Washington Metropolitan Area
Transit Authority

Zero-Emission Bus Transition Plan

March 2023

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ACRONYMS

Acronym	Description
AC	Alternating current
BEB	Battery-electric bus
BESS	Battery-electric storage system
BGE	Baltimore Gas & Electric Company
BRT	Bus rapid transit
CBA	Collective bargaining agreement
CNG	Compressed natural gas
DC	Direct current
EFC	Equity Focus Communities
FCDOT	Fairfax County Department of Transportation
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air conditioning
ICEB	Internal combustion engine bus
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour
kVA	Kilovolt-ampere
LEED	Leadership in Energy and Environmental Design standards
NFPA	National Fire Protection Association
O&M	Operations and maintenance
OEM	Original equipment manufacturer
Pepco	Potomac Electric Power Company
PVR	Peak vehicle requirement
RNG	Renewable natural gas
SAFE	Metro's System Safety and Environmental Management Department
SCM	Supply Chain Management
SMR	Steam methane reforming
ZE / ZEB	Zero-emission / Zero-emission bus

EXECUTIVE SUMMARY

PROJECT OVERVIEW

The Washington Metropolitan Area Transit Authority (Metro) has committed to transitioning its bus fleet to zero-emissions to reduce greenhouse gas emissions and improve air quality for the region. Metro has already begun the process to transition its approximately 1,600-bus Metrobus fleet and associated operating facilities to zero-emission technologies.

In 2021, Metro's Board of Directors adopted a resolution that commits the agency to 1) transition to a 100% zero-emission bus (ZEB) fleet by 2045, and 2) cease the purchase of internal combustion engine buses, including diesel, diesel-hybrid, and compressed natural gas, by 2030. This *Zero-Emission Bus Transition Plan* (Plan) presents a baseline framework and strategy for meeting and even exceeding these goals. It does so in consideration of Metro's service requirements, facility constraints, equity goals, resilience requirements, and workforce needs.

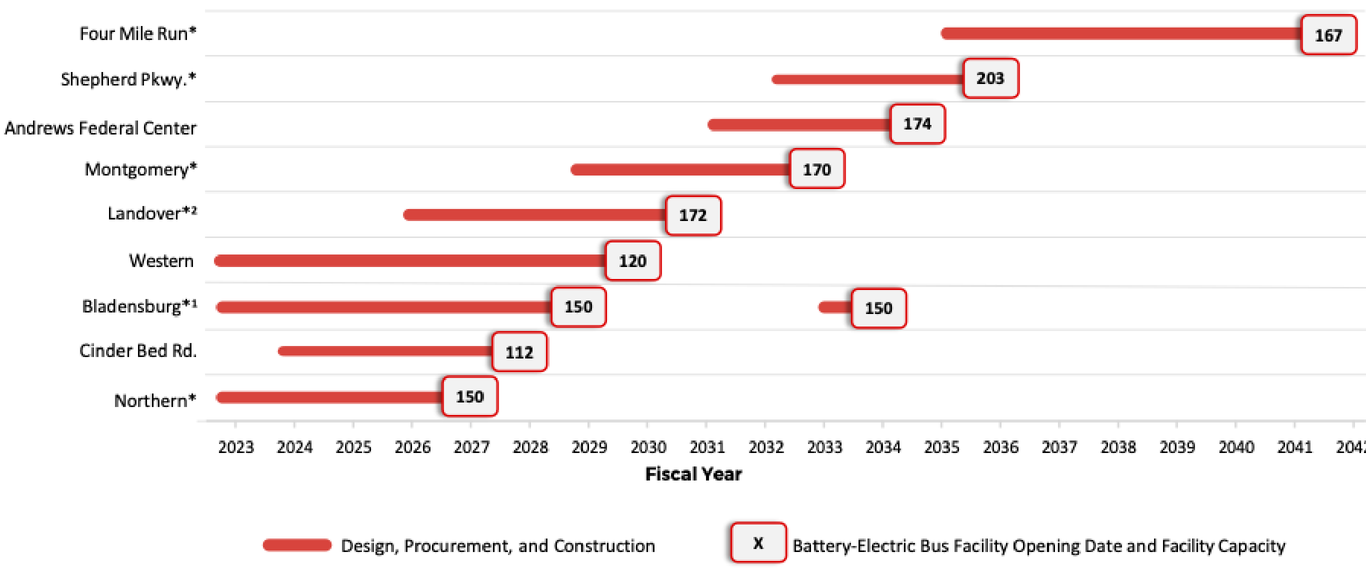
The Transition Plan sets out the actions necessary to complete the conversion to ZEBs by 2042 – three years ahead of the Board goal – and Metro is committed to continually updating this plan as opportunities arise to accelerate conversion further. The Plan is therefore a living document that will be updated periodically as technologies, markets, and service needs evolve, and additional opportunities to accelerate deployment are identified.

KEY FINDINGS

This ZEB Transition Plan presents the process, investments, and activities to convert the Metrobus fleet to zero-emissions by 2042. To meet this timeline, Metro must act aggressively and effectively on bus division construction and bus acquisitions, prepare the workforce for the transition, coordinate with the region's utilities to ensure power is delivered quickly, and pursue needed funding.

This Plan provides a conceptual rollout plan for conversion or reconstruction of Metro's bus divisions in 2041 (Fiscal Year 2042 in the figure below) to support a full zero-emission fleet by 2042. The garage conversion strategy balances fleet requirements, equity, and service objectives. Metro is already preparing for reconstruction work at Northern and Bladensburg garages, and Cinder Bed Road, Landover, and Western will be the other early conversion/reconstruction garages (Figure ES-1).

Figure ES-1. Projected Bus Facility Strategy and Timeline



Source: WSP, Metro

Notes: *High Equity Priority

[1] Bladensburg Stage 1 enables the garage to support approximately 150 battery-electric buses; Stage 2 will provide charging infrastructure for the final approximately 150 battery-electric bus charging positions.

[2] Landover will be constructed in two phases. The first phase's projected completion is in FY30, and the second phase's projected completion is in FY31.

The Transition Plan examined a wide variety of relevant activities and requirements necessary to convert Metro's existing fleet, facilities, and workforce to support ZEB operations. The incremental cost to Metro over the life of this program is projected to be $2.3 billion. This cost includes the incremental cost of new vehicle types and associated maintenance equipment, charging equipment and infrastructure, and operating and maintaining the fleet and facilities (above and beyond the cost to operate and make investments to support the current bus fleet).

This section summarizes the key findings in each of the research areas supporting the Plan, including Technology, Service Delivery, Equity, Facilities Assessment, Business and Workforce Planning, and Resilience.

TECHNOLOGY

Metro is focused on ZEBs – those with no tailpipe emissions. Currently, battery-electric and hydrogen fuel cell electric are the two types of zero-emission technologies in the market. Metro initially will deploy battery-electric buses and associated charging equipment and will continue to evaluate the cost, technical, and commercial maturity of fuel cell electric buses. As technology and service needs evolve, Metro will continue to reassess the state of zero-emission technologies and costs relative to its service requirements and may adjust its mix of technologies to meet Metro's operational needs.

SERVICE DELIVERY

Metrobus service is well-suited for the range that battery-electric buses provide – especially when considering that technology will continue to evolve. While current battery-electric buses do not have the range of fossil fuel powered buses, initial modeling showed that battery-electric buses can support 92% of Metro's service blocks. Even in extreme temperature conditions, battery-electric buses can meet 78% of Metro's current service. This high block completion rate is primarily due to relatively short durations and distances traveled of Metrobuses (medians of five hours and 60 miles, respectively).

Metro will first deploy battery-electric buses on the blocks that can be served by the current technology. To serve the few longer blocks, Metro will continue to assign its existing conventional internal combustion engine fleet (diesel, hybrid, and CNG) through the transition and, if battery range improves sufficiently over the next several years, later assign electric buses to those blocks. If range continues to be a challenge, Metro will consider hydrogen fuel cell electric buses (which have a longer range), opportunity charging, or both. Metro will continue to revisit battery-electric bus modeling and performance results as the bus network changes and evolves, and as the organization gains real-world experience operating these buses.

EQUITY

Metro is committed to providing equitable transportation, including with the transition to ZEBs. ZEBs can bring benefits to riders and residents near bus garages and bus routes by improving air quality, reducing noise, and improving overall quality of life from investment of new technology in the community. Many of Metro's garages, including Northern, Bladensburg, Shepherd Parkway, Montgomery, Landover, and Four Mile Run, are high priority for conversion from an equity standpoint (equity considers rider and adjacent community populations, particularly those of color, low-income and/or with disabilities). Of those, Northern, Bladensburg, and Landover are early conversion garages, enabling a balanced equity approach to the order of facility conversion.

FACILITIES ASSESSMENT

Preliminary facility analysis and design concepts find that Metro's garages are suitable for the conversion to facilities that can support battery-electric buses with sufficient vehicle capacity to support Metro's current service requirements. The estimated battery-electric bus capacity following conversion of all bus divisions is 1,568 buses, which very closely aligns with the organization's number of assigned buses (1,578)[1] and forecasted Fleet Plan requirements.[2]

To support battery-electric bus charging, all bus divisions will require power upgrades completed by Metro's electric utility providers: Potomac Electric Power Company (Pepco), Dominion Energy, and Baltimore Gas & Electric Company (BGE). Each garage is estimated to require between 12 and 22 MW of power. Metro has already begun and will continue to work closely and early with utilities to ensure that required infrastructure and power can be provided at each garage in alignment with the proposed project schedule.

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[1] As of December 2021

[2] See *Metrobus Fleet Management Plan*, 2021 (available at wmata.com)

BUSINESS AND WORKFORCE PLANNING

The transition creates the opportunity for staff throughout Metro, especially frontline workers, to gain new skills to support the new technology. The transition to ZEBs will directly affect employees, their assignments, and supporting equipment across the Metro system. This impact extends to human resources, procurement, mechanical, operations, and information technology-related functions, among others. The Plan identifies organizational, staff, and functional actions to support the transition.

Metro's Bus Maintenance and Operations departments will be the most immediately affected due to training and education requirements that are needed prior to maintaining a battery-electric bus. Bus Maintenance has approximately 800 personnel that will be affected by the transition to new technology, requiring specialized training in topics such as bus electrical systems, high voltage safety, personal protective equipment needs, diagnostics and troubleshooting, and dispatching. Metro's approximately 2,400 bus operators will also require training on safely and effectively operating a new propulsion system, including driving styles for energy conservation, dashboard familiarization, and monitoring states of charge. Training impacts include both the time for Metro's trainers to develop and deploy the training, as well as for all relevant employees to complete the new training.

Safety remains paramount during and after the transition. New training throughout the organization will help familiarize employees with the new technology, especially the high-voltage battery-electric bus systems. Additionally, Metro will train first responders to respond to any ZEB incidents to understand how to safely disengage a bus while keeping themselves safe.

RESILIENCE

The near-term focus on battery-electric buses increases Metro's reliance on the electric grid to provide bus service, and power outages can jeopardize bus operations. As Metro converts/reconstructs each bus division to support ZEBs, the Transition Plan provides a framework to evaluate site-specific needs for resilience solutions based on an assessment of the likelihood of power disruptions that are specific to that site and the lifecycle costs associated with various resilience measures. Potential resilience measures include: opportunity charging, microgrids, redundant utility power feeds to the facility, battery energy storage systems, and backup generators.

NEXT STEPS

To ensure a successful transition to ZEBs, Metro will undertake a series of actions in the areas of infrastructure, vehicles and service, workforce, and program planning. These include the following:

INFRASTRUCTURE

Advance the Plan's initial garage designs into detailed designs and construction plans, focusing first on the garages that will convert earlier in the transition. The Transition Plan provides a high-level summary of garage capacity and design to accommodate charging infrastructure. However, advanced design is required for each garage to start construction. Metro should fast-track the advanced designs and construction plans for garages scheduled to be completed earlier in the transition (i.e., Cinder Bed Road and Landover), and continue design and construction work already underway for Northern and Bladensburg. Accelerating this process will help Metro adhere to its schedule targets for facility ZEB conversion.

Continue actively engaging Pepco, Dominion Energy, and BGE to ensure off-site power infrastructure upgrades are ready when Metro completes construction at individual garages. The timing of power upgrades is a critical prerequisite for installing charging equipment and ensuring the facility phasing timeline is met – battery-electric buses cannot operate without power. Metro's utility team must work closely with the utilities to ensure facilities are planned, designed, and delivered to meet operational needs while optimizing cost savings for Metro, including through the application of rate-based subsidy programs.

Integrate resilience into facility design. Shifting to battery-electric buses increases Metro's reliance on the electric grid (electric system risks can stem from extreme climate events, cyberattacks, and other). Resilience strategies should be determined at time of facility design to incorporate the latest electric grid and climate data.

Test and implement charge management systems. Charge management software captures data from both the vehicles and charging infrastructure to optimize when, where, and how to charge a battery-electric bus fleet. A key benefit of charge management software is the ability to balance energy requirements that align with daily fleet pull-out requirements with the utility rate structure. Metro must review, test, and implement charge management systems that can be integrated with scheduling and yard management systems to ensure buses are charged and assigned to blocks that can be completed, while mitigating impacts to the electric grid and controlling costs.

VEHICLES/SERVICE

Capitalize on Metro's Zero-Emission Bus Deployment: Phase 1 to inform future ZEB efforts. Metro will collect data from its 12-bus deployment to assess the performance of buses and charging equipment in Metro's operating conditions, and better understand how the technology will meet our service and operational needs when scaled up. Metro will also incorporate lessons learned on safety, facility design, and bus and charging equipment specifications for the broader transition.

Conduct a ZEB technology study to assess fuel cell electric bus and battery-electric bus market and technology trends to guide future fleet requirements. Metro's ZEB Technology Study should evaluate forecasted economics, infrastructure and fueling requirements/sources (e.g., forecasted hydrogen production near the Metro region), and other operational considerations for fuel cell electric buses in comparison to battery-electric buses. Such a study allows Metro to monitor ZEB market and technology trends and implement the most viable, cost-effective, and feasible ZEB technology in the future. The study could also include demonstration and pilot testing of fuel cell electric bus technology.

WORKFORCE

Prepare the workforce for the transition to ZEBs. Training for Metro staff, specifically bus operations and maintenance related to battery-electric bus specific differences from hybrid and internal combustion engine buses, is needed for a successful transition. Vehicle maintenance staff will need specialized training in topics such as bus electrical systems, high voltage safety, personal protective equipment needs, diagnostics, and troubleshooting. Example bus operations specialized training include how to operate a battery-electric bus (including regenerative braking techniques), dashboard familiarization, and checking battery state of charge. As part of preparing the workforce, Metro also will assess the existing Collective Bargaining Agreement to ensure workforce requirements and target dates for implementation align with future maintenance and operations requirements of battery-electric bus fleet and supporting facilities.

Develop a comprehensive internal stakeholder engagement and communication plan. This outreach effort (including with union and frontline staff) will help explain Metro's Transition Plan, further build consensus on business and workforce planning needs, and empower employees to be a meaningful part of the transition.

PROGRAMMATIC

Aggressively pursue funding. Significant capital and operational costs are required to enable a successful ZEB transition. Federal, state, and regional funding opportunities, such as grant funds, will help Metro undertake facility designs, infrastructure upgrades, and workforce training. Metro will work with elected officials, the utilities, and other regional partners to build support for projects and explore necessary funding.

Create ZEB equity-specific tracking metrics. Equity-related metrics assist Metro in assessing how equitably the ZEB transition is proceeding and whether there are any disproportionate and unexpected impacts. These measures can track how equitably ZEBs are being deployed, delivering service, and creating benefits (e.g., air quality improvements) for Metro's riders and communities.

Continue to collaborate with other transit agencies in the Washington Metropolitan Area. Metro will continue to work with peer transit agencies to coordinate ZEB transition plans and seek opportunities to reduce costs and duplicative efforts, including utility coordination, first responder training, and community outreach and engagement. Metro also will continue to act as a regional partner to test and evaluate strategies for shared opportunity charging. Although investing in opportunity charging may not be a short-term need for Metro's own service, it can help provide operational flexibility, and leveraging Metrorail's station land may enable a more efficient transition to zero-emission technology for the region.

1 INTRODUCTION

1.1 OVERVIEW

The Washington Metropolitan Area Transit Authority (Metro) is in the process of transitioning its approximately 1,600-bus Metrobus fleet and associated operating facilities to zero-emission technologies as quickly as possible. Every trip that residents and visitors take with the Metro system instead of a car helps reduce greenhouse gas (GHG) emissions and improve air quality in the service area. Transitioning to zero-emission technology makes our transit system more environmentally sustainable, further improves local air quality, and improves the overall experience for Metrobus riders and the region.

Transitioning the Metrobus fleet to zero-emission buses (ZEBs) is a direct response to the Metro Board of Directors' (Board) resolution, adopted in June 2021, that aims to 1) transition to a 100% ZEB[3] fleet by 2045, and 2) cease the purchase of internal combustion engine buses (ICEBs), including diesel, diesel-hybrid, and compressed natural gas (CNG), by 2030. Metro's goals are in alignment with the trajectory of the larger transit industry, as agencies across the country adopt similar goals to transition their respective fleets to ZEBs. Metro has already initiated several zero-emission-related projects, including the completion of an electric bus alternatives assessment and the launch of Metro's Zero-Emission Bus Deployment: Phase 1. Phase 1 allows Metro to test 12 battery-electric buses (BEBs) (10 standard and two articulated) from different manufacturers beginning in 2023. Through Phase 1, Metro will collect data to better understand BEB performance, maintenance, and operational requirements. Data collected over the two-year program (expected to conclude by the end of 2024) will help inform future decisions on technology, infrastructure, and vehicle procurement.

To achieve its ZEB transition goals, Metro developed this document, the *Zero-Emission Bus Transition Plan* (Plan), to establish the strategy to successfully transition the fleet to all ZEBs. The Plan analyzes elements of Metro's existing service and operating conditions in the context of ZEB parameters, performance, and requirements. The findings of these analyses establish a transition strategy that defines the preferred technology, infrastructure design criteria, procurement strategies, construction and phasing timelines, costs, potential funding opportunities, and other key elements to guide Metro in the next steps towards meeting its goal to cease the purchase of ICEBs in 2030 and transition the entire fleet to ZEBs by 2045.

[3] A ZEB is either a battery-electric bus (BEB) or fuel cell electric bus (FCEB).

1.2 PURPOSE AND APPROACH

The Plan is a guidance document that outlines key program components and dependencies to support the successful evolution of the Metrobus fleet to 100% zero-emission operations. The Plan identifies a feasible path forward for Metro in light of current technology and bus service requirements; the Plan and our implementation strategy will update as these things evolve to ensure we transition our fleet as quickly as possible.

While a transition to ZEBs is expected to yield environmental benefits[4] for Metro and the service area, the transition to an all-ZEB fleet requires strategic planning to ensure that the adoption is efficient and effective. As compared to ICEBs, ZEBs – BEBs in particular – have reduced ranges (miles), are currently more expensive, and will require changes to training, maintenance, and standard operating procedures and protocols. For these reasons, Metro analyzed how the transition will impact the agency to ensure that it is well-prepared to integrate new technology into its operations.

The Plan is a culmination of interdependent analyses that were developed to evaluate Metro's service, facilities, equity goals, resilience needs, and workforce. Each analysis evaluated Metro's existing conditions in the context of ZEBs and identified strategies and next steps to achieve Metro's full-fleet transition. Once a technical approach was established – including technology and facility layouts – Metro developed a construction and procurement timeline for the transition that aligned with existing vehicle retirement/procurement schedules; ongoing construction activities; and Metro's goals, policies, and typical processes. The proposed transition schedule was then used to forecast the estimated lifecycle capital, operations and maintenance (O&M) costs, and potential environmental cost savings of the transition. The underlying assumptions and baseline parameters were based on input provided by Metro's subject matter experts, peer transit agencies, and ZEB market information.

The path to an all-ZEB future has its challenges, and Metro will approach its transition in a strategic and iterative way. Given the dynamic nature of service, operations, and market conditions, the Plan is considered a living document that will be updated periodically to capture pertinent changes to assumptions, timing, and technologies.

[4] ZEBs lack many of the moving parts and components that ICEB propulsion systems have. This characteristic reduces the amount of and frequency of routine maintenance, such as fluid changes. This ultimately reduces the amount of spare parts, tools, and labor needed to conduct maintenance. Brake wear is also significantly reduced due to regenerative braking which is made possible by the electric motors on ZEBs.

1.3 PLAN STRUCTURE

Following the Executive Summary, the Plan is organized into seven general sections, including:

- **Introduction** (this section): provides an overview of the Plan, its purpose, and the general flow and structure of the Plan.
- **Background**: provides general information on Metro, including its guiding policies and efforts, service area, and existing conditions and technologies.
- **Methodology**: describes the inputs, methodology, and outputs generated for/from each respective subject area. As previously noted, the Plan is a living document; the Methodology section will be revisited, adapted, and updated periodically as technologies and parameters change – which, in turn, may affect the results and conclusions of the Plan.
- **Fleet and Facility Analysis**: presents each garage's existing conditions and proposed ZEB improvements.
- **ZEB Transition Strategy**: details the strategy, including the construction timeline (and associated bus relocation strategy) and other transition-related considerations, such as business and workforce planning, resilience, and risks.
- **Costs and Funding**: presents lifecycle cost estimates and strategies that Metro can pursue to fund the transition.
- **Next Steps**: a summary of near-term (i.e., next five years) next steps to transition the Metrobus fleet to ZEBs.

2 BACKGROUND

The following section provides an overview of Metro's history, guiding policies and efforts, existing conditions, and ZEB technologies.

2.1 METRO HISTORY

Metro was created by an interstate compact in 1967 with a purpose to plan, develop, build, finance, and operate a balanced regional transportation system in the national capital area. Today, Metro is the third largest heavy rail transit system and sixth largest bus network in the U.S., providing approximately 100 million annual trips to residents and visitors in and around the nation's capital.[5]

Metro is supported by three core services: Metrorail, Metrobus, and MetroAccess. Metrorail is a heavy rail transit service that consists of six lines, 97 stations, and 128 miles of track. Metrobus is a fixed-route bus service that is supported by approximately 1,600 buses that serve 11,500 bus stops. Lastly, MetroAccess is Metro's paratransit service that provides approximately one million annual trips (2022).[6]

2.2 GUIDING POLICIES AND ACTIVITIES

The ZEB Transition Plan aligns with and supports regional policies to reduce emissions and improve sustainability. Metro has already initiated many projects, policies, and procedures to support the ZEB transition. Neighboring states, peer transit agencies, and others in the Metro service area have also adopted policies and established goals to improve air quality for the greater region. The following section summarizes some of the regional policies and actions that Metro is currently taking to support the transition.

2.2.1 REGIONAL POLICIES

DISTRICT OF COLUMBIA

The Clean Energy DC Omnibus Amendment Act of 2018 addresses the impacts of climate change by establishing goals and provisions to reduce GHGs in 2032 to 45% below the 2006 baseline. As it relates to transportation, the Act mandates that 100% of public buses, public fleets, private fleets of more than 50 vehicles, and taxis and limousines are to be zero-emission by 2045 (and 50% zero-emission by 2030). The Act also calls for the development of a strategy for at least 25% of vehicles registered in DC to be zero-emission by 2030, and beginning in 2021, 100% replacement of public buses and school buses with electric public buses upon end of their useful life.

[5] Metro Snapshot 2022 (https://www.wmata.com/about/history.cfm#:~:text=Metro%20began%20building%20its%20rail,a%20week%20with%201%2C500%20buses).
[6] Ibid.

MARYLAND

The Maryland Greenhouse Gas Emissions Reduction Act Reauthorization (GGRA)[7] set a 40% reduction target for statewide emissions by 2030 from 2006 levels. MDOT MTA subsequently established a goal to convert 50% of its Core Bus fleet in Greater Baltimore to ZEBs by 2030. This goal was also included in the more recent Greater Baltimore Regional Transportation Plan, along with a longer-term goal to convert 95% of the Core Bus fleet to ZEBs by 2045. The passage of SB 137 in 2021, which was amended by the enactment of SB 67 in 2022, confirmed that MDOT MTA is prohibited from entering into new procurements for non-ZEBs beginning in fiscal year 2023.

While some counties are following Maryland's GGRA guidance (Prince George's County as an example), Montgomery County in Maryland set its own more ambitious goal to reduce GHG emissions by 80% by 2027 and 100% by 2035 that includes significant investment in solar, buildings, and transportation.[8]

VIRGINIA

The Virginia Clean Economy Act establishes a clean energy standard in the state by requiring the electric grid to be 100% clean energy by 2050. The state plans to accomplish this by investing in renewable sources and strategies, such as onshore/offshore wind, distributed solar, and other in-state renewable technologies.

Further, in March 2021, the governor signed legislation directing the State Air Pollution Control Board to implement a low- and zero-emissions vehicle program for motor vehicles with a model year of 2025 and later.

2.2.2 RECENT METRO PROGRAM ACTIVITIES

CONSTRUCTION

- **Northern Bus Garage Reconstruction Project** – Northern Garage is a 100+ year-old facility that is not operational. The facility was closed in June 2019 and is expected to be demolished and replaced with a purpose-built, 150-bus, BEB facility with an estimated reopening in 2027.
- **Bladensburg Bus Garage Reconstruction Project** – Bladensburg Garage is currently undergoing construction improvements that will modernize the facility and improve essential bus operations and maintenance. The reconstruction includes the allocation of space for BEB infrastructure.
- **Western Bus Garage Replacement Project** – The existing Western Bus Garage has reached the end of its lifespan. The facility is becoming increasingly costly to maintain and cannot support Metro's transition to ZEBs. In 2022 the Metro Board approved acquiring an adjacent site to relocate Western Bus Garage and construct a new facility that will support a 100% zero-emission bus fleet upon opening. Planning and site acquisition efforts are underway.

PLANS AND POLICIES

- **Metrobus Fleet Management Plan** – In 2021, Metro released its Fleet Management Plan (FMP), detailing how Metro will modernize and maintain its bus fleet and supporting facilities to meet service

[7] 2030 GGRA Plan Executive Summary.
[8] MCG, Office of Energy and Sustainability, About Energy & Climate.

demands between 2021 and 2038. During this time span, the FMP assumes that Metro will progressively increase its ZEB fleet and concurrently cease the purchase of ICE buses, with its last batch of diesel buses being delivered in 2023. Further, the FMP accounts for purchasing only ZEBs in 2030 and the associated impact on the Metrobus fleet mix. Metro's existing procurement schedule is crucial to developing strategies to transition to ZEBs. For example, based on the Federal Transit Administration's (FTA) useful life requirements, buses are expected to be in operation for at least 12 years or 500,000 service miles, whichever comes first. Given that Metro will have ICEBs in the fleet until in the late 2030s, these buses may serve a crucial role in addressing service range shortfalls as ZEB technology evolves.

- **Zero-Emission Bus Deployment: Phase 1** – Metro is currently evaluating BEB performance under its Zero-Emission Bus Deployment: Phase 1. The program will consist of 12 BEBs (10 standard length and two articulated) operated from the Shepherd Parkway Garage, and will allow Metro to evaluate scalability, interoperability, and other performance-related metrics to better understand how BEBs and charging equipment perform.

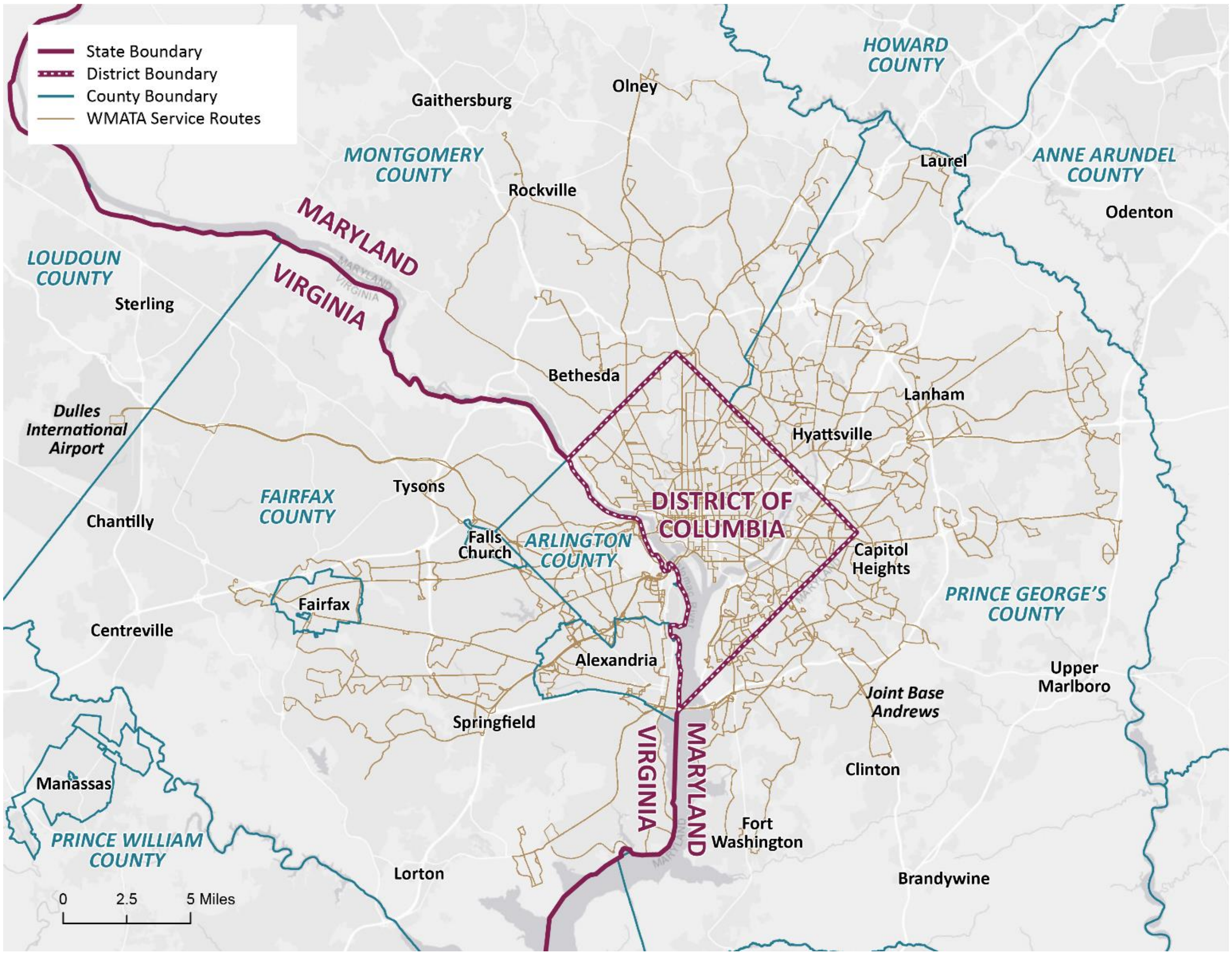
2.3 EXISTING CONDITIONS

2.3.1 SERVICE AREA

Metro serves a population of approximately four million within a 1,500-square mile jurisdiction.[9] The Metrobus service area encompasses the District of Columbia; Maryland's Montgomery and Prince George's counties; and Virginia's Arlington and Fairfax counties and cities of Alexandria, Fairfax, and Falls Church. Figure 2-1 illustrates Metro's service area as of 2021 (the time of the Plan's ZEB modeling efforts).

[9] Metro Milestones & History (2022) (https://www.wmata.com/about/history.cfm).

Figure 2-1. Metro's Service Area



Source: WSP, Metro (2021)

2.3.2 EQUITY RIDERS AND EQUITY FOCUS COMMUNITIES

Advancing equity within Metro and the ZEB transition are key agency goals. Equity is an important consideration for the deployment of any new technology or transportation project, including ZEB initiatives. The operation of ZEBs will yield benefits for both riders and residents by eliminating tailpipe emissions and reducing the noise pollution associated with the operation of existing buses.

