically viable 45’ coach, and 20-20’ cutaway blocks are designated as High EEJ priority.

Table 16. Technically Viable and High EEJ Priority Block Summary (August 2022 Schedule)

Item	TOTAL	20-29’ Cutaway	30’ Bus	40’ Bus	45’ Coach	60’ Articulated Bus
Number of Technically Viable & High EEJ Priority Blocks	**95**	**2**	**3**	**47**	**43**	**0**
% of Technically Viable Blocks	46%	100%	18%	45%	57%	0%
% of Total Blocks	21%	6%	3%	24%	37%	0%
% of Total Annual Bus Hours	12%	2%	1%	19%	25%	0%
% of Total Annual Bus Miles	14%	1%	2%	21%	26%	0%

Maple Grove Transit:

A total of two blocks—seven percent of Maple Grove Transit’s total August 2022 blocks—are both technically viable and a High EEJ priority relative to all Maple Grove Transit blocks (Table 17). Route 789 encompasses both blocks and runs along I-94 through Brooklyn Center, North Minneapolis, and Downtown Minneapolis, all of which are High Priority EEJ areas. Relative to these two blocks, all other Maple Grove transit blocks have significantly lower EEJ values fairly evenly distributed between the Medium-High and Medium EEJ priority tiers. No technically viable 40-foot or 60-foot blocks are designated High EEJ priority.

Table 17. Maple Grove Transit Technical Viability and High EEJ Priority Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
40’ Bus	0 (0%)	0%	0%
45’ Coach	2 (17%)	10%	9%
60’ Articulated Bus	0 (0%)	0%	0%
TOTAL:	**2 (7%)**	**3%**	**3%**

** Percentages expressed relative to agency’s total blocks*

MTS:

A total of seven blocks—five percent of MTS’ total August 2022 blocks—are both technically viable and a High EEJ priority. Notably, comparing Table 11 and Table 18, all of MTS’ technically viable cutaway and 40-foot bus blocks are designated as High EEJ priority. Technically viable blocks utilizing 45-foot coach buses are evenly split between Medium-High and Medium EEJ priority while technically viable 30-foot bus blocks are evenly spread across all four EEJ priority tiers. To maximize ZEB service in High EEJ priority areas, one possible strategy for further exploration and consideration in the mid- to long-term future as Metro Transit’s BEB fleet grows in size could be to include EEJ priority as a factor in determining which fixed routes are operated by MTS and which are operated by Metro Transit. This could provide additional time for MTS to transition towards ZEBs while still providing zero-emission service in High Priority EEJ areas. Exploration of this strategy could occur following Metro Transit’s planned projects in the short-term to continue gaining valuable experience to share with the region. Such a strategy would likely require that the block/route in question also score

Table 18. MTS Technical Viability and High EEJ Priority Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
20-29’ Cutaway	2 (6%)	2%	1%
30’ Bus	3 (3%)	1%	2%
40’ Bus	2 (13%)	5%	5%
45’ Coach	0 (0%)	0%	0%
TOTAL:	**7 (5%)**	**2%**	**2%**

** Percentages expressed relative to agency’s total blocks*

High for EEJ priority relative to Metro Transit's blocks consistent with the Metro Transit Zero-Emission Bus Transition Plan.

MVTA:

A total of 55 blocks—25 percent of MVTA's total August 2022 blocks—are both technically viable and a High EEJ priority (Table 19). A markedly higher share of MVTA's 45-foot coach bus blocks, hours, and miles, are designated as High EEJ priority compared to 40-foot bus blocks as all 45-foot coach bus blocks serve either downtown Minneapolis or St. Paul both of which are High Priority EEJ areas. The majority of the technically viable 45-coach blocks that are not a High EEJ priority run along Highway 169, I-394, and I-35E rather than Highway 77 and I-35W.

Table 19. MVTA Technical Viability and High EEJ Priority Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
40' Bus	21 (14%)	11%	12%
45' Coach	34 (52%)	35%	37%
TOTAL:	**55 (25%)**	**15%**	**17%**

** Percentages expressed relative to agency's total blocks*

Plymouth Metrolink:

The equity priority for much of Plymouth Metrolink's service area is fairly similar. Due to this similarity, Plymouth Metrolink's block-level EEJ values vary by less than 20 percent, a much lower variation compared to MTS and other STPs where block-level EEJ values can vary by as much as 60 percent. As a result of this high degree of similarity amongst Plymouth Metrolink blocks, 100 percent of Plymouth Metrolink's 19 technically viable August 2022 blocks (100 percent of all agency blocks) are also a High EEJ priority (Table 20).

Table 20. Plymouth Metrolink Technical Viability and High EEJ Priority Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
40' Bus	24 (100%)	100%	100%
TOTAL:	**24 (100%)**	**100%**	**100%**

** Percentages expressed relative to agency's total blocks*

SWT:

A total of 7 blocks—21 percent of SWT's total August 2022 blocks—are both technically viable and a High EEJ priority (Table 21). Blocks that travel along I-35W are typically higher EEJ priority than those along I-394 while blocks that stay closer to the urban core are typically EEJ priority than those traveling further afield into Carver County.

Table 21. SWT Technical Viability Summary and High EEJ Priority (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
45' Coach	7 (21%)	13%	12%
TOTAL:	**7 (21%)**	**13%**	**12%**

** Percentages expressed relative to agency's total blocks*

Fiscal Impact Modeling

Locally, Metro Transit has found that the capital cost of putting a BEB on the road is currently about 2.5 times that of a diesel bus.[12] As such, MTS and the STPs are focused on deploying BEBs in a fiscally efficient manner where the maximum benefit and usage can be garnered from these significant investments. To achieve a fiscally efficient deployment of BEBs, MTS and the STPs plan to prioritize BEB deployment on the longest technically viable blocks. To guide this focus, blocks are categorized into four fiscal efficiency tiers (Table 22**Error! Reference source not found.**) informed by naturally o ccurring groups and breakpoints in the ratio of block distance to maximum technically viable range by vehicle length defined in Table 8. For example, the maximum technically viable range of a 40-foot bus is 115 miles. This yields the following fiscal efficiency tiers for blocks operating 40-foot buses: High [≥ 92 miles], Medium-High [69 – 91.9 miles], Medium [46 – 68.9 miles], Low [< 46 miles].

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 (Table 22). For this analysis, only individual blocks contained in the August 2022 blocklist were reviewed. In the future, however, block groupings could be reviewed for additional deployment opportunities.

Table 22. Fiscal Efficiency Tiers by Technically Viable Block Distance

Block-Level Fiscal Efficiency Tier	% of Vehicle's Maximum Technically Viable Range
High	≥ 80%
Medium-High	60% – 79.9%
Medium	40% – 59.9%
Low	< 40%

35 percent of the technically viable MTS and STP August 2022 blocks are designated as High fiscal efficiency

FISCAL IMPACT PRIORITY RESULTS (AUGUST 2022 SCHEDULE)

To provide an example of how the fiscal impact portion of this methodology could influence BEB deployments, this methodology was applied to the MTS and STP August 2022 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 quarterly service changes.

Based on the Fiscal Efficiency categories outlined in the methodology above, 35 percent of the technically viable MTS and STP August 2022 blocks are designated as High fiscal efficiency. Overall, just over a tenth of the total annual bus hours and miles traveled across the entire MTS and STP fixed route network could be performed by operating similar size BEBs on just High fiscal efficiency blocks (Table 23). Broadly, longer blocks have higher fiscal efficiency than shorter blocks. The only vehicle type with more than half of its technically viable blocks designated as High fiscal efficiency is the 60' articulated bus type while neither of the two cutaway blocks have a High fiscal efficiency.

Table 23. Technically Viable and High Fiscal Efficiency Block Summary (August 2022 Schedule)

Item	TOTAL	20-29' Cutaway	30' Bus	40' Bus	45' Coach	60' Articulated Bus
Number of Technically Viable & High Fiscal Efficiency Blocks	**73**	**0**	**4**	**35**	**29**	**5**
% of Technically Viable Blocks	35%	0%	24%	34%	38%	71%
% of Total Blocks	16%	0%	5%	18%	25%	36%
% of Total Annual Bus Hours	12%	0%	3%	19%	22%	30%
% of Total Annual Bus Miles	13%	0%	3%	16%	24%	30%

Maple Grove Transit:

A total of 11 blocks—38 percent of Maple Grove Transit's total August 2022 blocks—are both technically viable and have a High fiscal efficiency (Table 24). Coach buses have the greatest share of technically viable High fiscal efficiency blocks at 50 percent representing nearly two thirds of total Maple Grove Transit bus hours and miles.

Table 24. Maple Grove Transit Technical Viability and High Fiscal Efficiency Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
40' Bus	0 (0%)	0%	0%
45' Coach	6 (50%)	62%	64%
60' Articulated Bus	5 (36%)	30%	30%
TOTAL:	**11 (38%)**	**38%**	**40%**

** Percentages expressed relative to agency's total blocks*

MTS:

A total of 11 blocks—8 percent of MTS' total August 2022 blocks—are both technically viable and have a High fiscal efficiency (Table 25). All coach bus blocks have a high fiscal efficiency while just 5 percent of all 30-foot bus blocks are both technically viable and have a High fiscal efficiency. The remainder of technically viable 30-foot bus blocks primarily have a Medium-High fiscal efficiency while the technically viable cutaway blocks both have a Medium fiscal efficiency.

Table 25. MTS Technical Viability and High Fiscal Efficiency Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
20-29' Cutaway	0 (0%)	0%	0%
30' Bus	4 (5%)	3%	3%
40' Bus	1 (6%)	3%	3%
45' Coach	6 (100%)	100%	100%
TOTAL:	**10 (7%)**	**3%**	**5%**

** Percentages expressed relative to agency's total blocks*

MVTA:

A total of 43 blocks—20 percent of MVTA's total August 2022 blocks—are both technically viable and have a High fiscal efficiency (Table 26). The remaining technically viable 45-foot coach blocks have primarily Medium fiscal efficiency while the majority of the remaining technically viable 40-foot blocks have a Medium-High fiscal efficiency. Seven of the technically viable 40-foot bus blocks have Low fiscal efficiency as their lengths are less than 55 miles long.

Table 26. MVTA Technical Viability and High Fiscal Efficiency Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
40' Bus	27 (18%)	19%	15%
45' Coach	16 (24%)	22%	22%
TOTAL:	**43 (20%)**	**20%**	**16%**

** Percentages expressed relative to agency's total blocks*

Plymouth Metrolink:

A total of 7 blocks—29 percent of Plymouth Metrolink's total August 2022 blocks—are both technically viable and have a High fiscal efficiency (Table 27). The remaining technically viable blocks are divided fairly evenly between Medium-High and Medium fiscal efficiency while only one has a Low fiscal efficiency.

Table 27. Plymouth Metrolink Technical Viability and High Fiscal Efficiency Summary (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
40' Bus	7 (29%)	38%	39%
TOTAL:	**7 (29%)**	**38%**	**39%**

** Percentages expressed relative to agency's total blocks*

SWT:

One block—representing three percent of SWT's total August blocks—is both technically viable and has a High fiscal efficiency (Table 28). The remaining technically viable blocks are primarily Medium-High fiscal efficiency while two have a Low fiscal efficiency.

Table 28. SWT Technical Viability Summary and High EEJ Priority (August 2022 Schedule)

Vehicle Type	Blocks	Hours	Miles
45' Coach	1 (3%)	2%	2%
TOTAL:	**1 (3%)**	**2%**	**2%**

** Percentages expressed relative to agency's total blocks*

Fixed Route Service Prioritization Summary (August 2022 Schedule)

By combining the three guiding principles (technical viability, equity and environmental justice, and fiscal impact) in a scalable way, the most promising blocks suitable for short-term BEB deployment can be identified. These most promising "Priority 1" blocks are defined as blocks that are technically viable, in a high EEJ priority area, and have high fiscal efficiency. Secondary priority "Priority 2" 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 29, by applying the full methodology to the illustrative example of the August 2022 MTS and STP service schedule, 86 blocks were identified as the most-promising (Priority 1 or Priority 2) blocks for short-term BEB deployment with at least one top priority block identified for each agency. Although an aggregate top priority tier of only 86 blocks may initially appear limiting, it is important to remember that this prioritization is representative of how MTS and the STPs could begin to deploy BEBs. This methodology was intended to identify block priority rather than the total potential opportunity to electrify MTS and STP 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 block may receive BEB service in the short-term. This methodology also establishes a prioritization scheme that can be used for future service schedules.

Table 29. Top Priority Blocks for Short-Term BEB Deployment (August 2022 Schedule)

Agency	Aggregate Priority 1*	Aggregate Priority 2*
Maple Grove Transit	-	1 Block (5%)
MTS	2 Blocks (7%)	5 Blocks (19%)
MVTA	18 Blocks (16%)	39 Blocks (34%)
Plymouth Metrolink	7 Blocks (29%)	8 Blocks (33%)
SouthWest Transit	-	6 Blocks (33%)
TOTAL:	**27 Blocks (13%)**	**59 Blocks (29%)**

Note: Aggregate Priority 1 blocks are those that are technically viable and have high EEJ Priority and High Fiscal Efficiency whereas Aggregate Priority 2 blocks are technically viable and have either high EEJ Priority and Medium-High Fiscal Efficiency OR Medium-High EEJ Priority and High Fiscal Efficiency

**Percentages expressed as the provider's priority blocks divided by their total number of technically viable blocks*

Overall, this section has established a fixed route service prioritization methodology informed by the experiences of peer transit agencies, community engagement, and based upon the guiding principles of scalability, technical viability, equity and environmental justice, and fiscal impact. Based on the illustrative application of this methodology to the August 2022 service schedule, it was determined that about 46 percent of all MTS and STP bus blocks are technically suitable for BEB service based on a conservative worst-case winter BEB range and that 27 (13 percent) of these technically viable blocks had both a high EEJ prioritization and high fiscal efficiency for implementation.

