Safety and Operations Committee

Board Action Item III-B

December 9, 2021

Approval of Metrorail and Metrobus Fleet Plans and Metrorail Service Standards

Washington Metropolitan Area Transit Authority

Board Action/Information Summary

◉ Action ○ Information	MEAD Number: 202322	Resolution: ◉ Yes ○ No

TITLE:

Bus and Rail Fleet Plans; Rail Service Standards

PRESENTATION SUMMARY:

Action item to request Board adoption of Metrobus Fleet Management Plan, Metrorail Fleet Management Plan, and updated Metrorail service standards.

PURPOSE:

The purpose of this presentation is to seek Board adoption of updated Metrobus and Metrorail Fleet Management Plans as well as updates to Metrorail service standards.

DESCRIPTION:

Metro maintains a fleet of approximately 1,600 buses and more than 1,250 railcars used to provide service throughout the Washington metropolitan region. These fleets are supported by maintenance facilities, operating divisions, and other system infrastructure. Fleet plans are long-term planning documents which align anticipated service levels, vehicle procurements, facility requirements, and enable coordination of associated capital investments.

Service standards guide deployment of service, inform capital investment and operating resource needs, and offer information to riders about Metro's rail service schedules. Rail service standards provide the framework for adding and adjusting service to respond to demand. Developments since rail service standards were adopted in 2012 and 2013 include changes in service patterns and ridership, service adjustments for system renewal, and the increased use of eight-car trains.

Please see the attached list of interested parties for conflicts of interest purposes.

Key Highlights:

- The Metrobus Fleet Management Plan includes a phased transition to a 100% zero-emission fleet, an expanded articulated bus fleet, and a total fleet size of 1,593 vehicles.

- The Metrorail Fleet Management Plan outlines the investments required to move to 100% eight-car train operations and 7-minute headways system-wide by 2030, which would include fleet expansion through purchase options in the 8000-Series railcar procurement as well as storage and shop capacity expansions and reconfigurations.

- Updated Metrorail service standards set minimum train frequencies, update passenger load standards, and direct staff to strive to operate 100% eight-car trains in passenger service.

Background and History:

Metro's bus fleet of approximately 1,600 vehicles, maintained at ten operating divisions throughout the region, consists of a mix of diesel, compressed natural gas, and diesel-electric hybrid buses, as well as one electric vehicle. The Metrobus Fleet Management Plan, which is periodically updated to reflect current and future fleet operations, forecasts anticipated ridership and network demand, details upcoming bus procurement and retirement plans, and discusses systemwide maintenance and facility needs through 2038. Proposed updates to the Metrobus Fleet Management Plan were presented to the Board of Directors in September 2021. The September 2021 presentation materials are available here.

The Metrorail Fleet Management Plan is periodically updated to reflect rail system operating conditions and anticipated future needs. Pre-pandemic, ridership was growing ahead of projections with a 7 to 8% increase in the first eight months of FY2020 and most lines above the rail standard of 100 passengers per car at peak load points. Metrorail ridership declined substantially during the Covid-19 pandemic and has recovered to approximately 30% of pre-pandemic levels on weekdays and 60% on weekends. The Metrorail Fleet Management Plan enables coordination of capital investments, including railcars, railcar storage, maintenance, traction power, and system throughput to meet future service needs through 2040.

Metro adopted its rail service standards in 2012 and 2013, which established weekday rush and non-rush minimum train frequencies throughout the system, defined rush hour passenger per car crowding standards, and specified Metrorail operating hours. Updates to the Metrorail Fleet Management Plan and Metrorail service standards were presented to the Board of Directors in October 2021. The October 2021 presentation materials are available here.

Discussion:

In June of 2021, Metro's Board of Directors directed a phased conversion of propulsion technology for the Metrobus fleet. Under this plan, only lower-emission and electric buses will be purchased beginning in FY2024. By FY2030, only electric or other zero- emission buses will be procured with the entire Metrobus fleet to be made up of zero- emission vehicles by FY2045. The updated Metrobus Fleet Management Plan is consistent with these Board-adopted zero-emission vehicle goals.

Metro plans to expand the size of its articulated bus fleet as a share of the total fleet from the current 4% to 12% by 2028. This will enable Metro to respond to crowding and service standards and is consistent with previous bus garage storage and maintenance capacity investments. It is also in line with articulated fleet shares at peer transit agencies.

Metrobus facilities are not currently configured to support an electric bus fleet. Capital investment in facility conversion and other electric bus support infrastructure will be required to begin the conversion of the fleet. Facility requirements include charging equipment, garage configuration changes, support and coordination with electric utilities, parts and material storage and other operational and safety considerations. Metro will continue to coordinate with regional electric utilities, jurisdictions and transit providers as it advances future fleet and facility plans.

In light of anticipated regional growth and ridership demand and system capacity constraints, the Metrorail Fleet Management Plan outlines steps to develop capacity for 100% eight-car train operations and the capability to run more frequent service at a 7-minute system headway level by 2030. To accommodate this level of service, the following capital investments are needed:

- Procurement of 8000-Series railcars to replace retiring 2000- and 3000-Series vehicles and support expansion of the fleet.
- Expansion of railyard storage and shop capacity to accommodate the operation and maintenance of eight-car trains and a larger railcar fleet.
- Continued investment in traction power capacity upgrades.

Updated Metrorail service standards include the establishment of minimum train frequencies during regular service, to include:

- Daytime and Early Evening: from opening to 9:30 pm, seven days a week:
  - 12 minutes on the Blue, Orange, Silver, Green, and Yellow Lines
  - 6 minutes on the Red Line
- Late Night: 9:30 pm until close, seven days a week:
  - 15 minutes on the Blue, Orange, Silver, Green, and Yellow Lines
  - 10 minutes on the Red Line

During weekday rush periods, the passenger loading standards target average passenger loads at maximum load points in the peak hour and the peak direction to be at or below 100 passengers per car, with the following definitions:

- Optimal: 80 to 100 passengers per car
- Crowded: 101 to 120 passengers per car

- Very Crowded: 121 or more passengers per car

These passenger loading standards also target average passenger loads at the maximum load points to be at or below a seated load during non-rush periods.

The updated standards also establish a goal of striving to operate 100% eight-car trains in passenger service.

FUNDING IMPACT:

Adoption of fleet plans and rail service standards do not obligate capital spending. Any associated requests for funding will be made separately through the capital program and budget processes.

TIMELINE:

Previous Actions	• **October 2012** – Rail Service Standards • **July 2013** – Rail Service Standards Phase II • **2015-2016** – Most recent update to Metrorail Fleet Management Plan • **December 2020** – Adoption of Metrobus Service Guidelines • **June 2021** – Adoption of a Sustainability Vision and Principles and Zero-Emission Vehicle Goals
Anticipated actions after presentation	• **FY2022** – Submission of Metrobus Fleet Management Plan to Federal Transit Administration • **FY2022** – Submission of Metrorail Fleet Management Plan to Federal Transit Administration

RECOMMENDATION:

Staff recommends adoption of the Metrobus and Metrorail Fleet Management Plans and the Metrorail service standards.