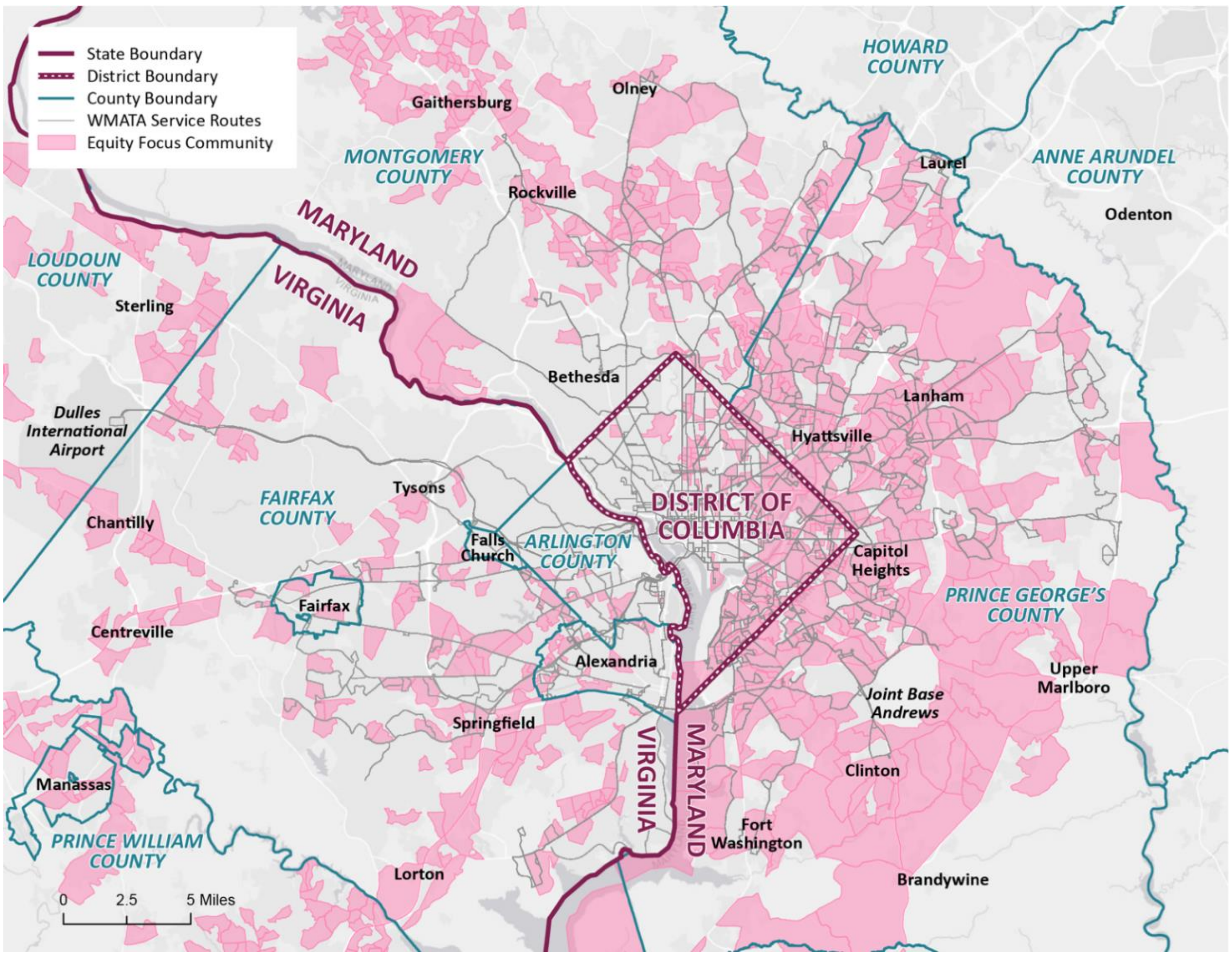
Bus riders tend to have greater social and environmental vulnerability. They often live in areas with poor air quality, and experience higher rates of disability and disease exacerbated by vehicle exhaust. The equitability of Metro's ZEB implementation must be measured in part by the public health benefits accruing to these communities.

Metro wants to ensure that groups that have been traditionally underrepresented are actively considered and prioritized in the decision-making process so that the people who will benefit the most from ZEBs can start accruing those benefits sooner.

The Metrobus system supports many Equity Riders and Equity Focus Communities (EFCs). Equity Riders are riders of Metro's system that are from historically disadvantaged populations, especially people of color, people with low-incomes, and/or with people with disabilities.[10] EFCs are block groups (communities) within the region that have the highest concentrations[11] of residents who identify as one or more of the aforementioned characteristics. Providing and prioritizing service to these riders and communities is essential to Metro's mission.

Figure 2-2 illustrates the EFCs in the service area. Most EFCs are concentrated on the eastern side of the service area. There are heavy concentrations of EFCs in Prince George's County surrounding the District of Columbia and in southeastern Montgomery County.

Figure 2-2. Metro's Service Area – Equity Focus Communities



Source: WSP, Foursquare ITP (2022)

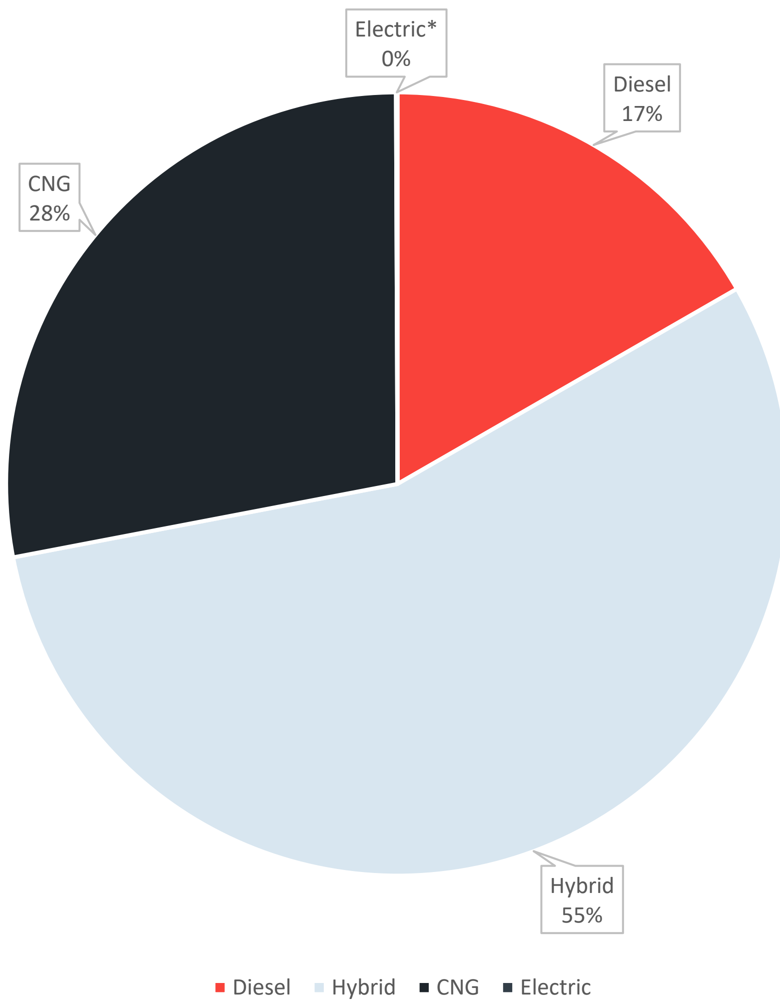
[10] Metro Equity Toolkit (September 2021).
[11] Top 30% of the region's block groups.

2.3.3 SERVICE AND FLEET

Metrobus' 1,578-bus fleet supports 179 routes and 2,005 service blocks (December 2021) (Table 2-1). The Metrobus fleet consists of three vehicle length categories: small, standard, and articulated. Small buses are typically 30-35 feet, standard buses are typically 35-42 feet, and articulated buses are 60 feet or more. The Metrobus fleet is also powered by a range of fuel/propulsion types, including diesel, diesel hybrid, CNG, and battery-electric (Figure 2-3).

Metro also owns and operates approximately 1,560 non-revenue service vehicles that support operations (driver relief, road calls, etc.) and are stored at garages and other locations throughout the system. These vehicles are not part of the bus fleet ZEB transition; however, as Metro converts its garages to support ZEBs, it may be useful to understand the number of non-revenue vehicles assigned to those garages. When converting garages to support ZEBs, Metro could also consider ways to build in flexibility to account for the future conversion of the non-revenue fleet that could happen at a later time.

Figure 2-3. Metrobus Fleet by Propulsion Type



Source: Metrobus 2021 Fleet Management Plan

Note: *The current inventory contains one battery-electric bus.

Table 2-1. Metrobus Service and Fleet Summary

Garage	Operational Days	Routes	Blocks	Peak Vehicle Requirement	Assigned Vehicles
Andrews Federal Center	Daily	13	155	72	158
Bladensburg	Daily	22	304	175	270
Carmen E. Turner Maintenance and Training Facility	No scheduled service.*				1
Cinder Bed Road	Daily	11	108	52	121
Four Mile Run	Daily	33	324	165	216
Landover	Daily	27	327	155	190
Montgomery	Daily	23	290	160	238
Northern	No scheduled service.**				
Shepherd Parkway	Daily	25	247	136	189
Southern Avenue	Weekdays Only	8	108	61	82
Western	Daily	17	142	94	113
West Ox	No scheduled service.**				
Total		**179*****	**2,005**	**1,070**	**1,578******

Sources: WSP, Metro December 2021 Bus Assignment, Metro December 2021 GTFS

Notes: *The Carmen E. Turner Maintenance and Training Facility is exclusively used for training and maintenance, no revenue service vehicles are dispatched from here.

**Northern and West Ox Garages currently are closed and do not operate revenue service. Northern is expected to reopen in 2027, and there are no plans to reopen West Ox for revenue service.

***Number of routes are approximate as some are operated from multiple garages.

****The "Assigned Vehicles" values are equal to PVR plus a spare factor (usually 20%) to account for maintenance programs. Current bus assignments at some Metro garages are greater than this number due to temporary COVID-19 service adjustments and ongoing bus requirements to support regular, but temporary, service increases during subway system repair/construction and special events (i.e., Federal government events, demonstration blockades, ready reserve buses, etc.).

2.3.4 GARAGES

Metrobus buses are currently dispatched from and maintained at nine of Metro's 11 bus operating garages (Carmen E. Turner is a training and maintenance facility).[12] Table 2-2 summarizes the location, status, functions, fuel type, and fleet associated with each garage. Figure 2-4 shows the location of Metro's garages in the context of the service area.

[12] Metro's Northern and West Ox garages are not currently active.

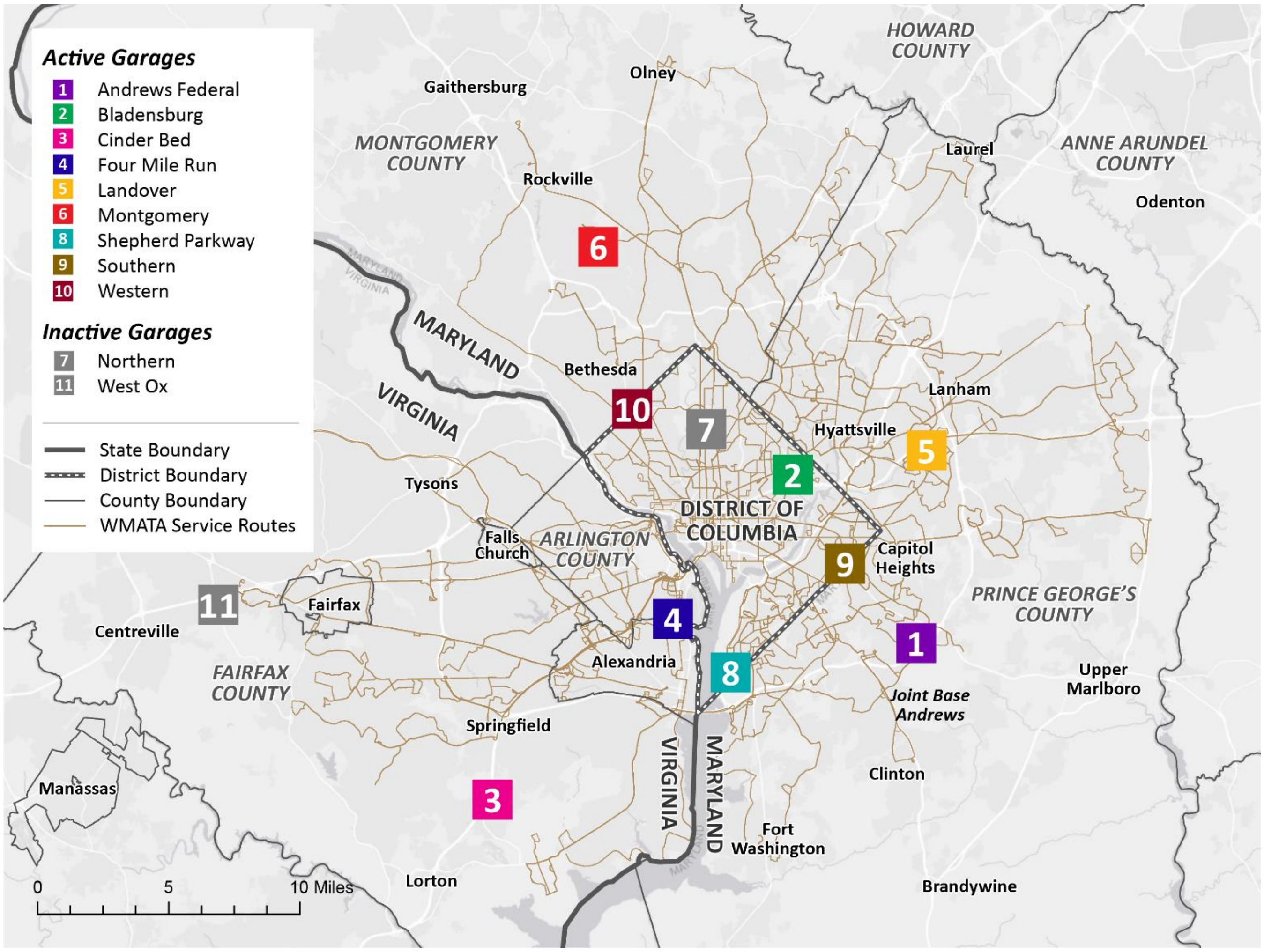
Table 2-2. Metrobus Garage Summary

Garage	Location	Function	Fuel Type	Assigned Bus Types	Status
Andrews Federal Center	Prince George's County, MD	Operating and Heavy Repair	Diesel	Standard	Fully operational.
Bladensburg	Washington, D.C.	Operating	CNG and Diesel	Small, Standard, and Articulated	Fully operational. Currently undergoing construction and replaced with a modern facility built to Leadership in Energy and Environmental Design (LEED) standards for storage and maintenance. Metro continues to evaluate the integration of BEB make-ready infrastructure.
Carmen E. Turner Maintenance and Training Facility	Prince George's County, MD	Heavy Repair and Training	N/A		Buses in need of major repairs (body work, paint, and heavy maintenance) are supported here. There are no plans to expand revenue bus parking or routine maintenance functions at this time.
Cinder Bed Road	Fairfax County, VA	Operating	Diesel	Standard	Fully operational.
Four Mile Run	Arlington County, VA	Operating	CNG and Diesel	Standard	Fully operational. One of two facilities that support CNG fueling.
Landover	Prince George's County, MD	Operating	Diesel	Small and Standard	Fully operational.
Montgomery	Montgomery County, MD	Operating	Diesel	Standard and Articulated	Fully operational.

Garage	Location	Function	Fuel Type	Assigned Bus Types	Status
Northern	Washington, D.C.	Operating	N/A		Inactive. Closed in June 2019 and expected to be reopened in 2027 as a purpose-built BEB facility.
Shepherd Parkway	Washington, D.C.	Operating	Diesel	Small, Standard, and Articulated	Fully operational. A new CNG facility is under construction at Shepherd Parkway and will also house Metro's 12-bus BEB Test & Evaluation Program.
Southern Avenue	Washington, D.C.	Operating	Diesel	Standard	Fully operational. Expected to cease revenue service operations once Northern reopens. However, Southern Avenue garage may support the transition to ZEBs by serving as a temporary bus garage.
Western	Washington, D.C.	Operating	Diesel	Small and Standard	Fully operational. Metro intends to construct a new garage on an adjacent parcel. In 2022 the Metro Board approved site acquisition planning efforts.
West Ox	Fairfax County, VA	Operating	N/A		Inactive. Owned by Fairfax County Department of Transportation (FCDOT). Metro has a 75-year joint use lease agreement for a portion of the parking and maintenance space. In March 2021, Metro halted revenue service from this location to reduce costs and improve efficiency. Metro will continue to use this garage for vehicle storage and other special projects.

Sources: WSP, Metrobus 2021 Fleet Management Plan

Figure 2-4. Metrobus Garages



Source: WSP, Metro (2021)

2.3.5 ELECTRIC UTILITIES

Metro's electric utilities are critical partners in the transition to a battery electric buses fleet. Figure 2-5 illustrates the electric utilities that provide service to Metrobus garages. They are:

- Pepco, which provides electric service to Washington, D.C., and surrounding communities in southern/western Maryland. Specific to Metrobus operations, this includes Andrews Federal Center, Montgomery, Northern, Shepherd Parkway, Southern, Western and the Carmen E. Turner Maintenance and Training facility.
- Dominion Virginia, which supplies electricity to the Commonwealth of Virginia, including garages at Cinder Bed Road, Four Mile Run, and West Ox.
- Baltimore Gas and Electric, which provides electric service to Metro's Landover garage.

Metro is already one of the largest regional consumers of electricity due to Metrorail. As a result, Metro has a long-standing capital construction and operational coordination relationships in place with its local electric utilities. Construction work outages and operational needs are routinely managed to ensure safe and reliable service to the region. In addition, dedicated tariffs for the Metrorail system are in place in Maryland and the District of Columbia service territories. In Virginia, Metrorail receives electric service under the state agency rate.

Building upon existing coordination and management structures, new areas of collaboration for the rollout of Metro's ZEB fleet and facilities will be required. In particular, how best to accelerate required BEB infrastructure deployment. Several major areas of partnership and coordination are anticipated to expand, including:

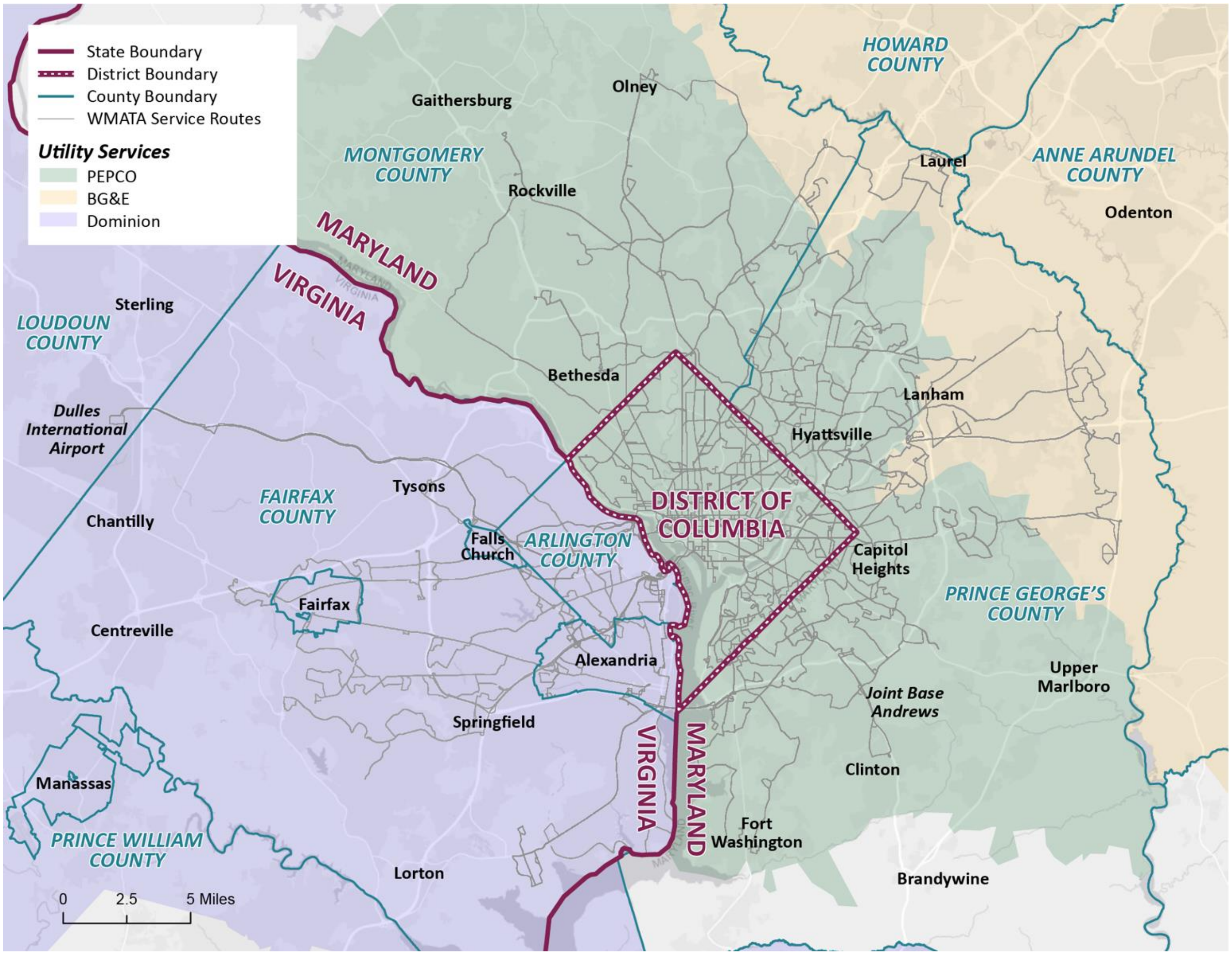
- **Grid Investment –** Large, localized power needs to electrify bus garages will require coordination to construct and provide electric distribution service for this new load. At Northern and Bladensburg bus garages, Metro is currently working with Pepco to determine distribution/capacity needs for BEBs at both sites - including coordination on investments for solar and how to address resiliency/backup power needs.
- **Programmatic and Technical Coordination –** Currently, an initial phase of electric utility electrification incentive programs is being implemented in the Washington, D.C., region - including Pepco's Transportation Electrification Program and Dominion's Smart Charging Infrastructure Pilot. Specifically, Metro intends to explore applying for funds from the Transportation Electrification Program – Transit Bus Offering for its Zero-Emission Bus Deployment: Phase 1 at Shepherd Parkway.

  Planning for future electric utility programs, as the region's investment in BEB fleet and facilities expands, is already underway. Specifically, Pepco's Climate Solutions Plan[13] filing proposes expanded customer-and utility-side-of-the-meter programs to support this wider need for infrastructure deployment. As Metro transitions to executing BEB facility capital investment in Virginia, Metro anticipates being able to utilize future iterations of rate-based programs based upon Dominion's successful Smart Charging Infrastructure program.
- **Tariff and Rates –** To support Metro's growth of battery electric buses, it is essential that an equitable electric tariff be developed for transit bus fleet operators in the Washington, D.C. area. As part of Pepco's Climate Solutions Plan, this emerging need was identified and was also noted in the Virginia Energy Purchasing Governmental Association electric service agreement.

  Rate/tariff development work has already begun with Metro's local electric utilities and will continue to be an area of collaboration and mutual learning to enable larger regional electric bus fleets to come into operation cost effectively. For example, throughout Metro's Zero-Emission Bus Deployment: Phase 1, Metro will collect charging data that can inform grid planning and load management in support of this process.

[13] Formal Case No. 1167, in the Matter of The Implementation of The Climate Business Plan.

Figure 2-5. Metro's Service Area – Utilities



Source: WSP, Metro, Pepco, BGE, Dominion (2021)

2.4 ZEB TECHNOLOGIES

A ZEB is typically defined as a bus that emits no local tailpipe emissions. In the transit market, there are two vehicles that fall under this standard: BEBs and FCEBs. The following subsections provide a brief summary of BEB and FCEB technologies and their general requirements.

BATTERY-ELECTRIC BUS

BEBs utilize an onboard energy storage system (i.e., batteries) to store and distribute energy to power an electric motor and other onboard systems.

BEBs can be "depot charged" at a storage facility when not in service, typically overnight or midday, and/or "opportunity charged" while in service, typically at a trip endpoint, such as a layover at a transit center. A depot charging strategy typically consists of buses with high-capacity (kilowatt-hour [kWh]) battery packs that are charged for several hours in conjunction with “slow” chargers – usually rated with less than 150 kilowatts (kW). An opportunity charging strategy typically consists of buses with low(er)-capacity battery packs that are charged for short periods of time with “fast” chargers – usually in excess of 150 kW. The specific charging strategy is largely based on the duty cycle and service characteristics of the fleet or route under consideration. It should also be noted that these strategies are not mutually exclusive; a combination of these strategies may be needed based on agency-specific needs.

BEBs can be charged via several dispenser types (conductive and inductive) and orientations (overhead or ground-mounted). Figure 2-6 presents the methods to dispense electricity to a BEB (from left to right): plug-in, overhead inverted pantograph, and inductive (wireless).

Figure 2-6. Battery-Electric Bus Charging Methods

Source: YorkMix, ABB (formerly ASEA Brown Boveri), and Long Beach Transit (left to right) (2022).

Based on the market’s current offerings, a standard (40-foot) BEB is expected to provide a range of approximately 150 miles – approximately half the range of an ICEB. However, the actual range of a BEB will vary based on a myriad of factors, including battery capacity (kWh); heating, ventilation, and air conditioning (HVAC) usage; driving behavior; and topography. Due to the varied performance, if meeting the required range is not a certainty, capital-intensive strategies must be considered to support the service. These include, but are not limited to, opportunity charging infrastructure, operational changes (which may include additional pull-outs and/or buses), and/or a mixed-fleet strategy with the supplementation of other fuel/technology types. BEBs, like other battery-based products, also experience battery degradation over time, meaning that the usable capacity (kWh), and thus range, will be reduced over the lifecycle of the battery. Therefore, it is essential to understand and consider the aforementioned factors when analyzing the range that BEBs can support – as this may vary day-to-day and during the lifecycle of the vehicle.

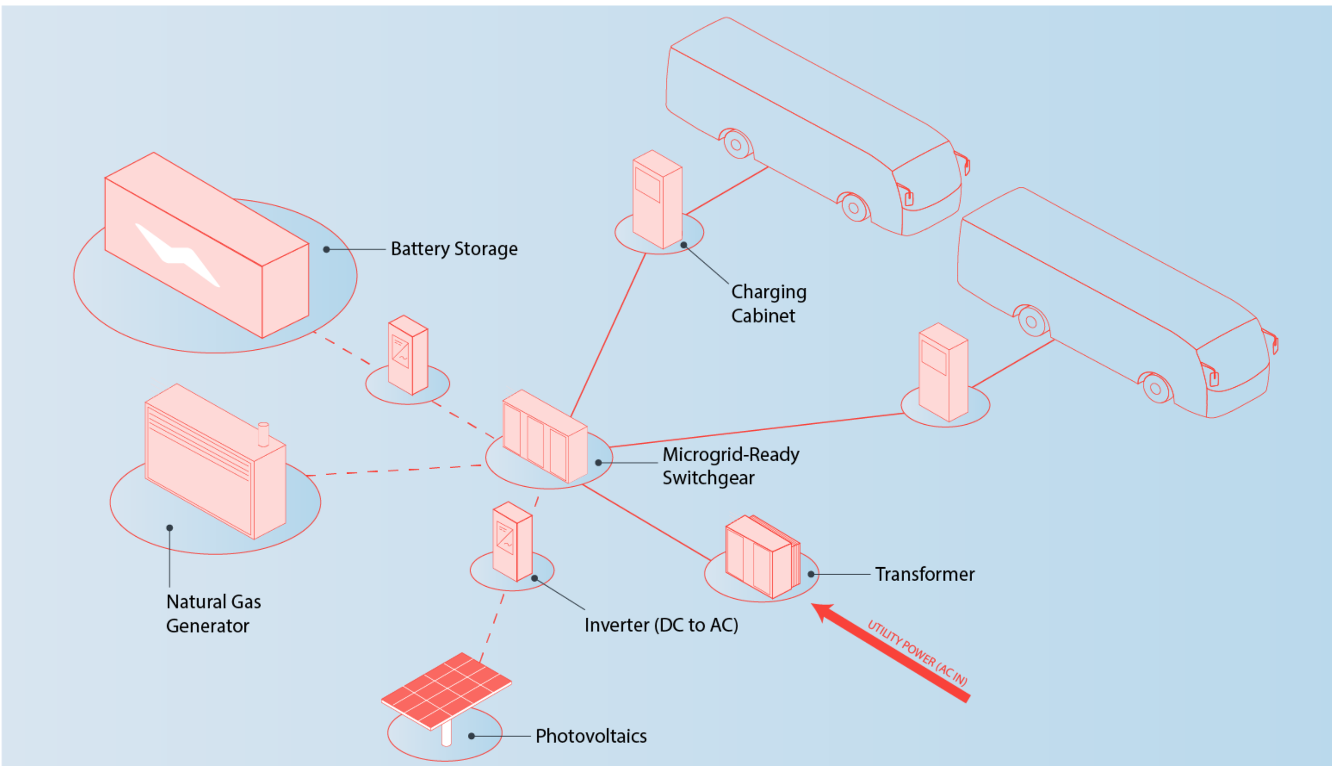
To charge BEBs sufficiently and safely, several infrastructure components are required, including:

- Charging equipment – dispense power and, in most cases, convert power from alternating current (AC) to direct current (DC).
- Transformer(s) – step down electricity to a safe and suitable limit.

- Switchgear(s) – allow for the isolation of power and protection of electrical power systems.

Other components can also be considered, such as battery storage, photovoltaics (solar panels), and backup generators. The equipment to support BEBs can take up considerable space at a depot. Therefore, in advance of implementation, it is essential to understand the electrical utility's access requirements in conjunction with service and operational requirements of the facility. Due to the potentially high power demand of charging several BEBs at once, and the limited spare capacity available in existing circuits, expanded or new electrical service is usually required to support BEBs. Figure 2-7 illustrates the various components of a possible BEB system (not Metro-specific) that also includes on-site power generation.

Figure 2-7. Typical Battery-Electric Bus System



Source: WSP (2022)

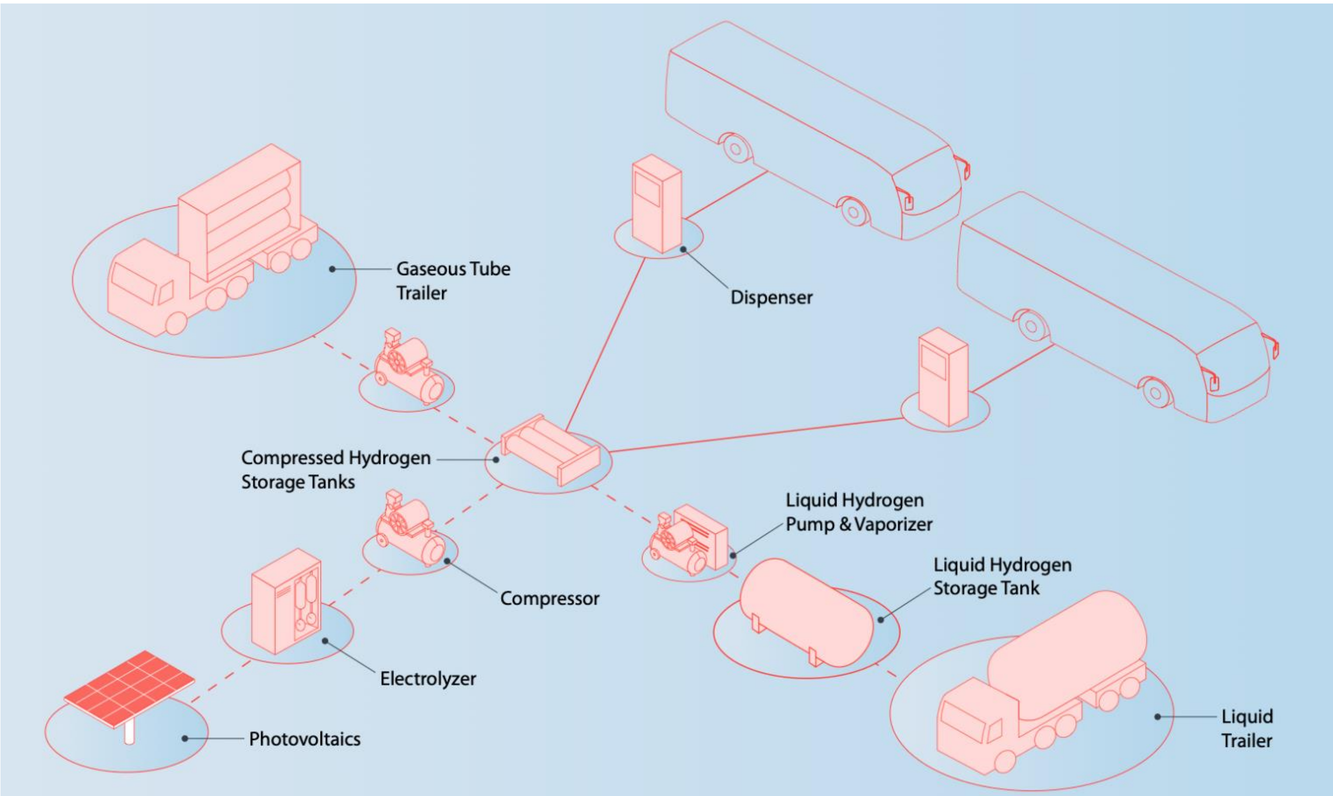
FUEL CELL ELECTRIC BUS

FCEBs store compressed gaseous hydrogen that is then distributed to onboard fuel cells that combine the hydrogen with oxygen to produce electricity to power an electric motor and other onboard systems. The fuel cell is used in conjunction with a small battery, which stores electricity and supplements the fuel cell's power during peak loads.