Despite having a smaller portion of High EEJ priority blocks, Maple Grove Transit is advantageously positioned to integrate BEBs from a technical standpoint given their high share of technically viable blocks (72 percent) in tandem with operating these vehicles from Metro Transit's Heywood Campus in the future. Although grid upgrades will be required to support any additional electric bus projects at the Heywood Campus beyond the short-term projects identified in Metro Transit's Zero-Emission Plan, Maple Grove Transit would be able to build upon the lessons learned and institutional knowledge at a campus that currently supports electric buses. Furthermore, more than half of the technically viable August 2022 blocks for both MVTA and Plymouth Metrolink featured desirable characteristics to prioritize when considering a transition towards BEBs. This methodology also identifies six top priority

SouthWest blocks that could be candidates for the four future electric coach buses identified in SouthWest Transit's successful 2022 Low-No grant application and expected to be in service by 2026. 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.

6.2.2 Demand Response Service

Demand Response Practices

As defined in law, Demand Response service is "any non-fixed route system of transporting individuals that requires advanced scheduling by the customer."[52] Demand response vehicles "may be dispatched to pick up several passengers at different pick-up points before taking them to their respective destinations and may even be interrupted in route to these destinations to pick up other passengers."[124] MTS and the STPs use fleets of smaller vehicles—ranging from 20'-29' Cutaways to vans and SUVs—to provide demand response service (often also referred to as Dial-A-Ride service).

Demand Response Estimation Methodology and Implementation Guidance

Although the daily requirements for demand response service change constantly, these requirements can be averaged over longer periods of time to estimate fleet requirements. To estimate the future MTS and STP demand response fleet needs, average daily miles for each type of vehicle within each system are divided by the assumed operational range for battery-electric vehicles of the same types. For example, a transit agency might operate demand response cutaways an average of 300 miles a day. As the assumed operational range for battery-electric cutaways is 60 miles, it would take five battery-electric cutaways to provide this average daily amount of service. Because service levels fluctuate daily and because transit agencies must aim to provide enough capacity to meet anticipated peak demand, a contingency of 10% additional capacity was assumed. The assumed operational ranges for demand response battery electric vehicles are depicted in Table 30. Table 31 depicts the future fleet needs to meet current service levels for MTS and the STP fleets, based on the above methodology.

Table 30. Demand Response Battery-Electric Vehicle Assumed Operational Range

Item	20-29' Cutaway	SUV	Van
Worst Case (MN Winter) Range *(Max. Technically Viable Range)*	60 mi	150 mi	100 mi

Note: The assumed operational range for SUVs and vans in Minnesota winter was informed by SouthWest Transit's experiences operating battery-electric vehicles and the caps they apply to daily mileage.

[124] Source: FTA Circular 2710.2A, FTA, 1988

Table 31. Estimated Future Fleet Needs to Meet Current Level of Service

Agency	Cutaways	SUVs*	Vans*
Maple Grove Transit	15	1	1
Increase From Existing	*+ 6*	*No Change*	*No Change*
Metro Mobility	2,032	42	-
Increase From Existing	*+ 1,433*	*+ 11*	*-*
Transit Link	280	-	-
Increase From Existing	*+200*	*-*	*-*
MVTA	28	-	3
Increase From Existing	*+ 9*	*-*	*+1*
Plymouth Metrolink	13	-	-
Increase From Existing	*+ 4*	*-*	*-*
SouthWest Transit	21	16	7
Increase From Existing	*+ 13*	*No Change*	*+ 2*

Note: Agency's must have FTA approval to purchase non-accessible vehicles for Dial-A-Ride service.

Current models of battery-electric vehicles are limited in range compared with their gas-powered counterparts. Because of this, it would require significantly more battery-electric vehicles to provide the same amount of service as gas-powered vehicles do today. Operating more vehicles would further require more operators, more storage space, and other accommodations. This analysis does not estimate those additional needs.

6.3 Facility Guidance

Suitable facilities, in addition to technically viable service, are required to successfully transition towards the operation of BEBs. The primary characteristics affecting a facility's suitability for BEBs are the electrical capacity and space required to install and operate the supporting electrical infrastructure and chargers necessary to recharge BEBs. Due to limitations regarding how different public funding sources can be utilized and challenges associated with the long lead times necessary to have the appropriate power provided to a BEB facility, only transit agency-owned facilities are considered for this facility assessment.

6.3.1 Existing Facility Assessment and Recommendations

MVTA

Eagan Bus Garage

The Eagan Bus Garage (EBG) is purpose-built for transit maintenance and operations. EBG is a suitable candidate for electrification because it has enough available space for electrification infrastructure and has access to enough potential power and multiple feeder circuits from Xcel Energy.

To renovate EBG for ZEBs, the existing electrical service to the garage will need to be augmented. The existing electrical infrastructure is unable to support more than one (1) 150kW nominal DC charging cabinet. Current power is provided through a 500kVA transformer that energizes a 1,600-amp capacity switchboard.

The open slots on the existing switchboard have the potential to support up to three (3) DC chargers and their subsequent five (5) dispensers. However, this potential is limited by the lack of power available from the smaller 500kVA transformer. The existing transformer sits on a concrete pad that is too small for the larger transformers offered by Xcel Energy. To replace the 500kVA transformer with a larger one capable of fully energizing the existing switchboard would require a power shutdown that would last days and could even last for weeks depending on the conditions underneath the original pad. During the transformer swap the existing wires connecting the transfer to the existing switchboard may be found to be too short and/or too small in diameter to connect to a larger transformer and to replace with longer larger diameter wires could increase the time to replace the existing transformer.

If the existing switchboard is fully utilized, the EBG could only provide three (3) of the forty-nine (49) chargers needed to sustain fully electric MVTA service. Because this power would be shared with other electrical uses at the EBG, MVTA could not take advantage of any Xcel Energy EV power rates which require that the electricity must be used for electric vehicle charging only. As a result, MVTA options are either:

Short-Term Phase 1 – BEB Existing Power Option

Energize the one (1) DC 150kW nominal charger with a model that can support sequential charging to three (3) dispensers. The charger could be installed on the existing mezzanine facing into the bus parking area and be energized from the existing switchboard.

- This option will quickly provide charging to three (3) BEBs located in positions compatible with the full electrification master plan.
- With only three (3) BEBs parked in row sized for five buses there is potential for diesel buses to be blocked by charging BEBs or diesel buses blocking access to the chargers. Consider parking all three BEBs in a row without sharing the parking track / row with diesel buses.
- MVTA would not be able to utilize the Xcel EV charging rates as this requires a switchboard and meter with only EV chargers. The existing switchboard and meter energize the existing building lights, HVAC, etc., plus the optional one (1) BEB charger

Short-Term Phase 1 – BEB New Power Option

Add a new transformer and connect it to an existing feeder circuit (there are two Xcel Energy circuits adjacent to the site and either would work[125]). This is necessary to create an electrical connection from the transformer to a new Main-Tie-Main (MTM) switchboard located on the mezzanine (Figure 42). Three (3) 150kW nominal DC chargers and five (5) dispensers would be added. While each charge can support three dispenses any quantity of 1,2, or 3 dispenses can be used. Five (5) BEBs would fill a complete row of buses within the Eagan garage and be more efficient to operate in groups of five (5) so BEB and diesel buses are not intermixed with diesel buses trapped behind charging buses and diesel buses parked blocking BEB charging positions.

*Taking advantage of two utility circuits available to the Eagan Bus Garage site for power resiliency and redundancy requires a Main-Tie-Main switchboard. Main-Tie-Main switchboards consist of two separate switchboards energized by **two separate** utility circuits joined by a transfer switch. If one of the circuits experiences an outage, the transfer switch engages, and the remaining circuit energizes both switchboards*

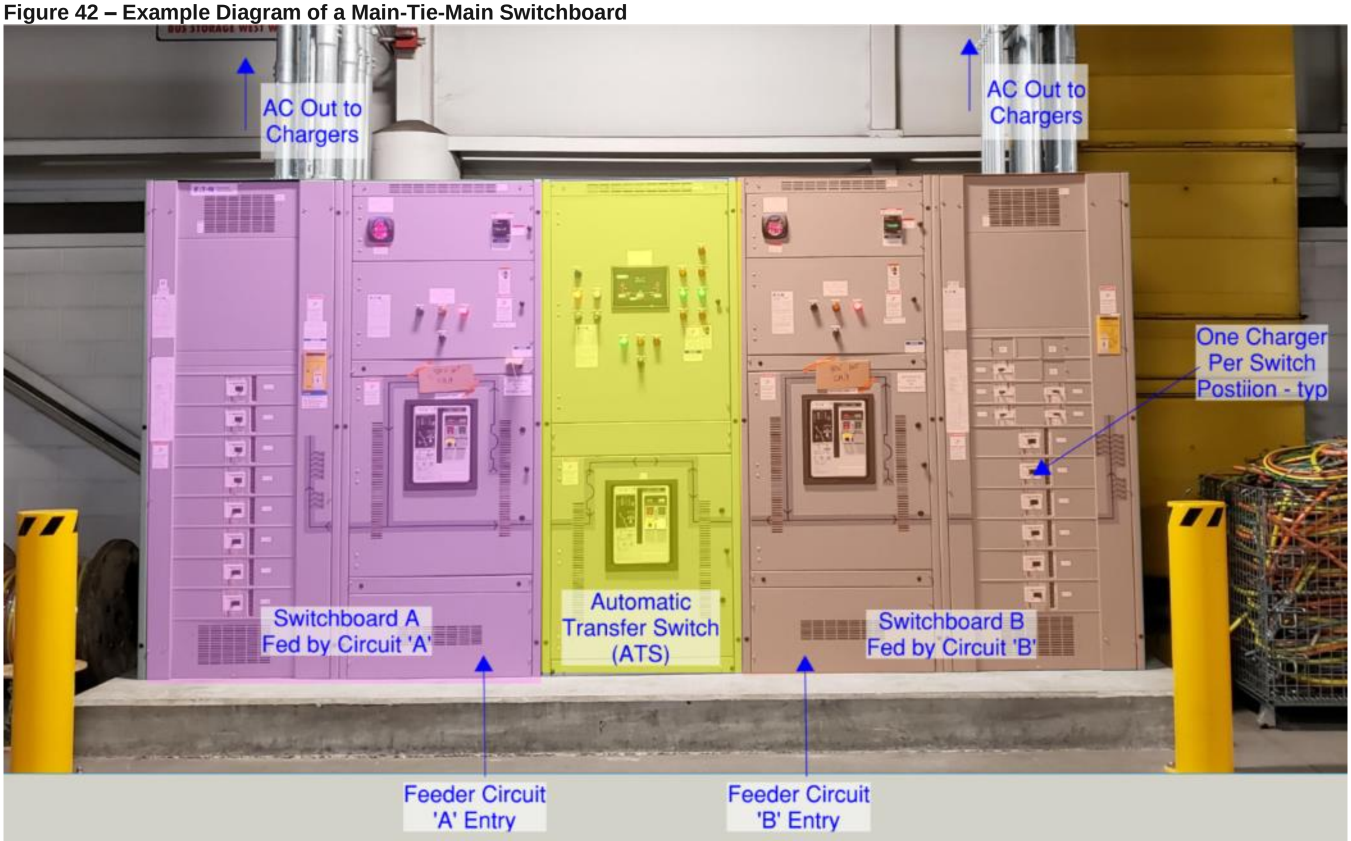
Source: https://jmkengineering.com/industrial-power-system-configuration-main-tie-main/

- These three (3) charges and their five (5) dispenses would provide enough charging capacity in an overnight parking session to keep all five (5) BEBs in daily transit operations.
- The new transformer would be the first of a likely total of five (5) future transformers needed to fully electrify the Eagan Bus Garage.

[125] Electrical Capacity on the Xcel Energy circuits are provided on a first come first serve basis, so the excess capacity on those circuits in 2022 may be utilized by another Xcel customer prior to MVTA electrifying the Eagan Bus Garage.

- The Circuit A (or B) section of a MTM switchboard would provide resiliency and eliminate the need to buy an additional switchboard until 48+ BEBs are on-site. This approach would allow for a phased and scalable early build out of the Electrification Master Plan Concept.
- However, this approach would cost more due to new electrical infrastructure components.
- Xcel Energy needs a period of up to 12 months to get the new transformer on site so coordination with Xcel would need to happen as soon as detailed design begins for new BEB chargers and MTM equipment and BEBs are ordered.