The following parties may have an interest in the decisions made by the Board with regard to the Metrobus and Metrorail Fleet Management Plans and the Rail Service Standards:

- A123 Systems
- AECOM
- Alstom
- BAE Systems Controls, Inc.
- Baltimore Gas & Electric Company
- BYD Motors, Inc.
- C3M Power Systems, LLC
- Center for Transportation and the Environment
- CH2M HILL, Inc.
- City Construction
- Clark Construction Group, LLC
- Construcciones y Auxiliar de Ferrocarriles (CAF)
- Craddock Local Solutions, LLC
- CRW Parts, Inc.
- Cummins, Inc.
- Daimler
- Dartco Transmission Sales & Service, Inc.
- DHA/RK&K Joint Venture
- Dominion Energy
- ElDorado National
- eVigilant Security
- F.H. Paschen
- Faiveley Transport
- Gannett Fleming-Parsons Joint Venture
- Genfare
- Gillig Corporation
- Hensel Phelps Construction
- Hitachi Rail
- Jacobs Engineering Group
- James River Petroleum (JRP)
- Johnson & Towers Baltimore, Inc.
- Johnson, Mirmiran & Thompson
- Kal Krishnan Consulting Services, Inc.
- Kawasaki
- Knorr Brake Company
- Laird Plastics, Inc.
- Leclanché
- LTK Engineering
- Lytx, Inc.
- Merak
- Microvast Power Solutions, Inc.
- Modine Manufacturing Company

- Mott MacDonald I&E, LLC
- Needles Eye
- Neopart Transit, LLC
- New Flyer of America, Inc.
- Northeastern Bus Rebuilders, Inc.
- Novabus
- Orion Management, LLC
- P & H Auto-Electric, Inc.
- Patuxent Roofing
- Pepco – an Exelon Company
- Phillips Corporation
- Potomac Construction
- Proterra
- RailQuick
- RAM Industrial Services, Inc.
- Saft America
- Siemens Mobility
- Standard Steel
- The Aftermarket Parts Company, LLC
- Tri-State Battery & Auto Elec., Inc.
- Urban Engineers
- Van Hool
- W. M. Schlosser Co. Inc.
- Washington Gas – a WGL Company
- WSP
- XALT Energy

Bus and Rail Fleet Plans and Rail Service Standards

Safety and Operations Committee
December 9, 2021

Purpose

Review content and request Board approval of the Metrobus Fleet Management Plan, Metrorail Fleet Management Plan, and Rail Service Standards

Metrobus Fleet Management Plan

Context

- Fleet plans updated periodically, most recently in 2017

- Aligns anticipated service levels, facility requirements, and bus procurements through 2038, consistent with Board-adopted zero-emission vehicle goals; guides long-term planning, does not obligate funds

- Fleet plans submitted to Federal Transit Administration (FTA); required for oversight and award of federal funds

Projected Fleet Level

- Maintain fleet size of **1,593 buses**; required for return to pre-pandemic service levels, accommodate existing and anticipated crowding over time
  - **1,270** vehicles operated in maximum service
  - **248** spare vehicles for maintenance requirements
  - **75** ready reserve vehicles suitable for use as needed

Bus purpose	Buses
Vehicles Operated in Maximum Service	1,270
Spares	248
Ready Reserve	75
Total Fleet	**1,593**

Metrobus Fleet Plan Strategy Summary

- Maintain fleet size of approximately **1,593 buses**, procuring 100 new vehicles per year
- **Begin adoption of electric buses,** starting with next bus procurement, and transition new bus procurements to 100% electric or other zero-emission technologies by 2030, fleet fully zero-emission by 2045
- Grow **articulated buses** as share of fleet from 4% **to 12%**, or 180 buses, to address crowding and increase system capacity
- **Spare ratio of 19.5%,** updated from 18.5%
  - Supports bus technology transition, increase in articulated buses, garage and fleet flexibility, and capital program needs (e.g., Platform Improvement Project)
  - Remains within FTA guidelines

Bus Fleet Strategy Capital Investment Estimates

- Increased capital costs:
  - Electric bus acquisition cost approximately **~$300,000** higher (~45%) than diesel bus
  - Average estimated infrastructure cost per electric bus of **~$400,000**; approximate project cost of **~$60m** for 150-bus garage
  - Approach to support electric charging infrastructure likely to differ by location:
    - Incremental addition to active major projects (e.g., Northern, Bladensburg). Lower incremental cost than retrofit or facility replacement
    - Retrofitting of existing facilities
    - Conversion likely to require facility replacement

Figures represent order of magnitude estimates based on external benchmarks and peer transit agencies. Not official estimates; additional work required for development of Metro facility projects.

Draft Strategy Order of Magnitude Estimated Incremental Capital Costs

Period	Incremental Capital Cost Estimate
6-Year Capital Program (FY22-FY27)	~$125-200m
10-Year Capital Plan (FY22-FY31)	~$400-500m
Draft Fleet Strategy (FY22-FY38)	~$900m-1b

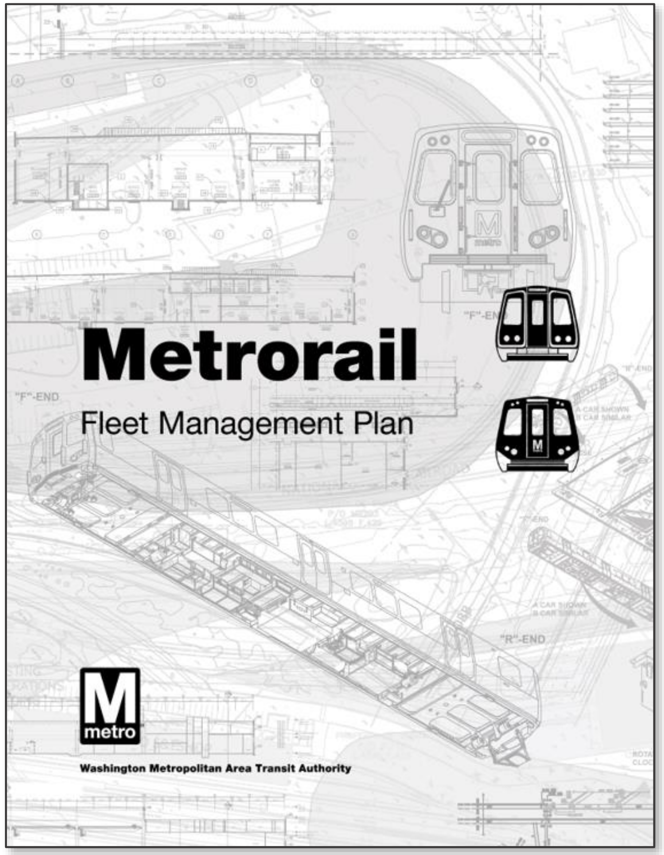
Next Steps

- Recommended Board adoption of Metrobus Fleet Management Plan
- Submit plan to Federal Transit Administration (FTA)
- Upcoming bus procurement contract to be initiated in FY2022, deliveries to begin in FY2024
- Electric bus facilities investment plan development

Metrorail Fleet Management Plan

Context

- Fleet plans updated periodically, most recently in 2016
- Enables coordination of capital investments, including railcars, railcar storage, maintenance, traction power, and system throughput to meet future service needs through 2040; guides long-term planning, does not obligate funds
- Fleet plans submitted to Federal Transit Administration (FTA); required for oversight and award of federal funds



Several factors determine overall Metrorail system capacity

Current system capacity can deliver **75% eight-car trains** at **8-minute** peak system headway*

Fleet size: number of railcars operating in daily service and spare requirements

Yard Storage: amount and configuration of railcar storage tracks in rail yards

Maintenance Shops: capacity of maintenance shops to service and overhaul railcars

Traction Power: capacity to provide power for vehicle propulsion

Core Throughput: maximum number of trains able to move through core segments of system, typically measured as trains per hour

Terminal Capacity: number of trains able to turn around at end-of-line terminals, typically measured as trains per hour

Stations: impact of platform lengths on maximum cars per train; dwell time impacts from crowding and station passenger flow

*Or 100% eight-car trains at 10-minute peak system headway. The system headway refers to the typical interval between trains departing end-of-line terminals. The Red Line and interlined segments, where two or more lines overlap, have lower effective headways. e.g., trains arrive at stations every 2.7 to 8 minutes at an 8-minute system headway and every 2.3 to 7 minutes at a 7-minute system headway.