Hydrogen is produced via steam methane reforming (SMR) or electrolysis. SMR, the most common method of producing hydrogen, uses high-pressure steam to extract hydrogen from a methane source, such as natural gas. Electrolysis uses an electric current to decompose water into hydrogen and oxygen. While hydrogen production via electrolysis has the potential of being zero-emission (with renewable electricity), the SMR process emits carbon dioxide.

While there are transit agencies that generate small quantities of hydrogen onsite (via electrolyzer), most hydrogen is generated by a supplier and delivered to a bus facility as a liquid.[14] After the hydrogen arrives on site, it is stored, vaporized, compressed, and dispensed. Figure 2-8 illustrates the various components and options for providing hydrogen to FCEBs. Note that all equipment presented herein is assumed to be on site (except for the delivery trailers).

Figure 2-8. Typical Fuel Cell Electric Bus System



Source: WSP (2022)

The operating range of FCEBs are similar to that of ICEBs, meaning a FCEB can typically replace an ICEBs at a 1:1 replacement ratio without significant changes to operations. However, one of the most pressing challenges for FCEB adoption is that the industry and market is still in early stages and there are only two original equipment manufacturers (OEMs) that produce standard FCEBs (ElDorado National and New Flyer). According to CALSTART, as of September 2021, of the 3,533 ZEBs deployed across the U.S., 169 (5%) of deployed ZEBs are FCEB. Onsite hydrogen operations also require ample space, and if renewable natural gas (RNG) – such as methane captured from organic matter – is not used as an alternative to natural gas during SMR operations, FCEBs may not be a sustainable vehicle to achieve lifecycle GHG emission reduction targets. Since electrolysis relies on an electric current, it offers the potential to provide fully renewable hydrogen if the electricity is renewably generated.

[14] Hydrogen can also be delivered as a gas or via pipeline. However, delivered gaseous hydrogen requires compression and liquid hydrogen is denser and contains greater energy content. As of December 2020, there were 1,600 miles of hydrogen pipeline in the U.S., primarily along the Gulf Coast – making this method not viable for the vast majority of transit operators.

Beyond challenges associated with the source of electricity, on-site electrolysis presents challenges in high upfront costs, space requirements, power demands, and scalability. In short, implementation of hydrogen fuel technologies at a site presents new complexities that often require specific site and operations analyses to assess.

An all-BEB or all-FCEB fleet (or combination of both) operation has the potential to yield many benefits – especially as it relates to local emissions. Metro remains technology neutral and will continue to monitor and consider both technologies as they both are expected to evolve and improve in the coming years (BEBs in terms of range and FCEBs in terms of production scale).

3 METHODOLOGY

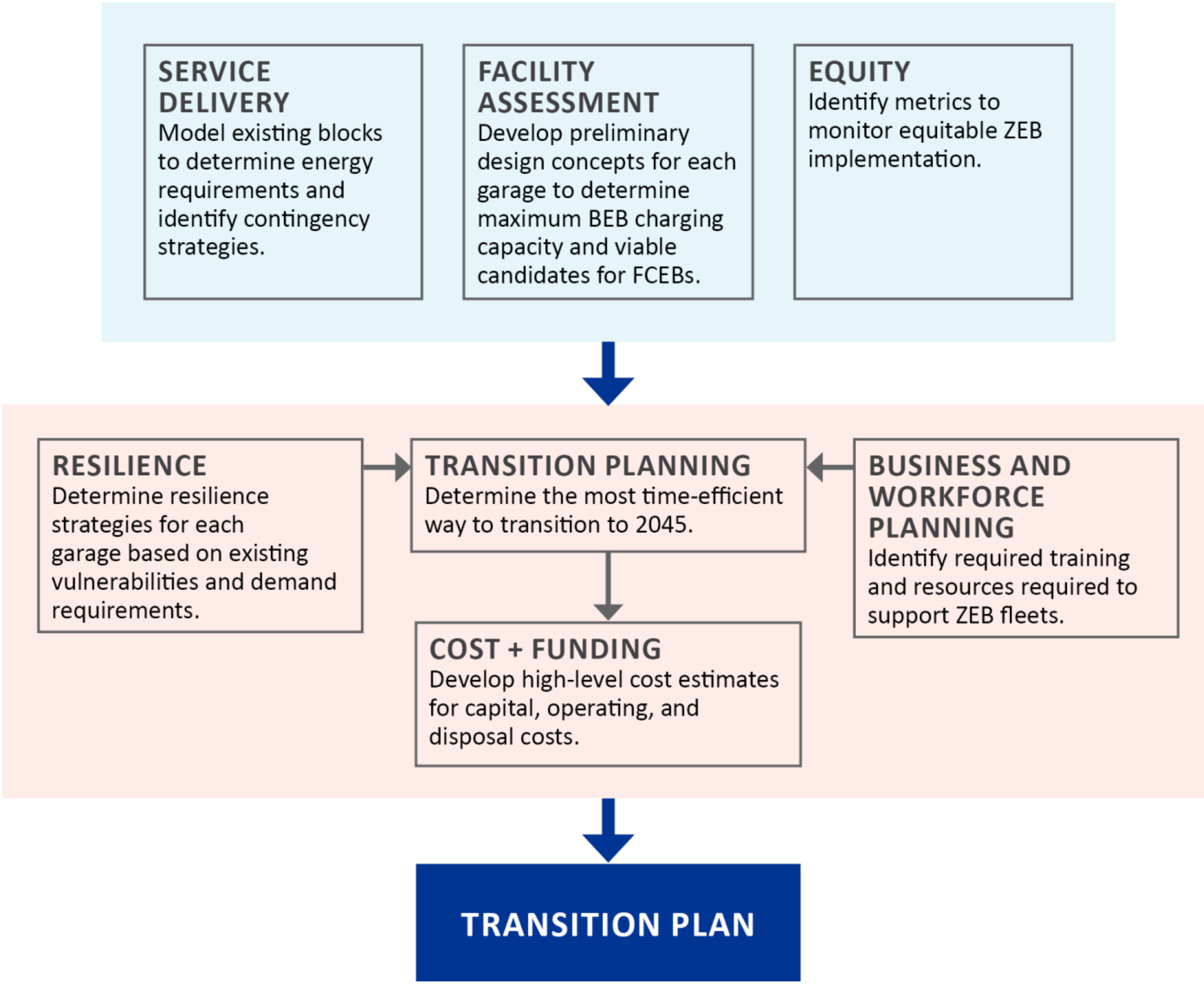
The following section provides an overview of the methodology used to assess and develop Metro's ZEB transition strategy over the course of a year.

3.1 OVERVIEW

To transition the fleet as quickly as possible, it is essential to understand how the integration of and ultimate full adoption of zero-emission technologies will affect all aspects of the Metrobus' operation. To determine this, Metro evaluated ZEBs in the context of service completion, facility requirements, equity implications, resilience strategies, and business and workforce planning. By evaluating these elements, Metro can identify areas of opportunity and/or challenges that will need to be mitigated. Figure 3-1 presents the various elements and describes how they inform Metro's transition.

As noted in the Introduction, given the dynamic nature of service, operations, and market conditions, the Plan is considered a living document and will be updated periodically to capture pertinent changes to assumptions, timing, and technologies.

Figure 3-1. Methodology Overview



Source: WSP (2022)

The following subsections provide a general overview of the approach taken to analyze the pertinent elements of Metro's transition.

3.2 SERVICE MODELING

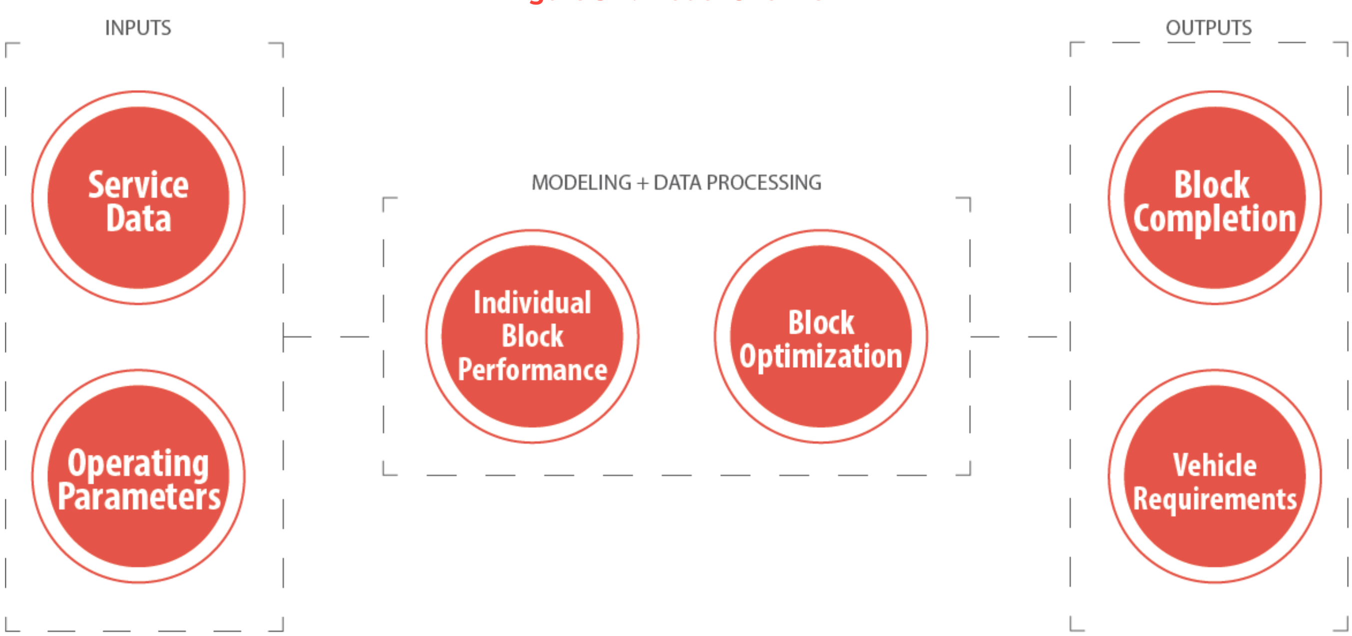
Service modeling was conducted to examine Metro's existing service schedule in the context of BEB technology and identify strategies that can be implemented to ensure that service can be delivered. Because FCEBs can operate at similar ranges to that of existing ICEBs and Metro's existing buses could be replaced with FCEBs at a 1:1 replacement ratio, service modeling analysis of FCEBs was not necessary.

The model estimated the energy required (kWh) for each service block[15] to determine the number of service blocks that can be completed with a single BEB on a single charge. For service blocks that cannot be completed with a single BEB, the model calculated the magnitude of failure (i.e., the additional energy required) to inform decision making on strategies that can make these blocks successful with BEBs.

The model considered and analyzed several factors that may impact the performance of a BEB, including the specific operating conditions, such as HVAC usage, stops and acceleration, and elevations, as well as prospective vehicle specifications such as battery capacity (factoring in a battery safety buffer), stated range, and weight. Due to the variability of BEB range, the model analyzed the service under two scenarios to represent the span of expected performance: “typical” and “intensive.” The typical scenario represented annual average temperature in the DC region, whereas the intensive scenario reflected greater HVAC use due to extreme weather conditions[16] and less recaptured energy from regenerative braking.

The model’s output included (by garage) service block completion rates, an estimate of BEBs needed to support the passing service blocks,[17] and contingency strategies for the failing service blocks. All of these outputs inform how Metro can successfully meet service during and at the conclusion of its transition to ZEBs. The outputs of the service modeling analysis also inform the energy needs, facility requirements, and costs of the transition. Figure 3-2 illustrates the modeling inputs, process, and outputs.

Figure 3-2. Model Overview



Source: WSP (2022)

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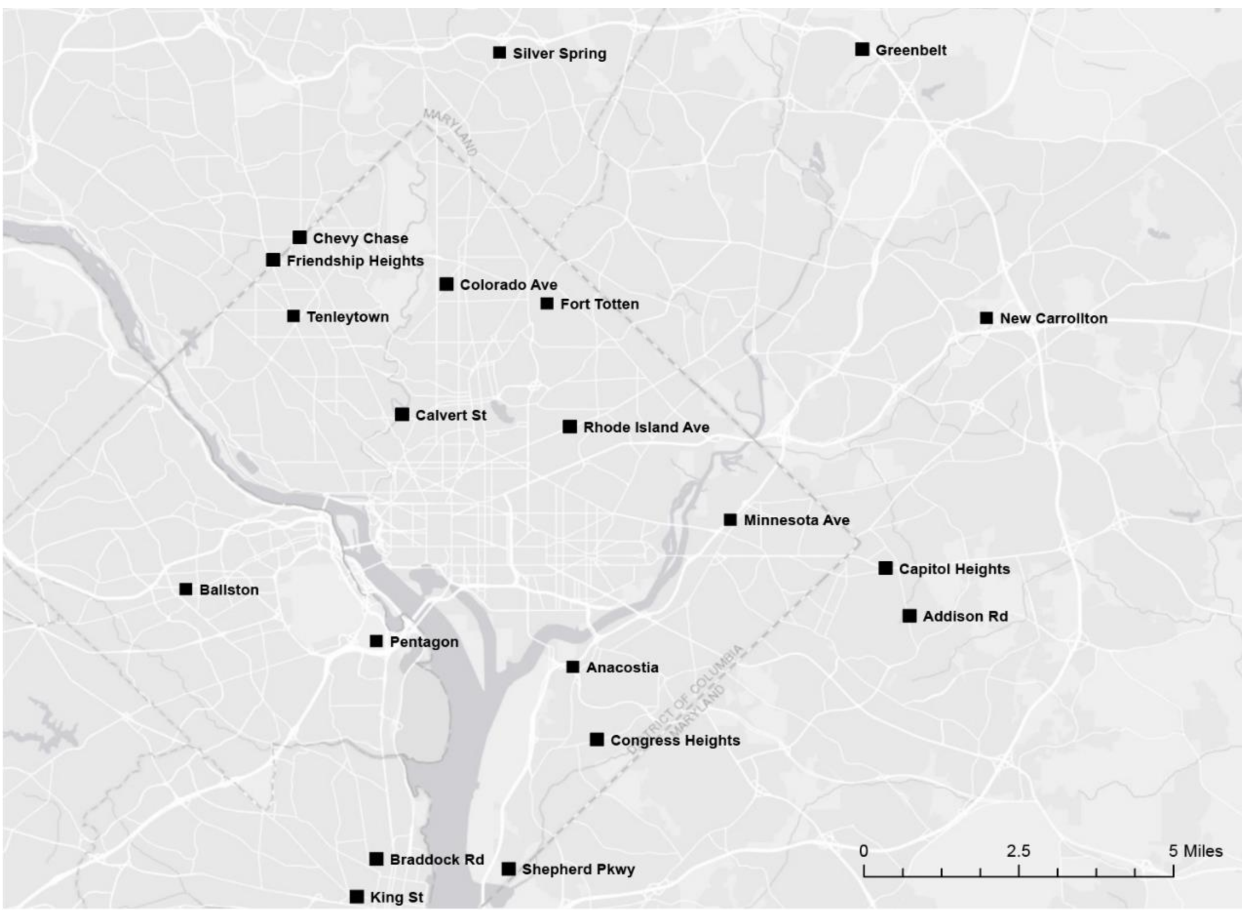
[15] A service block is a group of sequential trips that are assigned to a single bus. The block begins when the bus pulls out of the garage and ends when it returns to the yard. A bus may operate two or more blocks in a day – for example, an AM block and a PM block – while others may operate a single block for the day.
[16] Represented by the most extreme (low) average annual temperature.
[17] This estimate considers a “block pairing” scenario with midday charging between blocks operated by the same bus.

To supplement service that cannot be completed with a depot-charging strategy, the analysis also evaluated the impacts on service that integrating opportunity charging at layover locations may have. Metro staff identified 20 Metro-owned layover locations (areas that buses dwell at for short durations [averaging 13 minutes], typically at the end of trips or service blocks) that could serve as potential locations for opportunity charging (Figure 3-3.). The analysis created a prioritized list from these sites based on the dwell times of failing blocks, and buses were modeled to charge during layovers at each garage's highest-priority location. The findings of this analysis revealed the number of previously failed blocks/buses that would be able to complete service with the addition of opportunity charging. For some garages, the failed blocks do not layover at any of these 20 sites, and unless service changes are made to ensure buses layover at these sites, the failed blocks would not benefit from chargers at the 20 identified locations. Additionally, there are other areas in the system that Metro can consider as future sites for opportunity charging. For example, Metrorail stations typically are in the vicinity of substations that are likely to have an adequate amount of power to support opportunity charging. The benefits of opportunity charging may extend beyond Metro, so Metro also will consider the potential for shared opportunity charging with other local transit agencies to support ZEB deployment throughout the region. Each garage's ZEB Analysis section in this report gives an overview of the opportunity charging findings.

Figure 3-3. Analyzed Opportunity Charging Locations



Source: WSP, Metro (2022)

3.3 FACILITY ASSESSMENTS

Metro's existing bus garages will need to be retrofitted to accommodate the future all-ZEB fleet. The amount and placement of new fueling and/or charging equipment at Metro's garages could impact the number of buses that can be stored at a facility, ultimately affecting both service and operations. For this reason, future concepts were developed for the garages to identify, plan for, and, if needed, mitigate any potential impacts.

A baseline for garage concepts was developed from site visits, as-built drawings, vehicle inventories, and other related data. FCEBs and BEBs were assessed and considered at each garage in support of Metro's technology neutral goals.

At the time of this writing, Metro already had several plans and ongoing construction work underway at some of its garages. Consequently, conceptual drawings for Northern and Bladensburg Garages are not included in this version of the Transition Plan, as that work is already advancing separately. Further, Southern and West Ox are not planned as future Metrobus service dispatching locations, so they were not assessed for possible ZEB infrastructure enhancements. The specific plans for each of these garages includes:

- **Bladensburg Garage** – Bladensburg Garage is currently undergoing construction improvements that will modernize the facility and improve essential bus operations and maintenance. The reconstruction also includes the allocation of space for BEB infrastructure.
- **Northern Garage** – Northern Garage is a 100+ year-old facility that is currently not operational and needs a complete replacement. The facility was closed in June 2019 and is expected to be demolished and reopened as a purpose-built BEB facility in 2027.
- **Southern Avenue Garage –** Southern Avenue Garage is expected to close in FY 2026, per the *Metrobus Fleet Management Plan* (2021), and its existing service blocks will be assigned to neighboring bus garages upon closure. The garage may continue to be used to temporarily store buses while their assigned garages are being retrofitted or as a contingency option in the future if additional ZEB capacity is required.
- **West Ox Garage –** West Ox Garage is owned by Fairfax County Department of Transportation (FCDOT). Metro has a 75-year joint use lease agreement that entitles it to use of some parking and maintenance space. In March 2021, Metro announced the temporary closure of regular operations from its West Ox facility to allow for streamlined operations, reduced costs, and improved efficiency. Metro will retain this site's capacity for vehicle storage and other special projects, and in the future, this site can be reconsidered for dispatch.

The following subsections summarize the approach for developing FCEB and BEB facility concepts.

3.3.1 FUEL CELL ELECTRIC BUS

While generating hydrogen onsite could be a viable option for Metro, there are currently no examples of transit agencies generating the amount of hydrogen that any one Metro bus facility would require (average of 175 buses). For example, Alameda-Contra Costa County Transit (AC Transit) and Sunline Transit Agency are among the largest operators of FCEBs in the country, and they are capable of generating 65 kilograms (kg) and 900 kg of hydrogen per day via electrolyzer, respectively. For context, a FCEB typically has a 37 kg capacity, meaning, the average Metrobus garage would need to produce approximately 6,500 kg of hydrogen per day if relying on onsite generation alone – seven times the amount that has been demonstrated in actual practice.

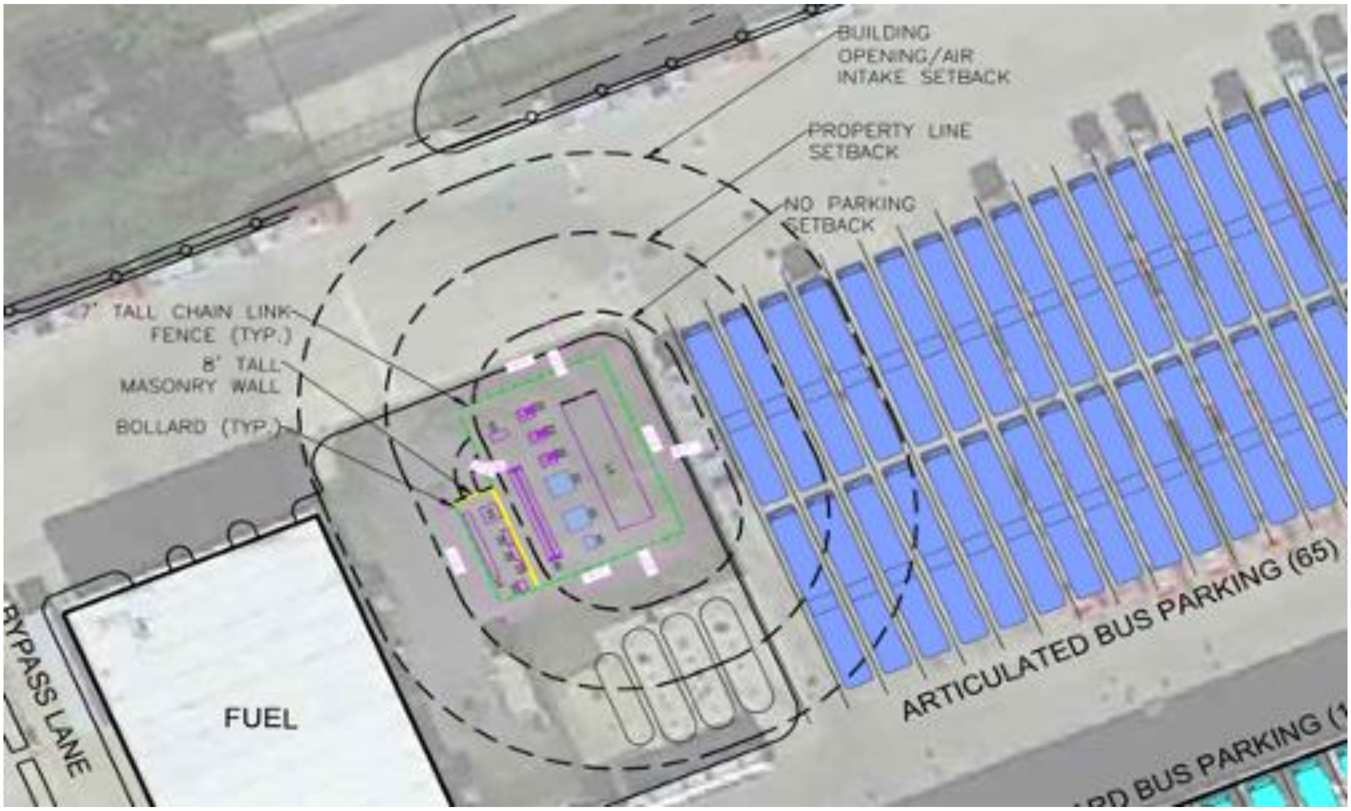
For this reason, as with most transportation-related hydrogen applications, delivering liquid hydrogen to the site is assumed to be the most viable for Metro. Although this strategy could alleviate the scalability issues that onsite generation has, delivered hydrogen is challenging for space-constrained facilities, as it requires a large footprint due to National Fire Protection Association (NFPA) safety-related setback requirements and the infrastructure needed to vaporize, compress, and dispense the hydrogen.

To determine whether a garage could support a mixed bus fleet with BEBs and FCEBs via delivered hydrogen, a test fit concept was developed. Each garage was assessed based on the assumption of maintaining and operating an 18,000-gallon liquified hydrogen tank – similar to Orange County Transportation Authority's (Figure 3-4). This amount of storage can fuel approximately 80 FCEBs daily, with liquid hydrogen deliveries required to refill the tank every 2-3 days. The dimensions for the tank, its supporting equipment, and NFPA required setbacks – including a 25-foot vehicle parking setback, a 50-foot property line setback, and a 75-foot building opening/air intake setback – were superimposed on facility site layouts (if applicable, in place of the existing CNG equipment yard) (Figure 3-5). This approach determined whether the site space for implementing a hydrogen fueling yard encroached into existing bus parking areas or requiring additional property acquisitions.

Figure 3-4. Orange County Transportation Authority's 18,000-Gallon Hydrogen Storage Tank

Source: Sustainable Bus (2020)

Figure 3-5. Delivered Hydrogen Footprint



Source: WSP (2022)

3.3.2 BATTERY-ELECTRIC BUS

To support a BEB fleet, Metro's garages will require new infrastructure, including containerized charging solutions, transformers, switchgears, and hundreds of feet of conduit that will route and support the transfer of electricity and communications between equipment (Figure 3-6 and Figure 3-7).

A base level of design guidelines[18] were developed with input from subject matter experts across Metro and applied to each garage concept developed in this Plan (Table 3-1).

[18] Design guidelines establish the framework for the BEB infrastructure improvements design parameters and process.

Table 3-1. BEB Facility Design Guidelines

Design Guidelines	Justification	Description
Overhead Inverted Pantograph	Safety	Eliminates bus operator interaction with the charging process once communication has been made between the bus and the pantograph.
	Efficiency	Requires no footprint in the bus parking area, thereby maximizing site capacity.
	Efficiency	No site trenching is needed since distribution can be carried overhead via conduit.
Modular Overhead Frame System	Efficiency	Distribution is easily accessible for maintenance, repairs, or future upgrades that may be required with emerging technology.
	Efficiency	The frame system is multi-purpose and can support lighting, photovoltaic (PV) arrays, and fire protection.
Bus Lane Width and Column Spacing	Efficiency	To maximize space, most bus lanes will be standardized at 12 feet wide. However, a single lane will be 14 feet wide (Metro's desired standard) to support pre-trip inspections of wheelchair lifts.
Bus Storage Stacking	Efficiency	To reduce the impact or risk of buses being charged blocking buses that need to pull-out for service, no more than three buses should be stacked in a single lane, where possible.
Bus Movements	Safety	To provide a safe and efficient bus circulation pattern, backing movements of buses are to be avoided.
Containerized Charging Solution	Current State of Technology	They are equipped with their own transformer, resulting in medium voltage being brought directly to the container.
	Efficiency	Reduces the complexity and quantity of conduit for electrical distribution (when compared to single charger solutions).
	Efficiency	Design to charge a large number of buses. This may reduce problems with unit-to-unit communications between charging cabinets.
Charging and Electrical Infrastructure to be Elevated	Efficiency	The raised equipment allows for maximum use of the space, thereby providing maximum bus capacity.
	Efficiency	The power distribution between charger and pantograph does not require any trenching or subsurface work. The only required duct bank is for the incoming medium voltage AC service.
	Current State of Technology	Elevated equipment and conduit are more accessible for repair, maintenance, and operations than if it were buried in an underground duct bank.

Source: Metro (2021)

Figure 3-6. Rendering of Overhead Inverted Pantograph Charging on a Modular Overhead Frame System

Source: WSP (2022)

Figure 3-7. Example of a Containerized Charging Solution and Individual Charger (for scale)

Source: ABB and Proterra (2022)

3.4 EQUITY ANALYSIS

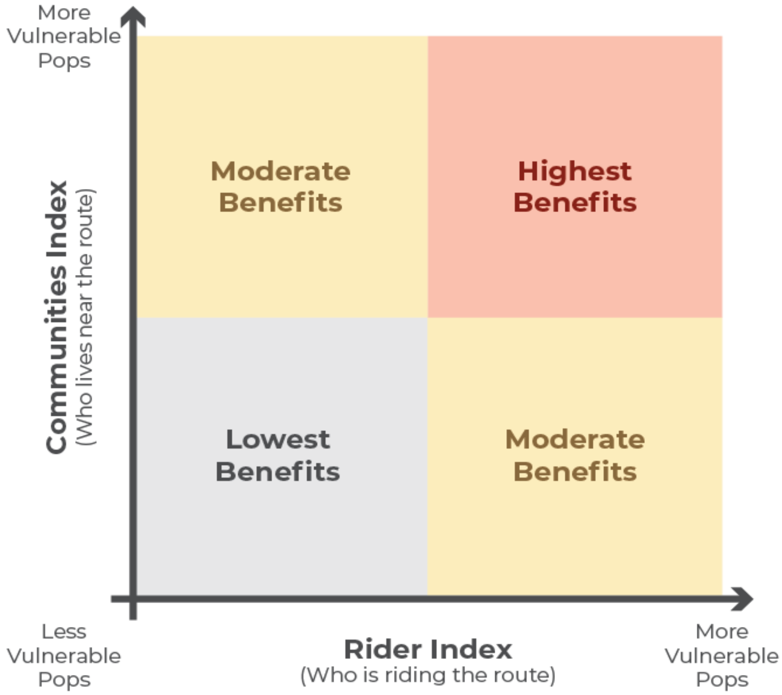
Bus riders are often more vulnerable to social and environmental challenges. Those that are, tend to live in areas of pre-existing poor air quality, experience disproportionate rates of diseases exacerbated by poor air quality (particularly diesel emissions), and have few transportation options other than bus transit. To prioritize and address those injustices, Metro evaluated service in the context of these communities and riders (particularly those of color, low-income and/or with disabilities). That analysis then informs the order in which garages and routes are transitioned to ZEB technologies to ensure Metro's investments prioritize equity.

The analysis relied on two calculated indices, one for riders (Equity Riders) and one for adjacent communities (Equity Focus Communities, EFCs). The Equity Rider Index provides Metro with an understanding of the riders who would benefit the most from the deployment of ZEBs (based on routes), and the EFC Index provides Metro with an understanding of the communities that would benefit the most from the deployment of ZEBs. Each route was evaluated and assigned a score for each index (by garage); the scores were then combined into a single score to identify the garages that should be considered for ZEB prioritization to maximize equitable outcomes. Bladensburg, Shepherd Parkway, Montgomery, Landover, and Four Mile Run were determined to be the most vulnerable. Northern garage is currently closed for renovation and therefore a full equity route analysis was not conducted in the Transition Plan (there are no routes currently assigned to this garage). It is not yet known which specific routes will operate out of this garage; however, a hypothetical analysis was conducted by selecting routes that operate within one mile of the garage and allocating them to Northern. Results indicate Northern would likely be a high equity priority. Additionally, Northern resides in an area designated as a Historically Disadvantaged Community.[19]

Figure 3-8 presents the scale of benefits for Equity Riders and EFCs and Figure 3-9 summarizes the results of the analysis.

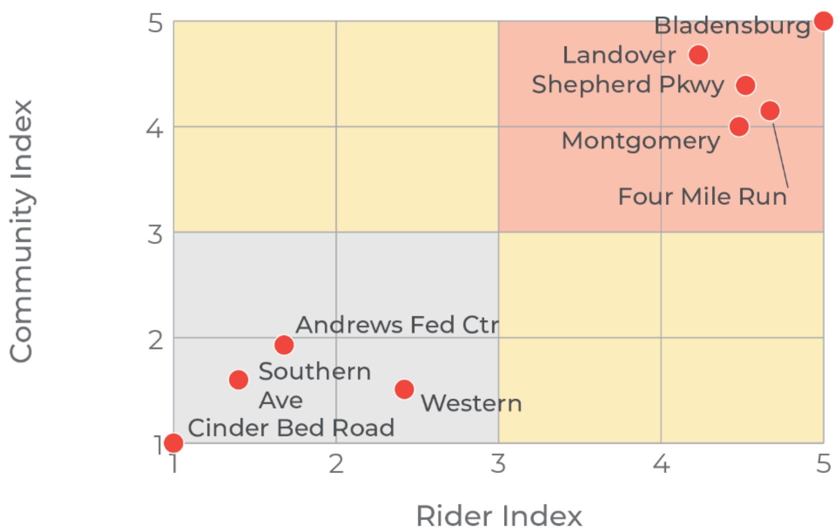
[19] https://www.transportation.gov/RAISEgrants/raise-app-hdc

Figure 3-8. Equity Riders and Equity Focus Communities Indices and Benefits



Source: Foursquare ITP (2022)

Figure 3-9. Equity Riders and Equity Focus Communities Scores



Source: Foursquare ITP (2022)
Note: Inactive garages (Northern and West Ox) were not analyzed as they currently do not provide revenue service.