Figure 42 – Example Diagram of a Main-Tie-Main Switchboard



Electrification Master Plan Concept

The Eagan Bus Garage has a bus storage capacity of ninety-eight (98) 40-45-ft bus parked positions within the garage. The high percentage of routes / blocks found to be not-viable for electrification indicates that a substantial portion of BEBs would return to the depot for charging needing their maximum charge during their average 8 hour dwell time at the depot. Note this dwell time includes nightly service activities (wash, interior clean, etc.) so not all 8 hours is available solely for charging. Utilizing a 1:2 ratio of chargers to dispenser would provide enough charging capacity but significantly impact the size of charging infrastructure (new charging equipment mezzanines, electrical service size, charger count) that while technically achievable in the existing Eagan Garage would be better accommodated in a purpose built facility. The floor plans are shown using a 1:2 ratio of chargers to dispensers, the entire fleet could be electrified with forty-nine (49) DC chargers (Table 32). This ratio would provide up-to three hour charging times per bus which would be compatible with a standard nightly layout and parking duration but requires the buses return to the depot with a higher state or charge.

The forty-nine (49) DC chargers could be located on the existing mezzanine between the existing bus parking and bus maintenance bays as shown by the light blue areas in Figure 43. Alternatively, a new mezzanine could be constructed in front of the bus wash, as shown in pink on Figure 43. This alternate configuration would still allow buses to drive under the mezzanine and access the wash but be adjacent to and accessible from the existing mezzanine.

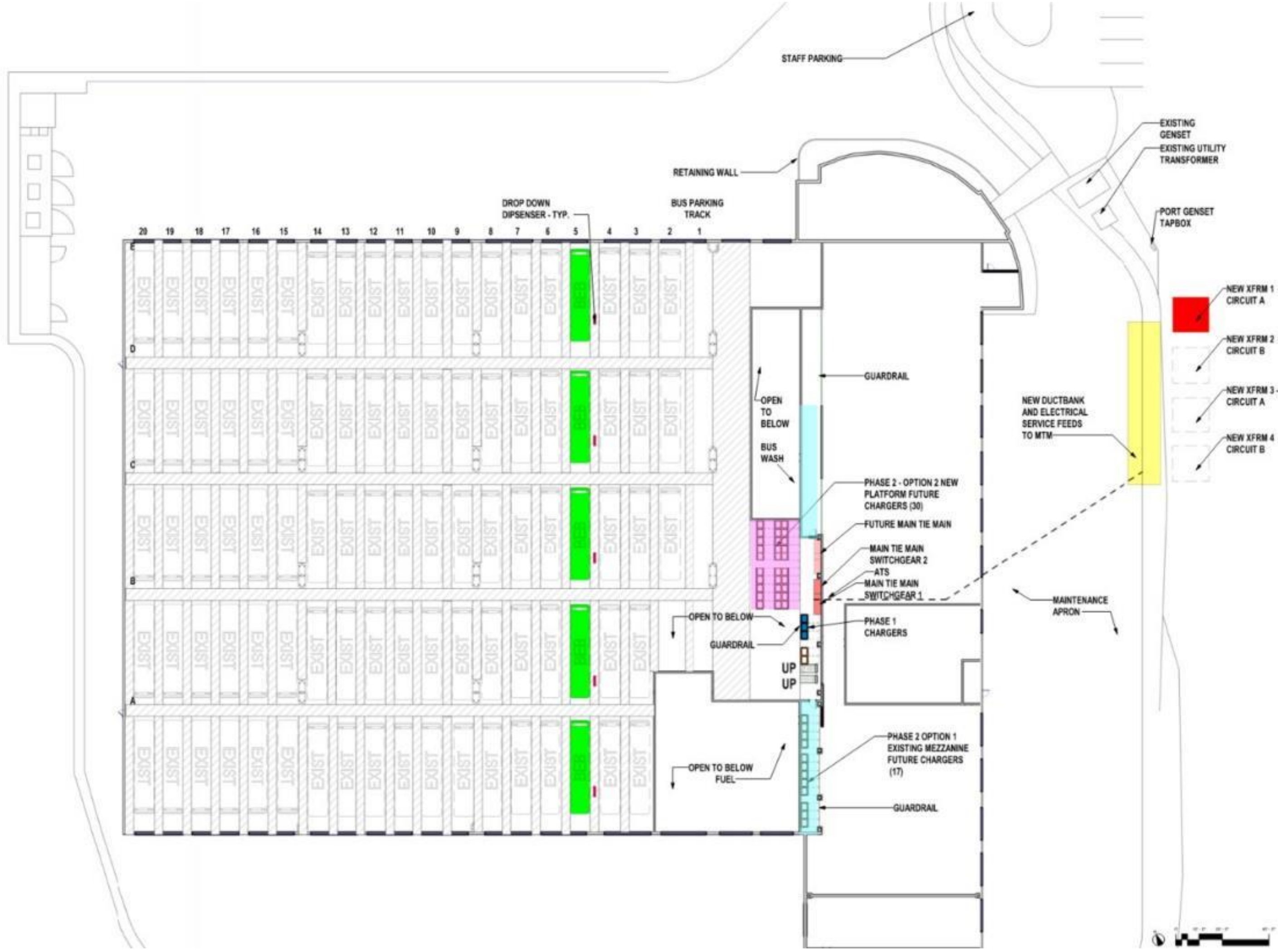
Four (4) sets of new MTM switchboards are estimated to be needed. These would provide power distribution to the chargers and allow for resiliency and redundancy by utilizing different Xcel Energy feeders to energize each side of the switchboard, as shown in Figure 42. In the event of an electrical disruption in Circuit A, the automatic transfer switch (ATS) would engage and Circuit B would be able to provide power to all chargers on both the A and B switchboard sides. This configuration would reduce the need for on-site generation to provide the kind of power resiliency needed when BEBs become the majority vehicle type at the Eagan garage. The use of MTM switchboards allows for resiliency due to Xcel Energy having two existing utility circuits serving the Eagan site without the need for additional emergency generators. This resiliency works if either power is lost on either of the two circuits but does not provide power in the event of a total power loss like an Xcel Energy system blackout.

The anticipated full power load of 7.35 MW would be split between the two (2) available Xcel circuits (A and B) that are accessible to the Eagan site (Table 32). The split is necessary to energize the two different sides of the MTM switchboards and provide power resiliency and redundancy. Four (4) new transformers would be needed, with two (2) energized by the A circuit and two (2) energized by the B circuit.

Table 32: Eagan Bus Garage Full Electrification Summary

Garage	Buses	Chargers	MW
Eagan Bus Garage	98	49	7.35
98 BEBs divided by 2 (1:2 shared ratio) x 150kW charger = 7.35 MW			

Figure 43 – Eagan Charging Option Plan

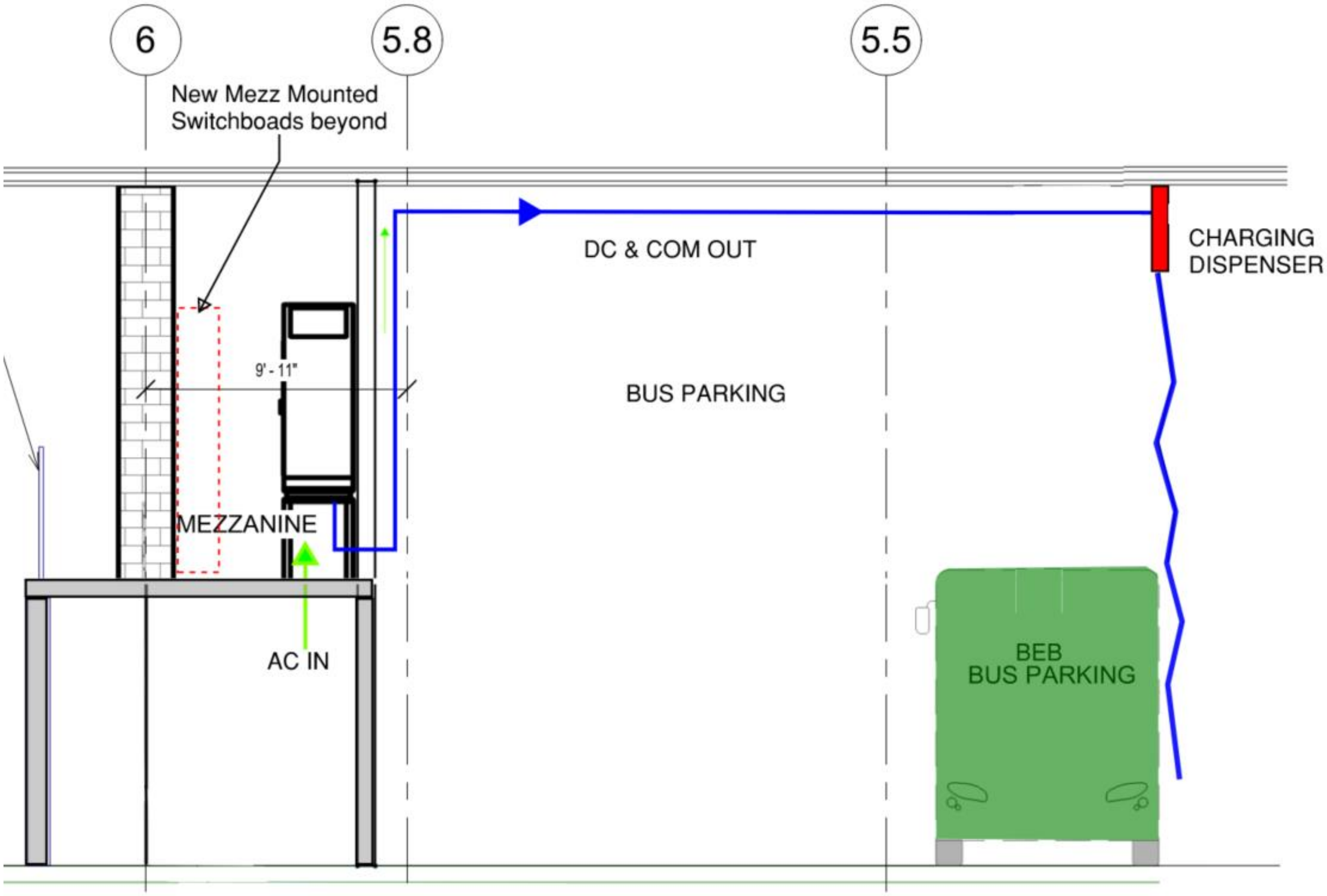


Typically, dispensers are ground mounted. In the EBG, these could be located in existing striped areas and protected by existing bollards around existing columns. However, not all future charging positions are adjacent to parking garage columns. To add flexibility and serve all parking positions, dispensers could instead be suspended from ceiling with a cord retraction system (manual, motorized hoist/reel, etc.) (Figure 44).

Eagan Operations could pilot this configuration with the first five (5) dispensers and determine whether it could subsequently be scaled across the whole garage. Alternately, the first five (5) dispensers could be ground mounted and include one (1) or more overhead pantograph dispensers could be built over one of the charging positions. Overhead pantographs are costly and require man lifts for maintenance. However, they also alleviate the day-to-day labor costs of plugging and unplugging cords, which could become tedious for more than 30+ vehicles.

Multiple charger OEMs such as ChargePoint, Heliox and Siemens can connect multiple dispenser types (cord and pantograph) to the same charger. This hybrid approach would provide MVTA with another way to test dispensing technologies and gain familiarity with their strengths and weaknesses.

Figure 44 – Mezzanine Charger Location



Burnsville Bus Garage

The Burnsville Bus Garage is a re-purposed dock-high warehouse that was converted to function as a transit bus operations and maintenance facility. It is currently not in operation due to significant renovations. The Burnsville Bus Garage Modernization project will shift liquid fueling from the building exterior to the interior, construct a new exterior wash facility, expand maintenance bays, add a shop, and add a storage mezzanine. These changes are shown in Figure 46.

Figure 45 - Transformer & Utility Switch

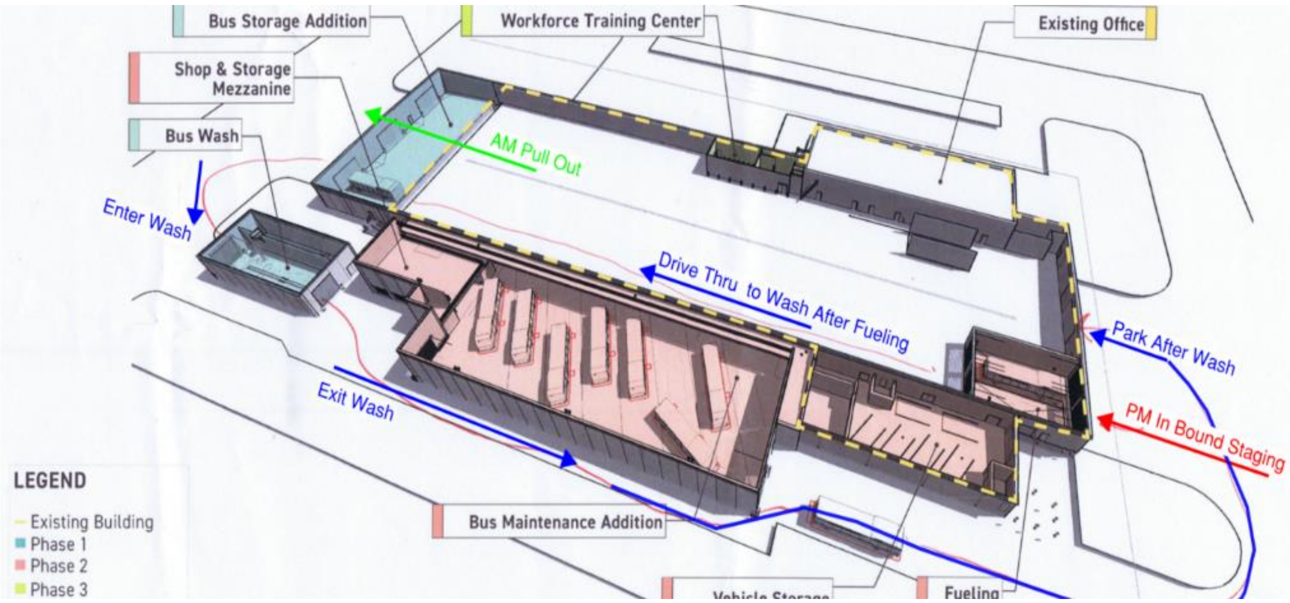
Unfortunately, the new 500kVA transformer and custom transformer pad are not suitable for upgrades that would support the full-time BEB charging in the near or long-term. Due to the location of the transformer in relation to the overhead entry doors into the vehicle storage and fueling area, upgrading the transformer size to allow for increased charging capacity would block access to the vehicle storage and fueling areas, as shown in Figure 45.