Impact of System Capacity on Riders

More frequency and capacity enable serving more riders and improving customer experience

System Headway (End-of-Line Interval Between Trains*)	Line Capacity (Passenger Throughput)	Capacity Improvement
8-minute 75% eight-car trains (current)	5,000 to 6,000 passengers / hour	-
7-minute 100% eight-car trains	6,850 passengers / hour	~20%
6-minute 100% eight-car trains	8,000 passengers / hour	~35-40%

- Shorter wait times
- Better chance of boarding
- Less crowding
- Seats available more often

*The system headway refers to the typical interval between trains departing end-of-line terminals. The Red Line and interlined segments, where two or more lines overlap, have lower effective headways. e.g., trains arrive at stations every 2.7 to 8 minutes at an 8-minute system headway and every 2.3 to 7 minutes at a 7-minute system headway.

Lead Time and Development for Capacity Investments

Long-term system planning and investment requires decisions made well in advance

Railcars

- **Initiating new railcar procurement** — ~5-8 years
- **Exercising railcar procurement option** — ~1+ years

Yards & Shops

- **Expanding rail yard or shop capacity** — ~2-6 years
- **Building new rail yard or shop facility** — ~5-10 years

System Expansion

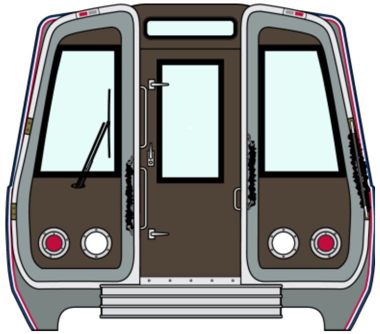
- **Opening new rail line** — ~20+ years

Completion

Lead time required

M metro

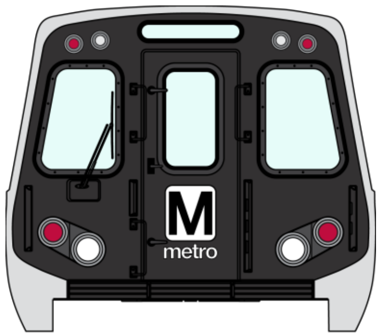
Current and Future Fleet Composition



Railcar Series	Entered Service	Current	2030
2000-Series	1983-1984	74	0
3000-Series	1984-1988	276	0
6000-Series	2006-2008	180	180
7000-Series	2015-2020	748	748
8000-Series	2025-	0	256 – 800
TOTAL		**1,278**	**TBD**

Metrorail Fleet Plan Strategy Summary

- Prepare for regional growth by planning for **100% eight-car train operations** and capacity to run more frequent service at a **7-minute system headway level by 2030**
  - Expand fleet through 8000-Series procurement options
  - Expand rail yard and maintenance shop capacity and improve efficiency for eight-car train operations
  - Continue traction power upgrades



Rail Fleet Strategy Capital Investment Estimates

- Incremental investment levels range from approximately **$1.05b to $1.95b** to enable Metro to deliver anticipated all **eight-car train** service with **7-minute or 6-minute minimum train frequencies**

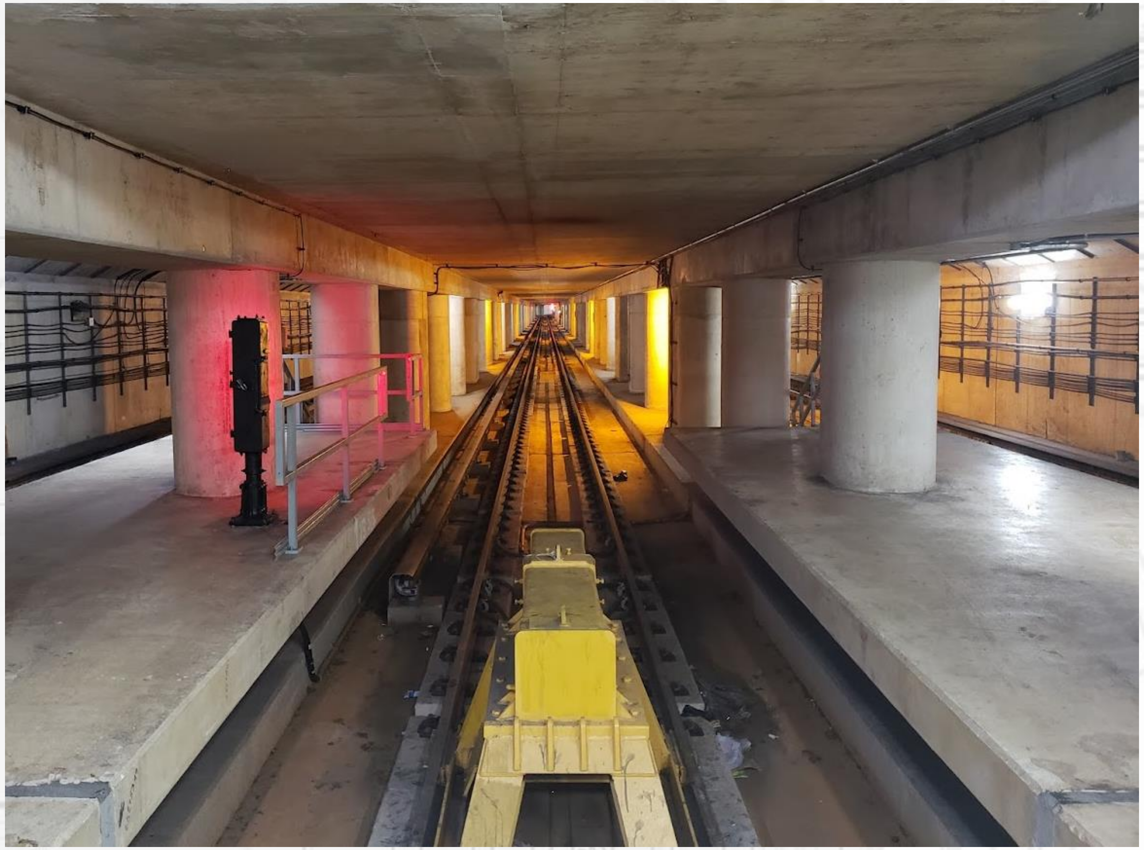
Figures represent order of magnitude estimates based on preliminary analysis. Not official estimates; additional work required for development of Metro facility projects.

Category	**2030 7-Minute System Headway**	Beyond 2040 6-Minute System Headway
Yard Improvement and Expansion	**~$250m**	~$500m
Shop Improvement and Expansion	**~$200m**	~$400m
Fleet Expansion 8000-Series Railcars	**~$600m**	~$1.05b
Total	**~$1.05b**	~$1.95b

Current planning scenario

Next Steps

- Recommended Board adoption of Metrorail Fleet Management Plan
- Submit plan to Federal Transit Administration (FTA)
- Develop rail yard investments and propose projects for inclusion in capital improvement program



Largo Tail Tracks

Rail Service Standards

Context

- Most recent Board review and adoption of Metrorail service standards in 2012 and 2013; Metrobus service guidelines updated in December 2020

- Opportunity to update standards to reflect current conditions and operating practices
  - Changes in service patterns and ridership
  - More service adjustments for system renewal
  - Increased use of eight-car trains

Minimum Train Frequencies

Regular Service

- Daytime and Early Evening:
  Opening to 9:30 pm, 7 days a week
  - **12 Minutes**
    - Blue, Orange, Silver, Green, Yellow Lines
  - **6 minutes**
    - Red Line
- Late Night:
  9:30 pm until close, 7 days a week
  - **15 Minutes**
    - Blue, Orange, Silver, Green, Yellow Lines
  - **10 minutes**
    - Red Line

Passengers Loads

- Weekday rush period average passenger loads at or below 100 passengers per car (PPC)
    - Optimal: 80 to 100 passengers per car
    - Crowded: 101 to 120 passengers per car
    - Very Crowded: 121 or more passengers per car
- Non-rush period average passenger loads at or below seated load