4 FLEET AND FACILITY ANALYSIS

This section summarizes each garage's existing conditions and presents the findings of the service modeling analysis (as of December 2021) and the proposed ZEB facility concepts.

It should be noted that facility concepts for Bladensburg, Northern, Southern, and West Ox Garages are not included in this section. Design plans for Bladensburg and Northern Garages are ongoing and were under development in advance of and during the ZEB transition analysis. Southern Avenue and West Ox Garages will not be used for revenue service in the future; therefore, no ZEB facility concepts were developed. However, Southern Avenue and West Ox Garages may continue to be used to temporarily store buses or as a contingency option in the future if additional ZEB capacity is required.

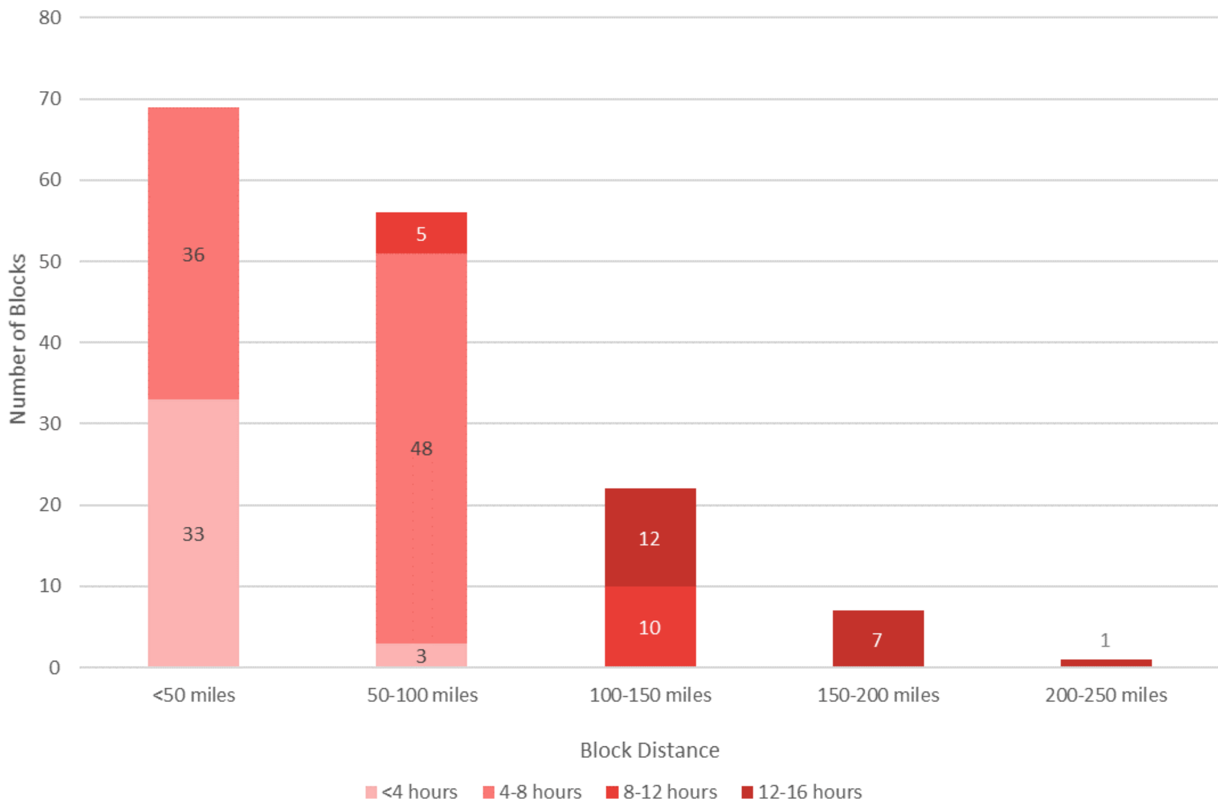
4.1 ANDREWS FEDERAL CENTER GARAGE

4.1.1 EXISTING CONDITIONS

SERVICE AND FLEET ANALYSIS

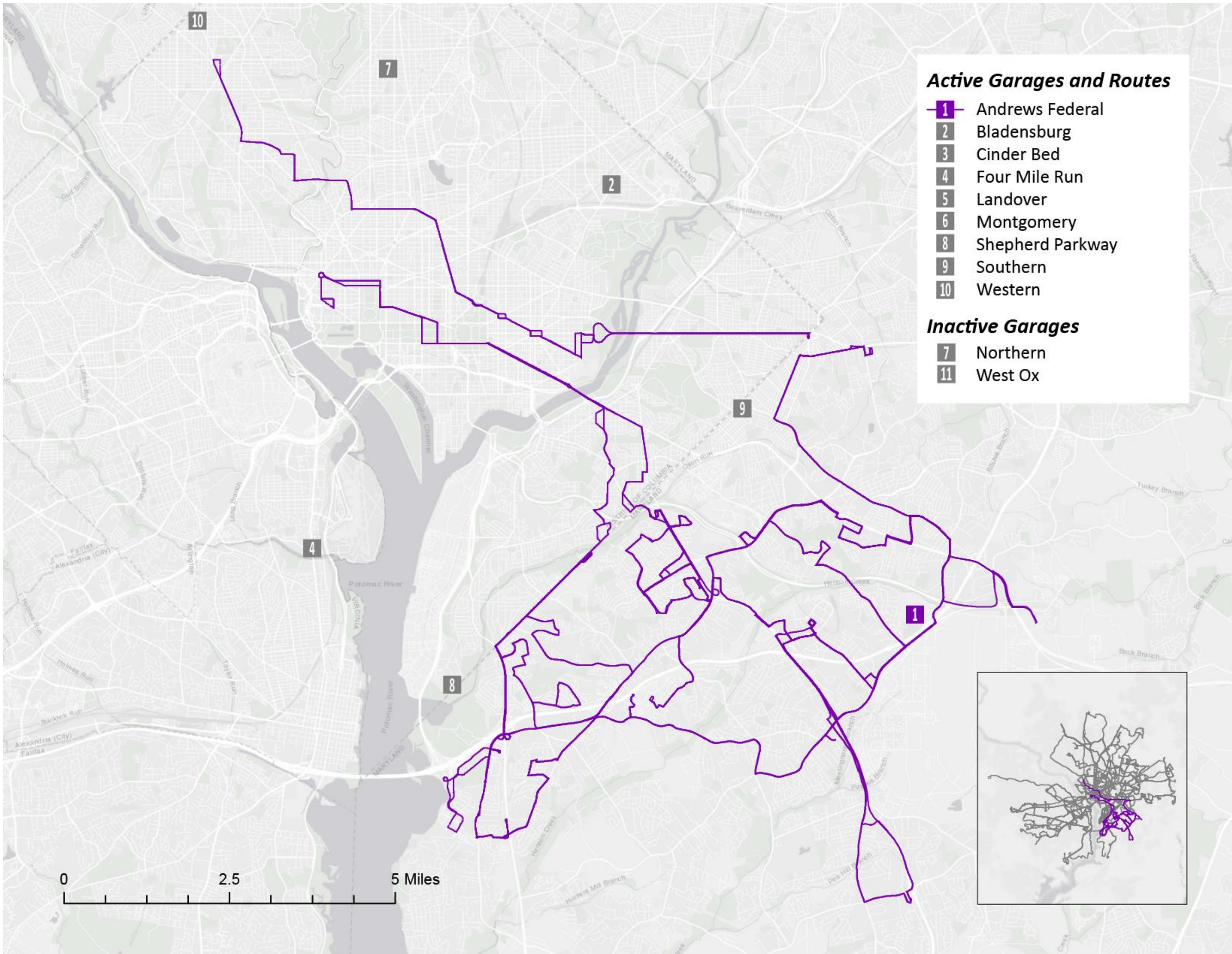
As of December 2021, 158 40-foot buses are stored, maintained, and dispatched from Andrews Federal Center Garage. The garage's fleet supports 13 routes (155 weekday blocks with a 72-bus peak vehicle requirement [PVR]) that primarily serve Southern Prince George's County, Maryland, with some routes serving Washington, D.C. The garage's service blocks range from 29 to 209 miles and operate between three and 16 hours. Figure 4-1 presents the garage's blocks by distance and duration, and Figure 4-2 illustrates Andrews Federal Center Garage's routes in the context of Metro's other garages.

Figure 4-1. Andrews Federal Center Garage – Block Distribution by Distance and Duration



Source: WSP, Metro (December 2021)

Figure 4-2. Andrews Federal Center Garage – Garage and Route Map



Source: WSP, Metro (December 2021)

FACILITY ANALYSIS

The Andrews Federal Center Garage is located in Prince George's County, Maryland. Based on field observations, the site appears to have safe and efficient site circulation, and has many characteristics that are conducive for ZEB operations, including:

- Employee parking is separate from the bus parking and service areas.
- Buses can be parked, serviced, and exit the site with few backing movements.
- The service cycle follows a forward-moving counterclockwise flow. This is desirable for the safe and efficient operation of bus circulation. The driver sits on the left side of the bus, which provides the best line of sight for left-hand turns.

However, there are also some challenges that will need to be resolved or mitigated to ease the transition to ZEBs, including:

- Bus parking is stacked four buses deep, which could pose a problem for pullout if there is a breakdown.

- There is existing subsurface infrastructure in the form of easements, utility runs, and stormwater management vaults. Technical solutions to address these items will need to be determined in the advanced design process.

Table 4-1 summarizes existing conditions at Andrews Federal Center Garage.

Table 4-1. Andrews Federal Center Garage – Existing Facility Conditions Summary

Category	Description
Location	Prince George's County, Maryland
Fuel Type	Diesel
Utility Provider	Pepco
Utility Service: Voltage/Transformer Rating (kVA)/and Peak Demand (kVA)	Building 1: 480/2,000/565 Building 2: 480/2,000/536 Building 3: 480/2,000/826
Functions	Operating Garage and Heavy Repair
Bus Parking	Outdoor
Maintenance Capacity	19 maintenance bays (9 articulated and 10 standard)
Existing Parking Capacity	174 total (34 articulated and 140 standard)

Source: WSP, Metro

4.1.2 FUTURE ZEB CONDITIONS

SERVICE AND FLEET ANALYSIS

Under existing conditions, between 82% and 94%[20] of Andrew Federal Center Garage's blocks can be supported by BEBs. These passing blocks can be supported by 50 to 63 BEBs depending on operating conditions, with the remaining assigned buses being available to support the "failed" blocks that have higher energy demands than the modeled battery capacity.

Under the typical modeling scenario, all blocks that failed had a service duration that exceeded 13 hours. For the intensive scenario, all blocks that failed had a service duration that exceeded nine hours. Table 4-2 summarizes the modeling results for Andrews Federal Center Garage.

Table 4-2. Andrews Federal Center Garage – Modeling Results Summary

Category	Results
Total Blocks	155
Passing Blocks	82% to 94%*

[20] Intensive and typical modeling scenarios, respectively.

Category	Results
Buses Needed for Passing Blocks	50 to 63
Buses Available for Failing Blocks	95 to 110

Source: WSP, Metro
Note: *Intensive and typical modeling scenarios, respectively.

Andrews Federal Center Garage's service blocks have a relatively high completion percentage; therefore, it does not appear that capital-intensive strategies to support the failed blocks (such as opportunity charging or additional buses) are required. Furthermore, no failing blocks from Andrews Federal Center Garage layover at any of the 20 opportunity charging locations. Based on the Fleet Management Plan (2021), Metro will have several ICEBs in the fleet through the late 2030s. Accordingly, dispatching ICEBs on demanding blocks until retirement and/or slight service changes appears to be the most suitable strategy to address the failed blocks as battery technology continues to improve.[21]

FACILITY ANALYSIS

BATTERY-ELECTRIC BUS CONCEPT

Andrews Federal Center Garage can support 174 charging positions, 140 for standard buses and 34 for articulated buses – resulting in no loss or impact to existing capacity. The proposed site layout utilizes the existing east/west bus parking configuration. Adjustments were made to ensure that column foundations remained out of the existing subsurface utility easements. Table 4-3 summarizes the proposed equipment needed to support the future all-BEB garage, and Figure 4-3 illustrates Andrews Federal Center Garage existing and proposed future site layouts.

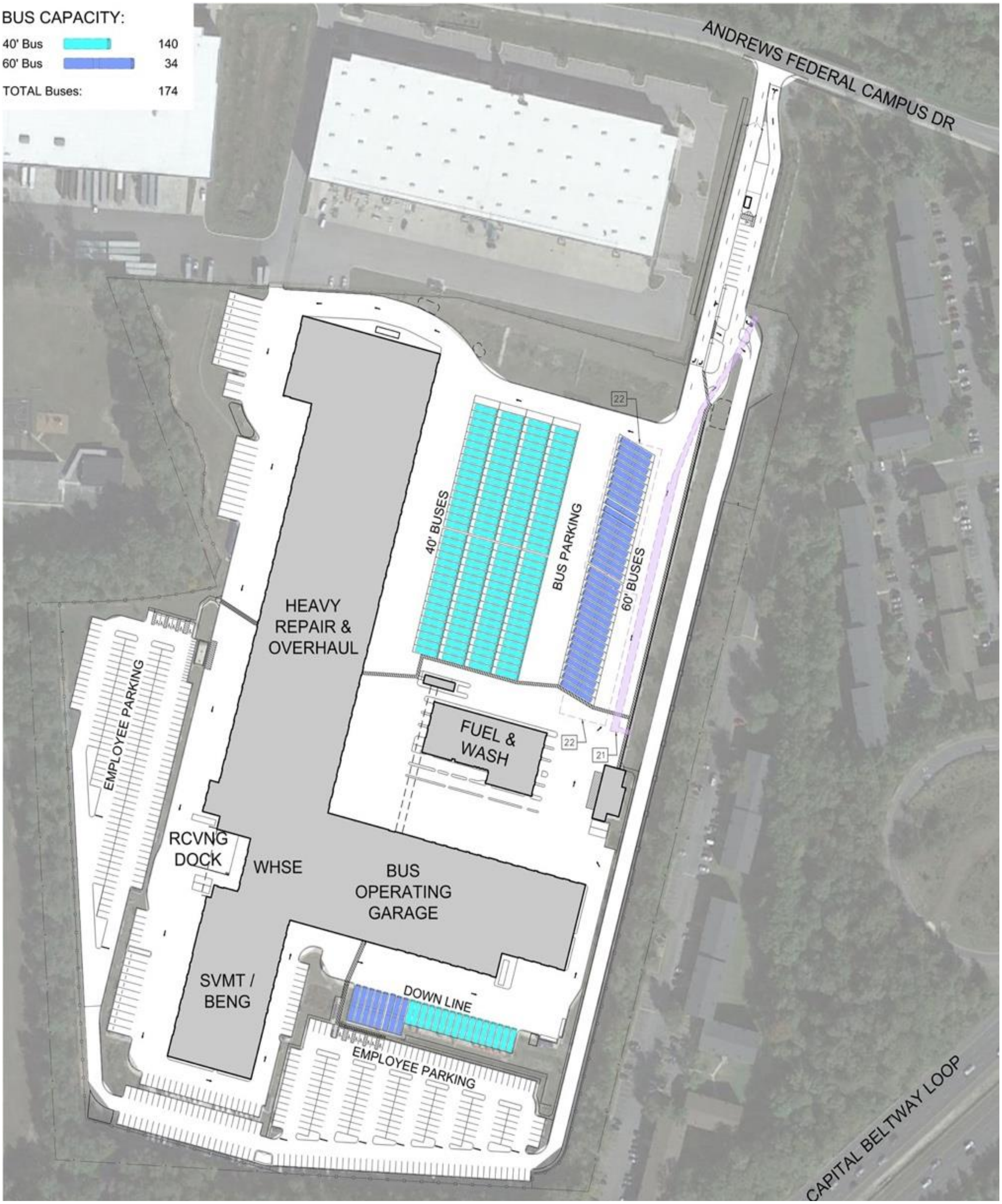
Table 4-3. Andrews Federal Center Garage – BEB Concept Summary

Category	Description
Charging Positions	174 total (34 articulated and 140 standard)
Proposed Charger Type and Specification	(9) 2 MW charging units
Connected Load	18 MW
Electrical Infrastructure Enhancements	Medium voltage (MV) service and MV switchgear

Source: WSP (2022)

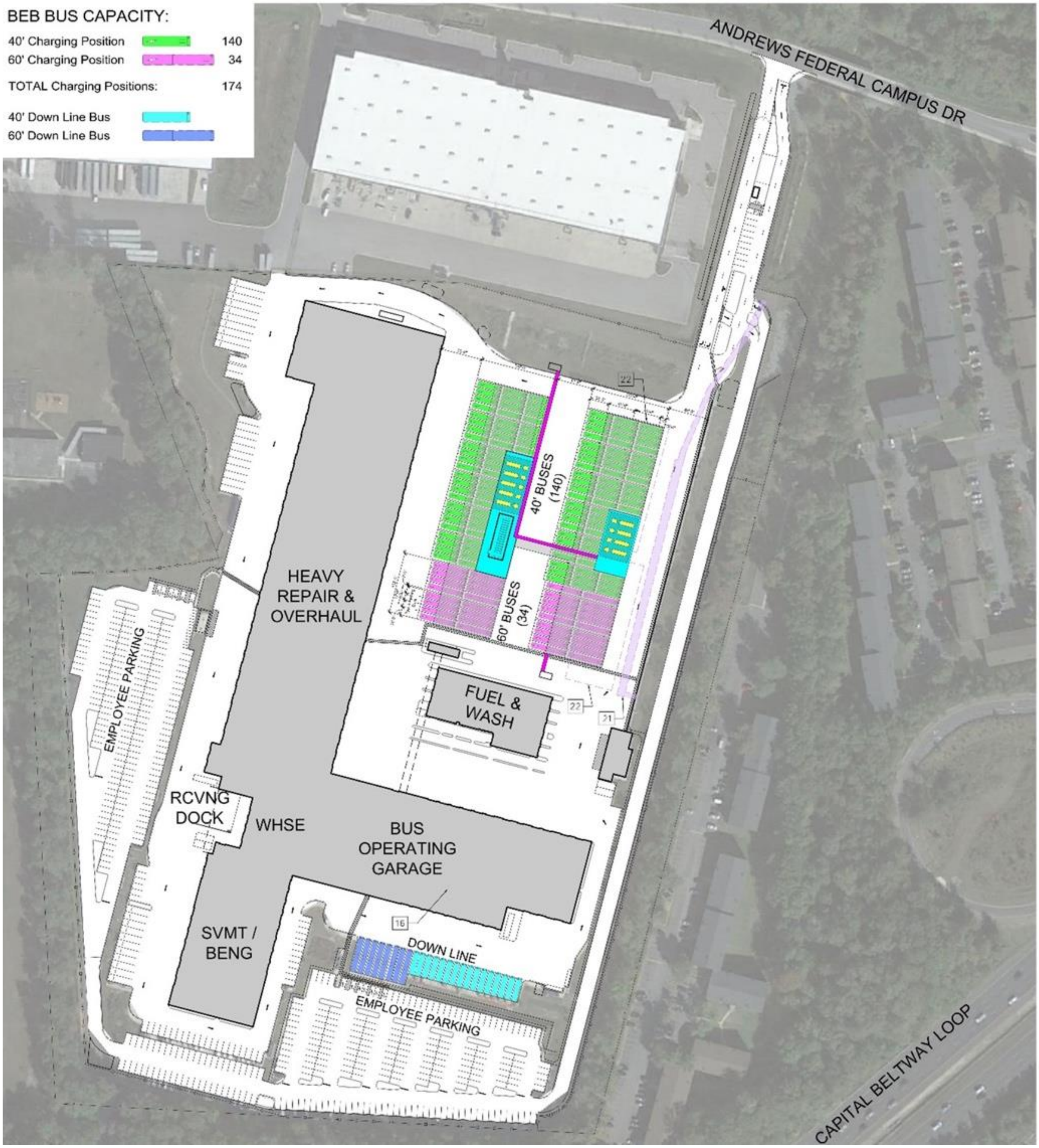
[21] Expected 7% annual improvement in range, per Bloomberg New Energy Finance (BNEF), 2021. *Hitting the EV Inflection Point.*

Figure 4-3. Andrews Federal Center Garage – Existing Site Layout



Source: WSP, Metro (2022)

Figure 4-4. Andrews Federal Center Garage – Proposed Site Layout



Source: WSP, Metro (2022)

FUEL CELL ELECTRIC BUS CONCEPT

An analysis of spatial requirements for a liquid hydrogen tank necessary to support 50 FCEBs, plus the required safety setbacks, and other supporting infrastructure, resulted in FCEB capacity of only 147 buses (or less than 85% of current bus capacity).

The reduced ZEB fleet size of 147 buses plus the average block's very short range and duration (62 miles and 5:43 hours), make BEBs a much more viable and cost sensitive service delivery solution (Table 4-4). Therefore, at this time, Andrews Federal Center Garage is being considered for a BEB transition pursuant to Metro's ZEB goals. However, Metro will continue to monitor FCEB technology and consider its integration if the spatial and market challenges (as noted in Section 3.3.1) are mitigated.

Table 4-4. Andrews Federal Center Garage – Capacity

Garage	Current Capacity	Current Assigned	BEB Capacity	FCEB Capacity	FCEB Parking Difference
Andrews Federal Center	175	158	174	147	-28

Source: WSP (2022)
Note: Current Capacity = number of buses that can current be parked at this facility; BEB Capacity = number of BEBs charging spaces available at this facility based on preliminary design and FCEB Capacity = number of parking spaces available based on room for hydrogen fueling equipment and NFPA setback requirements.

4.2 BLADENSBURG GARAGE

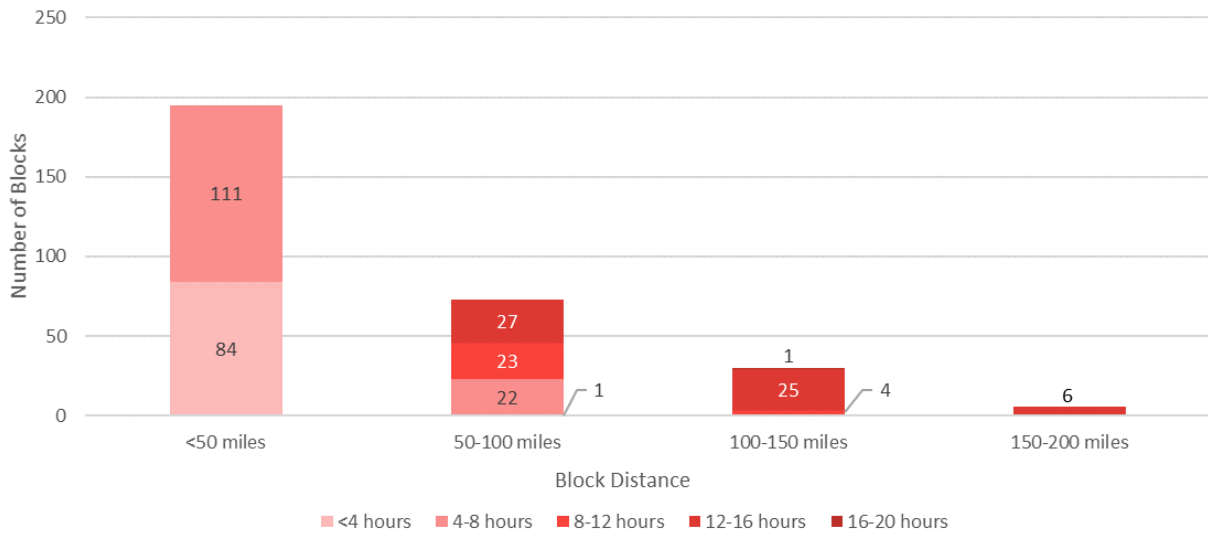
Bladensburg Garage is currently undergoing construction improvements that will modernize the facility and improve essential bus operations and maintenance; the reconstruction includes the allocation of space for BEB infrastructure. Facility concepts for Bladensburg are currently in development at Metro and are not reassessed here.

4.2.1 EXISTING CONDITIONS

SERVICE AND FLEET ANALYSIS

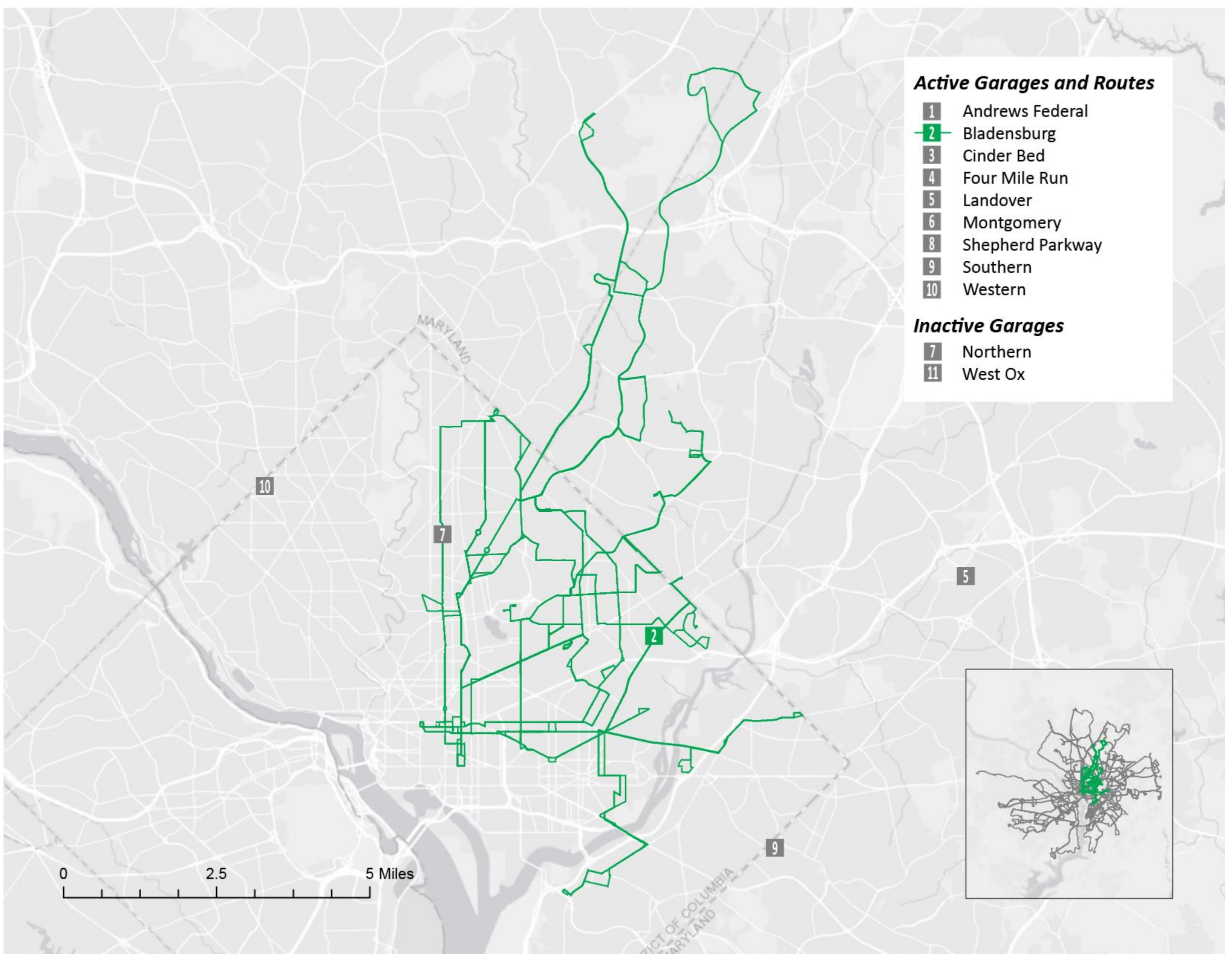
As of December 2021, 270 35-foot, 40-foot, and 60-foot buses are stored, maintained, and dispatched from Bladensburg Garage. The garage's fleet supports 22 routes (304 weekday blocks with a 175-bus PVR) that primarily serve Northeast and Northwest Washington D.C., with several routes serving further north to Calverton, Maryland. The garage's blocks range in both duration and distance: the shortest block is 10 miles in distance and approximately two hours in duration, whereas the longest block is 182 miles and is operated for 16 hours. The majority of the garage's blocks are relatively short with less than 50-mile ranges and eight-hour durations. Figure 4-5 categorizes the blocks by distance and duration, while Figure 4-6 presents Bladensburg Garage-serving routes in the context of Metro's other garages and routes.

Figure 4-5. Bladensburg Garage – Blocks by Distance and Duration



Source: WSP, Metro (December 2021)

Figure 4-6. Bladensburg Garage – Garage and Route Map



Source: WSP, Metro (December 2021)

4.2.2 FUTURE ZEB CONDITIONS

SERVICE AND FLEET ANALYSIS

It is expected that 289 (95%) of Bladensburg Garage's 304 blocks could be completed by a BEB in the typical operating scenario, assuming the bus is dispatched with a full charge. The number of passing blocks will decrease to 244 blocks (80%) in the intensive scenario due to the more challenging weather conditions and higher energy consumption due to elevation gains.

In both scenarios, the majority of the garage's blocks that are unable to be successfully completed are still completing over 50% of the block. One of the 15 failing blocks in the typical scenario and three of the 60 failing blocks in the intensive scenario, however, can only complete less than half the block distance when using BEB.

Table 4-5. Bladensburg Garage – Modeling Results Summary

Category	Results
Total Blocks	304
Passing Blocks	80% to 95%*
Buses Needed for Passing Blocks	108 to 148
Buses Available for Failing Blocks	122 to 162

Source: WSP, Metro
Note: *Intensive and typical modeling scenarios, respectively.