To support full utilization of the Burnsville Bus Garage by BEBs, upgrades would be required (Table 33). The existing switchboard has rated capacity to support three stand-alone 150kW nominal DC chargers, but the 500 kVA transformer does not. As a result, no Level 3 150kW DC charger is anticipated to be able to be energized by the existing electrical service (Table 33).

Table 33: Burnsville Bus Garage Full Electrification Summary

Garage	Buses	Chargers	MW
Burnsville Bus Garage	74	37	5.55
74 BEBs divided by 2 (1:2 shared ratio) x 150kW charger = 5.55 MW			

Figure 46: - In Progress Bus Garage Modernization Concept Plan

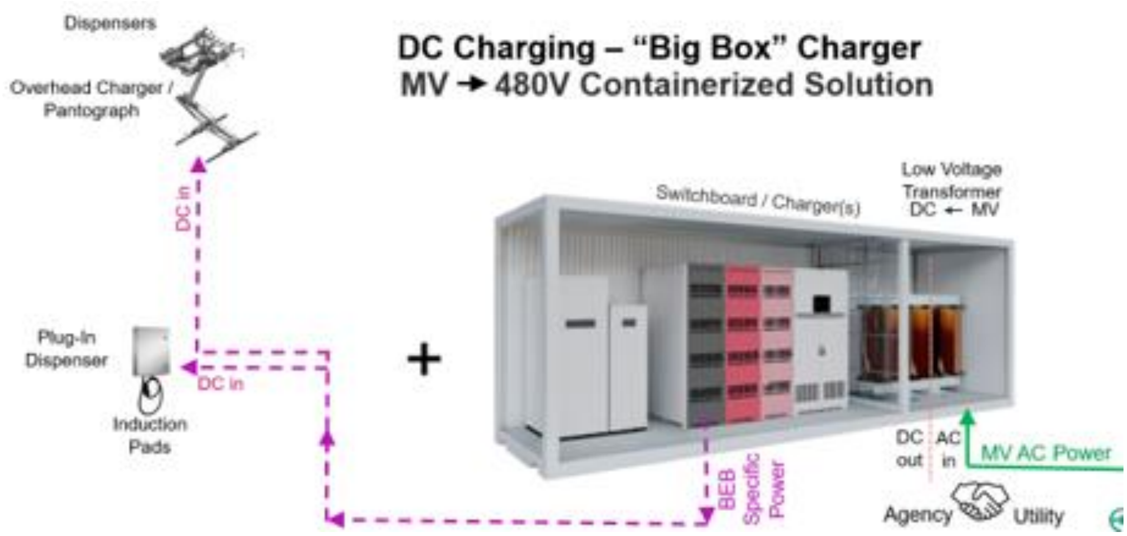


Electrification Master Plan Concept – The Burnsville site is congested, especially on the north side of the site. Multiple options are possible depending on type of chargers selected (singular traditional standalone DC 150kW nominal charger or containerized ‘Big Box’ charger), as shown in Figure 47 – Figure 49.

Figure 47: - Multiple Charger Cabinets Needed for Multiple Dispensers

Figure 48: - Traditional Stand-Alone DC Charger with Remote Dispenser

Figure 49: - Containerized 'Big Box' Charger



All the BEB electrification options at the Burnsville Bus Garage require new Xcel Energy electrical transformers and/or medium voltage switches to supply charging power.

- **Short-Term Only BEB Chargers**
  Three (3) charging cabinets can be installed along either interior side of the bus parking garage.
  - The chargers could be situated against the wall and out of the flow of bus traffic in similar spaces to where return air ducts and concrete columns are currently located. Each charger can energize up to three dispensers so only three (3) DC charger cabinets are needed.
  - However, while the chargers and accompanying dispensers fit to allow five to six (5-6) BEBs to be charged with wall mounted plug-in dispensers, a new electrical switchboard would be required. With the new switchboard there could only be a limited number, approximately 12-16, of perimeter located chargers and this concept would not be fully scalable. Adding perimeter chargers will also add additional equipment within an already congested facility. Additional alterations discussed below would be required at some point in the future to fully electrify.
- **Option 1 – New Enclosed Mezzanine**
  A new enclosed charging mezzanine could be added, potentially located over the existing retention

pond between the new bus parking addition and the bus wash. Utilizing the structural properties of the precast walls, the new charging mezzanine could be designed so as not to reduce the pond's capacity. New electrical transformers would be located at grade within or near the utility easement as shown in Figure 50.

  - New switchboards and thirty-seven (37) stand-alone chargers utilized in a 1:2 charger to dispenser ratio would be housed on the new mezzanine. This elevated position would allow for reduced distance to overhead charging dispensers.
  - However, complicated construction over the retention pond would rely on the structural strength of existing walls for support. A fully enclosed building suspended over a retention pond would create additional costs.

- **Option 2 – Big Box Chargers**
  Big box chargers (which bundle the medium voltage transformer, chargers, and switchboard all in a single container) could be utilized to energize up to thirty-seven (37) dispensers per container. As shown in Figure 50 seventy-two (72) BEBs could be connected for charging at one time. Currently two OEM vendors on the market, Hitachi and Proterra, offer such big box chargers.
  - While configurations vary by OEM, no electrical infrastructure besides the dispensers would be required inside the bus parking area. Depending on OEM, the containers could directly take in medium voltage power, eliminating the need for additional Xcel Energy transformers on site. The big box charger can be purchased in a size suitable for 30 chargers but with only the 3 charging modules needed for 5-6 BEBs in the short-term. Additional charging modules can be added within the containerized system as BEBs are added to the garage. This arrangement would be compatible with both plug-in and overhead pantograph dispensers and even a mix of the two.
  - However, this approach locks in a significant portion of chargers to a single charging OEM. This approach also uses newer technology with limited worldwide and US experience. The size of the big box chargers requires a location somewhere within the southern grassy front yard area. This would limit future staff parking expansion. Large duct bank and penetrations would be needed to bring DC and communications power from the charging container to the dispensers within the garage. While charger OEMs state than their big box chargers are rated for extreme cold temperatures and chargers generate enough of their own heat to remain in operation during these events, interior locations are still preferred when available to minimize potential exposure to weather.

- **Option 3 – Charging Mezzanine Within New Planned Addition**

Elements of the renovation of the Burnsville Bus Garage are still not completed. The new bus maintenance and storage expansion, as shown in blue Figure 50, is currently in conceptual planning and the programmatic elements are not solidified. A portion of the enclosed first floor or second floor shop and storage mezzanine could be reserved to hold new electrical switchgears and standalone charging cabinets.

  - The site footprint would not expand beyond what is currently planned. The enclosed space on the mezzanine would be sized to hold all the electrical infrastructure and only the dispensers would be located in the existing parking garage.
  - However, the charging mezzanine may not allow for the currently planned full shop and storage area, because that space would instead be used for charging infrastructure in new. Two to four new Xcel transformers would be required (4-6 MW) depending on the quantity of chargers.

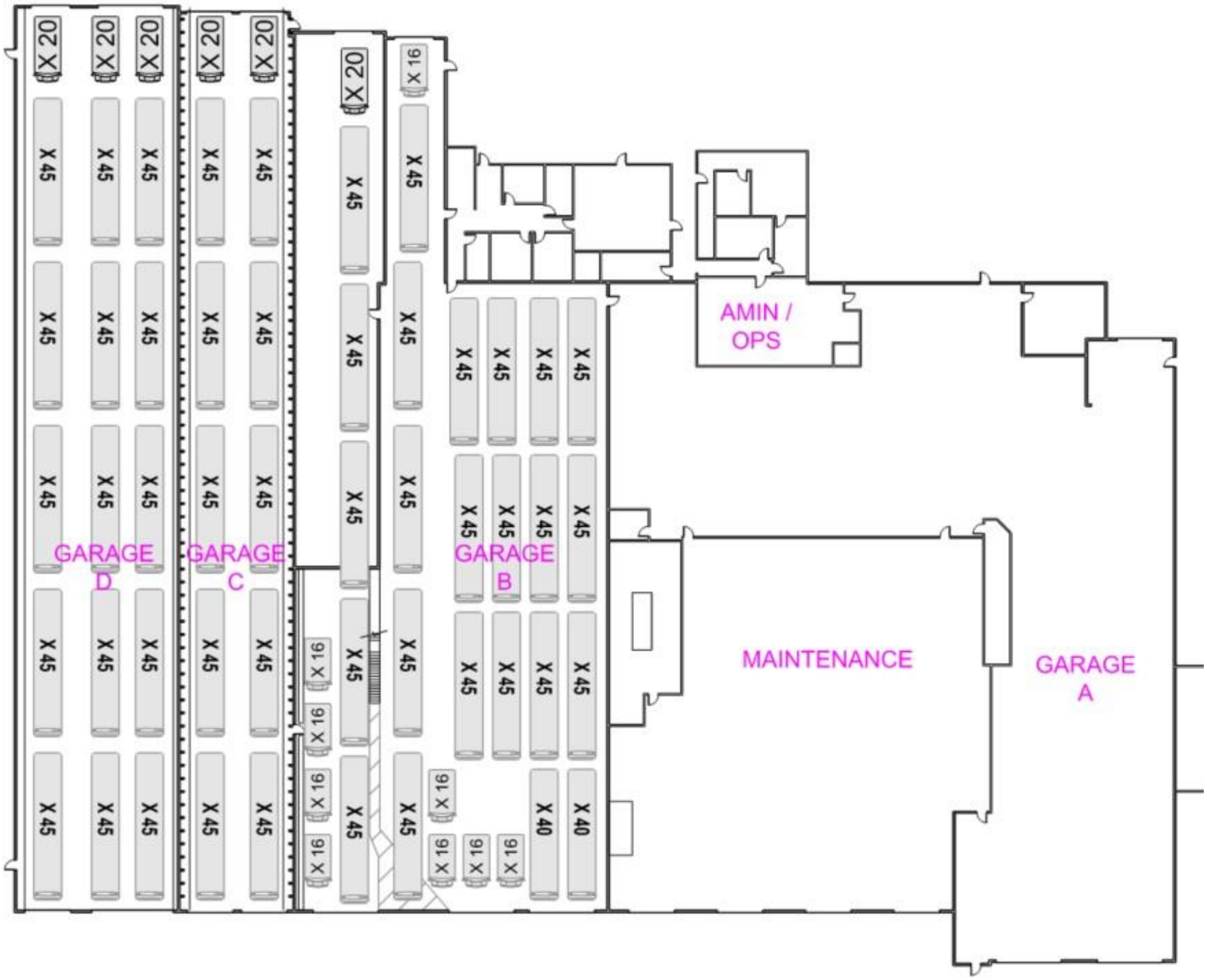
Figure 50 – Burnsville Master Plan Electrification Concepts

SouthWest Transit

Eden Prairie Bus Garage

The Eden Prairie Bus Garage is a former materials recycling collection facility that has been renovated and repurposed to serve as a bus maintenance and operations facility and indoor garage. There are four distinct parking garages within the facility (Figure 51):

Figure 51 – Existing Southwest Operations / Maintenance Facility



Garage A — Currently used for cutaway and smaller vehicle parking. Three Level 2 EV chargers are located within this bay. As part of the 2022 Low Emissions and No Emissions Grant program, new Level 2 EV chargers are being installed with cords accessible to the exterior of this garage along the west wall.

Garage B — Originally designed for recycler trucks lift and dump their beds, this garage has an unusually high thirty four (34) foot height (Figure 52). It is a column free space that currently houses six (6) parking tracks that buses are backed into. Two (2) additional pull-though parking tracks allow buses to enter from the north side, passing through fuel and wash areas. There is an occupied mezzanine over the fuel and wash areas that holds a large conference room. This mezzanine is accessed by two stairs; one perpendicular to the six (6) back in parking tracks and one parallel with the parking tracks that separates the six (6) back in tracks from the two (2) pull thought tracks.