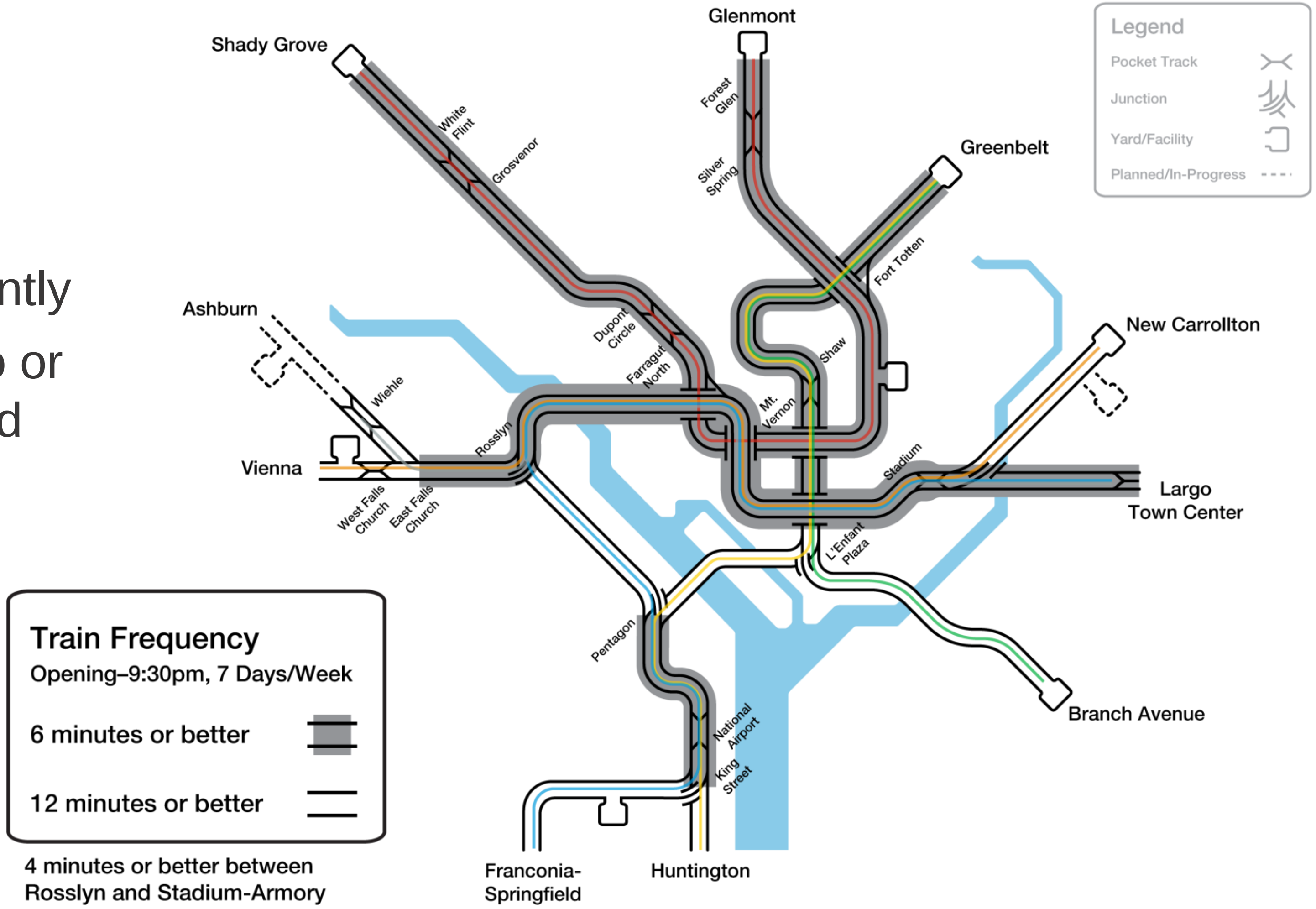
Measured as average passenger loads at maximum load points in the peak hour and peak direction

Eight-Car Trains

- Goal: Operation of 100% eight-car trains in passenger service

Effective Train Frequency by Segment

- Most riders receive better service than minimum line frequencies
  - Peak service runs more frequently
  - Interlined segments, where two or more lines overlap, and the Red Line have higher effective frequencies



Train frequency of **6 minutes or better** at **65 stations** (71% of all stations)

Recommendation

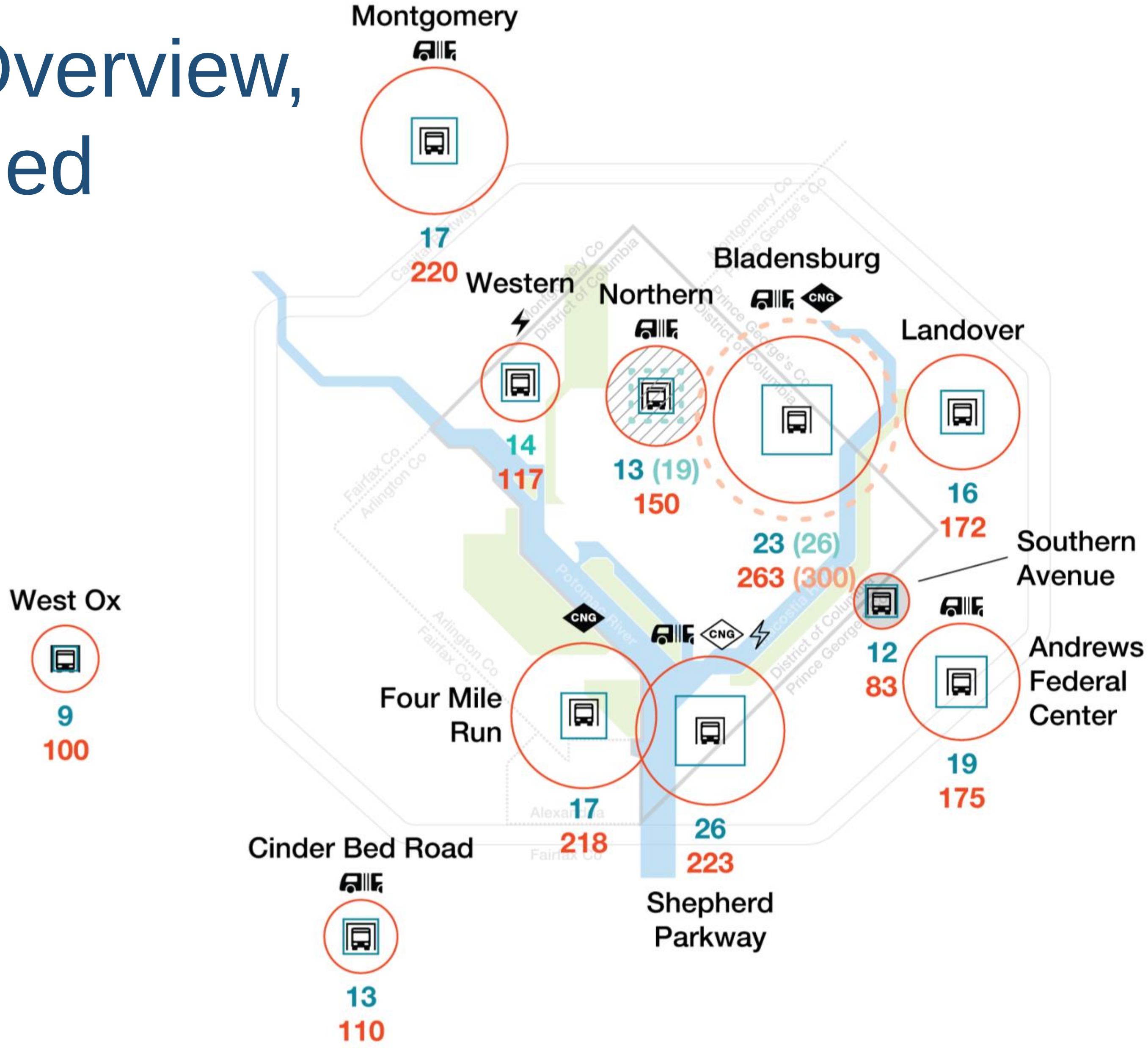
- Board adoption of Metrobus Fleet Management Plan, Rail Fleet Management Plan, and Rail Service Standards