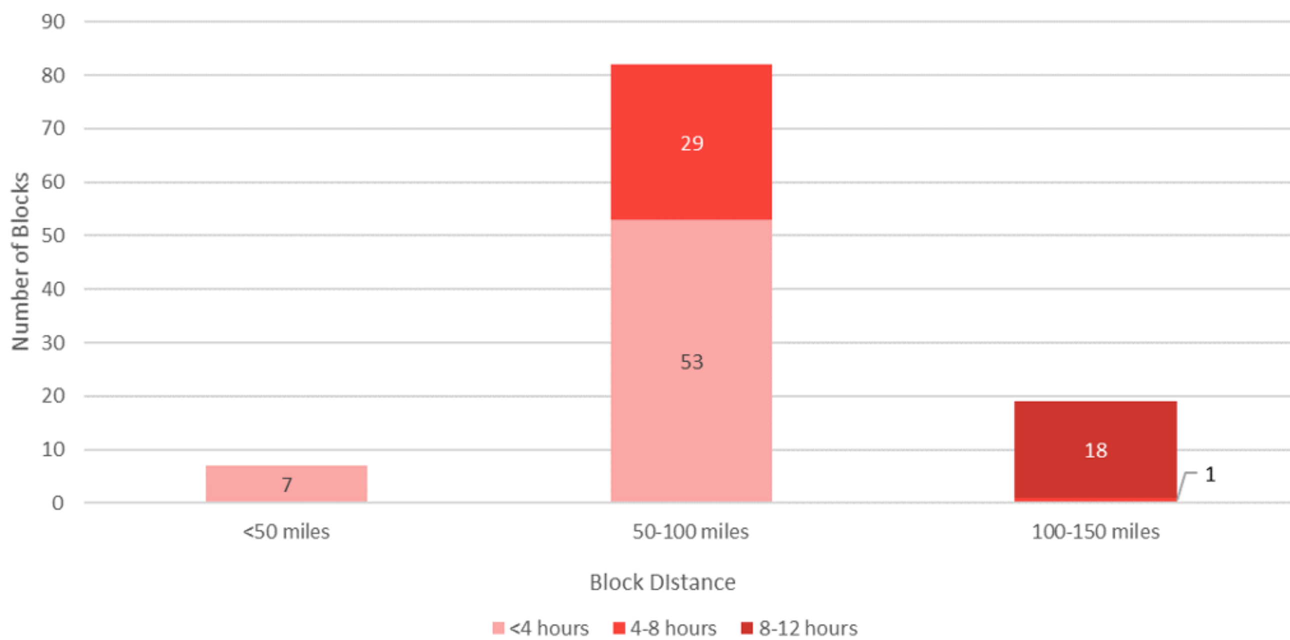
4.3 CINDER BED ROAD GARAGE

4.3.1 EXISTING CONDITIONS

SERVICE AND FLEET ANALYSIS

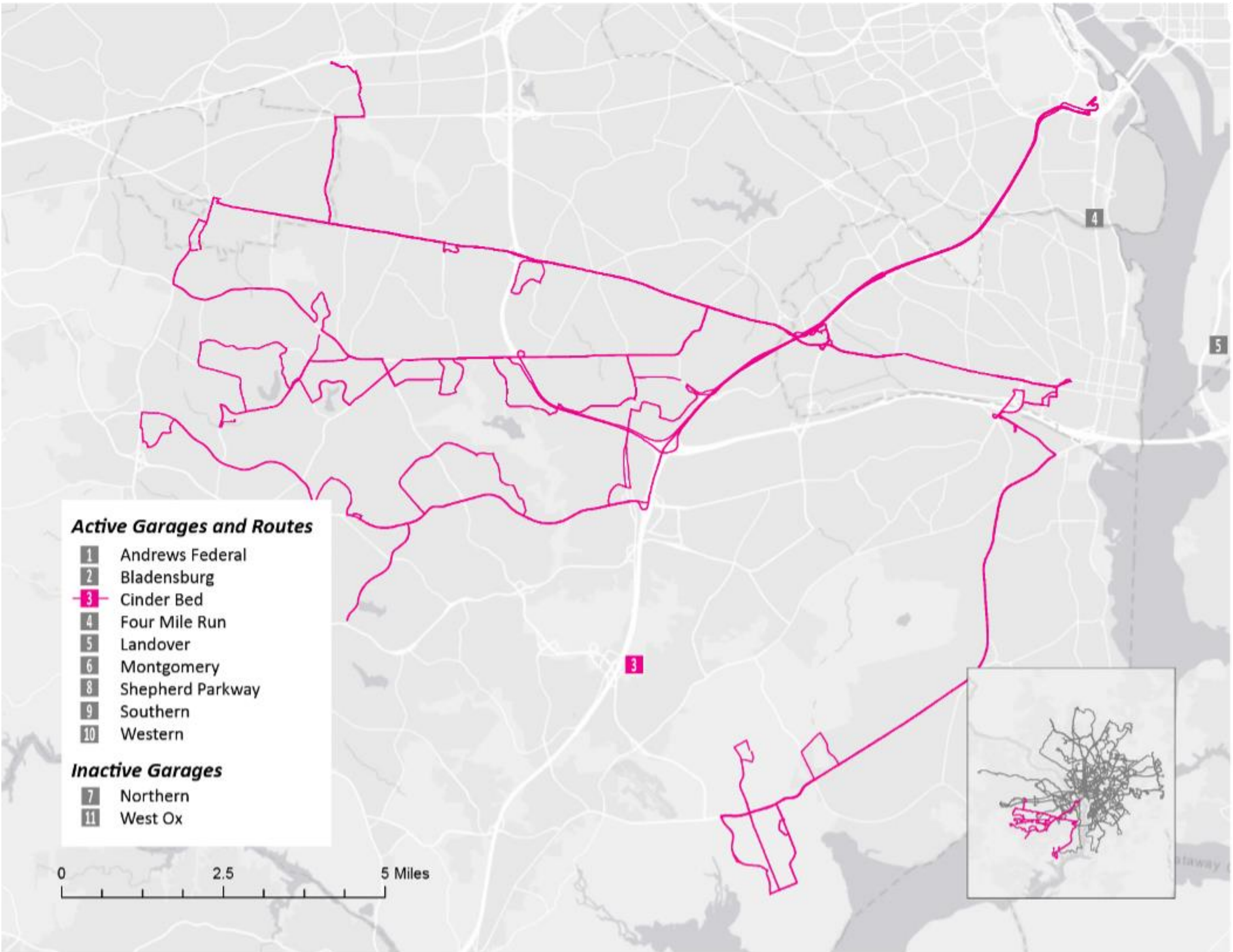
As of December 2021, 121 40-foot buses are stored, maintained, and dispatched from Cinder Bed Road Garage. The garage's fleet supports 11 routes (108 weekday blocks with a 52-bus PVR) that primarily serve Fairfax County, Virginia. The garage's service blocks range from 26 to 139 miles and operate between two and 10 hours. Figure 4-7 presents the garage's blocks by distance and duration, and Figure 4-8 illustrates Cinder Bed Road Garage's routes in the context of Metro's other garages.

Figure 4-7. Cinder Bed Road Garage – Block Distribution by Distance and Duration



Source: WSP, Metro (December 2021)

Figure 4-8. Cinder Bed Road Garage – Garage and Route Map



Source: WSP, Metro (December 2021)

FACILITY ANALYSIS

The Cinder Bed Road Garage is located in Fairfax County, Virginia. Based on field observations, the site appears to have safe and efficient site circulation, and has many characteristics that are conducive for ZEB operations, including:

- Employee parking is separate from the bus parking and service areas.
- Buses can be parked, serviced, and exit the site with few backing movements.
- The service cycle follows a forward-moving counterclockwise flow. This is desirable for the safe and efficient operation of bus circulation. The driver sits on the left side of the bus, which provides the best line of sight for left-hand turns.

However, there are also some challenges that will need to be resolved or mitigated to ease the transition to ZEBs, including:

- Bus parking is stacked six buses deep, which could pose a problem for pullout if there is a breakdown.

- There is existing subsurface infrastructure in the form of easements, utility runs, and stormwater management vaults. Technical solutions to address these items will need to be determined in the advanced design process.
- The stair tower on the north side of the bus parking area is directly in front of six rows of buses. This has created a situation where the buses in these rows are reversed and must back into the spaces. This does not currently impact daily operations, as the buses parked in these rows are not being used for daily service.

Table 4-6 summarizes existing conditions at Cinder Bed Road Garage.

Table 4-6. Cinder Bed Road Garage – Existing Facility Conditions Summary

Category	Description
Location	Fairfax County, Virginia
Fuel Type	Diesel
Utility Provider	Dominion
Utility Service: Voltage/Transformer Rating (kVA)/and Peak Demand (kVA)	Maintenance and Administration Building: 480/2,000/189 Fuel and Wash Area: 480/750/Unknown
Functions	Operating Garage
Bus Parking	Outdoor
Maintenance Capacity	13 maintenance bays (7 articulated and 6 standard)
Existing Parking Capacity	160 total (160 standard)

Source: WSP, Metro

4.3.2 FUTURE ZEB CONDITIONS

SERVICE AND FLEET ANALYSIS

Under existing conditions, between 88% and 100%[22] of Cinder Bed Road Garage's blocks can be supported by BEBs. These passing blocks can be supported by 46 to 53 BEBs depending on operating conditions, with the remaining assigned buses being available to support the "failed" blocks that have higher energy demands than the modeled battery capacity.

For the intensive scenario, all blocks that failed had a service duration that exceeded eight hours. Table 4-7 summarizes the modeling results for Cinder Bed Road Garage.

[22] Intensive and typical modeling results, respectively.

Table 4-7. Cinder Bed Road Garage – Modeling Results Summary

Category	Results
Total Blocks	108
Passing Blocks	88% to 100%*
Buses Needed for Passing Blocks	46 to 53
Buses Available for Failing Blocks	68 to 75

Source: WSP, Metro
Note: *Intensive and typical modeling scenarios, respectively.

Cinder Bed Road Garage's service blocks are fully capable of supporting BEBs based on modeling; therefore, it does not appear that capital-intensive strategies to support the failed blocks (such as opportunity charging or additional buses) are required. Furthermore, no passing or failing blocks from Cinder Bed Road Garage layover at any of the 20 opportunity charging locations. Based on the Fleet Management Plan (2021), Metro will have several ICEBs in the fleet through the late 2030s. Accordingly, dispatching ICEBs on demanding blocks until retirement and/or slight service changes appears to be the most suitable strategy to address the failed blocks as battery technology continues to improve. [23]

FACILITY ANALYSIS

BATTERY-ELECTRIC BUS CONCEPT

Cinder Bed Road Garage can support 112 charging positions for 112 standard Metrobuses. The proposed site layout utilizes the existing north/south bus parking configuration. Adjustments were made to ensure that column foundations remained out of the existing subsurface utility easements. The issue of the stair tower was resolved by providing adequate space between the bus parking area and the stair tower. A block of dedicated parking, including potential spots for up to 24 articulated buses for a partner transit agency is included in the layout – these 24 spaces are not charging positions. Table 4-8 summarizes the proposed equipment needed to support the future all-BEB garage, and Figure 4-9 and Figure 4-10 illustrate Cinder Bed Road Garage existing and proposed future site layouts.

Table 4-8. Cinder Bed Road Garage – BEB Concept Summary

Category	Description
Charging Positions	112 total (112 standard)
Proposed Charger Type and Specification	(6) 2 MW charging units
Connected Load	12 MW
Electrical Infrastructure Enhancements	Medium voltage (MV) service and MV switchgear

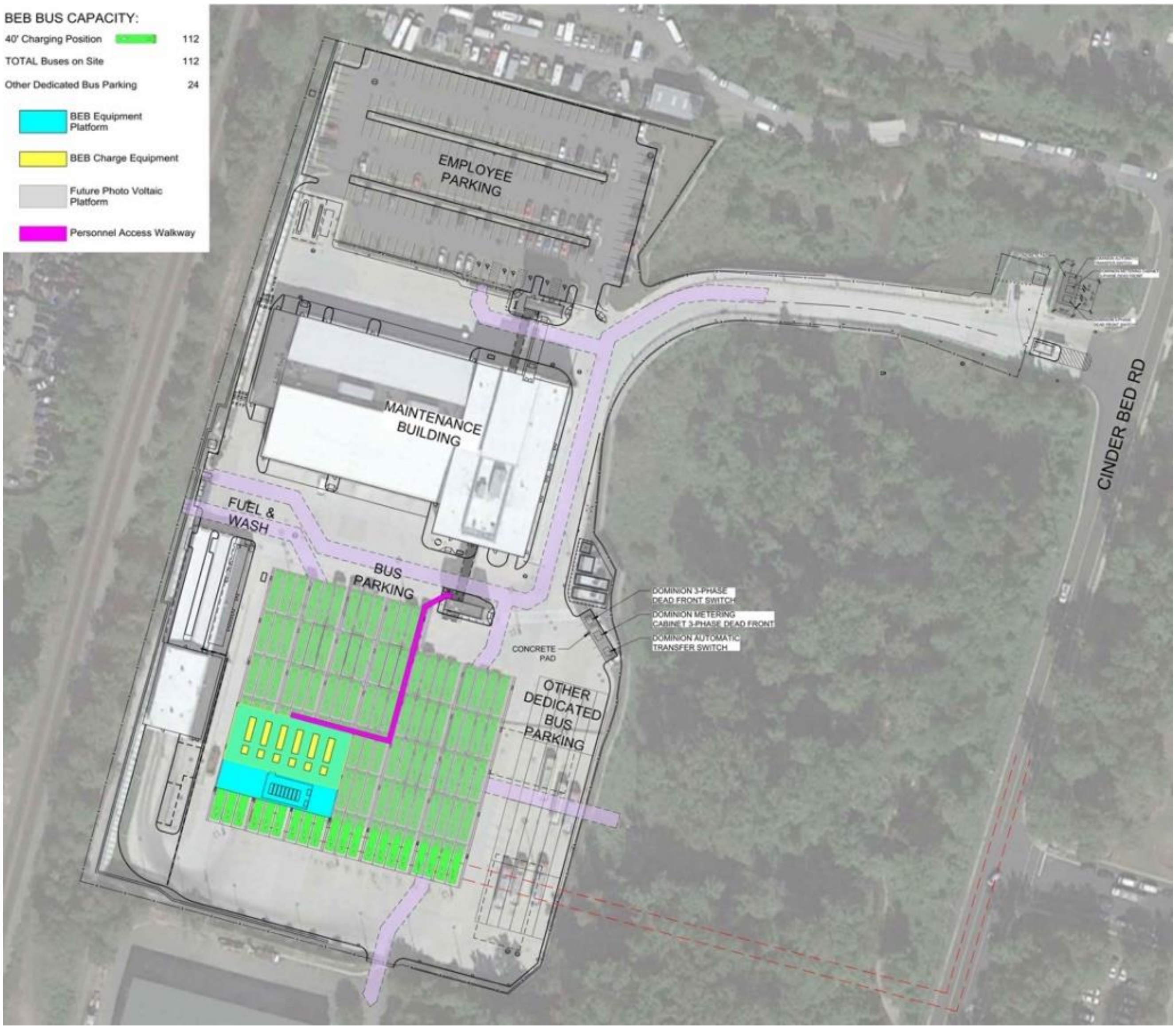
Source: WSP (2022)

[23] Expected 7% annual improvement in range, per Bloomberg New Energy Finance (BNEF), 2021. *Hitting the EV Inflection Point.*

Figure 4-9. Cinder Bed Road Garage – Existing Site Layout

Source: WSP, Metro (2022)

Figure 4-10. Cinder Bed Road Garage – Proposed Site Layout



Source: WSP, Metro (2022)

FUEL CELL ELECTRIC BUS CONCEPT

An analysis of spatial requirements for a liquid hydrogen tank necessary to support 50 FCEBs, plus the required safety setbacks, and other supporting infrastructure, resulted in a reduction in the garage's ZEB capacity from 112 BEBs to 88 FCEBs (or 55% of current bus capacity) (Table 4-9).

The ZEB fleet size reduction, plus the average block's very short range and duration (66 miles and 4:03 hours), make BEBs a much more viable and cost sensitive service delivery solution. Therefore, this version of the Transition Plan considers Cinder Bed Road Garage for a BEB transition pursuant to Metro's ZEB goals. However, Metro will continue to monitor FCEB technology and consider its integration if the spatial and market challenges (as noted in Section 3.3.1) are mitigated.

Table 4-9. Cinder Bed Road Garage – Capacity

Garage	Current Capacity	Current Assigned	BEB Capacity	FCEB Capacity	FCEB Parking Difference
Cinder Bed Road	160	121	112	88	-72

Source: WSP (2022)
Note: Current Capacity = number of buses that can current be parked at this facility; BEB Capacity = number of BEBs charging spaces available at this facility based on preliminary design and FCEB Capacity = number of parking spaces available based on room for hydrogen fueling equipment and NFPA setback requirements.

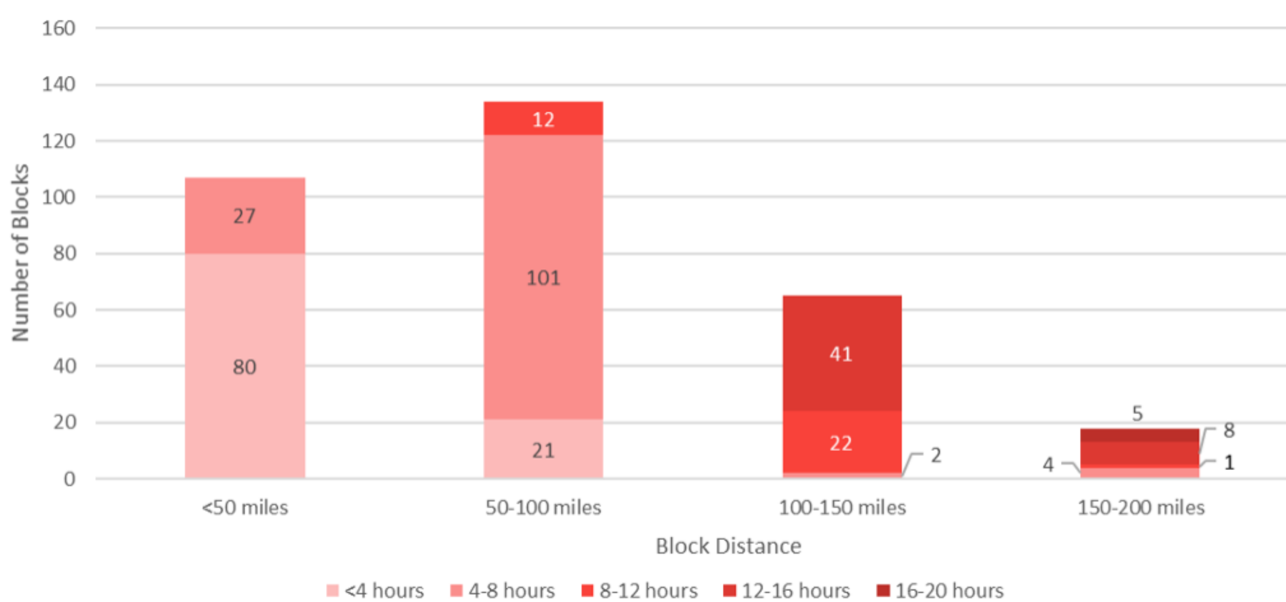
4.4 FOUR MILE RUN GARAGE

4.4.1 EXISTING CONDITIONS

SERVICE AND FLEET ANALYSIS

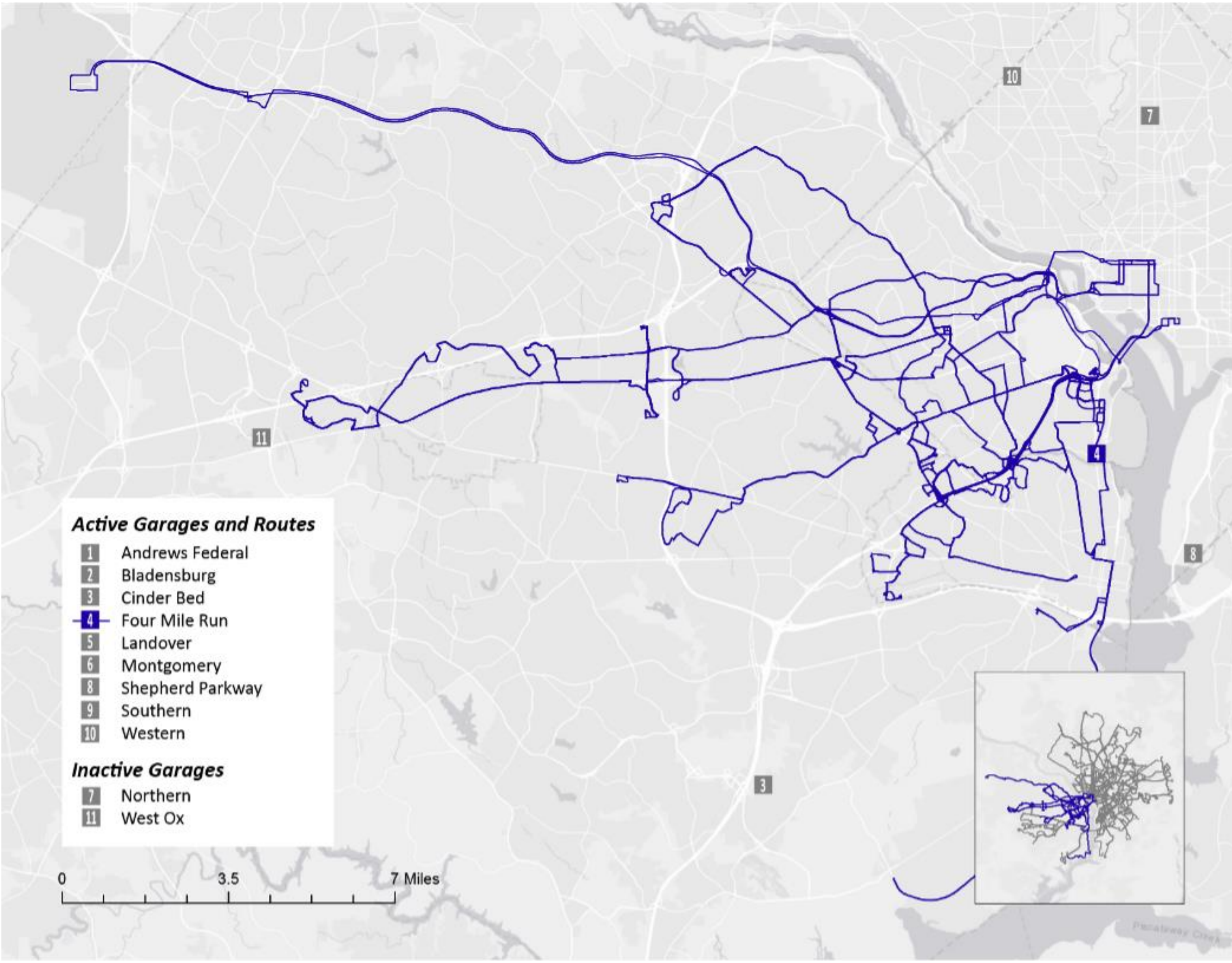
As of December 2021, 216 40-foot buses are stored, maintained, and dispatched from Four Mile Run Garage. The garage's fleet supports 33 routes (324 weekday blocks with a 165-bus PVR) that primarily serve Arlington and Fairfax counties in Virginia, with routes going as far as the Washington Dulles International Airport. The garage's service blocks range from 10 to 187 miles and operate between an hour and 17 hours. Figure 4-11 presents the garage's blocks by distance and duration, and Figure 4-12 illustrates Four Mile Run Garage's routes in the context of Metro's other garages.

Figure 4-11. Four Mile Run Garage – Block Distribution by Distance and Duration



Source: WSP, Metro (December 2021)

Figure 4-12. Four Mile Run Garage – Garage and Route Map



Source: WSP, Metro (December 2021)

FACILITY ANALYSIS

The Four Mile Run Garage is located in Arlington County, Virginia. Based on field observations, the site is at crush capacity and site circulation is inefficient. The garage has many characteristics that are conducive for ZEB operations, including:

- Located near routes that it serves.
- Located directly adjacent to Dominion electrical substation.

However, there are also many challenges that will need to be resolved or mitigated to ease the transition to ZEBs, including:

- Bus parking space is limited, requiring buses to be maneuvered and parked in tight configurations.
- Site circulation is constrained due to the site being split by South Glebe Road.
- Backing movements are required for bus parking.

Table 4-10 summarizes existing conditions at Four Mile Run Garage.

Table 4-10. Four Mile Run Garage – Existing Facility Conditions Summary

Category	Description
Location	Arlington County, Virginia
Fuel Type	CNG and Diesel
Utility Provider	Dominion
Utility Service: Voltage/Transformer Rating (kVA)/and Peak Demand (kVA)	Maintenance and Administration Building: 480/500 /Unknown Fuel and Wash Area: 480/200/Unknown
Functions	Operating Garage
Bus Parking	Outdoor
Maintenance Capacity	17 maintenance bays (10 standard)
Existing Parking Capacity	218 total (218 standard)

Source: WSP, Metro

4.4.2 FUTURE ZEB CONDITIONS

SERVICE AND FLEET ANALYSIS

Under existing conditions, between 75% and 89%[24] of Four Mile Run Garage's blocks can be supported by BEBs. These passing blocks can be supported by 104 to 140 BEBs depending on operating conditions, with the remaining assigned buses being available to support the "failed" blocks that have higher energy demands than the modeled battery capacity.

Under both modeled scenarios, all blocks that failed had a service duration that exceeded seven hours. Table 4-11 summarizes the modeling results for Four Mile Run Garage.

[24] Intensive and typical modeling results, respectively.

Table 4-11. Four Mile Run Garage – Modeling Results Summary

Category	Results
Total Blocks	324
Passing Blocks	75% to 89%*
Buses Needed for Passing Blocks	104 to 140
Buses Available for Failing Blocks	76 to 112

Source: WSP, Metro
Note: *Intensive and typical modeling scenarios, respectively.

Because Four Mile Run Garage's service blocks have a relatively high completion percentage, it does not appear that capital-intensive strategies to support the failed blocks (such as opportunity charging or additional buses) are required. That said, with opportunity charging simulated at Pentagon Station, the analysis found that the number of passing blocks will improve from 89% to 92% in the typical scenario, and from 75% to 81% in the intensive scenario. Based on the Fleet Management Plan (2021), Metro will have several ICEBs in the fleet through the late 2030s. Therefore, dispatching ICEBs on demanding blocks until retirement and/or slight service changes appears to be the most suitable strategy to address the failed blocks as battery technology continues to improve.[25]

FACILITY ANALYSIS

BATTERY-ELECTRIC BUS CONCEPT

Four Mile Run Garage can support 167 charging positions, 142 for standard buses and 25 for articulated buses. The proposed site layout requires a complete rebuild in place of the existing garage. The layout maximizes the largest portion of the north half of the site for bus storage. Bus storage is broken into three groups to limit the depth of the stacked buses. Table 4-12 summarizes the proposed equipment needed to support the future all-BEB garage, and Figure 4-13 and Figure 4-14 illustrate Four Mile Run Garage existing and proposed future site layouts.

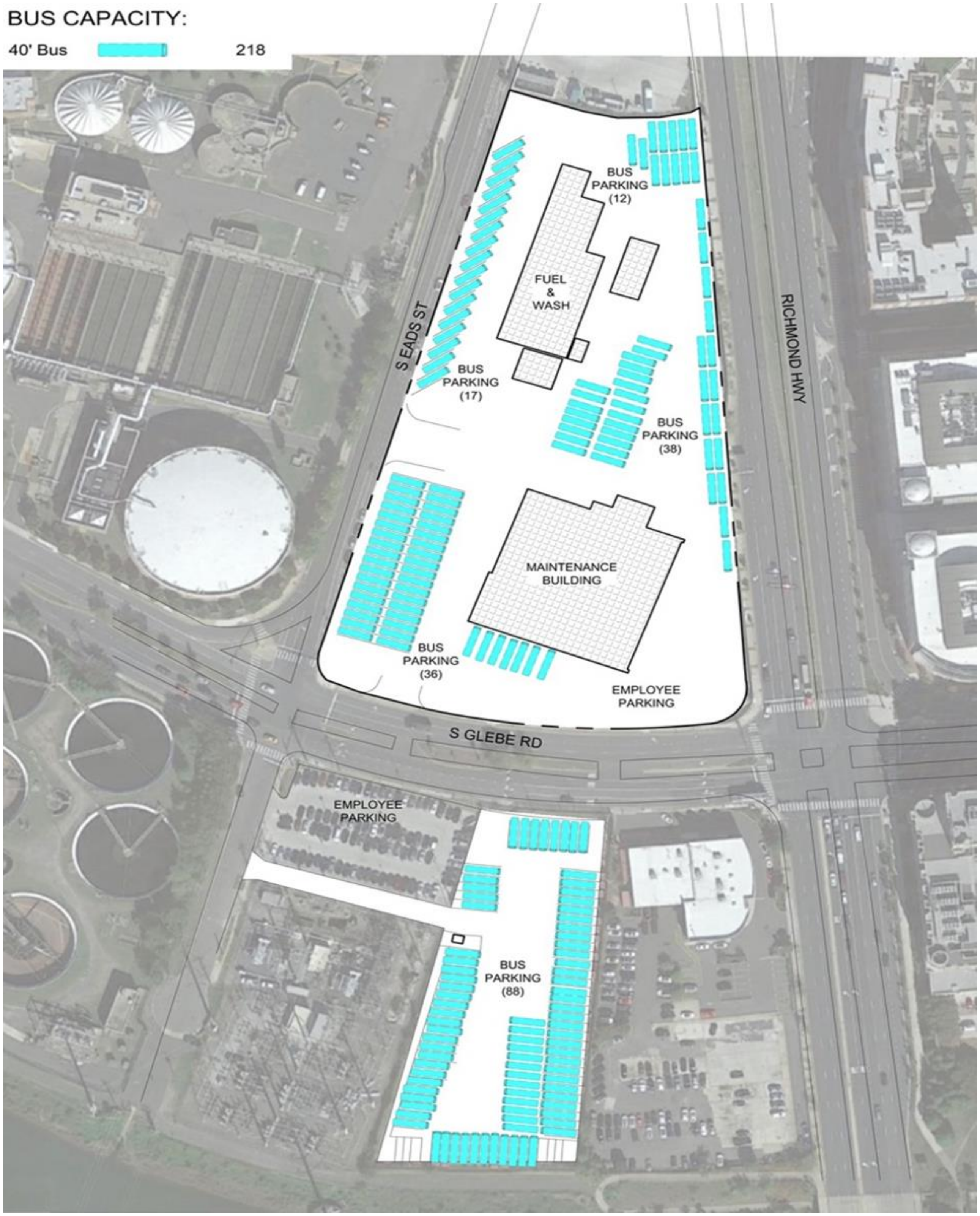
Table 4-12. Four Mile Run Garage – Modeling Results Summary

Category	Description
Charging Positions	167 total (25 articulated and 142 standard)
Proposed Charger Type and Specification	(9) 2 MW charging units
Connected Load	18 MW
Electrical Infrastructure Enhancements	Medium voltage (MV) service and MV switchgear

Source: WSP (2022)

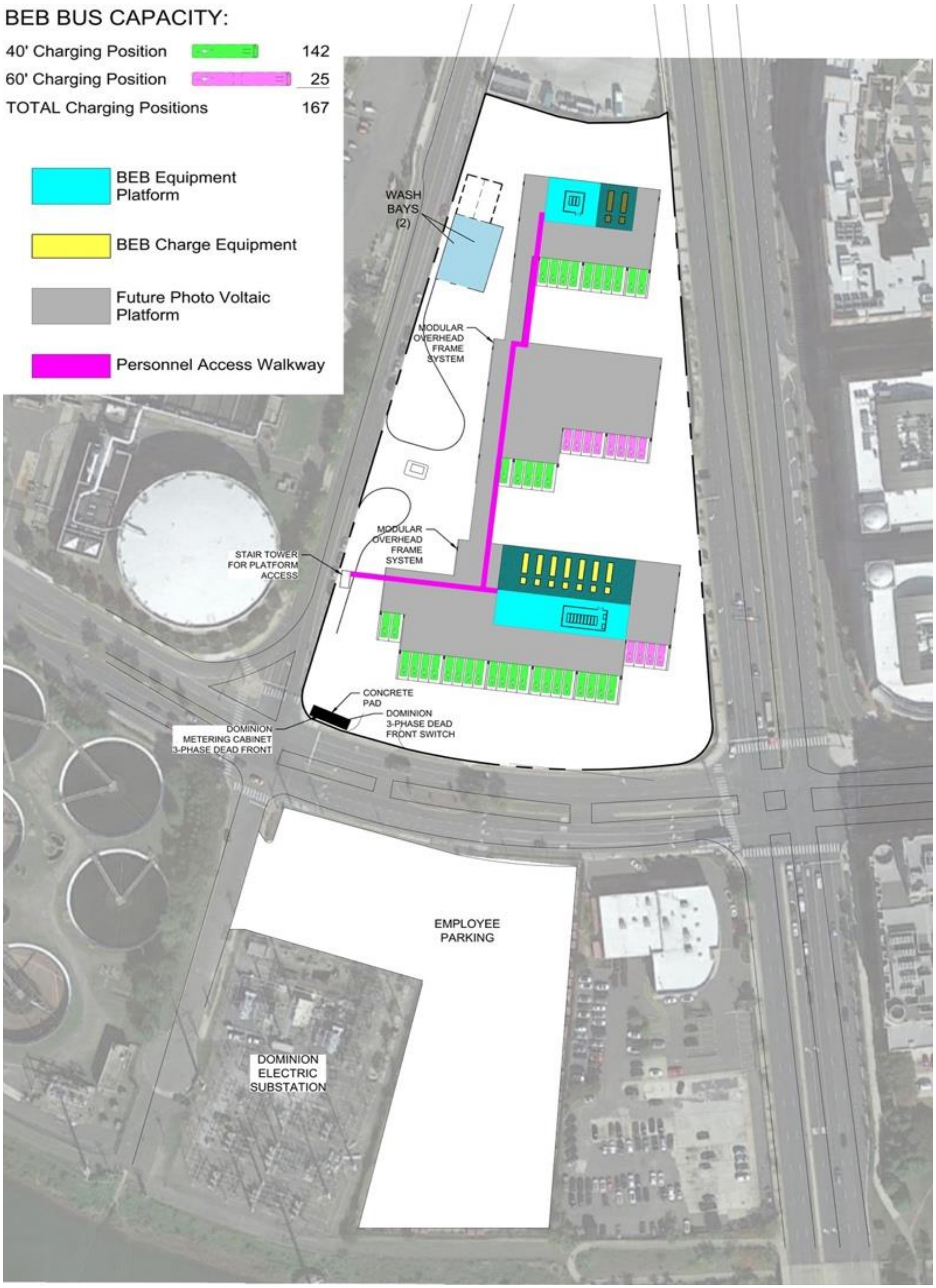
[25] Expected 7% annual improvement in range, per Bloomberg New Energy Finance (BNEF), 2021. *Hitting the EV Inflection Point.*

Figure 4-13. Four Mile Run Garage – Existing Site Layout



Source: WSP, Metro (2022)

Figure 4-14. Four Mile Run Garage – Proposed Site Layout



Source: WSP, Metro (2022)

FUEL CELL ELECTRIC BUS CONCEPT

An analysis of spatial requirements for a liquid hydrogen tank necessary to support 50 FCEBs, plus the required safety setbacks, and other supporting infrastructure, resulted in a reduction in the garage's total fleet capacity by 78 buses (to less than 65% of current bus capacity).