Figure 52 - View into Parking Garage B with High Ceiling & Mezzanine and Access Stair to the Right

Garage C — This garage holds two (2) tracks of pull-through bus and shuttle parking tracks. They are accessed from the north and exit out to the south. The walls are precast tees with ribs facing in towards the parking tracks. There are three (3) foot wide raised concrete curbs along both perimeter walls. The roof structure is lower than in Garage B.

Garage D – This garage holds three (3) pull-through parking tracks. They are accessed from the north and exit out to the south. The wall are precast, but have flat panels with no precast ribs extending in towards the parking tracks. There are smaller eighteen (18) inch raised curbs along the perimeter walls.

The facility is currently served by a single 500kVA transformer that is located at the middle south end of the rear parking lot. There is an Xcel Energy power right-of-way, from which the existing transformer is fed, that runs along the southwest side of the facility, along the adjacent railway tracks. The power feed from the existing transformer connects to existing switchboard located within the Parts Room (Figure 53. The existing switchboard does not have enough capacity to be utilized for new Level 3 chargers and is landlocked by being within the Parts room. This prohibits expansion of the gear. A single charger requires more power than is available in the existing switchboard and would push the switchboard over the limit.

Figure 53 - Existing Switchgear Land Locked in Parts Room

Electrification Master Plan Concept – SouthWest Transit maintains a current fleet of ninety-one (91) vehicles. These come in a mix of 45-ft coaches, 40-ft transit buses, 12 to 20-ft cutaways, vans, and other demand response SUVs. To fully electrify this large and diverse fleet, a new charging electrical service is anticipated to require 6.90MW (Table 34). Achieving this capacity would take four (4) 1,750 kVA transformers. These new transformers will not be able to be installed adjacent to the existing 500 kVA transformer because this location conflicts with plans for a new vehicle storage garage along the south edge of the south parking lot (although the exact timing and siting of this new garage is not yet set). The new vehicle storage garage is currently sized to hold twelve (12) 45-ft coaches or twenty-four (24) demand response shuttles and vans.

Table 34: Southwest Transit Bus Garage Full Electrification Summary

Garage	Vehicles	Chargers	MW
Southwest Transit Bus Garage	91	46	6.90
91 BEBs divided by 2 (1:2 shared ratio) x 150kW charger = 6.90 MW			

- **Transformer Concept**
  Instead of near the current transformer location, the new charging transformers could be placed along the southwest corner of the site in an existing unpaved area adjacent to the Xcel Energy's right-of-way.
  - This potential location is adjacent to the utility right of way and it would potentially be possible to supply feeders from two separate circuits to provide resiliency and redundancy to the future electrified fleet.
  - However, the new transformers are located across the site from the proposed new electric charging infrastructure mezzanine.

- **Charging Mezzanine Concept**
  The proposed new enclosed electric charging mezzanine could be built within Parking Garage B in

the space over the bus parking areas. To keep the garage column free, the new charging mezzanine would be supported along the east edge of Garage B, span over the six (6) parking tracks and be supported by additional columns in line adjacent to the existing mezzanine access stair.

An optional enclosed charging mezzanine extension could be built over the wash exit. This optional mezzanine is proposed to utilize the structural strength of the existing west precast panels for support in lieu of adding additional columns along the western edge of the new mezzanine.

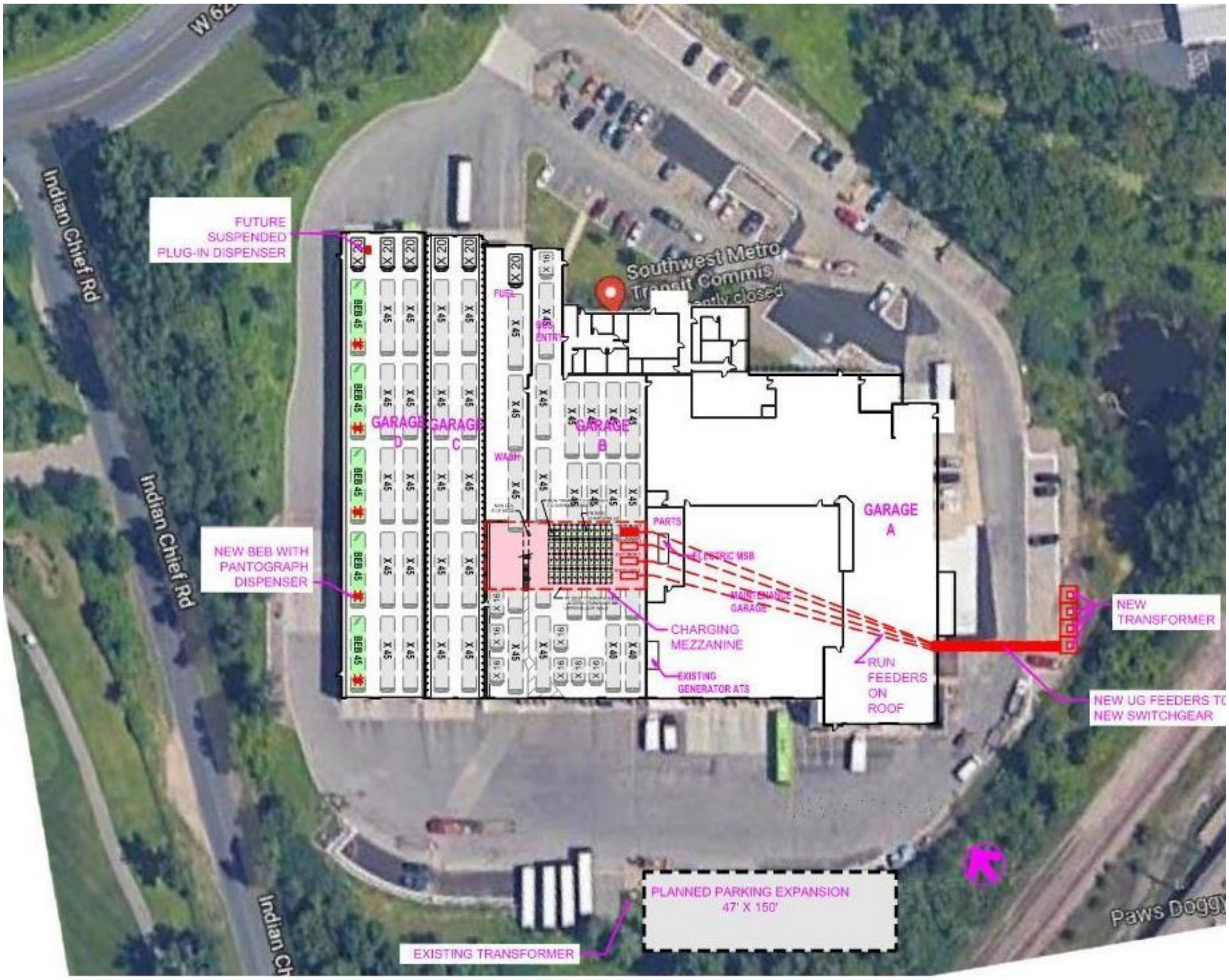
As shown on Figure 50, the new charging mezzanine would hold forty-six (46+) 150kW nominal DC Level 3 chargers. If utilized at a 1:2 ratio (one charger energizes two dispensers) the forty-six (46) chargers will provide adequate charging for each vehicle parked and charged during a normal overnight charging period—up-to a three-hour charging time per bus.

The new electrical mezzanine will fit above the top of the buses and the bottom of the existing roof structure. The floor of the new charging mezzanine would be aligned with the existing occupied mezzanine. The two existing mezzanine access stairs could continue to be utilized and allow for access to the new charging mezzanine. The new charging mezzanine size would also accommodate new switchgear—likely one or two per transformer—ideally in a redundant feed condition with a MTM switchboard (refer to Figure 42). Feeders from the new transformer could rise up the east side of the existing exterior wall of Garage A and run across the roof into Garage B though a roof penetration. This would limit the need to bore or trench across the site and under/through the maintenance bays and would also be less disruptive to the on-going on-site transportation activities.

- Chargers on the mezzanine will be able to have access to supply the charging dispensers suspended from roof structure above the bus parking and charging positions. Dispensers would be a mix of plug-in and pantographs as SWT desires. Smaller height vehicles such as cutaways and vans will only be able to utilize plug-in charging. The charging mezzanine will be interior and lessen the impact of cold weather to charger operations.
- However, construction of the new charging mezzanine will be disruptive to Garage B during construction. The cost of a new charging mezzanine would be higher than that of ground mounted chargers and switchgear (although with the congested site and planned parking garage expansion there were no viable ground mounted spaces suitable for a ground mounted charging infrastructure yard identified in the onsite tour). Garage B roof's is lower than the adjacent Maintenance Garage roof and so no side wall entry into the new charging mezzanine would be possible. Feeder penetrations will need to be added to the Garage B roof.

- **Garage D Charging Concept**
  As shown in Figure 54, an initial electrical master plan concept location for five (5) replacement BEBs is shown for Garage D and highlighted green. The electrification master plan concept will allow the current parking spaces and arrangements to be retained. Based on the width of circulation aisles between parking tracks it is recommended to use pantograph chargers where possible on taller vehicles. While the new charging mezzanine will be large enough to add additional chargers for the planned new standalone parking expansion, the parking expansion should be planned to include electrical and space provisions for chargers and dispensers as part of the expansion. Similar to the main facility, a mezzanine space over the parking area of the new expansion would provide ample space for switchboards, chargers and overhead dispenser power distribution.

Figure 54 - SWT Electrification Master Plan Concept



SouthWest Station

SouthWest Station can be utilized for opportunity charging if desired or needed. Opportunity charging at the pedestrian loading and unloading platforms would use overhead pantographs. Plug-in charging is not recommended in any spaces with public access. If demand response or other shuttle or smaller vehicles are to be charged at the transit center, the recommendation is that they do so in a fenced, secure and non-public location.

6.3.2 Potential Future Facility Screening and Recommendations

MTS, Plymouth, and Maple Grove Transit store their vehicles at operator owned or leased facilities. This arrangement poses issues for funding and constructing the necessary upgrades to support ZEB service. As discussed in Section 5.3.2, for public money to be used to build ZEB infrastructure, MTS and the STPs would need to either (A) own the sites or (B) enter into a lease for the sites for the duration of the useful life of the infrastructure.

Looking beyond existing sites that are currently used by MTS and the STPs, it may become necessary to construct new storage and maintenance facilities for ZEBs in the future. This is because fleet sizes may increase and because new kinds of maintenance and upkeep (including charging) may need to be performed for a ZEB fleet.

Screening Criteria and Methodology

To identify suitable sites for potential future ZEB storage and maintenance facilities, a screening process was applied to parcels throughout the seven-county metropolitan region. This process started with a database of all property either owned by the Metropolitan Council or otherwise used as a park-and-Ride facility.

Properties were screened with Geographic Information Systems (GIS) software on the basis of the following spatial criteria:

- Greater than 140,000 square feet
- Within 0.25 miles of a major arterial roadway or highway
- Within 0.75 miles of an electrical substation
- Not in an environmentally sensitive area such as:
    - Parkland
    - Wetlands
    - Waterways
    - Primary Flood Zone
- Not on residentially zoned land

After this screening process, a selection of several dozen parcels remained. These parcels were then individually scrutinized for compatibility, and a number were eliminated because they were currently in heavy use by a transportation service. This final screening process resulted in identification of eleven suitable parcels distributed throughout the metropolitan region (Figure 55 & Table 35).