Appendix

Bus Facility Capacity Overview, Current and Programmed

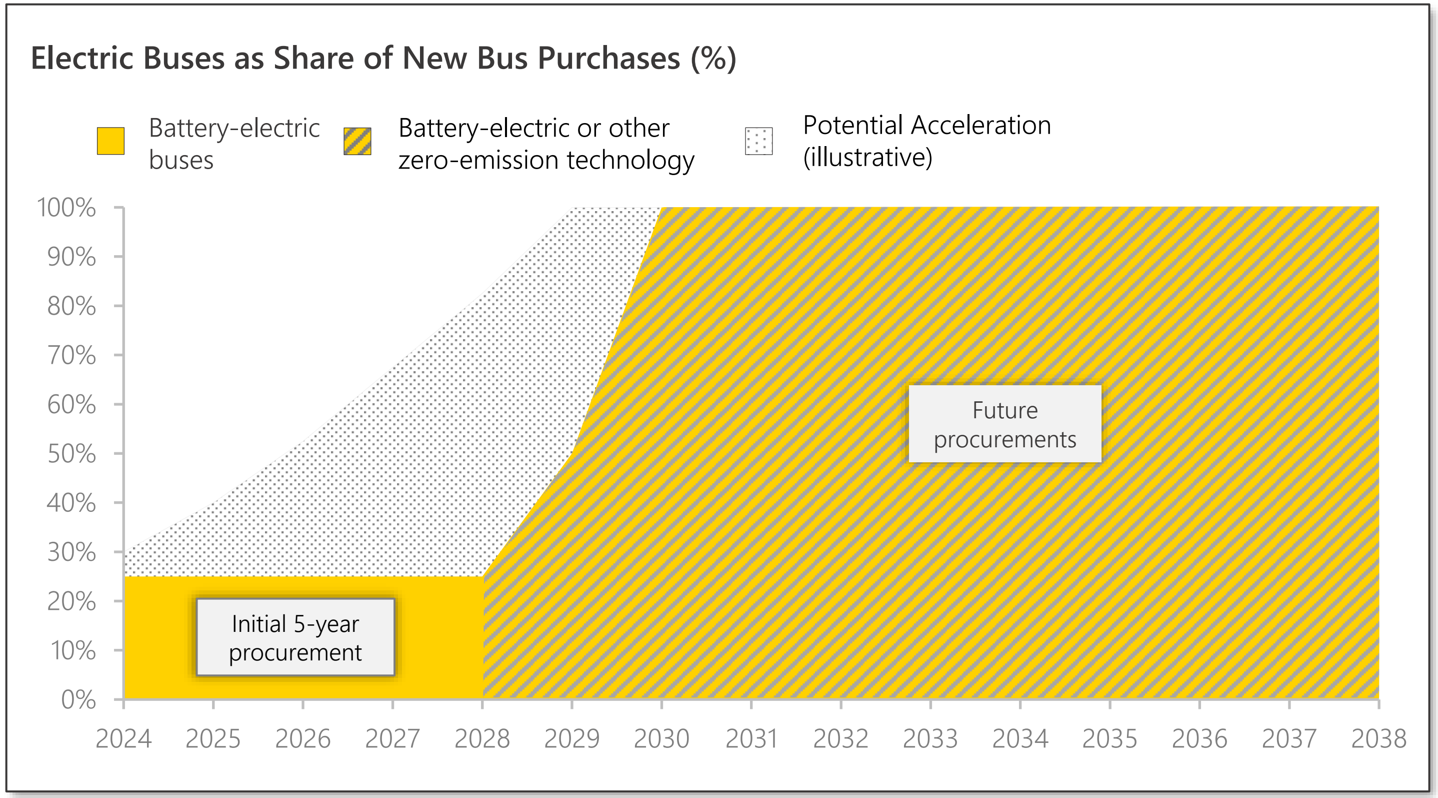
Legend

- Bus Division
- Current Bus Parking Capacity
- Planned Bus Parking Capacity
- Maintenance Bays
- Planned Maintenance Bays
- Division Slated to Close
- Division Currently Closed for Reconstruction
- Articulated Bus Maintenance Bays
- Compressed Natural Gas (CNG)-Capable
- CNG Capability Pending
- Electric Bus Home Garage
- Electric Bus Home Garage Pending



Graphic not to scale

Metrobus Propulsion Technology Strategy



- Bus Fleet Strategy contemplates **phased approach** to electric bus adoption
  - Purchase only **lower-emission and electric buses** in next bus procurement
  - Transition to **100% zero-emission bus purchases by 2030**
  - Fleet **100% zero-emission by 2045**
- Strategy weighs flexibility and adaptability with the potential for faster adoption of electric or other zero-emission buses if:
  - 1-for-1 replacement is possible sooner
  - More funding is available
  - Facility capacity and infrastructure improvements are realized more quickly

Articulated Bus Procurement Strategy

- Expand 60-foot articulated buses as a share of the active Metrobus fleet – from 4% to 12% (180 buses)
- Enables Metro to respond to crowding and service standards, including routes with anticipated ridership demand growth, without an increase in overall fleet size
- Consistent with previous bus garage storage and maintenance capacity investments
- In line with articulated fleet shares at peer transit agencies

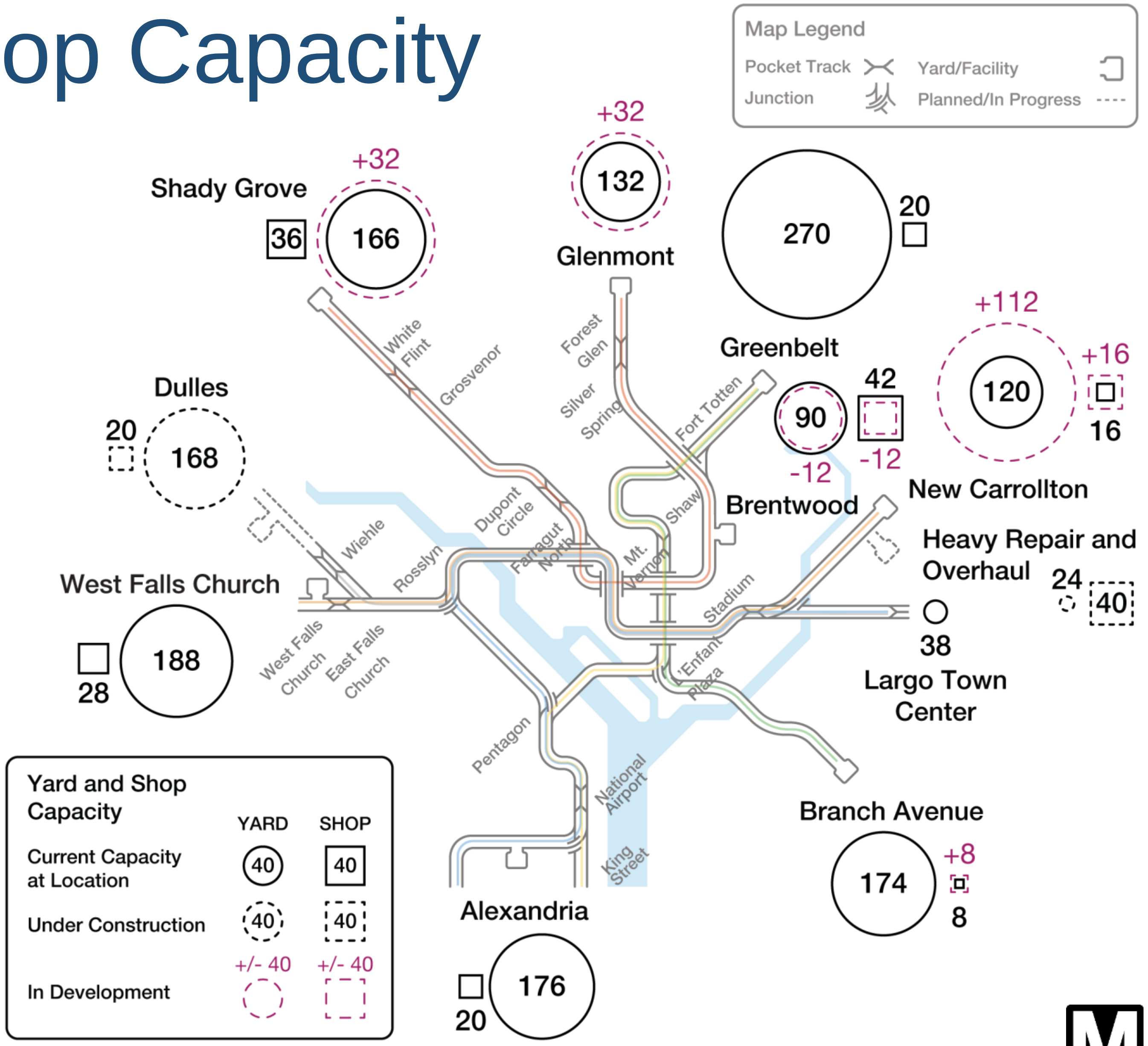
Peer Agency	% Articulated
King County Metro	55%
New York City Transit	19%
Chicago Transit Authority	16%
Los Angeles County Metropolitan Transit Authority	16%
Southeastern Pennsylvania Transit Authority	13%
Miami Dade Transit	11%
Massachusetts Bay Transit Authority	10%
Maryland Mass Transit Administration	7%
Washington Metropolitan Area Transit Authority	**4%**
Metro Atlanta Rapid Transit Authority	3%