The ZEB fleet size reduction from 167 to 140 buses, plus the average block's very short range and duration (66 miles and 5:48 hours), make BEBs a much more viable and cost sensitive service delivery solution. Therefore, this version of the Transition Plan considers Four Mile Run for a BEB transition pursuant to Metro's ZEB goals. However, Metro will continue to monitor FCEB technology and consider its integration if the spatial and market challenges (as noted in Section 3.3.1) are mitigated.

Table 4-13. Four Mile Run Garage – Capacity

Garage	Current Capacity	Current Assigned	BEB Capacity	FCEB Capacity	FCEB Parking Difference
Four Mile Run	218	216	167	140	-78

Source: WSP (2022)
Note: Current Capacity = number of buses that can current be parked at this facility; BEB Capacity = number of BEBs charging spaces available at this facility based on preliminary design and FCEB Capacity = number of parking spaces available based on room for hydrogen fueling equipment and NFPA setback requirements.

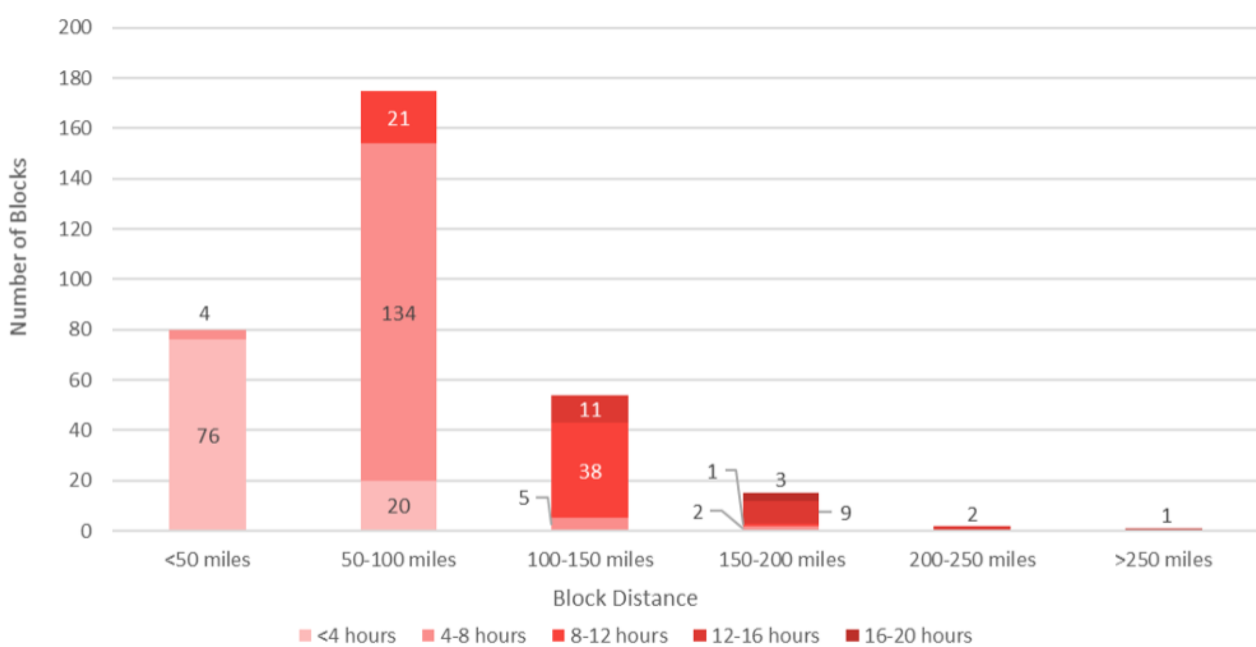
4.5 LANDOVER GARAGE

4.5.1 EXISTING CONDITIONS

SERVICE AND FLEET ANALYSIS

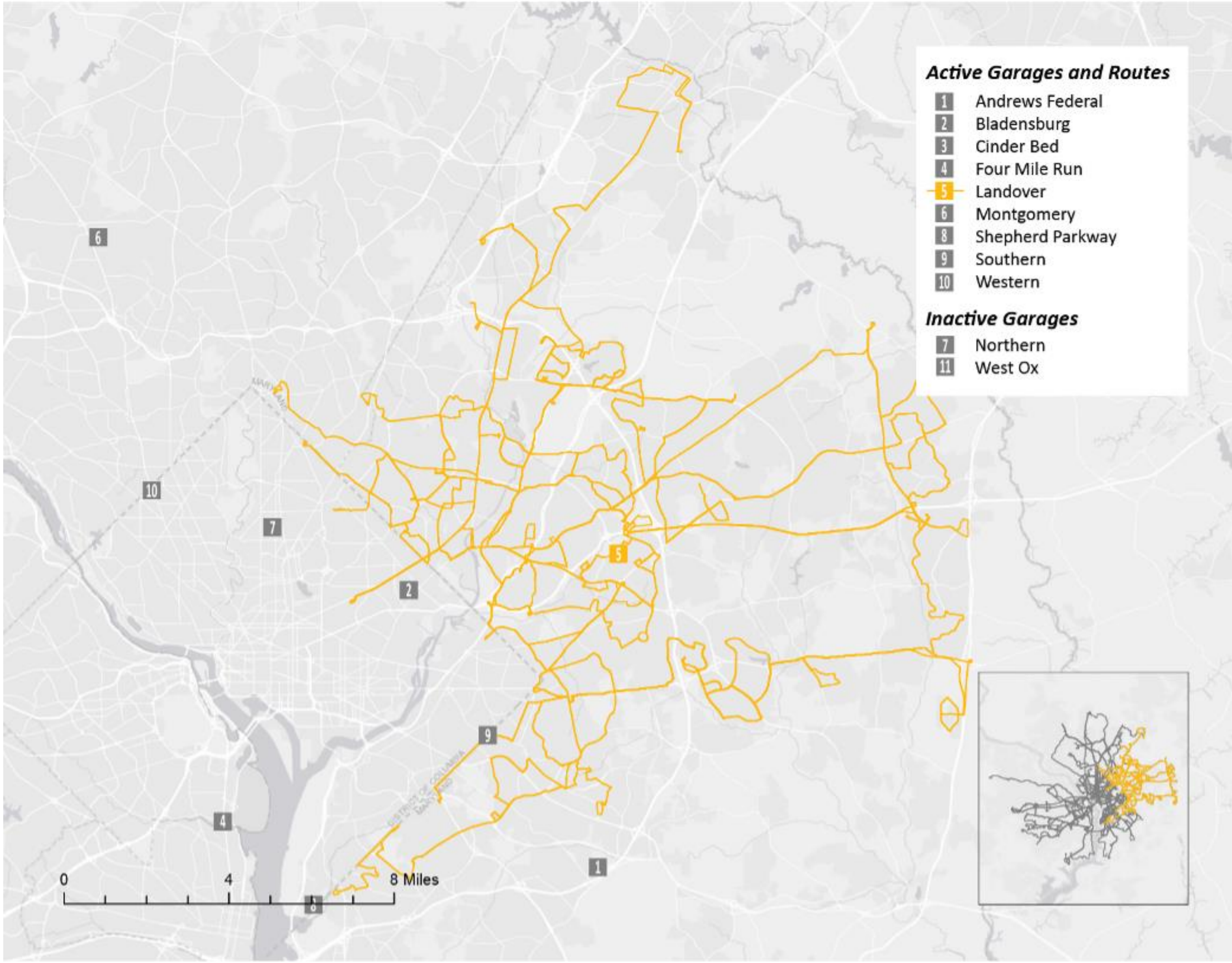
As of December 2021, 190 40-foot buses are stored, maintained, and dispatched from Landover Garage. The garage's fleet supports 27 routes (327 weekday blocks with a 155-bus PVR) that primarily serve northern, central, and southern portions of Prince George's County, Maryland. The garage's service blocks range from 26 to 261 miles and operate between two and 16 hours. Figure 4-15 presents the garage's blocks by distance and duration, and Figure 4-16 illustrates Landover Garage's routes in the context of Metro's other garages.

Figure 4-15. Landover Garage – Block Distribution by Distance and Duration



Source: WSP, Metro (December 2021)

Figure 4-16. Landover Garage – Garage and Route Map



Source: WSP, Metro (December 2021)

FACILITY ANALYSIS

The Landover Garage is located in Prince George's County, Maryland. Based on field observations, the site appears to have safe and efficient site circulation. The garage has many characteristics that are conducive for ZEB operations, including:

- Employee parking is separate from the bus parking and service areas.
- Buses can be parked, serviced, and exit the site with few backing movements.
- The service cycle follows a forward-moving counterclockwise flow. This is desirable for the safe and efficient operation of bus circulation. The driver sits on the left side of the bus, which provides the best line of sight for left-hand turns.
- The proximity of the garage to the Carmen E. Turner Facility is a benefit for bus engineering.

However, there are also some challenges that will need to be resolved or mitigated to ease the transition to ZEBs, including:

- There is existing subsurface infrastructure in the form of easements, utility runs, and stormwater management vaults. These include 30- and 72-inch storm sewers, and a 10-inch sanitary sewer. Technical solutions to address these items will need to be determined in the advanced design process.

Table 4-14 summarizes existing conditions at Landover Garage.

Table 4-14. Landover Garage – Existing Facility Conditions Summary

Category	Description
Location	Prince George's County, Maryland
Fuel Type	Diesel
Utility Provider	BGE
Utility Service: Voltage/Transformer Rating (kVA)/and Peak Demand (kVA)	Maintenance and Administration Building: 480/Unknown /131
Functions	Operating Garage
Bus Parking	Outdoor
Maintenance Capacity	16 maintenance bays (16 standard)
Existing Parking Capacity	172 total (172 standard)

Source: WSP, Metro

4.5.2 FUTURE ZEB CONDITIONS

SERVICE AND FLEET ANALYSIS

Under existing conditions, between 80% and 92%[26] of Landover Garage's blocks can be supported by BEBs. These passing blocks can be supported by 114 to 146 BEBs depending on operating conditions, with the remaining assigned buses being available to support the "failed" blocks that have higher energy demands than the modeled battery capacity.

Under both modeling scenarios, all blocks that failed had a service duration that exceeded six hours. Table 4-15 summarizes the modeling results for Landover Garage.

[26] Intensive and typical modeling results, respectively.

Table 4-15. Landover Garage – Modeling Results Summary

Category	Results
Total Blocks	327
Passing Blocks	80% to 92%*
Buses Needed for Passing Blocks	114 to 146
Buses Available for Failing Blocks	44 to 76

Source: WSP, Metro
Note: *Intensive and typical modeling scenarios, respectively.

Landover Garage's service blocks have a relatively high completion percentage; therefore, it does not appear that capital-intensive strategies to support the failed blocks (such as opportunity charging or additional buses) are required. That said, with opportunity charging simulated at New Carrollton, the analysis found that the number of passing blocks will improve from 92% to 99% in the typical scenario, and from 80% to 88% in the intensive scenario. Based on the Fleet Management Plan (2021), Metro will have several ICEBs in the fleet through the late 2030s. As a result, dispatching ICEBs on demanding blocks until retirement and/or slight service changes appears to be the most suitable strategy to address the failed blocks as battery technology continues to improve. [27]

FACILITY ANALYSIS

BATTERY-ELECTRIC BUS CONCEPT

Landover Garage can support 172 charging positions, 147 for standard buses and 25 for articulated buses. The proposed site layout utilizes the existing herringbone bus parking configuration. Adjustments were made to ensure that column foundations remained out of the existing subsurface utility easements. Table 4-16 summarizes the proposed equipment needed to support the future all-BEB garage and Figure 4-17 and Figure 4-18 illustrate Landover Garage's existing and proposed future site layouts.

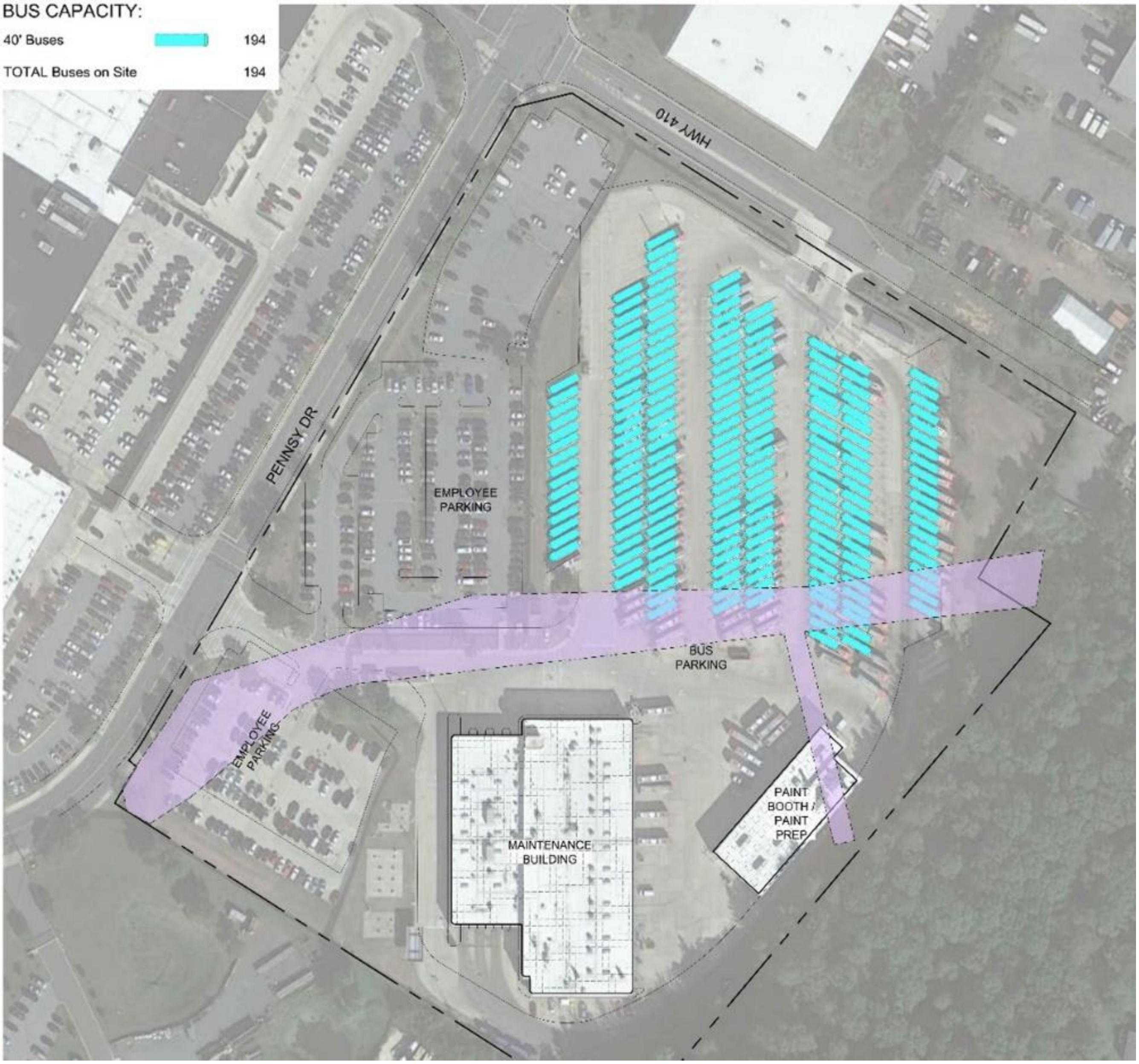
Table 4-16. Landover Garage – BEB Concept Summary

Category	Description
Charging Positions	172 total (25 articulated and 147 standard)
Proposed Charger Type and Specification	(9) 2 MW charging units
Connected Load	18 MW
Electrical Infrastructure Enhancements	Medium voltage (MV) service and MV switchgear

Source: WSP (2022)

[27] Expected 7% annual improvement in range, per Bloomberg New Energy Finance (BNEF), 2021. *Hitting the EV Inflection Point.*

Figure 4-17. Landover Garage – Existing Site Layout



Source: WSP, Metro (2022)

Figure 4-18. Landover Garage – Proposed Site Layout

Source: WSP, Metro (2022)

FUEL CELL ELECTRIC BUS CONCEPT

An analysis of spatial requirements for a liquid hydrogen tank necessary to support 50 FCEBs, plus the required safety setbacks, and other supporting infrastructure, resulted in a reduction in the garage's total fleet capacity to 160 buses.

The ZEB fleet size reduction from 172 to 160 buses, plus the average block's very short range and duration (69 miles and 5:21 hours), makes BEBs a much more viable solution (at this point) (Table 4-17). Therefore, this version of the Transition Plan considers Landover Garage for a BEB transition pursuant to Metro's ZEB goals. However, Metro will continue to monitor FCEB technology and consider its integration if the spatial and market challenges (as noted in Section 3.3.1) are mitigated.

Table 4-17. Landover Garage – Capacity

Garage	Current Capacity	Current Assigned	BEB Capacity	FCEB Capacity	FCEB Parking Difference
Landover	172	190	172	160	-12

Source: WSP (2022)
Note: Current Capacity = number of buses that can current be parked at this facility; BEB Capacity = number of BEBs charging spaces available at this facility based on preliminary design and FCEB Capacity = number of parking spaces available based on room for hydrogen fueling equipment and NFPA setback requirements.

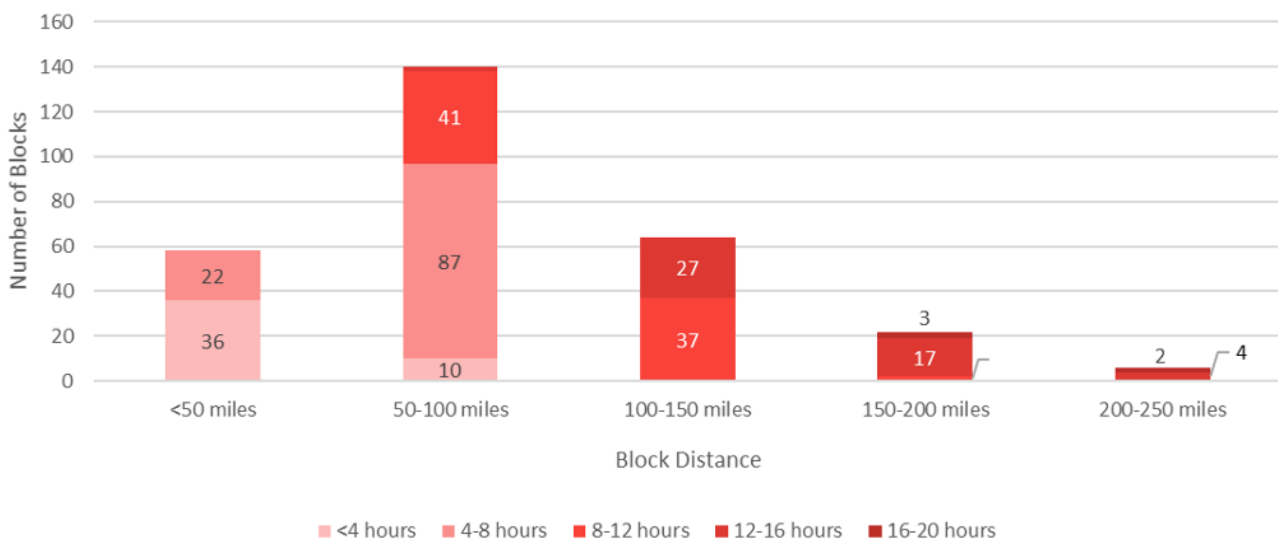
4.6 MONTGOMERY GARAGE

4.6.1 EXISTING CONDITIONS

SERVICE AND FLEET ANALYSIS

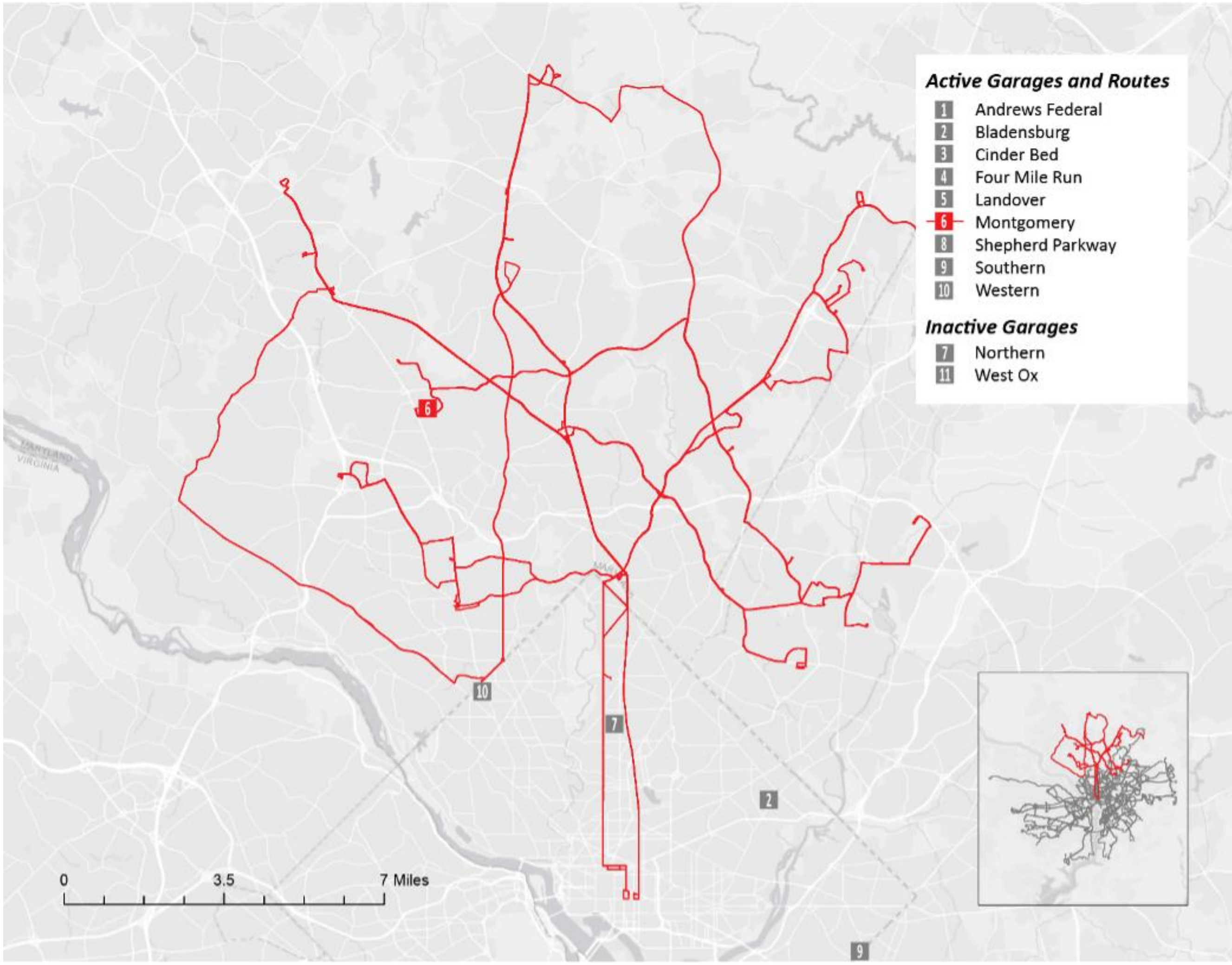
As of December 2021, 238 40- and 60-foot buses are stored, maintained, and dispatched from Montgomery Garage. The garage's fleet supports 23 routes (290 weekday blocks with a 160-bus PVR) that primarily serve Montgomery County, Maryland, with some routes serving Washington, D.C. The garage's service blocks range from 16 to 216 miles and operate between three and 17 hours. Figure 4-19 presents the garage's blocks by distance and duration, and Figure 4-20 illustrates Montgomery Garage's routes in the context of Metro's other garages.

Figure 4-19. Montgomery Garage – Block Distribution by Distance and Duration



Source: WSP, Metro (December 2021)

Figure 4-20. Montgomery Garage – Garage and Route Map



Source: WSP, Metro (December 2021)

FACILITY ANALYSIS

The Montgomery Garage is located in Montgomery County, Maryland. Based on field observations, the site appears to have safe and efficient site circulation. The garage has many characteristics that are conducive for ZEB operations, including:

- Buses can be parked, serviced, and exit the site with few backing movements.
- The service cycle follows a forward-moving counterclockwise flow. This is desirable for the safe and efficient operation of bus circulation. The driver sits on the left side of the bus, which provides the best line of sight for left-hand turns.
- A Pepco electrical substation is located on the same block as the garage.

However, there are also some challenges that will need to be resolved or mitigated to ease the transition to ZEBs, including:

- There is existing subsurface infrastructure in the form of easements, utility runs, and stormwater management vaults. These include a 66-inch water main and a 40-inch storm sewer. Technical solutions to address these items will need to be determined in the advanced design process.
- Employee parking is off-site.

Table 4-18 summarizes existing conditions at Montgomery Garage.

Table 4-18. Montgomery Garage – Existing Facility Conditions Summary

Category	Description
Location	Montgomery County, Maryland
Fuel Type	Diesel
Utility Provider	Pepco
Utility Service: Voltage/Transformer Rating (kVA)/and Peak Demand (kVA)	Maintenance and Administration Building: 480/Unknown /Unknown
Functions	Operating Garage
Bus Parking	Outdoor
Maintenance Capacity	17 maintenance bays (3 articulated and 14 standard)
Existing Parking Capacity	203 total (23 articulated and 180 standard)

Source: WSP, Metro

4.6.2 FUTURE ZEB CONDITIONS

SERVICE AND FLEET ANALYSIS

Under existing conditions, between 64% and 84%[28] of Montgomery Garage's blocks can be supported by BEBs. These passing blocks can be supported by 86 to 139 BEBs depending on operating conditions, with the remaining assigned buses being available to support the "failed" blocks that have higher energy demands than the modeled battery capacity.

Under the typical modeling scenario, all blocks that failed had a service duration that exceeded eight hours. For the intensive scenario, all blocks that failed had a service duration that exceeded 7.5 hours. Table 4-19 summarizes the modeling results for Montgomery Garage.

Table 4-19. Montgomery Garage – Modeling Results Summary

Category	Results
Total Blocks	290

[28] Intensive and typical modeling results, respectively.

Category	Results
Passing Blocks	64% to 84%*
Buses Needed for Passing Blocks	86 to 139
Buses Available for Failing Blocks	99 to 152

Source: WSP, Metro
Note: *Intensive and typical modeling scenarios, respectively.

Montgomery Garage's service blocks have a relatively high completion percentage; accordingly, it does not appear that capital-intensive strategies to support the failed blocks (such as opportunity charging or additional buses) are required. Moreover, with opportunity charging simulated at Silver Spring, the analysis found that the number of passing blocks will improve from 84% to 94% in the typical scenario, and from 64% to 90% in the intensive scenario. Based on the Fleet Management Plan (2021), Metro will have several ICEBs in the fleet through the late 2030s. Dispatching ICEBs on demanding blocks until retirement and/or slight service changes thus appears to be the most suitable strategy to address the failed blocks as battery technology continues to improve.

FACILITY ANALYSIS

BATTERY-ELECTRIC BUS CONCEPT

Montgomery Garage can support 170 charging positions, 155 for standard buses and 15 for articulated buses. The proposed site layout utilizes the existing herringbone bus parking configuration. Adjustments were made to ensure that column foundations remained out of the existing subsurface utility easements. Table 4-20 summarizes the proposed equipment needed to support the future all-BEB garage and Figure 4-21 and Figure 4-22 illustrate Montgomery Garage existing and proposed future site layouts.

Table 4-20. Montgomery Garage – BEB Concept Summary

Category	Description
Charging Positions	170 total (15 articulated and 155 standard)
Proposed Charger Type and Specification	(9) 2 MW charging units
Connected Load	18 MW
Electrical Infrastructure Enhancements	Medium voltage (MV) service and MV switchgear

Source: WSP (2022)

Figure 4-21. Montgomery Garage – Existing Site Layout

Source: WSP, Metro (2022)

Figure 4-22. Montgomery Garage – Proposed Site Layout

Source: WSP, Metro (2022)

FUEL CELL ELECTRIC BUS CONCEPT

An analysis of spatial requirements for a liquid hydrogen tank necessary to support 50 FCEBs, plus the required safety setbacks, and other supporting infrastructure, resulted in a reduction in the garage's total fleet capacity by 74 buses reducing current bus capacity by one-third.

The ZEB fleet size reduction from 170 to 146 buses, plus the average block's very short range and duration (74 miles and 6:48 hours), make BEBs a much more viable and cost sensitive service delivery solution. Therefore, this version of the Transition Plan considers Montgomery Garage for a BEB transition pursuant to Metro's ZEB goals. However, Metro will continue to monitor FCEB technology and consider its integration if the spatial and market challenges (as noted in Section 3.3.1) are mitigated.

Table 4-21. Montgomery Garage – Capacity

Garage	Current Capacity	Current Assigned	BEB Capacity	FCEB Capacity	FCEB Parking Difference
Montgomery	220	238	170	146	-74

Source: WSP (2022)
Note: Current Capacity = number of buses that can current be parked at this facility; BEB Capacity = number of BEBs charging spaces available at this facility based on preliminary design and FCEB Capacity = number of parking spaces available based on room for hydrogen fueling equipment and NFPA setback requirements.