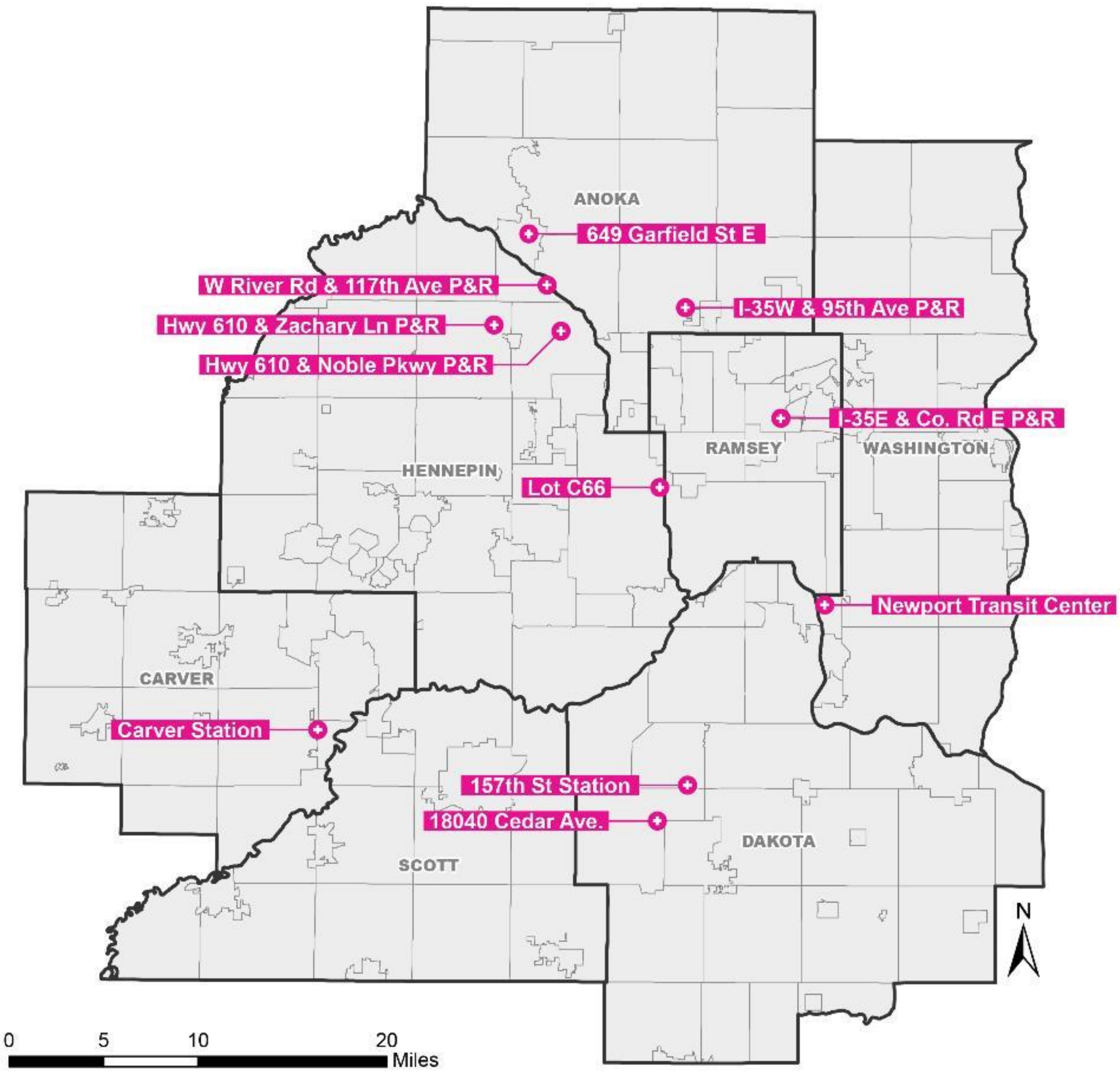


Figure 55 Final Sites Identified as Suitable for Future Bus Facility

Screening Process Results

It is likely that multiple sites distributed across the metro region will be required to meet future storage and maintenance needs. The screening process demonstrated that options for an ideal ZEB facility location are limited, but not zero.

Existing park-and-ride parcels stood out in this framework as particularly well-suited, due to their size, proximity to major roads, and ownership status. In 2020, during the COVID-19 pandemic, service was suspended to over 30 park-and-ride facilities due to low demand. Special focus should be paid to these sites.

Table 35 Potential Battery Electric Bus Facility Sites

Alias	Address	City / County	Current Use	Current Owner
649 Garfield	649 Garfield St. E	Anoka / Anoka	Vacant Lot	City of Anoka
W River Rd & 117 Ave P&R	6020 117th Ave. N	Champlin / Hennepin	Active Park and Ride	Metro Transit
Hwy 610 & Zachary Ln P&R	11332 96th Ave. N	Maple Grove / Hennepin	Inactive Park and Ride	City of Maple Grove
Hwy 610 & Noble Pkwy P&R	4401 95th Ave. N	Brooklyn Park / Hennepin	Active Park and Ride	Met Council
I-35W & 95th Ave P&R	9721 Naples St. NE	Blaine / Anoka	Active Park and Ride	Met Council
I-35E & County Rd E P&R	912 County Rd. E	Vadnais Heights / Ramsey	Active Park and Ride	Met Council
Lot C66	883 29th Ave. SE	Minneapolis / Hennepin	Parking Lot	University of MN
Newport Transit Center	250 Red Rock Cr.	Newport / Washington	Inactive Park and Ride	Washington County Regional Rail Authority
Carver Station	1607 Hartwell Dr.	Carver / Carver	Active Park and Ride	City of Carver
157th St Station	15865 Pilot Knob Rd.	Apple Valley / Dakota	Inactive Park and Ride	City of Apple Valley
18040 Cedar Ave	7385 181st St. W	Lakeville / Dakota	Active Park and Ride	Met Council

Recommendation

For facilities not owned by the Council or another government entity, in order to make ZEB upgrades, the Council would need to either purchase the site or enter into a long-term garage lease of 25 years or greater. In this scenario MTS would lease the garage and assign it to a contractor.

The benefit of a long-term lease is that Xcel Energy would have assurance that the cost of any electrical upgrades they make to deliver expanded electrical service would be recouped over the lease term. Additionally, any MTS or agency electric fleet improvements will also have time for depreciation and to allow full lifecycle use of any improvements. If vacated at the end of the lease the physical charging cabinets and dispensers could be removed and re-installed at a new facility if they were purchased and installed as MTS or agency equipment. The conduits and conductors would need to stay at the leased facility and would likely not be usable (i.e., correct length and configuration) for reuse anyway.

7.0 Long-Term Fleet Management Plan

FTA has requirements on the ratio of spare buses agencies do not have in service.[126] As the FTA funds a portion of transit agency's fleet maintenance, the FTA considers spare ratios "during the review of grant applications proposing to replace, rebuild, or add vehicles to the applicant's fleet."[126] Due to the changes in service over the last three years stemming from the COVID-19 Pandemic as well as operator shortages, MTS and the STPs are operating significantly fewer vehicles than they were in 2019 which has led to spare ratios that exceed FTA thresholds. MTS and the STPs are working with the FTA to develop a plan to bring service levels and fleet size back into alignment by 2025. As a result of these efforts, MTS and the STPs ability to pursue acquiring any new vehicles with federal funding is significantly limited beyond previously initiated procurements regardless of propulsion system. As such the only planned electric vehicle procurements in the next three years are the 10 electric vehicles, including four fully electric coach buses and six new electric SouthWest Prime vehicles, that Southwest Transit was awarded funding for in August 2022 as part of their successful Low-No grant application.

[126] Source: *FTA Circular 9030.1E – Urbanized Area Formula Program: Program Guidance and Application Instructions*, FTA, January 2014

8.0 Milestones

Each transit agency covered by this plan operates in a different context. Because of this, each transit agency may have different goals and definitions of success.

8.1 SouthWest Transit

SouthWest Transit has set a goal of operating 100% zero-emission vehicles by 2050.[13] SWT is already operating three electric vehicles for demand response service. SWT is committed to working with the Met Council to meet its goals.

SWT will continue to pursue discretionary grant opportunities. SWT was recently awarded 2022 Low-Emissions and No-Emission Grant award, which secured over $8 million for the purchase of four fully electric coach buses and six new SouthWest Prime vehicles and associated charging equipment. Funded by this award SouthWest Transit will operate the region's first battery electric coach buses and will also expand its zero-emission bus demand-response fleet.

8.2 Minnesota Valley Transit Authority

MVTA's short-term goals commit the authority to continue to pursue discretionary grant funding for ZEB technology, including but not limited to, Low Emissions and No Emissions grants and Bus and Bus Facilities grants.

8.3 Metropolitan Transportation Services, Maple Grove Transit, and Plymouth Metrolink

In the short-term, MTS, Maple Grove Transit, and Plymouth Metrolink will conduct a study into the feasibility of MTS-owned (or long-term leased) storage and maintenance facilities. These facilities could be used by MTS transit services as well as suburban transit-providers like Plymouth Metrolink. This study will further investigate the impacts of such a facility on operating contracts and other considerations.

In the mid- to long-term future as Metro Transit's BEB fleet grows in size, Metro Transit and MTS may include EEJ priority routes as part of the criteria for determining which fixed routes are operated by MTS and which fixed routes are operated by Metro Transit. This could provide additional time for MTS to make large changes to operations and gain long-term interest in a bus garage. Exploration of this strategy could occur following Metro Transit's planned projects in the short-term to continue gaining valuable experience to share with the region. Such a strategy would likely require that the block/route in question also score High for EEJ priority relative to Metro Transit's blocks consistent with the Metro Transit Zero-Emission Bus Transition Plan.

8.4 Maple Grove Transit

In the short-term, Maple Grove Transit will work with Metro Transit to learn from that agency's zero-emission bus experience. Relying on this first-hand knowledge, Maple Grove Transit will then develop plans for the transition of its own fleet, occurring after 2027.

9.0 Opinion of Probable Costs

MTS and the STPs resolve to implement a plan for ZEB transition with costs that are feasible and responsible. Fiscal impact is one of the four guiding principles for the transition to ZEBs, as discussed in Section 4. As such, all costs associated with the implementation of ZEBs and their supporting infrastructure need to be within the capital and operating budget constraints of each agency.

To highlight the future constraints that might be expected, this section provides a rough summary of the kinds of vehicle, facility, and electrical infrastructure costs that may be incurred in the ZEB transition. Each estimate is based on the needs that were identified in Section 6 of this plan.

9.1 Vehicles

The primary cost variable of the transition to ZEBs will be the cost of switching the transit fleet from gas-powered vehicles to vehicles powered with zero-emission technology. As zero-emission technology changes and improves, the estimates of a future needed fleet size are likely to change, in some cases significantly (Table 36).

9.1.1 Fixed Route Vehicles

Although only about 41 percent of the MTS and STP August 2022 blocks are technically viable for BEB service given current technology, if MTS and the STPs were to replace all vehicles providing fixed route service as of July 2022 with ZEBs at a 1:1 ratio, probable capital costs per agency are estimated to range from $35 million to $60 million for agencies with smaller fleets up to nearly $200 million for agencies with larger fleets such as MVTA. Additionally, as electric coach buses are a larger capital investment than cutaways or even 40-foot buses, agencies with fewer large coach buses, like Plymouth Metrolink, also have lower estimate cost ranges. Probable capital cost ranges presented in Table 36 reflect current costs in 2022 dollars and are subject to the barriers, constraints, and risks identified in Section 11.0.

Table 36: Probable Fixed Route Vehicle Implementation Capital Costs

Transit Provider	Total Fixed Route Vehicles	Cost Range (2022$)*
Maple Grove Transit	39	$49M - $60M
MTS	106	$71M - $87M
MVTA	158	$179M - $219M
Plymouth Metrolink	35	$35M - $43M
SouthWest Transit	67	$83M - $102M

** Note: Fixed route vehicle opinion of probable costs is based on the total number of total fleet regardless of current ownership as of July 2022. Probable costs are informed, in part, by the 40-foot and 60-foot cost estimates used in the Metro Transit ZEB Transition Plan (February 2022) as well as the State of Washington's purchasing schedule and price list last updated in Summer-Fall 2022. Unique itemized costs for each fixed route vehicle type are applied and then total to identify probable implementation costs.*

9.1.2 *Demand Response Vehicles*

As cutaways, SUVs, and Vans are much smaller than traditional heavy-duty fixed route buses, the unit costs for these vehicles are much lower. However, given the state of the industry as of this writing, cutaway models currently on the market offer less value than other BEB types, as discussed in Section 3.3.2 and Section 11.3. This necessitates significantly larger fleets. Based on the Demand Response fleet sizes identified in Section 6.2.2, probable demand response vehicle capital costs range from $2.8 million to $557 million per agency. Because the projected vehicle need for MTS Metro Mobility fleet is over six times greater than the demand response fleet size for other providers, the total probable capital cost range for this fleet is substantially greater than other providers.

Table 37: Probable Demand Response Vehicle Implementation Costs

Transit Provider	Vehicle Type	Quantity	Cost Range (2022$)
Maple Grove Transit	Cutaways	15	$3M - $4M
Maple Grove Transit	SUVs	1	$40K - $50K

Maple Grove Transit	Vans	1	$60K – $80K
Metro Mobility	Cutaways	2,032	$436M - $557M
Metro Mobility	SUVs	42	$1.7M - $2.2M
Transit Link	Cutaways	280	$60M - $77M
MVTA	Cutaways	28	$6M – $7.7M
MVTA	Vans	3	$190K - $250K
Plymouth Metrolink	Cutaways	13	$2.8M - $3.6M
SouthWest Transit	Cutaways	21	$4.5M – $5.8M
SouthWest Transit	SUVs	16	$650K - $830K
SouthWest Transit	Vans	7	$450K - $580K

* Note: Demand response vehicle opinion of probably costs is based on the estimated future Demand Response fleet needs identified in Section 6.2.2. Probable costs are informed, in part, by Oklahoma State Contract SW0797C price schedule updated 5/31/22 and Minnesota State Contract A-175(5) price schedule updated 11/1/22. Unique itemized costs for each fixed route vehicle type are applied and then total to identify probable implementation costs.

9.2 Facilities

Future expected facility costs are dependent on the expected fleet size. Currently nearly 2,500 electric vehicles are estimated to be needed to provide current levels of demand response service. These vehicles could be kept at a large number of smaller garages or a small number of larger garages.

As discussed in Section 6.3.1, the three existing publicly owned garages could be converted to store and maintain electric vehicles. Fully electrifying the three existing garages owned by transit agencies range from about $7.4 million to $15.6 million depending on the facility and electrification scenario (Table 38).

New facilities are also likely to be needed. The cost to acquire and provide access to sites that are currently privately-owned is not knowable and thus excluded from this estimate. In Section 6.3.2, potential garage sites already in public ownership and boasting adequate existing access were surveyed.