Note: Standard length buses are 40 feet long.

Railcar Storage and Shop Capacity

Capacity expansions to deliver 7-minute system headway:

- Red Line: Add a net of **52 storage spaces**
  - Opening Heavy Repair & Overhaul facility will allow Brentwood conversion to primarily support Red Line Railcar Maintenance and Track Equipment Maintenance
- New Carrollton: Add **112 storage spaces** and **16 shop spaces**
- Branch Avenue: Add **8 shop spaces**



Service Demand Projections

Metro could outgrow current service levels based on long-term projected ridership at core peak load points

Planning for **100% eight-car train operations** and capacity to run more frequent service at a **7-minute system headway level by 2030**

Average Peak Hour Passengers per Car (PPC) at Peak Load Points

	System Headway	2020 Actual [1]	2030 Forecast	2040 Forecast
RD	8-minute	121	132	141
	7-minute		100	107
YL	8-minute	107	102	109
	7-minute		89	95
GR	8-minute	105	112	125
	7-minute		98	110
BL	8-minute	89	119	127
	7-minute		88	93
OR	8-minute	109	158	167
	7-minute[2]		101	107
SV	8-minute	107	143	148
	7-minute		101	105

PPC <100 (green) PPC 100-120 (yellow) PPC > 120 (red)

1 – 8-minute scenario includes a mix of six- and eight-car trains; 7-minute scenario includes 100% eight-car trains. Reflects Red Line operation of two-line pattern and other lines with interlined segments. FY2020 actual ridership is based on October 2019 weekday ridership – higher than forecast levels on some lines.

2 – Assumes two tripper trains providing additional one-way service are operated on Orange Line.

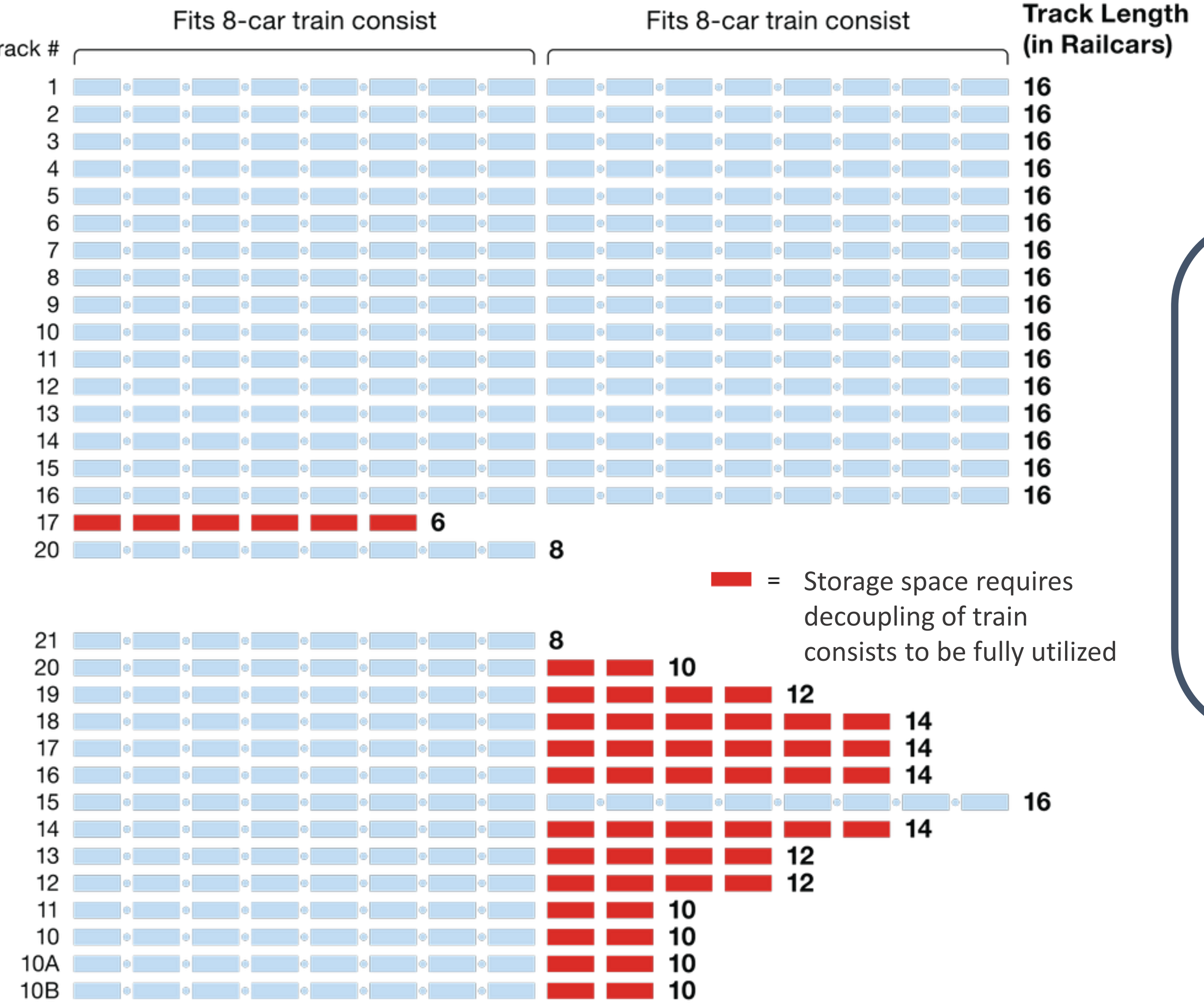
Railcar Storage Efficiency for Eight-Car Trains

Greenbelt Yard

Storage track lengths allow almost full utilization of yard with 8-car train consists

Shady Grove Yard

Most storage track lengths inefficient for storage of 8-car train consists



Opportunity to increase efficiency of eight-car train operations with yard improvements

Railcar Maintenance Efficiency

- Railcar shops without eight-car tracks complicate yard and maintenance operations

- Opportunity to configure capacity expansions to support maintenance of full eight-car train consists on posted rail tracks, consistent with global best practices