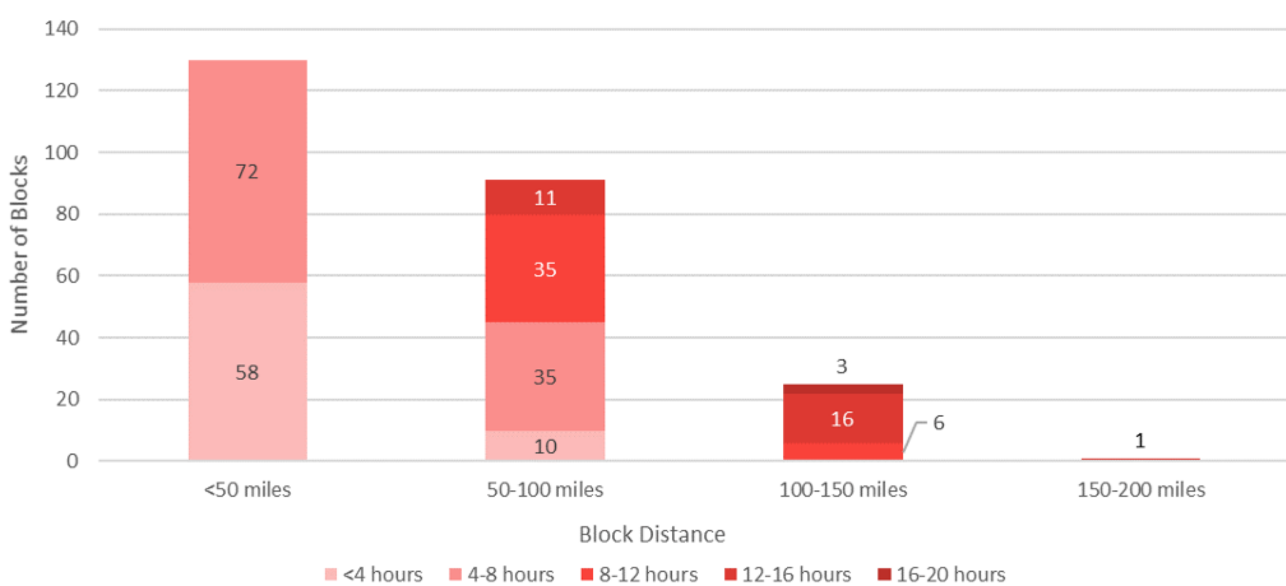
4.7 SHEPHERD PARKWAY GARAGE

4.7.1 EXISTING CONDITIONS

SERVICE AND FLEET ANALYSIS

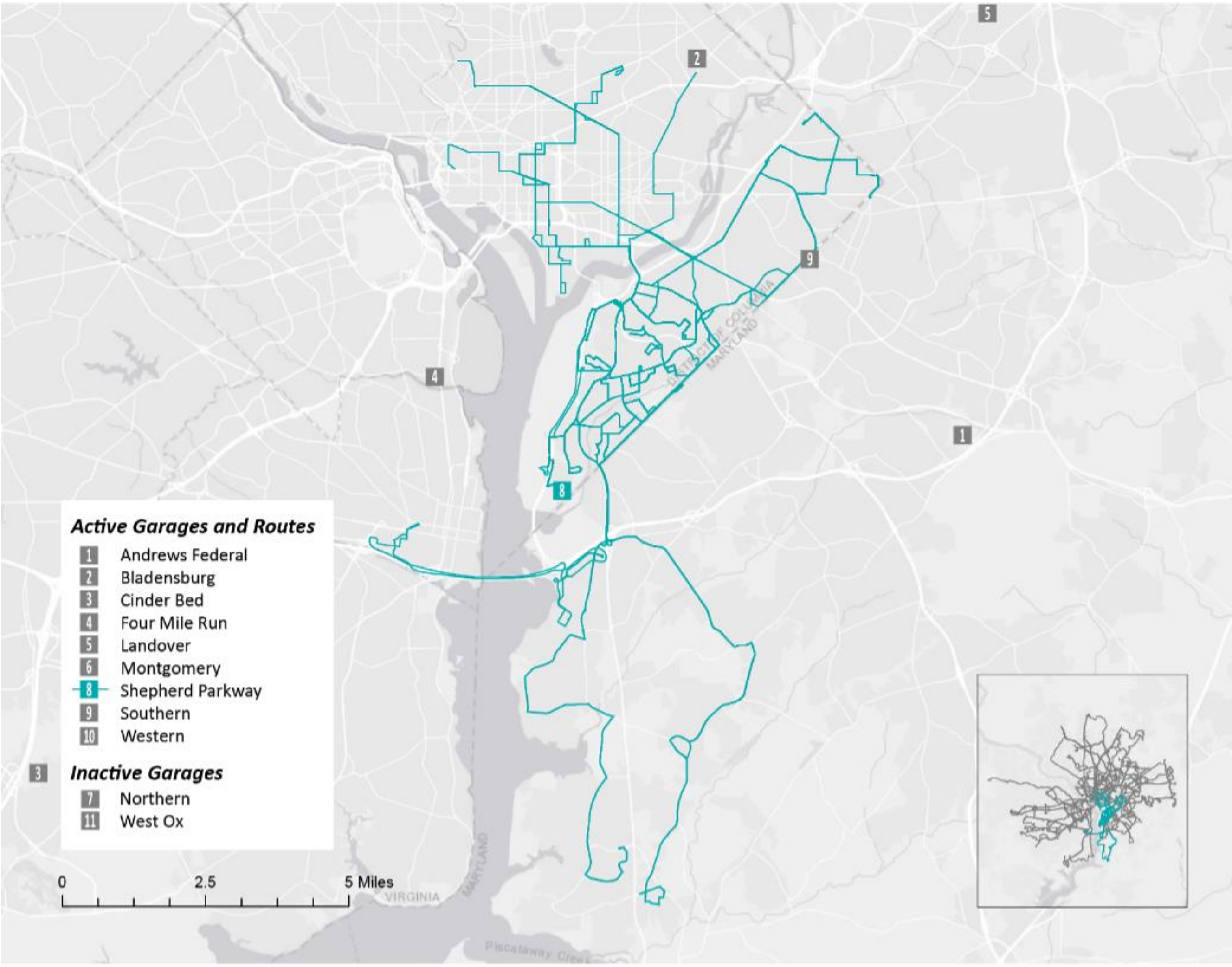
As of December 2021, 189 35-foot, 40-foot, and 60-foot buses are stored, maintained, and dispatched from Shepherd Parkway Garage. The garage's fleet supports 25 routes (247 weekday blocks with a 136-bus PVR) that primarily serve Northeast and Southeast Washington, D.C. The garage's service blocks range from 21 to 150 miles and operate between two and 16 hours. Figure 4-23 presents the garage's blocks by distance and duration, and Figure 4-24 illustrates Shepherd Parkway Garage's routes in the context of Metro's other garages.

Figure 4-23. Shepherd Parkway Garage – Block Distribution by Distance and Duration



Source: WSP, Metro (December 2021)

Figure 4-24. Shepherd Parkway Garage – Garage and Route Map



Source: WSP, Metro (December 2021)

FACILITY ANALYSIS

The Shepherd Parkway Garage is located in Washington, D.C. Based on field observations, the site appears to have safe and efficient site circulation, and has many characteristics that are conducive for ZEB operations, including:

- Employee parking is separate from the bus parking and service areas.
- Buses can be parked, serviced, and exit the site with few backing movements.
- The service cycle follows a forward-moving counterclockwise flow. This is desirable for the safe and efficient operation of bus circulation. The driver sits on the left side of the bus, which provides the best line of sight for left-hand turns.
- Office of the State Superintendent of Education school bus parking to the south creates a strong possibility of land use synergy for electrification investments.

Table 4-22 summarizes existing conditions at Shepherd Parkway Garage.

Table 4-22. Shepherd Parkway Garage – Existing Facility Conditions Summary

Category	Description
Location	Washington, D.C.
Fuel Type	Diesel and CNG*
Utility Provider	Pepco
Utility Service: Voltage/Transformer Rating (kVA)/and Peak Demand (kVA)	Building 1: 480/2,500/37 Building 2: 480/225 /37 Building 3: 480/750 /47
Functions	Operating Garage
Bus Parking	Outdoor (covered by concrete parking deck for employees)
Maintenance Capacity	26 maintenance bays (6 articulated and 20 standard)
Existing Parking Capacity	207 total (67 articulated and 140 standard)

Source: WSP, Metro
Note: *CNG construction project is ongoing.

4.7.2 FUTURE ZEB CONDITIONS

SERVICE AND FLEET ANALYSIS

Under existing conditions, between 85% and 95%[29] of Shepherd Parkway Garage's blocks can be supported by BEBs. These passing blocks can be supported by 102 to 123 BEBs depending on operating conditions, with the remaining assigned buses being available to support the "failed" blocks that have higher energy demands than the modeled battery capacity.

Under the typical modeling scenario, all blocks that failed had a service duration that exceeded 13 hours. For the intensive scenario, all blocks that failed had a service duration that exceeded eight hours. Table 4-23 summarizes the modeling results for Shepherd Parkway Garage.

[29] Intensive and typical modeling results, respectively.

Table 4-23. Shepherd Parkway Garage – Modeling Results Summary

Category	Results
Total Blocks	247
Passing Blocks	85% to 95%*
Buses Needed for Passing Blocks	102 to 123
Buses Available for Failing Blocks	66 to 87

Source: WSP, Metro
Note: *Intensive and typical modeling scenarios, respectively.

Shepherd Parkway Garage's service blocks have a relatively high completion percentage, and therefore, it does not appear that capital-intensive strategies to support the failed blocks (such as opportunity charging or additional buses) are required. In addition, with opportunity charging simulated at Anacostia Station, the analysis found that the number of passing blocks will improve from 95% to 99% in the typical scenario, and from 85% to 93% in the intensive scenario. Based on the Fleet Management Plan (2021), Metro will have several ICEBs in the fleet through the late 2030s. Dispatching ICEBs on demanding blocks until retirement and/or slight service changes would thus appear to be the most suitable strategy to address the failed blocks as battery technology continues to improve.[30]

FACILITY ANALYSIS

BATTERY-ELECTRIC BUS CONCEPT

Shepherd Parkway Garage can support 203 charging positions, 140 for standard buses and 63 for articulated buses. The proposed site layout utilizes the existing north/south bus parking configuration. The existing concrete deck above the bus parking area will be utilized to mount the pantographs. Table 4-24 summarizes the proposed equipment needed to support the future all-BEB garage, and Figure 4-25 and Figure 4-26 illustrate Shepherd Parkway Garage existing and proposed future site layouts.

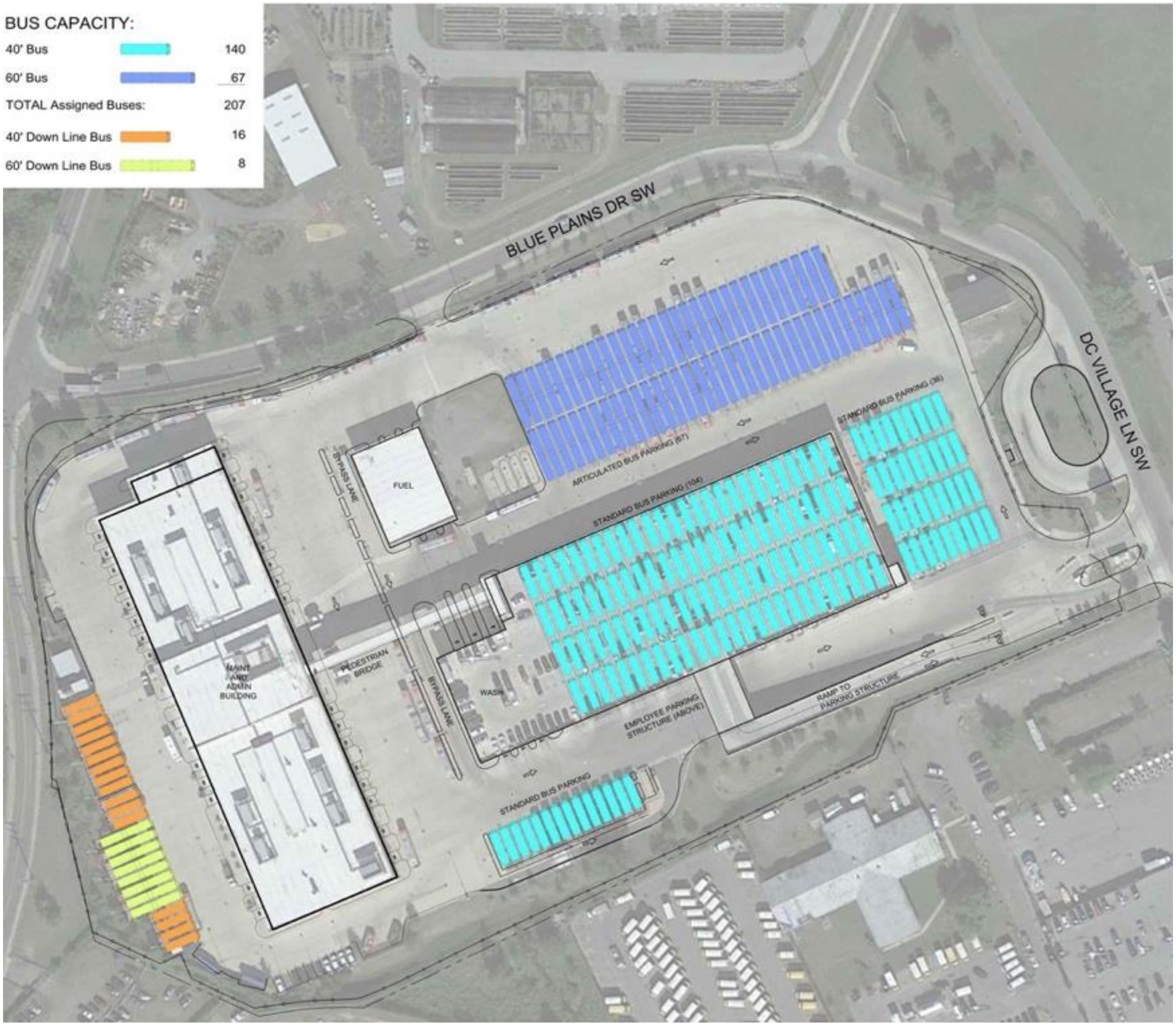
Table 4-24. Shepherd Parkway Garage – BEB Concept Summary

Category	Description
Charging Positions	203 total (63 articulated and 140 standard)
Proposed Charger Type and Specification	(11) 2 MW charging units
Connected Load	22 MW
Electrical Infrastructure Enhancements	Medium voltage (MV) service and MV switchgear

Source: WSP (2022)

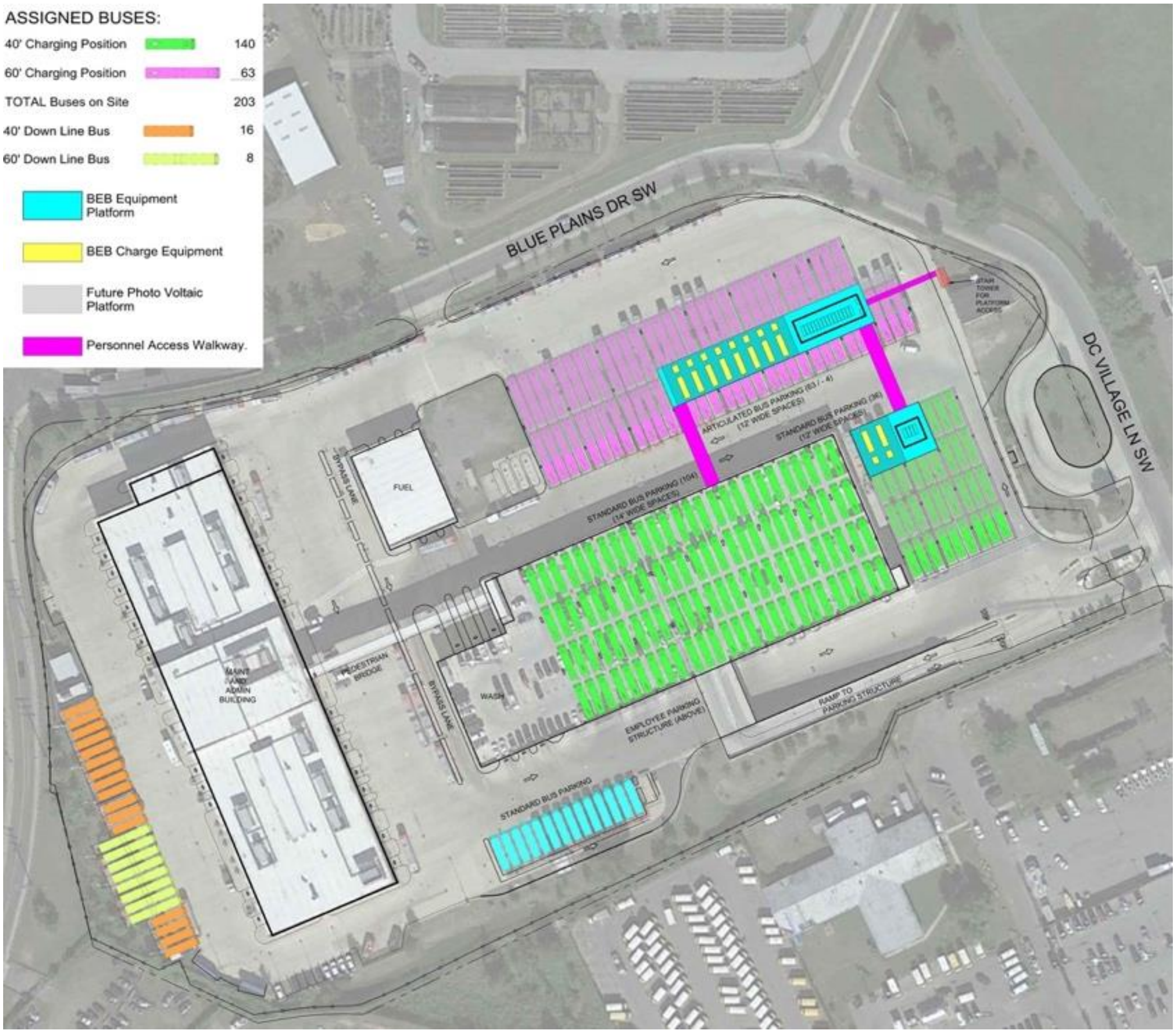
[30] Expected 7% annual improvement in range, per Bloomberg New Energy Finance (BNEF), 2021. *Hitting the EV Inflection Point.*

Figure 4-25. Shepherd Parkway Garage – Existing Site Layout



Source: WSP, Metro (2022)

Figure 4-26. Shepherd Parkway Garage – Proposed Site Layout



Source: WSP, Metro (2022)

FUEL CELL ELECTRIC BUS CONCEPT

Shepherd Parkway Garage is a potential candidate for FCEBs. If the CNG yard is repurposed to support delivered hydrogen, a small fleet of up to 80 FCEBs could be operated from this location.[31]

[31] A test fit determined that Shepherd Parkway Garage only has space available for one 18,000-gallon liquified hydrogen tank and associated pumps, vaporizer, compressor, and compressed gas buffer tanks. This amount of storage could fuel approximately 80 FCEBs daily, with liquid hydrogen deliveries required to refill the tank every two to three days.

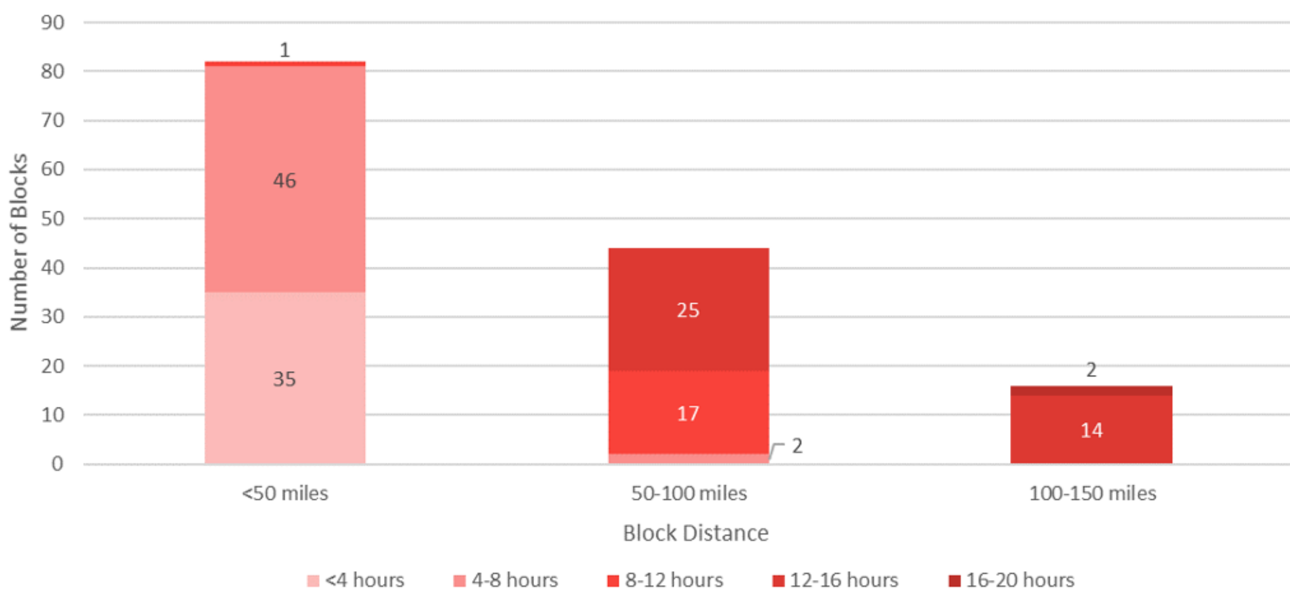
4.8 WESTERN GARAGE

4.8.1 EXISTING CONDITIONS

SERVICE AND FLEET ANALYSIS

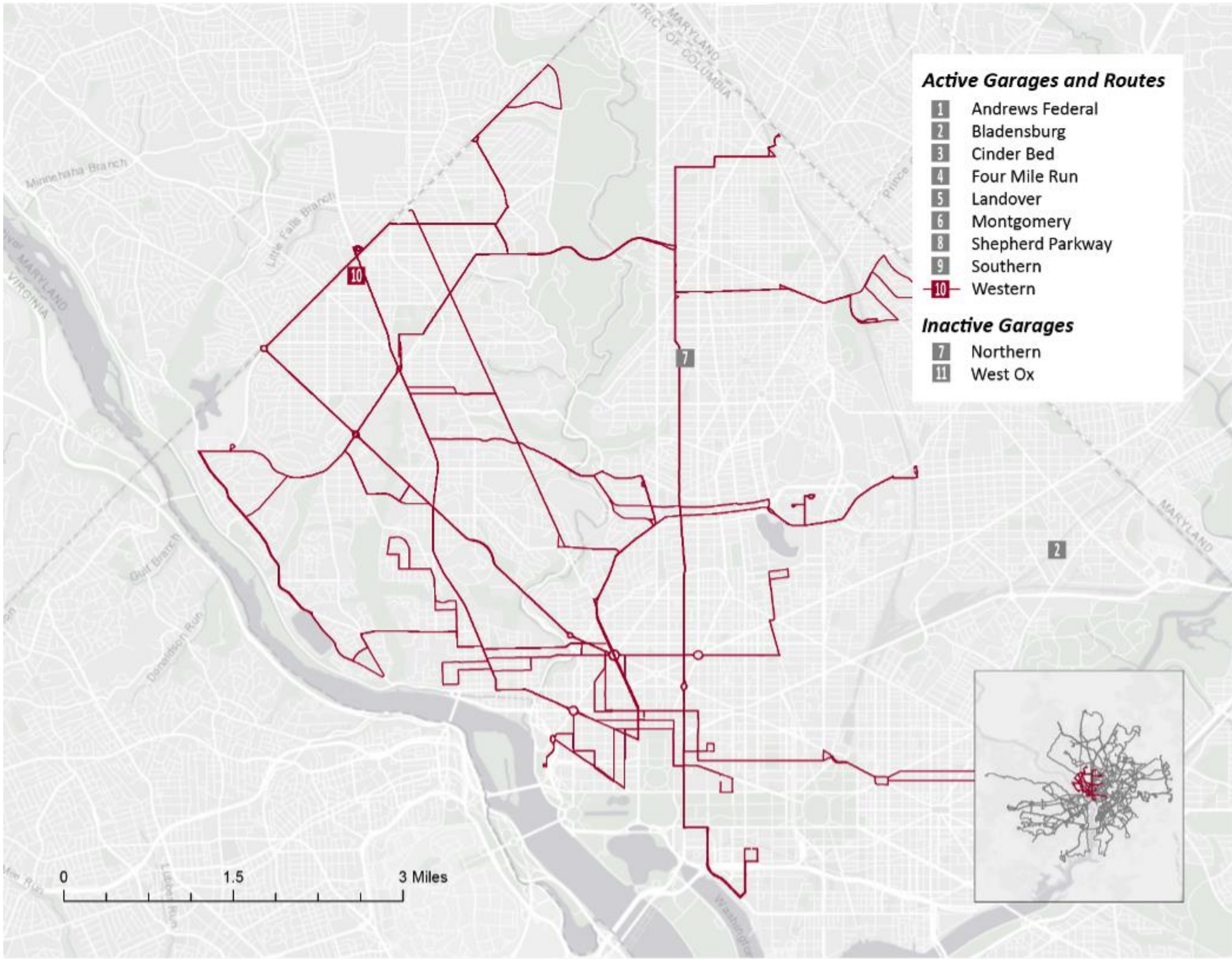
As of December 2021, 113 35-foot and 40-foot buses are stored, maintained, and dispatched from Western Garage. The garage's fleet supports 17 routes (142 weekday blocks with a 94-bus PVR) that primarily serve Northwest and Northeast Washington, D.C. The garage's service blocks range from 12 to 146 miles and operate between an hour and 16 hours. Figure 4-27 presents the garage's blocks by distance and duration, and Figure 4-28 illustrates Western Garage's routes in the context of Metro's other garages.

Figure 4-27. Western Garage – Block Distribution by Distance and Duration



Source: WSP, Metro (December 2021)

Figure 4-28. Western Garage – Garage and Route Map



Source: WSP, Metro (December 2021)

FACILITY ANALYSIS

The Western Garage is located in Washington, D.C. Based on field observations, the site is at crush capacity and site circulation is inefficient. The garage has no characteristics that are conducive for ZEB operation.

There are many challenges that will need to be resolved or mitigated to ease the transition to ZEBs, including:

- Bus parking space is limited, requiring buses to be parked in tight configurations.
- Site circulation is constrained due to the space constraints of the site.
- Backing movements are required for bus parking.

Table 4-25 summarizes existing conditions at Western Garage.

Table 4-25. Western Garage – Existing Facility Conditions Summary

Category	Description
Location	Washington, D.C.
Fuel Type	Diesel
Utility Provider	Pepco
Utility Service: Voltage/Transformer Rating (kVA)/and Peak Demand (kVA)	Maintenance and Administration Building 1: 480/Unknown/Unknown
Functions	Operating Garage
Bus Parking	Outdoor
Maintenance Capacity	14 maintenance bays (14 standard)
Existing Parking Capacity	117 total (117 standard)

Source: WSP, Metro

4.8.2 FUTURE ZEB CONDITIONS

SERVICE AND FLEET ANALYSIS

Under existing conditions, between 77% and 97%[32] of Western Garage's blocks can be supported by BEBs. These passing blocks can be supported by 56 to 83 BEBs depending on operating conditions, with the remaining assigned buses available to support the "failed" blocks that have higher energy demands than modeled battery capacity.

Under the typical modeling scenario, all blocks that failed had a service duration that exceeded 14 hours. For the intensive scenario, all blocks that failed had a service duration that exceeded 10 hours. Table 4-26 summarizes the modeling results for Western Garage.

Table 4-26. Western Garage – Modeling Results Summary

Category	Results
Total Blocks	142
Passing Blocks	77% to 97%*
Buses Needed for Passing Blocks	56 to 83
Buses Available for Failing Blocks	30 to 57

Source: WSP, Metro
Note: *Intensive and typical modeling scenarios, respectively.

Western Garage's service blocks have a relatively high completion percentage; accordingly, it does not appear that capital-intensive strategies to support the failed blocks (such as opportunity charging or additional buses) are required. Furthermore, with opportunity charging simulated at Tenleytown, the analysis found that the number of passing blocks will improve from 97% to 99% in the typical scenario, and from 77% to 83% in the intensive

[32] Intensive and typical modeling results, respectively.

scenario. Based on the Fleet Management Plan (2021), Metro will have several ICEBs in the fleet through the late 2030s. The implications of these findings mean that dispatching ICEBs on demanding blocks until retirement and/or slight service changes appears to be the most suitable strategy to address the failed blocks as battery technology continues to improve. [33]

FACILITY ANALYSIS

BATTERY-ELECTRIC BUS CONCEPT

The current Western Bus Garage site cannot accommodate BEBs without redevelopment into a multi-story facility. An evaluation determined it would be more efficient to build a new facility on an adjacent property to minimize operational impacts during construction. In 2022, the Metro Board approved site acquisition and funds to initiate the planning and National Environmental Policy Act process for the new facility. Initial layout concepts indicate a new purpose-built facility can support 120 BEBs.

Table 4-27 summarizes the proposed equipment needed to support the future all-BEB garage, and Figure 4-29 illustrates Western Garage's existing site layouts. Conceptual site layouts for the new, proposed Western Garage facility on the adjacent site are ongoing (and not included here).

Table 4-27. Western Garage – BEB Concept Summary

Category	Description
Charging Positions	120 total (120 standard)
Proposed Charger Type and Specification	(6) 2 MW charging units
Connected Load	12 MW
Electrical Infrastructure Enhancements	Medium voltage (MV) service and MV switchgear

Source: WSP (2022)

[33] Expected 7% annual improvement in range, per Bloomberg New Energy Finance (BNEF), 2021. *Hitting the EV Inflection Point.*

Figure 4-29. Western Garage – Existing Site Layout

Source: WSP, Metro (2022)

FUEL CELL ELECTRIC BUS CONCEPT

Metro will continue to monitor FCEB technology and consider its integration if the spatial and market challenges (as noted in Section 3.3.1) are mitigated.

5 ZEB TRANSITION STRATEGY

The following section describes the ZEB transition strategy to meet Metro's ZEB goals as quickly as possible, along with an overview of other transition-related considerations.

5.1 FACILITY PHASING

The facility phasing plan provides a framework for the order in which garages will be retrofitted (or rebuilt), their respective construction timelines, the type of closure for construction (partial or full), the identification of garages at which buses can be temporarily stored and dispatched, and the BEB-readiness of these garages in alignment with Metro's proposed procurement schedule. The overall phasing and specific construction and garage conversion timelines will be refined as facility-specific design and construction plans advance.

Considering that there are many paths that Metro can take to reconstruct its garages to support BEB infrastructure, it was essential to establish guiding principles to ensure that the order and manner in which garages are transitioned (also referred to as "phasing") is aligned with the standards, vision, and goals of Metro:

- Ensure safety in all program aspects.
- Integrate equity in deployment planning to ensure that disadvantaged populations, particularly those of color, low-income, and/or with disabilities, are key beneficiaries of Metro's ZEB transition.
- Ensure reliable service and minimize service disruptions during the transition.
- Control costs and manage financial risks.
- Meet the Metro Board's adopted ZEB goals while also exploring options for accelerating the transition.

5.1.1 CONSTRUCTION TIMELINE, DELIVERY SCHEDULE, AND RELOCATION FACILITIES

Metro's transition to BEBs (pursuant to the facility concepts proposed in Section 4) will require a significant amount of construction at each garage. The construction and staging of the proposed overhead canopy structure, alone, will require the temporary relocation of buses to other garages. To ensure that Metro can continue to deliver reliable service and minimize service impacts during the transition (an essential ZEB Transition Plan guiding principle), construction timelines were developed based on the partial or full closure of garages during construction. The garages that could support the temporary storage/dispatch of buses while their assigned garage is undergoing retrofits were also identified. All of these elements were developed with the underlying understanding that BEBs cannot be operated unless charging infrastructure is in place to support them. Therefore, construction and bus deliveries were aligned to ensure that buses are delivered at the conclusion of, or after, facility retrofits are complete.

As previously mentioned, there are several plans for ongoing construction at Metrobus garages. The following provides a summary of these facilities and their relation to the transition.

- **Northern Garage** - Currently in a construction phase. Northern Garage's planned reopening in 2027 is a critical path project. This is because Metro will need a BEB-capable garage to store newly delivered BEBs in advance of subsequent construction at other garages.
- **Bladensburg Garage** – Construction of a new garage is currently underway for Metro's ~300 buses. Metro is modifying the original construction design plan for this garage to include space and infrastructure to support an electric bus fleet. The modification enables this garage to support approximately 150 BEBs and 150 internal combustion engine buses when opened, following its multiyear construction project. A second project stage to support charging positions for the remaining ~150 BEBs to make the garage 100% BEB will be implemented in the mid-2030s. This second phase of BEB construction will include installation and purchase of the charging equipment to convert this garage into 100% electric operations. The two-stage approach is proposed in this Plan to accommodate near-term bus procurements plans with infrastructure feasibility.
- **Southern Garage –** This garage is expected to close. However, it may continue to be used for temporary bus storage or "swing space" on an as-needed basis during other garage's construction activities.
- **Western Garage** – The existing site has reached its useful life and a new, purpose-build BEB garage is being designed at an adjacent lot. The existing Western Garage will also be a candidate for "swing space" when the new garage is constructed.
- **West Ox Garage –** West Ox is not currently being used for revenue service; however, it will support temporary bus relocations during construction at Cinder Bed Road and Four Mile Run.

Table 5-1 summarizes the order in which garages will be transitioned, their respective construction timelines, the garages that are planned to support temporary bus relocations during construction, and the number of BEB deliveries planned per fiscal year. Figure 5-1 presents the timelines for other stages of the garage transitions (design, etc.) and the identification of garages that have the equity highest scores (i.e., serve the most Equity Riders and/or Equity Focus Communities).

Table 5-1. ZEB Transition Strategy – Projected Construction Timeline and Bus Delivery Summary (Fiscal Year)

Garage	Closure Type	Bus Relocation Facility*	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Northern	N/A																						
Cinder Bed Road	Full	WO																					
Bladensburg	N/A	NO, SA, MG																					
Western	N/A	WE																					
Landover	N/A	SA																					
Montgomery	Full	BL, WE																					
Andrews Federal Center	Full	SA, NO																					
Shepherd Parkway	Full	SA, AN																					
Four Mile Run	Full	WO, SH, AN																					
Projected Annual BEB Deliveries**					25	25	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Source: WSP (2022)

Notes: BL = Bladensburg, LA = Landover, SA = Southern Avenue, SH = Shepherd Parkway, MG = Montgomery, NO = Northern, WE = Western, FM = Four Mile Run, WO = West Ox, CB = Cinder Bed Road, and AN = Andrews Federal Center.