Without considering land and right-of-way, the cost of construction for a new one hundred vehicle garage is estimated to be $79 million - $114 million (Table 39). The cost of construction for a new 200 vehicle garage is estimated to be between $92 million - $133 million (Table 39). To accommodate the estimated future demand response fleet needs for about 2,500 vehicles, approximately 25 100 vehicle garages or 13 200 vehicle garages would be needed. This substantial increase in garage needs is primarily driven by the estimated future Metro Mobility fleet size should this fleet be transitioned to a fully electric fleet with current technology.

Table 38: Probable Implementation Costs for Electrifying Existing Transit Agency-Owned Garage Facilities

Facility	Facility Size (BEBs Stored / Operated)	Cost Range
Eagan Bus Garage		
Short-Term *BEB Existing Power Option*	3	$127K - $162K [a]
Short-Term *BEB New Power Option*	5	$1.2M - $1.45M [b]
Full BEB Master Plan	98	$15.6M - $19.9M
Burnsville Bus Garage		
Short-Term *Only BEB Chargers*	6	$1.14M – 1.46M [c]
Option 1 *New Enclosed Mezzanine*	74	$11.6M - $14.9M
Option 2 *Big Box Chargers*	72	$6.53M - $8.35M
Option 3 *Charger Mezz Within New Planned Addition*	74	$13.4M - $14.5M
SouthWest Transit Garage		
Early Pilot BEBs	5	$2.14M - $2.74M [d]
Full BEB Master Plan	91	$15.1M - $19.3M

a note: non-scalable solution supporting max one (1) charger
b note: cost includes boring for new + 3 future xfrmr, MTM switchboard to support 48 BEBs and is scalable solution
c note: cost includes new transformer and new switchboard with scalable capacity
d note: cost includes buildout of full mezz and first switchboard with additional capacity. Pilot costs and other interim buildout cost directly reduce full build out cost total

Table 39: Probable Implementation Costs for New Garage Facilities

Transit Provider	Cost Range (per facility, 2022$) [a]	Cost Range (Full Build Out, 2022$) [a]
100 Vehicle Garage	$60 Million - $115 Million	$1.54 Billion - $2.9 Billion
200 Vehicle Garage	$70 Million - $135 Million	$910 Million – $1.8 Billion

a note: Costs exclude real estate acquisition, relocation, and contingency

9.3 Chargers

The ZEB fleet of the future will need an expansion of electrical infrastructure to provide power in garages. In addition, while not identified as needs at this point in time MTS or the STPs, in the future, may wish to pursue on-route or opportunity charging to allow for a longer range on vehicles. Opportunity charger pricing will vary by distance from utility entrance to new switchgear and quantity and type of chargers. Price in Figure 40 assumes 40kW charger cabinet energizing pantograph on mast, new concrete transformer pad to accept utility provided transformer and new switchboard.

Table 40: On-Route or Opportunity Charging Installation

Charger Type	Cost Per Item
Opportunity Charging	$747,500

9.4 Available Funding Resources and Resulting Funding Shortfalls

Based on the funding needs identified above and an assessment of MTS and STP's current projections, MTS and the STPs must identify additional resources that can cover the cost of electrifying their fleets. Traditional formula funding will support the transition to a zero-emission fleet (e.g., using federal formula funds to cover the base price of a zero-emission bus and Low-No grants for the incremental cost difference), but MTS and the STPs will likely require additional funding to offset the higher costs associated with zero-emission technology. To put some context around the capital budget implications, in the 23-28 Capital Improvement Plan, the annualized average federal funding is $32M and Regional Transit Capital (RTC) is $21M. MTS and the STPs may choose to pursue funding opportunities at the federal, state, and local level, as necessary and as available. Federal Funding sources MTS and STP may consider include:

- United States Department of Transportation (USDOT)
    - Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Grants
- Federal Transportation Administration (FTA)
    - Bus and Bus Facilities Discretionary Grant
    - Low-or No-Emission Vehicle Grant
        - Metropolitan & Statewide Planning and Non-Metropolitan Transportation Planning
    - Urbanized Area Formula Grants
- State of Good Repair Grants
- Federal Highway Administration (FHWA)
    - Congestion Mitigation and Air Quality Improvement Program
    - Flexible Funding Program –Surface Transportation Block Grant Program
- Environmental Protection Agency (EPA)
    - Environmental Justice Collaborative Program-Solving Cooperative Agreement Program
- Statewide Competitive Grant Funds
    - MnDOT Vehicle and Infrastructure/Clean Transportation Grants
- Met Council (Regional Funds)
    - Regional Transit Capital Grants
    - Regional Solicitation Grants (Federal DOT Discretionary Grants)

10.0 Workforce Development

The transition to zero-emission transit vehicles requires a skilled workforce. Congress and the Federal Transit Administration have recognized the importance of this by placing a requirement to examine and evaluate an agency's workforce as part of its Zero Emission Fleet Transition Plan. The plan is required to receive funding under FTA's Buses and Bus Facilities Competitive Grant Program and/or the Low or No Emission Competitive Grant Program. Grants include set asides for workforce development.

Zero-emission technology represents a significant change for the transportation sector. The internal combustion engine has been the leading ground transportation propulsion system for one hundred years. The programs and policies to develop the workforce to operate and maintain the internal combustion engine are well developed, from equipment manufacturers to technical schools to apprenticeship programs. Knowledge and expertise of the internal combustion engine are widely available. Knowledge and expertise in zero-emissions technology, however, are not widely available. As an emerging technology, there is a scarcity of skilled zero-emission technology operators and maintainers, as well as increasing demand for their skills as more transit agencies, transit contractors, and related competing industries expand their use of the technology.

Prior to the COVID-19 pandemic, nearly 450,000 people were employed in public transportation—96 percent were employed in operations, including 63 percent in vehicle operations, 14 percent in vehicle maintenance, and 9 percent in facility maintenance.[127] Approximately 40 percent of public transportation jobs are held by Baby Boomers—workers aged 55 and older.[128] This generation is increasingly leaving the workforce and taking their knowledge and experience with them. A successful transition to a zero-emission fleet will require intentional approaches to current and future transit workforce challenges.

10.1 Workforce Challenges

According to the National Transit Institute, "the public transportation industry faces a significant skills shortage among its frontline workforce, driven by changing demographics, retirement of experienced workers, pervasive technological advances, increased demand for service, and competition from other industries."[129] The transit workforce trend in the Twin Cities metro area mirrors the national trend and is compounded by the complexity of a workforce made up of multiple agencies and contracted staff. Although each agency and contractor have policies and practices to recruit, train, and retain the staff needed to operate the regional transit systems, significant challenges remain in each of these areas.

10.1.1 Recruit

Transit agencies, paratransit agencies, and contractors in the metro area struggle to fill vacant operator and maintenance positions even as many have increased wages, offered hiring bonuses, and worked proactively to remove or reduce other barriers. From a nearly 24/7 work environment to staffing peaks during peak travel demand to negative interactions with the public, transit faces recruiting challenges even before factoring in competition from different industries.

10.1.2 Train

The transition to zero-emission means new technology and equipment for operators and technicians to learn to use and maintain. This equipment is often more complex, from increased system computer interfaces to battery electric propulsion systems. The need for training is evident in the risk of incorrect

[127] Source: *2021 Public Transportation Fact Book,* American Public Transportation Association, 2021.
[128] Source: *Workforce Implications of Transitioning to Zero-Emission Buses in Public Transit*, National Center for Sustainable Transportation White Paper, Jakovich, S., and Reeb, T., June 2022
[129] Source: *Advancing Frontline Workforce Development Meeting: Synthesis*, National Transit Institute, 2020.

diagnostics and incorrect repairs. The transition to zero-emission technology also challenges the typical training process of passing knowledge from experienced staff to inexperienced staff through apprenticeship, mentorship, and on-the-job training. Finally, access to training, especially online or virtual training, is a challenge for a workforce that typically does not have an assigned internet-connected computer workspace like administrative or management staff.

10.1.3 Retain

Agencies and contractors face challenges retaining experienced staff, with "vehicle operators in all transit modes…experience the highest turnover due in large part to voluntary terminations."[129] Retention challenges include wage and career growth potential in competing industries and 24/7 work environment. With the transition to zero-emission technologies, the competition for a skilled workforce will likely be higher in the near term requiring intentional steps to retain trained workers.

10.2 Workforce Development Strategies

Overcoming the challenge of recruiting, training, and retaining a skilled zero-emission workforce requires intentional action. It's important to understand what is required of the frontline workforce, where its skills are lacking, and how programs can be successfully implemented that prepares current workers, and ensures future hires have the skills, to work with zero emission infrastructure.

10.2.1 Needed Skill Sets

The Transit Cooperative Research Program's (TCRP) Research Report 219: Guidebook for Deploying Zero-Emission Transit Buses (2021)[40] identifies three key best practices relating to personnel training and development:

- Ensuring adequate safety training related to high voltage hazards and hydrogen fuel (as applicable).
- Requiring OEMs to conduct first responder training and specifying training materials, needs, and responsibilities in the procurement contract.
- Careful coordination of training prior to or in conjunction with bus delivery.

At a high level, workforce training should cover three phases:

- Phase 1: Foundational Electrical/Electronics Principles.
- Phase 2: Zero-Emission Bus Systems and PPE.
- Phase 3: OEM-Specific Training.

Phase 1: Electrical/Electronics (E/E) Principles

Learning elements covered in the foundational phase of training will include (but will not be limited to) the following key elements identified by the International Transportation Learning Center (ITLC):

- **Foundational Skills**
    - Ability to read basic wiring diagrams
    - Safe handling of low-voltage batteries
    - Troubleshooting and repairing basic circuit faults
    - Inspecting and testing relays
    - Demonstrating proficient use of digital multi-meters
    - Repair wiring and terminals
- **Multiplexing**
    - Reading and interpreting ladder logic diagrams
    - Using LED indicator lights to troubleshoot the system

    - Identifying symbols used for input and output electrical systems
- **Electronics Skills**
    - Ability to inspect and test capacitors, diodes, and other electronic modules
    - Differentiate between analog and digital signals
    - Ability to describe the purpose of data communication protocols CAN/SAE J1939 and SAE J1708
    - Differentiate between direct current (DC) and alternating current (AC)
    - Demonstrate use of an oscilloscope and a graphing multimeter
    - Inspect and troubleshoot gateway modules

Phase 2: Zero-Emission Systems and Personal Protective Equipment

After establishing foundational skills, workforce development training should focus on familiarizing workers with the structure, major components, and functionality of both Battery Electric and Fuel Cell Electric Buses, as well as the associated elements of Personal Protective Equipment (PPE), Safety, and High-Voltage Systems. This will focus on the application of fundamental electronics skills for high-voltage bus systems to ensure safe and effective maintenance.

Phase 3: OEM Training

Once maintenance technicians have a solid foundation in E/E components, ZEB systems, and safety protocol for working on high-voltage systems, the focus of training can shift to familiarizing with the specific make and model of buses ordered by the agency.

10.2.2 Skills Assessment

While the introduction of zero-emission technology will be a dramatic shift away from internal combustion engine maintenance, the existing workforce and future hires with mechanical training have the base knowledge and skills that can be built upon to successfully maintain this new technology.

The baseline assessment for skills of maintenance technicians should be their proficiency at diagnosing and repairing electrical and electronic faults on traditional buses (12- and 24-volt electrical systems). These foundation skills will aid in the transition to ZEB-specific skills, including working on systems with upwards of 800 volts and using specialized tools and instruments to diagnose electrical faults. The assessment of these baseline skills should be done in coordination with contracted bus operators to tap into the expertise of maintenance supervisors, who will be able to estimate the percentage of technicians who are already proficient at using specialized tools to diagnose issues.

Technicians should be evaluated to determine who holds National Institute for Automotive Service Excellence (ASE) Transit Bus certifications for Electrical/Electronic systems (H6), or comparable training from the automobile and trucking sectors. Beyond the certifications, employees may have previous internal training from another employer, trade school, or third party that may give the employee experience with similar systems. Employees who have previous experience with hybrid drive internal combustion engines are well suited to working with zero emission technologies due to their understanding of electric drive motors. Agencies should focus on developing these skills across the maintenance department as they will not only prepare for future zero emission vehicles and infrastructure but are transferable to the electrical and ITS components on existing vehicles as well.

10.2.3 Identifying Skills Gaps

It is important to engage the workforce in the process of assessing the gap between baseline skills and those needed to work on ZEBs. The success of this technology depends on the commitment of frontline staff to maintain this equipment safely and effectively. It benefits the agencies to support contracted bus operators in the development of surveys and questionnaires for specific subject areas that allow technicians and workers to rate their own abilities on a scale from ahigh level of familiarity to complete unfamiliarity, with varying levels of ability and comfort between the two. Surveying shop-floor supervisors, trainers, and leads (along with documenting technicians with ASE E/E certifications and other training) will provide a better understanding of existing E/E and ZEB skill levels among the current workforce. The high-level goal of well-developed surveys is to identify skill gaps with the goal of effectively harnessing workforce training funds, resources, and worker hours on-the-job to close the gaps.

It's important to communicate to the technicians that the sole purpose of this survey is to develop an understanding of current levels of competency in certain skills that will be used to inform deployment of targeted trainings. A low score on the survey only represents the opportunity to provide additional training. There is potential for those workers with strong existing skills in E/E to be tapped as the primary targets for training on ZEBs or to be identified as mentors to support other workers in future training.