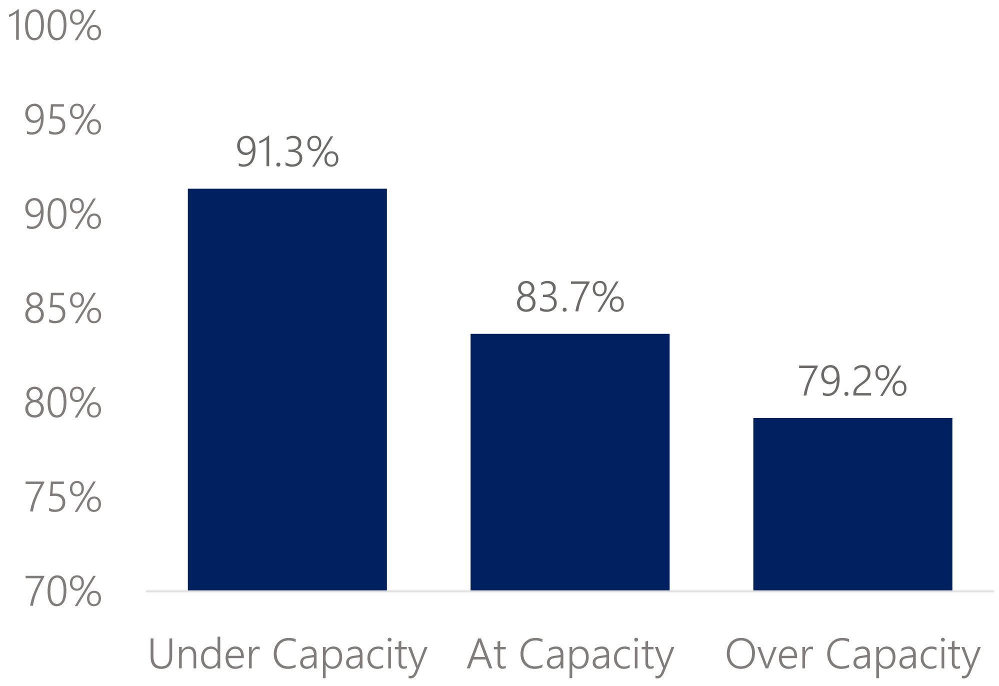
Shady Grove posted rail maintenance bay

Rail Yard Factors Impacting Service Delivery

More reliable service delivery in yards with:

- Lower railcar **storage capacity** utilization
- Simpler yard **track layouts** capable of storing **eight-car trains**
- Lower level of **shop-related operations** and maintenance equipment
    - Includes assembling and decoupling trains to support maintenance shops configured for married pairs

Days Meeting Service Requirements by Yard Capacity Utilization, 2019, %



Changes from previous projections and potential Covid-19 implications

- 2016 plan projected system to require 6-minute system headway at 100% eight-car trains by 2030; updated plan revised to 7-minute system headway with 100% eight-car trains by 2030
- Exact pace of post-pandemic ridership recovery remains uncertain
- For purposes of fleet and system planning, anticipated capacity growth previously expected to be needed in 2025 deferred to 2030

Current Rail Service Standards, adopted 2012-2013

- Define rush hour passenger per car crowding standards
- Set weekday rush and non-rush train frequencies
- Specify operating hours

2012-2013 Service Standards

Rush Period Passenger Load: Below an average of **100 passengers per car** (PPC) and between 80 and 120

Rush Period: 2.5 to 3 minutes on core interlined segments and up to **6 minutes** on all other segments except Arlington Cemetery, which will be **12 minutes**

Weekday Midday: Up to **6 minutes** on core interlined segments and up to **12 minutes** on all other segments.

Weekday Evenings: Up to **15 minutes** on core interlined segments and up to **20 minutes** on all other segments.

Weekend: Unspecified.

Limitations of Current Standards

- Fixed rush period standard
- Less emphasis on off-peak and no standards for weekend service

Service Standard Categories

Guide deployment of service, inform capital investment and operating resource needs, and offer information to the public about how Metro plans and schedules rail service

- **Minimum Train Frequencies**
  - Establish how frequently trains arrive at each station during base service periods
  - Defines minimum level of service quality for riders; impacts average wait times

- **Passenger Load Standards**
  - Define target passenger loads and crowding levels for service planning and capacity investments
  - Used to plan line-specific service levels during busy periods and informs total system capacity needs

SUBJECT: BUS AND RAIL FLEET PLANS AND RAIL SERVICE STANDARDS

RESOLUTION
OF THE
BOARD OF DIRECTORS
OF THE
WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

WHEREAS, Pursuant to Compact Section 9(b) and Board Bylaws Article II.1, the Board of Directors is primarily responsible for policy, financial direction, oversight, and WMATA's relationships with customers, jurisdictional partners, and signatories; and

WHEREAS, The Federal Transit Administration (FTA) requires that WMATA submit comprehensive bus and rail fleet management plans adopted by the Board in support of its application for federal capital grants for new vehicles and facilities; and

WHEREAS, The Metrobus Fleet Management Plan (Attachment A) and Metrorail Fleet Management Plan (Attachment B) are for planning purposes and do not obligate the Authority's capital spending which is determined through the capital budget process; and

WHEREAS, The Board has previously adopted and amended Metrorail service standards to plan service, facilitate reporting system performance, and develop long-term capacity investments (Res. 2012-29, 2013-20, and 2017-11); and

WHEREAS, The Board desires to update Metrorail service standards;

NOW, THEREFORE, be it

RESOLVED, That the Board of Directors adopts the Metrobus Fleet Management Plan and Metrorail Fleet Management Plan, as set forth in Attachments A and B, respectively, for planning purposes; and be it further

RESOLVED, That the Board of Directors repeals all prior Metrorail service standards and adopts the following Metrorail service standards:

1. Minimum train frequencies during regular service -
    a. From system opening until 9:30 pm, seven days a week, trains will arrive at least every 12 minutes on the Blue, Orange, Silver, Green, and Yellow Lines and at least every 6 minutes on the Red Line;

b. From 9:30 pm until system close, seven days a week, trains will arrive at least every 15 minutes on the Blue, Orange, Silver, Green, and Yellow Lines and at least every 10 minutes on the Red Line; and

2. Passenger loads–

a. During weekday rush periods, average passenger loads at the maximum load points in the peak hour and peak direction will be at or below 100 passengers per car, with 80 to 100 passengers defined as "optimal," 101 to 120 passengers defined as "crowded," and 121 or more passengers defined as "very crowded";

b. During non-rush periods, average passenger loads at the maximum load points will be at or below a seated load;

3. Train length – Metrorail will strive to operate 100% eight-car trains; and be it finally

RESOLVED, That in order to meet Federal Transit Administration's bus and rail fleet plan submission deadlines and to incorporate the updated Metrorail service standards into the Fiscal Year 2023 Budget, this Resolution shall be effective immediately.

Reviewed as to form and legal sufficiency,

/s/Patricia Y. Lee
Patricia Y. Lee
Executive Vice-President and General Counsel

WMATA File Structure No.:
6.6.7 Bus Fleet Planning & Acquisition
19.14 Rail Fleet Planning & Purchase
20.5.1 Rail Scheduling

Attachment A

Washington Metropolitan Area
Transit Authority

Metrobus

Fleet Management Plan

Revision and Version Notes Page

Version 1.01	December 2021	Initial Submission

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Executive Summary

The Metrobus Fleet Management Plan details how Metro will modernize and maintain its bus fleet and supporting facilities to meet service demands between 2021 and 2038.

Metrobus Overview

Metrobus service operates on 245 routes and 159 lines, reaching over 10,600 stops and covering over 2,396 street miles in the Washington metropolitan area. As of FY2022, a fleet of nearly 1,600 vehicles is stored and maintained at 10 bus divisions throughout the region. Service is provided on a combination of local, limited-stop (MetroExtra), and express routes connecting the region to Metrorail, employers, medical centers, schools, colleges, universities, airports, military installations, and other commuter rail facilities.