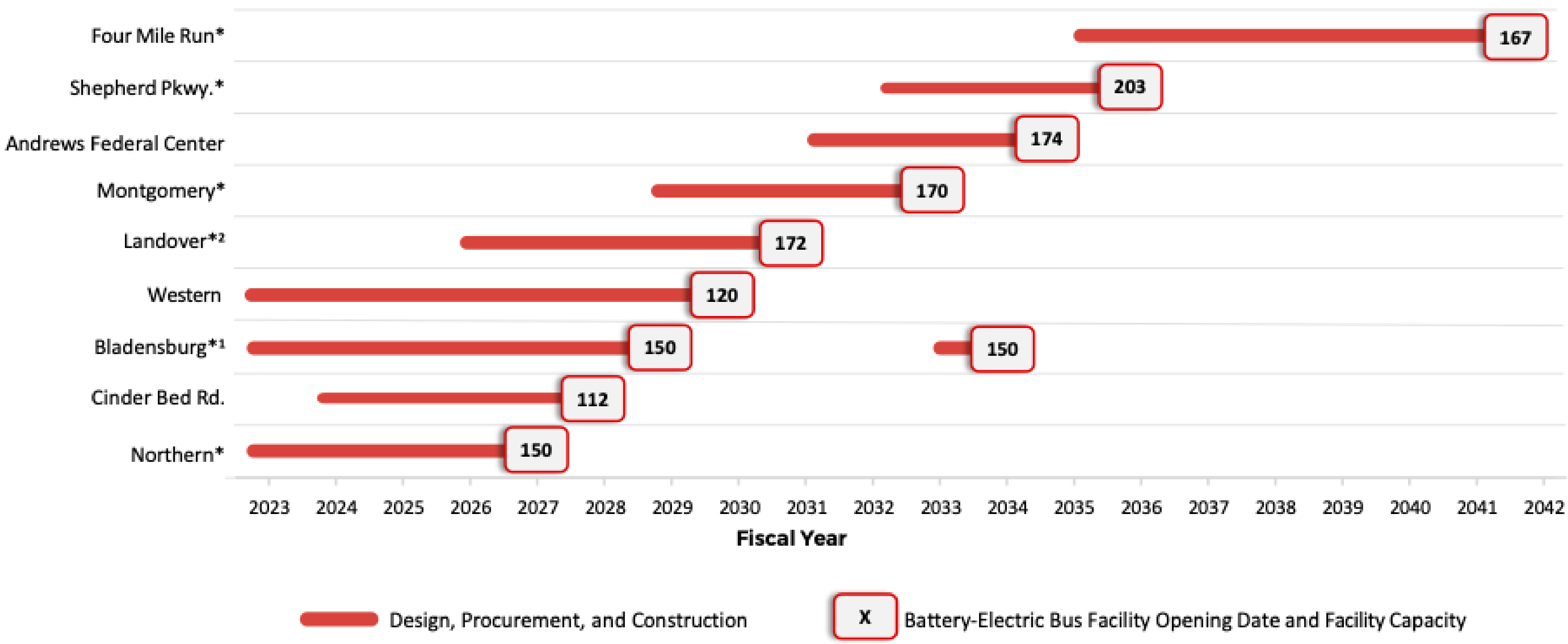
The proposed schedule does not consider the project delivery type (design/build, design/bid/build, etc.). Therefore, design, request for proposal, and other stages are not factored into the timeline.

*Based on an initial assessment, subject to change as Metro progresses through design and construction phases. These facilities may be used separately or together.

**BEBs delivered in FY24 to FY26 will be deployed at multiple garages (with mobile or plug-in chargers).

** Excludes Metro's Zero-Emission Bus Deployment: Phase 1 BEBs. Twelve BEBs expected in FY2023 and FY2024.

Figure 5-1. Projected Bus Facility Strategy and Timeline



Source: WSP (2022)

Notes: *High Equity Priority

[1] Bladensburg Stage 1 enables the garage to support approximately 150 battery-electric buses; Stage 2 will provide charging infrastructure for the final approximately 150 battery-electric bus charging positions.

[2] Landover will be constructed in two phases. The first phase's projected completion is in FY30, and the second phase's projected completion is in FY31.

In the process of developing and evaluating the facility phasing plan, several takeaways and considerations were identified:

- The fleet and facilities will be fully transitioned by 2042 under this analysis.
- Transitioning the fleet as quickly as possible is primarily constrained by the rate of garage conversions as opposed to BEB delivery schedules.
- In addition to Northern and Bladensburg, Cinder Bed, Landover, and Western garages are amongst the first divisions Metro plans to convert due to a combination of their respective equity outcomes, favorable service modeling results, and they are newer (fewer required retrofits), and therefore, well-suited for a more efficient transition to BEB technologies than older garages.
- The CNG garages (e.g., Four Mile Run and Shepherd Parkway) are the last to be transitioned to ensure that Metro's CNG fleet can continue to be fueled and maintained.
- The completion schedule cannot be compressed from this proposed plan unless:
    - More than one garage can be shut down at any time (this will require additional swing space throughout the system).
    - Construction timelines can be reduced.
- To support the BEB electrification construction projects in this Plan, Metro will require swing space for 100-175 buses from 2031 to the end of the transition.

5.2 BUSINESS AND WORKFORCE PLANNING

To successfully transition to a ZEB fleet, Metro will need to proactively prepare for new requirements by revisiting existing business processes and developing a new workforce curriculum to prepare Metro's existing workforce to safely maintain and operate BEBs, and to partner with regional and national workforce development organizations to support the recruitment of new talent. The Workforce Development strategy analyzed the training impacts to different departments. The impacts include the different types of training that staff will need, how they fit into the zero-emission transition timeline, as well as estimates of the overall time needed for training. The analysis also assessed whether additional trainers would be needed to support the transition. In the following findings, a "trainer day" is defined as an eight-hour workday for a single person, while a "training day" is defined as eight hours of training for an individual.

The key findings include the following:

- In general, training for mechanics can be scaled to align with the overall ZEB roll-out at each facility (as opposed to all training conducted at a single time).
- Metro's Bus Maintenance Department will be the most impacted due to training and education requirements that are needed *prior* to the daily maintenance of a BEB. For context, Metro recruits approximately 30 bus mechanics every year and each mechanic requires approximately 57 days of training. In total, Bus Maintenance has approximately 800 personnel that will be supporting the fleet transition, and these personnel will require approximately 11,000 ZEB training days. Metro will consider investing in additional trainer(s) that are dedicated to developing the ZEB curriculum. The

fleet and facility transition serves as an excellent opportunity to entice new employees that are interested in operating and maintaining ZEBs. A few example training courses are listed below:

- Foundational Electrical Principles
- High Voltage Safety Basics
- Depot Charger Familiarization
- Depot Charger Troubleshooting & Repair

- The Bus Transportation Department has over 2,600 personnel that will be impacted by the transition to a ZEB fleet. There are over 3,000 *training* days needed, with over 500 *trainer* days. A few example training courses are listed below:
  - BEB 101
  - Depot Charger Familiarization
  - Foundational Electrical Principles
  - PPE Safety & Care
- Within the Washington Metropolitan Region there are over 10,000 emergency responders supporting Metro's system. Emergency responders will undergo proper PPE safety training and training for how to safely disengage the bus. In order to accomplish this, training will be staggered to prioritize emergency responders who serve areas where BEBs will be operating.

In addition to workforce investments, Metro will need to account for a multitude of business processes and planning. Metro gathered information from its departments including Information Technology (IT), Supply Chain Management, and System Safety and Environmental Management to better understand department needs and how their teams will be impacted. New technologies such as charge management and software connecting BEBs to infrastructure will require collaboration between Bus Services, Supply Chain Management, and the Office of Performance Management to ensure future technology solutions effectively support Metro operational needs.

Below is a list of next steps (near-term action items) and opportunities identified for ZEB business and workforce implementation activities.

5.2.1 BUSINESS PROCESS NEXT STEPS AND OPPORTUNITIES

- As a near-term priority, Metro will take steps, proactively and collaboratively, to modify the Collective Bargaining Agreement (CBA) to effectively manage annual location "picks" in Bus Maintenance between BEB and non-BEB divisions. A pick is defined as a service block that an operator selects multiple times per year. The frequency of when and how picks occur is stated in the Metro CBA. Bus Maintenance mechanics have an annual pick to determine which division they are assigned to. Since operators can complete their training in two to three days, the pick considerations for operators are not as critical. However, pick considerations for Bus Maintenance employees require careful coordination with Metro Training and Bus Maintenance to align ZEB-specific training with the re-opening of a ZEB division. An incentives program/initiative may increase the willingness for operators and mechanics to select BEB divisions for their service pick. An example of how multiple Metro departments collaborate and coordinate (IT, Bus Maintenance, and Bus Transportation), charge management software will be tested in future BEB deployments. Such software tests will provide insight into how roles and responsibilities may change for Bus Transportation and Bus Maintenance staff, and they also will provide Metro with demand-load data that can reduce costs.

- Metro has an opportunity to revisit the Business Plan for Bus Transportation and Bus Maintenance based on the findings and lessons-learned from its Zero-Emission Bus Deployment: Phase 1. Key Performance Indicators (KPIs) can be organized by vehicles, infrastructure, and workforce segments that align with requirements of a ZEB transition.
- Supply Chain and Bus Maintenance can coordinate to understand new inventory requirements of BEBs and charging infrastructure and assess if more room will be needed in equipment/parts storage rooms. This is particularly important for facilities that will operate mixed fleets (ICEBs and BEBs). Additionally, Metro will closely monitor planned BEB deliveries and charging installation to ensure the organization's workforce has the necessary Personal Protective Equipment (PPE).

5.3 RESILIENCE PLANNING

As Metro transitions away from fossil fuels and towards new bus propulsion technologies, it recognizes the importance of maintaining the resilience of the bus network. The near-term focus on BEBs increases Metro's reliance on the electric grid to provide bus service, and power outages will create a greater relative risk to the provision of bus service. Further, climate change may increase potential threats to the electric grid due to water level rise, changes in precipitation patterns, extreme weather events, and dramatic changes in temperature.

With the deployment of ZEBs, Metro will consider how to appropriately address the risk of power supply disruptions to reliably serve riders. This assessment must balance the likelihood of a power supply disruption and its impacts with the costs of possible mitigation measures. Metro will assess resilience needs on a facility-by-facility basis, when developing designs for the reconstruction or conversion of each facility throughout the transition.

Over the past several years, the available data did not report any unplanned outages lasting more than one day and five hours at any Metro bus division. Climate change could, however, increase the frequency and duration of outages in the future.

FACILITY-SPECIFIC RESILIENCE FRAMEWORK

To provide power redundancy resilience for the bus fleet, we assess potential resilience measures for their fit with the needs of the Metro system and specific bus depots:

- Opportunity charging.
- Microgrids.
- Redundant utility power feeds to the facility.
- Battery Energy Storage Systems (BESS).
- Backup generators (stationary and mobile).

During the development of charging infrastructure designs at each garage, Metro will further evaluate these options to design a site-specific power resilience solution with net life cycle costs that are aligned to the likelihood of grid power disruptions of various types and durations.

For each garage, the analysis will begin with an assessment of whether opportunity charging – in addition to overnight depot charging – is required or preferred to enhance overall bus operations. The use of opportunity charging may reduce or eliminate additional resilience investments required to address expected grid outages that would affect depot charging. Based on the Service Delivery modeling analysis, opportunity charging increased the number of passing blocks for different bus facilities in intensive and typical scenarios. However, the percentage of failed blocks is relatively low (less than 8%) and the cost associated with opportunity charging is high, that it may be more prudent to wait to invest in opportunity charging until the ZEB fleet percentage increases and block failure becomes more of a risk. In addition to resilience benefits, opportunity charging may also provide increased operational flexibility to Metro and benefits to other regional bus operators who may be able to share this infrastructure.

Similarly, if investment in a microgrid at the facility is warranted based on projected net life-cycle cost savings for depot operations and BEB depot charging, the microgrid may also be able to ensure continuation of depot charging through some or all expected grid outrages, thus reducing or eliminating the need for additional resilience investments. These resilience benefits of the microgrid should be assessed and may enhance the microgrid project economics.

If these analyses indicate that additional or other resilience investments are required, the choice between the other options will be based on an analysis of the net life cycle cost of each, relative to the expected increase in resilience they provide by protecting against specific types of expected outages. The projection of future outages can be informed by historical data on the frequency and duration of past outages, as well as any plans by the local utility to upgrade or strengthen the relevant portion of its distribution system.

Redundant utility feeds often provide only a marginal increase in overall power reliability and can be very expensive, depending on the locations of nearby substations and existing spare capacity and installed infrastructure. The increased reliability provided by a redundant utility feed may be worth the cost at some depots, and not at others.

The choice between a stand-alone BESS or a fossil fuel generator to provide resilience will require a balancing of sustainability goals against costs (and spatial capacity) and will also be affected by the duration of expected future outages. To provide the same power and energy, BESS are currently significantly more expensive than fossil fuel generators, though BESS costs are projected to decrease over time.

Implementing a facility-specific resilience strategy at the time of facility design will allow Metro to incorporate the latest grid and climate data in assessing needs and deploy any clean emerging technologies to supply backup power. The flexible approach also allows Metro to incorporate hydrogen fuel cell technology as appropriate.

PROVISION OF ADDITIONAL SERVICES

Currently, the Metrobus fleet provides additional services that Metro will need to maintain when transitioning to a ZEB fleet. For example, Metrobus serves as a backup solution providing bus bridges in the case of Metrorail service disruptions. In emergency situations, buses also serve as temporary heating or cooling centers for displaced residents. Based on current BEB battery capacities, we estimate BEBs can provide at least 10 hours of heating or cooling when used as an emergency shelter. FCEBs may have the capability to provide extended heating and cooling times to help with longer duration needs.

5.4 RISKS

The ZEB market and environment is extremely dynamic. Technology is still maturing and Metrobus service regularly changes and is still adapting to ridership trends following the COVID-19 pandemic. These uncertainties, combined with changing market conditions, are areas Metro must continue to evaluate and adapt to (where applicable) in order to ensure that plans, contingencies, and mitigations are in place to lessen the impact of any disruptions.

During the analysis, several general risk categories and associated risks were identified for potential mitigation strategies. Table 5-2 highlights some of the key risks that Metro will continue to monitor before, during, and after the fleet transition (in no particular order).

Table 5-2. Key Risk Categories and Mitigation Tactics Summary

Risk Category	Risk	Potential Mitigation(s)
Execution	Metro does not meet the 2030 and 2045 Board-adopted goals.	Maintain ZEB Executive Steering Committee and dedicated cross-departmental ZEB teams.
Funding	Lack of available funding for infrastructure and vehicles.	-Update cost estimates as plans develop. -Provide sufficient contingency assumptions in cost estimates to mitigate funding gaps. -Aggressively pursue external funding opportunities, such as Federal Grants. -Explore third-party or other funding mechanisms.
Electric Utility Support	Schedule delays and long lead times for utility upgrades to provide needed power for charging.	-Maintain ongoing utility coordination. -Identify and share garage transition schedule with utilities.
Facility Construction	Schedule delays in project initiation or completion.	-Develop design criteria to establish foundational BEB facility design requirements. -Manage the coordination and schedule of project team(s) to ensure that key milestones are met.
Vehicle and Equipment Acquisition	Supply chain-related delays for materials, vehicles, and infrastructure.	-Provide sufficient buffer in the schedule times to accommodate any potential schedule impacts.
Dispatch and Service Delivery	BEBs may not provide the required range.	-Model bus ability to complete service before deploying buses. -Select appropriate technology to monitor and manage bus charging.
Resilience	BEBs are inoperable if there is an extended loss of grid power.	Implement cost-effective strategies that can prolong service and operations during potential power outages.
Training	Inefficiencies, safety issues, and cost overruns in service delivery, operations, and maintenance.	Ensure that Metro's workforce is adequately trained on ZEBs.

Source: WSP, Metro (2022)

6 COSTS AND FUNDING

The following section presents the approach to lifecycle cost modeling, the estimated costs for the ZEB transition strategy, and an overview of funding opportunities available to Metro.

6.1 OVERVIEW

A critical consideration in any transition process is understanding the attributed cash costs – the direct costs incurred by acquiring capital, operating and maintaining, and disposing the fleet and associated facilities – and the non-cash costs – or "benefits" associated with reduced emissions and other environmental factors.[34]

Lifecycle costs were first developed for a baseline "No Build" Scenario – which assumes that Metro continues to operate its current fleet through Fiscal Year (FY) 2055 (replacing all diesel and diesel-hybrid vehicles with diesel-hybrids, and CNG vehicles with CNG models). After the No Build Scenario cost estimate was developed, costs associated with the ZEB transition were modeled. The costs of the ZEB transition net of the No Build Scenario's costs provides the incremental (additional) costs associated with transitioning the Metrobus fleet to ZEBs.

The lifecycle cost model inputs include fleet size, fuel/technology type, vehicle annual mileage, vehicle efficiency, bus acquisition schedule, required facility and utility improvements, fueling or charging strategy, and fuel and utility price structure. Information and data from fuel providers, agencies operating ZEBs, and vehicle OEMs were all captured and considered to ensure that cost trends in the industry were reflected in the model. The values presented are subject to change and are based on the most current information. All costs are estimated in current year dollars and escalated to year of expenditure (YOE) dollars in the results. Escalation assumptions include a construction cost index for facility improvement costs, projected consumer price index for urban consumers for routine labor and material costs, producer price index for bus chassis manufacturers for bus purchase costs, and U.S. Energy Information Administration price forecasts for CNG, diesel, and electricity rates for transportation sector applications. The price forecasts reflect recent market conditions through late October 2022, which includes significant increases in cost escalation when compared to historical averages.

Table 6-1 summarizes the cost categories captured in the lifecycle cost analysis.

[34] While the Metro service area does not have the same emissions monetization regulations, including cap and trade or carbon taxes as states such as Washington, Oregon, and California, monetizing these benefits based on U.S. Department of Transportation and Environmental Protection Agency guidance on pricing environmental impacts, ensures societal effects are considered when comparing the cost of transitioning to new technologies.

Table 6-1. Modeled Cost Categories and Descriptions

Cost Type	Cost Category	Cost Variable
Cash Costs	Capital	Vehicle
		Vehicle modifications and contingency
		Facility costs for charging or fueling Infrastructure
		Major component replacement
	O&M	Vehicle maintenance, tools, training, and equipment
		Tire replacement costs
		Vehicle fuel/energy costs
		Charging and fueling infrastructure maintenance costs
		Training costs
	Disposal	Bus disposal costs or salvage value
Non-Cash Costs (Benefits)	Environmental	Vehicle emissions (including tire and brake wear)
		Upstream emissions
		Noise impacts

Source: WSP (2022)

6.2 CASH COSTS

If Metro were to continue to operate an all-ICEB fleet ("No Build" Scenario) through FY 2055, direct cash costs (capital, O&M, and disposal) would be approximately $5.0 billion.[35] The transition to an all-battery electric bus (BEB) fleet over the same time period would cost $7.4 billion – an incremental cost increase of approximately $2.3 billion.

Capital expenditures (vehicles and infrastructure) represent the largest category of increased costs over the continuation of current operations. The increase in capital costs is directly correlated with the fleet size of each garage; thus, the garages with the largest number of assigned buses (e.g., Bladensburg, Shepherd Parkway, and Four Mile Run) will be the most expensive to transition. Operating expenditures (e.g., training, maintenance, and energy costs) are the second largest portion of expected increases in costs; however, these are relatively small when compared to capital costs – these too are correlated with the number of assigned buses per facility. The costs of vehicle disposal are also factored in the analysis but are assumed to be identical in the No Build and ZEB transition scenarios. This is consistent with the assumption that the fleet size remains constant and the FTA-

[35] The analysis covers facility improvement costs through Fiscal Year 2042 and fleet acquisition costs through FY 2041, with full lifecycle operation of vehicles through FY 2055.

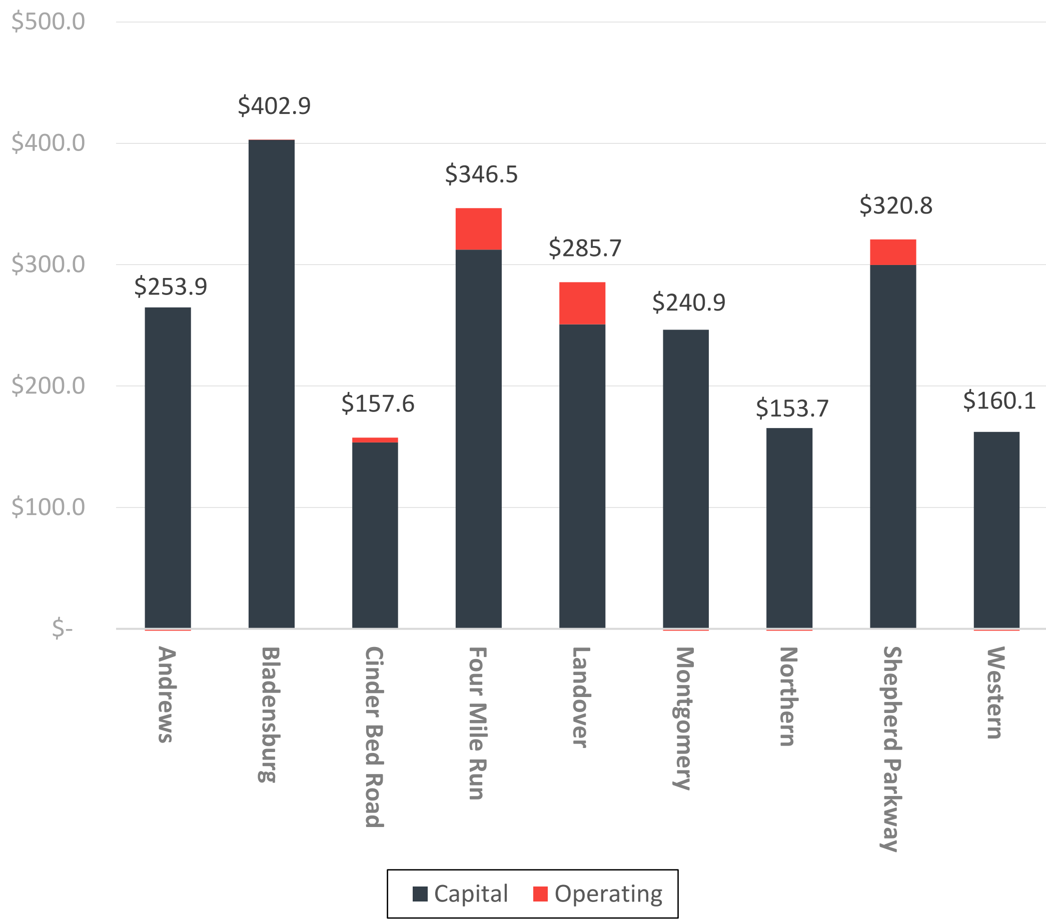
assumed $5,000 salvage value for buses at the end of their useful life. Table 6-2 presents the cost of the ZEB transition (as compared to the No Build scenario) and Figure 6-1 summarizes the cash costs per garage.

Table 6-2. Lifecycle Programmatic Cash Costs for No Build and ZEB Transition (YOE in Millions)

Cost Category/Variable		No Build	ZEB Transition	Incremental Expenses
Capital	Vehicle	$1,610	$2,389	$779
	Vehicle modifications and contingency	$208	$367	$158
	Facility costs for charging or fueling Infrastructure	$39	$1,123	$1,085
	Major component replacement	$240	$477	$237
	Capital Costs Subtotal	*$2,097*	*$4,356*	*$2,258*
O&M	Vehicle maintenance, tools, training, and equipment	$2,207	$2,194	-$13
	Tire replacement costs	$84	$92	$8
	Vehicle fuel/energy costs	$613	$438	-$175
	Charging and fueling infrastructure maintenance costs	$59	$120	$62
	Training costs	$1	$183	$182
	O&M Costs Subtotal	*$2,963*	*$3,027*	*$63*
Disposal	Bus disposal costs or salvage value	-$12	-$12	$0
	Disposal Costs Subtotal	*-$12*	*-$12*	*$0*
	Cash Costs Total	***$5,049***	***$7,371***	***$2,322***

Source: WSP (2022)

Figure 6-1. Incremental Lifecycle Cost Estimates by Garage (YOE in Millions)



Source: WSP (2022)
Notes: Values rounded to the nearest tenth. The incremental O&M costs are largely impacted by utility service provider, fleet make-up in the no-build (CNG vs. hybrids) and fleet makeup (40- vs. 60-foot). The overall O&M costs for Northern are lower in the ZEB Transition Plan due to lower utility rates in the Pepco service area, a higher proportion of 60-foot buses which have a greater cost advantage over hybrid-diesel buses, and a no-build fleet of hybrid buses vs. CNG buses, the latter having lower operating costs.
Southern Avenue and West Ox may continue to be used to temporarily store buses or as a contingency option in the future if additional ZEB capacity is required and are therefore not assessed here.

6.3 BENEFITS

Metro's transition to ZEBs will provide benefits to the service area and region beyond cash cost savings. As societies begin to address the impact of emissions on the climate and communities, environmental damages are increasingly being monetized as part of federal funding and discretionary grant requirements.

As compared to Metro's existing ICEB fleet, a preliminary analysis shows an all BEB fleet would reduce GHG emissions by 83% (99,980 metric tons) per year. Tailpipe GHG emissions are eliminated; however, upstream emissions from power production exist. Critical tailpipe emissions including nitrous oxide, sulfur oxide, and volatile organic compounds are all but eliminated – reducing these emissions per year (compared to Metro's existing ICEB fleet) by 41, 0.4, and 3.5 metric tons, respectively. Particulate matter attributed to both tailpipe emissions and brake and tire wear is reduced per year (compared to Metro's existing ICEB fleet) by 3.2 metric tons, or 36%. Noise reductions, stemming from the quieter operations of electric vehicles in comparison to internal combustion engines, are based on Altoona testing showing a 10 A-weighted decibel reduction[36] in BEBs.

Monetizing benefits of continued operations of a ICEB fleet, assuming purchases of CNG and hybrid buses, in comparison with a BEB fleet, Metro's ZEB transition strategy would yield approximately $497 million in benefits over the lifecycle analysis period (through FY2055). This is a result of an estimated reduction of $183 million in vehicle emissions, $306 million in upstream GHG emissions, and $8 million in noise reductions.

6.4 FUNDING OPPORTUNITIES

There are several funding sources available to support a fleet conversion and the associated infrastructure needed for the conversion. Both formula and competitive opportunities at the federal, state, and regional levels, were assessed and categorized based on "funding potential." The funding potential was determined based on several factors including, but not limited to, the amount of funding available in the program; the expected level of competition for grant awards from the program; and the level of alignment with the grant program's scope and/or objectives. It should be noted that a combination of sources will be needed to support the transition – for example, in FY22, the FTA's Bus and Bus Facilities Discretionary Grant had an award ceiling of $37.2 million – this would support the purchase of approximately 35 buses – a fraction of Metro's full fleet.

Metro has already received one Low or No Emission Vehicle Program grant from the Federal Transit Administration (FTA); Metro should continue to pursue this annual opportunity, as well as other FTA grants. Increases in funding for key FTA 5339 programs, specifically, may be relevant for Metro with a relatively high potential for success (Table 6-3).

[36] A-weighted decibel (dBA or dB(A)) is an expression of the relative loudness of sounds as perceived by the human ear.

Table 6-3. Potential Funding Sources Overview

Administering Agency: Opportunity	Program Type	Funding Eligibility	Total Funding Amount (FY22 – FY26)	Award Ceiling (FY22)
FTA: Bus and Bus Facilities Formula Funds Grant	Formula	ZEBs, Charging Infrastructure, and Maintenance Facilities	$5.1B	$10.9M
FTA: Bus and Bus Facilities Discretionary Grant	Discretionary			$37.2M
FTA: Low or No Emission Vehicle Program	Discretionary		$5.6B	N/A

Source: WSP (2022

7 NEXT STEPS

The Plan addresses requirements across Metro, including for service delivery, facilities conversion, equity considerations, resilience strategies, and business and workforce requirements. The next steps listed here represent key action items that Metro will undertake in the near-term (i.e., over the next five years) based on the current Transition Plan as it relates to infrastructure, vehicles/service, workforce, and programmatic activities. Metro also will continue to evaluate opportunities to complete the transition more quickly.

INFRASTRUCTURE

Advance the Plan's initial garage designs into detailed designs and construction plans, focusing first on the garages that will convert earlier in the transition. The Transition Plan provides a high-level summary of garage capacity and design to accommodate charging infrastructure. However, advanced design is required for each garage to start construction. Metro should fast-track the advanced designs and construction plans for garages that scheduled to be completed earlier in the transition (i.e., Cinder Bed Road and Landover), and continue design and construction work already underway for Northern and Bladensburg. Accelerating this process will help Metro adhere to its schedule targets for facility ZEB conversion.

Continue actively engaging Pepco, Dominion Energy, and BGE to ensure off-site power infrastructure upgrades are ready when Metro completes construction at individual garages. The timing of power upgrades is a critical prerequisite for installing charging equipment and ensuring the facility phasing timeline is met – battery-electric buses cannot operate without power. Metro's utility team must work closely with the utilities to ensure facilities are planned, designed, and delivered to meet operational needs while optimizing cost savings for Metro, including through the application of rate-based subsidy programs.

Integrate resilience into facility design. Shifting to battery-electric buses increases Metro's reliance on the electric grid (electric system risks can stem from extreme climate events, cyberattacks, and other). Resilience strategies should be determined at time of facility design to incorporate the latest electric grid and climate data.

Test and implement charge management systems. Charge management software captures data from both the vehicles and charging infrastructure to optimize when, where, and how to charge a battery-electric bus fleet. A key benefit of charge management software is the ability to balance energy requirements that align with daily fleet pull-out requirements with the utility rate structure. Metro must review, test, and implement charge management systems that can be integrated with scheduling and yard management systems to ensure buses are charged and assigned to blocks that can be completed, while mitigating impacts to the electric grid and controlling costs.

VEHICLES/SERVICE

Capitalize on Metro's Zero-Emission Bus Deployment: Phase 1 to inform future ZEB efforts. Metro will collect data from its 12-bus deployment to assess the performance of buses and charging equipment in Metro's operating conditions, and better understand how the technology will meet our service and operational needs when scaled up. Metro will also incorporate lessons learned on safety, facility design, and bus and charging equipment specifications for the broader transition.

Conduct a ZEB technology study to assess fuel cell electric bus and battery-electric bus market and technology trends to guide future fleet requirements. Metro's ZEB Technology Study should evaluate forecasted economics, infrastructure and fueling requirements/sources (e.g., forecasted hydrogen production near the Metro region), and other operational considerations for fuel cell electric buses in comparison to battery-electric buses. Such a study allows Metro to monitor ZEB market and technology trends and implement the most viable, cost-effective, and feasible ZEB technology in the future. The study could also include demonstration and pilot testing of fuel cell electric bus technology.

WORKFORCE

Prepare the workforce for the transition to ZEBs. Training for Metro staff, specifically bus operations and maintenance related to battery-electric bus specific differences from hybrid and internal combustion engine buses, is needed for a successful transition. Vehicle maintenance staff will need specialized training in topics such as bus electrical systems, high voltage safety, personal protective equipment needs, diagnostics, and troubleshooting. Example bus operations specialized training include how to operate a battery-electric bus (including regenerative braking techniques), dashboard familiarization, and checking battery state of charge. As part of preparing the workforce, Metro also will assess the existing Collective Bargaining Agreement to ensure workforce requirements and target dates for implementation align with future maintenance and operations requirements of battery-electric bus fleet and supporting facilities.

Develop a comprehensive internal stakeholder engagement and communication plan. This outreach effort (including with union and frontline staff) will help explain Metro's Transition Plan, further build consensus on business and workforce planning needs, and empower employees to be a meaningful part of the transition.

PROGRAMMATIC

Aggressively pursue funding. Significant capital and operational costs are required to enable a successful ZEB transition. Federal, state, and regional funding opportunities, such as grant funds, will help Metro undertake facility designs, infrastructure upgrades, and workforce training. Metro will work with elected officials, the utilities, and other regional partners to build support for projects and explore necessary funding.

Create ZEB equity-specific tracking metrics. Equity-related metrics assist Metro in assessing how equitably the ZEB transition is proceeding and whether there are any disproportionate and unexpected impacts. These measures can track how equitably ZEBs are being deployed, delivering service, and creating benefits (e.g., air quality improvements) for Metro's riders and communities.

Continue to collaborate with other transit agencies in the Washington Metropolitan Area. Metro will continue to work with peer transit agencies to coordinate ZEB transition plans and seek opportunities to reduce costs and duplicative efforts, including utility coordination, first responder training, and community outreach and engagement. Metro also will continue to act as a regional partner to test and evaluate strategies for shared opportunity charging. Although investing in opportunity charging may not be a short-term need for Metro's own service, it can help provide operational flexibility, and leveraging Metrorail's station land may enable a more efficient transition to zero-emission technology for the region.

The path to an all-ZEB future has its challenges, and Metro will approach its transition in a strategic and iterative way. Accordingly, the Plan provides Metro with the foundation framework with which to begin this transition process. Given the dynamic nature of service, operations, and market conditions, the Plan is considered a living document that will be adapted and updated periodically to capture pertinent changes to assumptions, timing, and technologies.