At this stage in the process, it is expected that most of the workforce will need training in high-voltage systems and safety, as well as the new forms of diagnostic tools associated with ZEB maintenance. Implementation of ZEB buses will require a shift to new diagnostic tools and methods. Familiarity with the new diagnostic procedures and troubleshooting techniques should be emphasized through early stages of workforce training and before bus delivery; training material from the selected ZEB OEM (if identified) can aid in development of these procedures and techniques.

10.2.4 Training Development Strategies

The transition to zero emission technology will be one of the biggest changes to transit vehicle maintenance since the introduction of the internal combustion engine. The workforce may be apprehensive about how this will affect their job security, particularly when management administers a survey to determine their skill level. To combat this anxiety, agencies should develop a committee that includes both operations management and labor leaders (whether they are union leaders or respected technicians in non-represented shops) to ensure that labor is a partner in the development of a training program. Their inclusion will support technicians in assessing their abilities openly and accurately in the skills gap survey. They will also be able to provide valuable feedback on what parts of the training are or are not effective when maintenance staff begin maintaining zero emission equipment.

This team can offer insight into the training requirements needed to overcome skills gaps and the responsibilities of the vehicle OEM. As technical skills may be best transferred by engaging trainees through a combination of hands-on exercises, computer simulations, classroom instruction, training mock-ups, and on-the-job exercises, the team can determine what learning aids and hands-on exercises should be implemented for classroom learning to supplement education on theory and principles to reflect the variety of ways individuals learn. There is significant value in the existing workforce's experience and working collaboratively throughout the process will be a key to the program's success.

Each vehicle OEM will have its own specific high-voltage safety and training protocols and will be experts in the training needed for their specific equipment. Once a manufacturer is chosen, agencies should coordinate with the OEM to administer training to supplement in-house safety training, policies, and procedures related to high-voltage safety. Agencies should coordinate with their utility providers and first responders to become familiar with best practices and training on high-voltage safety practices.

10.2.5 Workforce Training Funding

Similar to the price difference between an internal combustion engine (ICE) bus and a ZEB, the training costs to prepare the workforce of this emerging technology will initially represent an increased investment.

Elements to include when considering training budgets involve:

- Classroom training hours
- Instructor hours (Preparation and Instruction)
- Instructor hourly wages and benefits
- Instructor costs per class
- Instructor cost per trainee
- On-the-job learning training hours
- Mentor hours and hourly cost
- Mentor cost per trainee
- Facilities cost
- Training materials/mock-ups/software/simulation cost

A key component in estimating training costs is referencing the results of the skills gap analysis. It can be assumed that the existing workforce and future transit staff will initially lack the knowledge to support this new technology. This will require an increased investment in the development of contracted employees than may have previously been expected. There are currently FTA grants that not only provide funding for workforce development but require grant funds be spent on it. This investment will empower agencies to take necessary steps to develop the technical skills needed in their frontline workers.

10.2.6 Regional Collaboration

The Metropolitan Council and Metro Transit have built successful workforce development programs, including the Metro Transit Revenue Equipment Technician Program, Metro Transit Bus Mechanic Technician Apprenticeship, construction trades training for rail construction projects, and the Environmental Services Construction Inspection Training Program. These programs are often partnerships with workforce development organizations and community technical colleges to recruit, prepare, or train potential staff to meet known or anticipated workforce needs. Regional collaboration with Suburban Transit Providers to expand and build a workforce development program for zero-emission technologies may improve efficiency and share costs across all organizations. Regional collaboration will also provide an opportunity to create an intentional information-sharing environment among the existing organizations, which can be beneficial when implementing new and evolving technology.

11.0 Barriers, Constraints, and Risks

The advantages of ZEBs are well known. This technology promises to decrease greenhouse gas emissions, reduce reliance on fossil fuel consumption, improve air quality, and provide a more pleasant experience for riders.

Many of the challenges to ZEB implementation are also well known—at least among transit agencies. ZEBs have higher capital costs for vehicles and supporting infrastructure, increase energy costs per mile, face limitations in range, necessitate extensive coordination with utilities on electrical upgrades and special rates for electricity, raise issues of facility ownership, and portend changes to service and operations.

While good planning and foresight can help to lessen the impacts of these local challenges, some potential barriers to ZEB implementation are a result of factors outside of MTS and STP's control. These include 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 Contracted Services & Facilities Operational Intricacies

MTS and some STPs have structured their operating contracts to put the daily obligation of providing service to the selected contractor. While MTS and Plymouth staff interact daily with contractors to ensure contract and regulatory compliance in addition to collaborative resolution of issues, the contractor generally provides a turnkey experience for the operation of the agencies' services. The agencies provide specific pieces of capital equipment, such as vehicles and associated ITS equipment, but rely on their contractors to provide the facilities, maintain associated systems, handle insurance requirements, and manage all personnel necessary to deliver the service.

MVTA and SWT have a more integrated management and operating environment. For both organizations, their contractors work out of agency owned facilities and interact closely with the STPs daily in order to provide service. This relationship is more "hands-on" where the groups collaborate to determine what operational changes and facility investments are needed to improve the efficiency of the service.

Because of this structure, SWT and MVTA are better positioned to introduce zero emission vehicles at their agencies. The cooperative relationship with their contractor and direct ownership of facilities infrastructure provides flexibility to handle the operational changes that this technology will bring. SWT has successfully introduced several battery electric SUVs into its Prime microtransit service.

Assuming MTS and other STPs decide to provide its own facilities for its contractors, there are several considerations that need to be made in the contract structure. These considerations include:

- Will the agency act as a landlord of the facility and "lease", at no cost, to the contractor who would take responsibility to maintaining the property? This would likely be similar to the arrangement the contractors have with commercial leases now.
- Will the agency provide any equipment beyond the building and zero emission vehicle infrastructure, such as furnishings, maintenance tools, and non-computer hardware, or will that be the responsibility of the contractor?
- How will the agency handle any changes to the facility a contractor may want to make, such as potentially investing in a security system to control access to the parts room?
- Because the agency will own the facility, there will be more opportunities to help control operating costs through investments like energy efficient lighting, installing solar panels,

contracting with a separate company for services like snow removal, etc. These new requirements may decrease operating costs but could require an increased level of agency involvement not previously necessary.

- The ownership of a facility also introduces new risks. Should there be a defect in the agency supplied equipment or facilities, the agency may be liable if an injury or property loss occurs that is outside of the operating contractor's control.
- Will two operating contractors be allowed to work out of one facility? Which one is responsible for maintaining the facility? How will that affect liabilities like workers compensation requirements for either contractor?
- How will the agency audit the facilities to ensure they remain in a state of good repair?
- How will the agency close out the contract and potentially transfer the facility to a new contractor at the end of its term?

The agencies currently have language in their contracts providing standards on how contractor should maintain the provided vehicles, revenue equipment, charging infrastructure, and associated capital items. This can be built upon to include any responsibilities contractors may have for facilities maintenance.

Consideration should be given to how operating contracts will be structured before building or renovating a facility for agency ownership. It may be beneficial to consult with SWT and MVTA or other transit agencies to determine best practices on how to best manage such facilities with an operations contractor.

11.2 Long-Term Level of Service Changes

11.2.1 Operator Shortages

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.[130] While the pandemic has exacerbated the operator shortage, it existed prior to the pandemic. Fortunately, MTS and the STPs have not been as impacted by an operator shortage as many of their peers. To address this constraint, MTS and STPs are working with their contractors to expand and retain its existing workforce, including providing pay increases over and above what was initially agreed to in the operating contracts. Moving forward, the lack of operators may constrain MTS and STP's ability to transition to ZEBs.

MTS and the STPs have taken efforts to expand and retain its existing workforce including increased wages mid-way through operating contracts

11.2.2 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).[131] Lockdowns, business closures, remote-learning, and telecommuting were largely responsible for the sustained 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

[130] Source: *Bus driver shortage hurts D.C. region's ability to return to pre-pandemic transit service levels*, Washington Post, November 2021.
[131] *Impacts of COVID-19 on public transit ridership*, International Journal of Transportation Science and Technology, November 22, 2021.

active transportation modes rather than by transit as officials 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 three years. As lockdowns have been lifted, an increasing portion of the public has become vaccinated, and cases of the virus diminished in number and severity, transit ridership has begun to rebound. However, overall transit ridership was still down 35 percent in the third quarter of 2022 compared to the equivalent period of 2019.[132] 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 in Minnesota, are preparing for an increase in demand for neighborhood-to-neighborhood trips, as well as non-peak period trips, while peak period trips to 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.[133]

11.3 Production and Supply Chain Constraints

A significant 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 $55M to $1.1B, for the next 5 years.[134] 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.

Currently there are five large BEB manufacturers that are approved to sell heavy-duty 30-foot+ BEBs to U.S. transit agencies: ElDorado, New Flyer, Proterra, Gillig, and Novabus/Volvo.[135] Although many other manufacturers are considering entering the U.S. BEB market (including BEB manufacturers with operations in other countries such as Van Hool and Arrival) 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.

The market for battery-electric coach buses is even more limited as only MCI/New Flyer has a battery-electric coach bus that has passed Altoona testing at the time of writing. The battery-electric coach bus market will likely be driven by demand from private operators, as public transit agency usage of this vehicle type is less widespread.

Makers of light- and medium-duty electric vehicles (e.g., vans and cutaways) such as Ford, Chevrolet, GreenPower Motor Company, Lightning eMotors and Rivian face these same problems and more. Cutaways are typically manufactured in a multi-stage process by which the vehicle is built upon a truck frame and then batteries and a drive train are installed to the base model. This process can involve

[132] Source: APTA Q3 2019 and Q3 2022 ridership data used to compare ridership to pre-pandemic levels, https://www.apta.com/research-technical-resources/transit-statistics/ridership-report/, December 21, 2022
[133] Source: *After Massive Transit Losses during the Pandemic, Agencies Are Planning a Comeback*, Urban Institute, December 2021.
[134] Source: Federal Transit Administration, January 2022.
[135] 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*).

moving incomplete vehicles from one location to another and can involve sourcing parts from a more diverse supply chain, adding further complications.

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 these different vehicle types. Thus, manufacturing capacities for both BEB and charger manufacturers are likely to constrain BEB deployment in the U.S. for the next several years.

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

With the increase in available federal funds and the surge of agencies being compelled to go green, transportation economists are predicting that the electric bus market will grow by 31 percent between 2021 and 2026.[136] This trend may pose difficulties for hundreds of U.S. transit agencies, as they simultaneously line up to acquire BEBs and charging infrastructure.

In addition to the buses and chargers themselves, spare parts and replacement batteries may be just as difficult to acquire in the coming years. Although BEBs share many parts with 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 factor in transit agencies' 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 an agency's ability to transition to BEBs in the short-term.

11.4 Speed of Innovation

Traditionally, MTS has issued large multi-year procurements for MTS and STP 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 MTS paying a premium for each bus as well as the supporting infrastructure, as manufacturers are generally more price competitive for larger orders. Many of MTS' internal costs associated with a procurement are generally the same regardless of the size of the procurement. However, doing procurements more often would increase MTS and STP's staff time spent completing 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 Build 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.

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

Charging scenarios and equipment are typically determined based on an analysis of routes and blocks in a transit agency's network. If MTS or STP 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, MTS and the STPs are planning to start with smaller ZEB and supporting infrastructure procurements before gradually increasing procurement size.

Another risk for MTS and the STPs 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.

11.5 Electrical Grid Capacity

Compared to conventional diesel buses, BEBs require significantly greater 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 MTS and STPs, but also other Xcel Energy or relevant electrical utility customers. As a result, the available electrical capacity on the grid could be utilized by other customers. For example, entities such as a large delivery or commercial fleets adopting electric vehicles (e.g., USPS, 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 MTS and the STPs have 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 MTS or an STP. For this reason, it will be essential that MTS, the STPs, and Xcel Energy review project plans on an annual basis and stay in close coordination with each other's capital plans.

11.6 Strategies and Objectives to Address Barriers, Constraints, and Risks

Throughout this Transition Plan, MTS and the STPs have identified several objectives and strategies to address and mitigate the barriers, constraints, and risks associated with transitioning to ZEBs (Table 41). As MTS and STP 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 41: 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	MTS and STP will collaborate with Xcel Energy to develop project timelines that coordinate with Xcel Energy timelines for planning, engineering, construction	Section 11.5
Level of Service Changes	Continually evaluate ZEB service implementation prioritization methodology to tailor service to ridership and available workforce levels	Section 6.2
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 11.4 Section 6.2
Level of Service Changes	Provide paid training to operators and mechanics	Section 11.2.1
Speed of Innovation Supply Chain Constraints	Evaluate multiple ZEB and supporting infrastructure manufacturers in smaller orders before proceeding to larger orders	Section 11.4 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 11.4 Section 11.3

12.0 Updates to the Transition Plan

MTS and the STPs envision the Transition Plan to be a living document that will be revised and updated periodically as MTS, the STPs, and the transit industry's knowledge of ZEBs continues to grow. At a minimum, MTS and the STPs will update the Transition Plan every five years for submittal to the Minnesota State Legislature. With each update to the Transition Plan, MTS and the STPs will provide an update regarding the progress MTS and the STPs 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.

390 Robert Street North
St Paul, MN 55101-1805
651.602.1000
TTY 651.291.0904
public.info@metc.state.mn.us
metrocouncil.org

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