Key Conclusions

The Metrobus Fleet Management Plan provides a forward-looking plan for Metrobus operations. This plan covers current and projected bus fleet service levels, ridership projections, bus fleet requirements including fleet replacement and retirement plans, vehicle types, and bus facility plans.

In accordance with the conclusions summarized within this document, Metro plans to:

- Operate a steady state Metrobus fleet size of approximately 1,593 total vehicles.
- Increase use of higher capacity articulated buses, growing from 4% to 12% of the active Metrobus fleet, enabling expanded Metrobus service capacity on high ridership corridors.
- Begin migration toward a 100% zero-emission bus fleet by 2045 through initial focus on electric buses, along with an expanded use of compressed natural gas (CNG) or other lower-emission buses as a transitional strategy while electric bus technologies mature.
- Convert at least one additional garage to support electric bus operations by the end of the decade and begin development of projects for additional conversions to be completed by the early 2030s.
- Adopt a spare ratio of 19.5% to support the anticipated increased maintenance requirements of the expanded articulated bus fleet as well as the adoption of new propulsion technologies and other special projects.

Ridership and Service

Metrobus and Metrorail experienced significant ridership decline in 2020 as a result of the coronavirus pandemic. By fall 2021, Metrobus ridership had recovered to approximately two-thirds of pre-pandemic levels. While the long-term effects of the pandemic remain uncertain, Metro is preparing for continued ridership recovery over the next several years. As this is a planning document forecasting demand through 2038, preparations regarding the Metrobus fleet and facilities are intended to respond to forecasted long-term ridership demand.

The Metrobus long-term ridership forecast predicts that Metrobus ridership will recover to pre-pandemic levels and then increase by an average of 0.23% annually through 2038. Overall, this will result in an increase of about 19,000 daily trips, from about 425,000 weekday boardings in 2019 to 444,00 by 2038. Because this growth is expected to be distributed unevenly along Metrobus routes and lines, service patterns will be adjusted over time to respond. While ridership is anticipated to grow in the long run, Metro expects to accommodate this modest increase in ridership with the existing fleet size and an expanded articulated bus fleet.

Metro is committed to providing equitable transportation to the region, as communities are stronger when everyone has access to reliable and affordable transportation. Public transportation connects people to jobs, housing, health care, schools, grocery stores, and more, and ensuring broad access and eliminating barriers to using transit is important to the agency's success. Metro is advancing recommendations from the Bus Transformation Project, including restructuring the bus network to improve access to destinations, increase ridership, and make efficient and equitable use of resources, and transitioning to cleaner buses and upgrading its facilities to improve the region's air quality and reduce greenhouse gas emissions.

Some initiatives that align with the priorities in the Bus Transformation Project Strategy are already underway. In September 2021, Metro implemented more frequent, all day service at 12- to 20-minute headways or better on 36 of the most-used bus lines. Fare changes included free transfers between rail and bus and a cheaper weekly bus pass. Metro and local jurisdictions are also partnering to speed up buses and improve reliability by implementing dedicated bus lanes, transit signal priority, queue jumps, and violation detection and enforcement policies.

Electric Bus Transition

Metro is beginning its transition to electric buses producing zero tailpipe emissions, which will support a clean and sustainable region, reduce greenhouse gas and on-the-road vehicle emissions, decrease vehicle noise, and improve the overall customer experience. Throughout the United States, many major metropolitan areas, including the Metro service area, have set zero-emission goals and made investments in electric buses. In June of 2021, Metro's Board of Directors approved a bus procurement strategy and fleet composition targets which would create a 100% zero-emission fleet by 2045 and fully transition new bus purchases to electric or other zero-emission technologies by 2030.

In the near-term, Metro will focus on the procurement of electric buses while continuing to evaluate the development of other zero-emission technologies, including hydrogen fuel cell buses. Hydrogen fuel cell vehicles are an emerging technology with limited demonstrations to date, but may represent an important component of Metro's long-term zero-emission implementation. This document will generally refer to buses by their specific propulsion type.

Metro is initiating a 12-bus test and evaluation program at its Shepherd Parkway Operating Division, with two articulated and ten standard length electric vehicles joining the Metrobus fleet by the end of

FY2023. Through this evaluation program, Metro will gather additional data and operational experience to inform plans to move forward with an electric bus program. Transitioning beyond this test and evaluation to a larger overall electric bus fleet will require close coordination with local, regional, and federal partners. Areas of coordination will include energy infrastructure investments and increases in funding for capital investments associated with electric bus technology.

Current challenges towards a full conversion of the Metrobus fleet to electric vehicles include higher capital costs when compared to traditional buses, unique infrastructure requirements, operating limitations (including range and battery life), and reliability. As electric bus technology matures, some initial hurdles are expected to subside, especially with regards to these vehicles' reliability, availability, and battery storage capacity.

Fleet Procurement

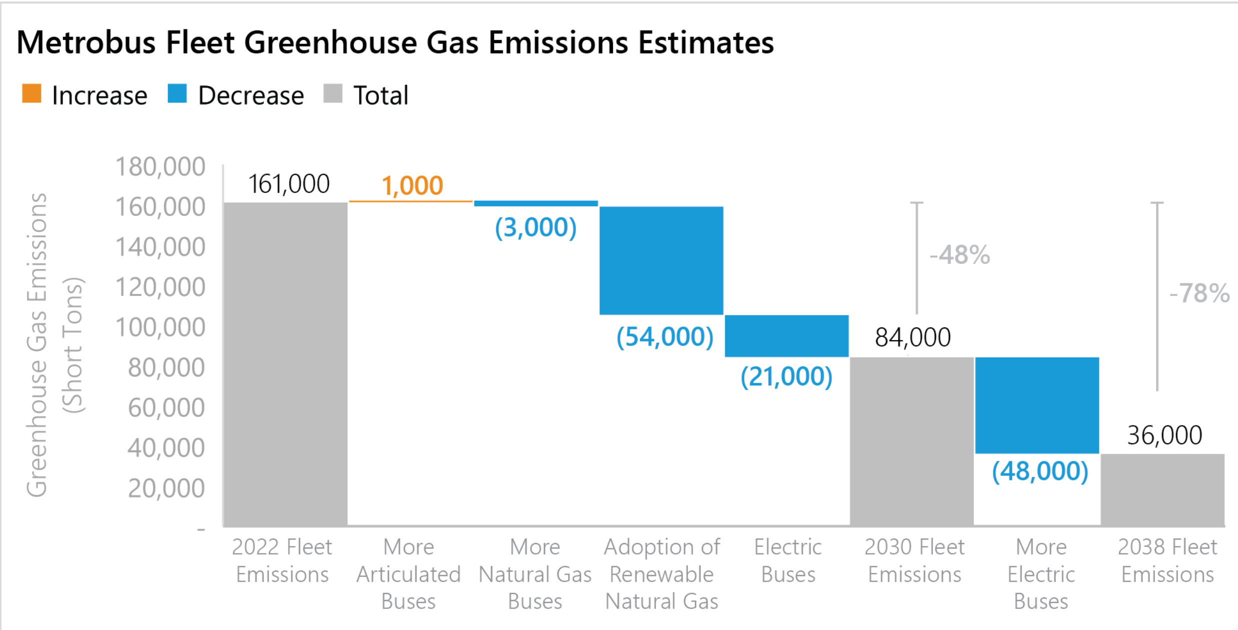
Metrobus currently operates a mixed fleet of compressed natural gas (CNG), diesel, and hybrid buses with one electric bus. Metro plans to shift its new procurements to electric and CNG buses with a transition to purchasing all electric buses by FY2030. Table E-1 outlines the projected procurement approach, by fuel type, outlined in this fleet plan. Metro plans to remain flexible in its procurement plans as facility support capacity and technology performance continue to evolve in the coming years.

Table E-1: Total Projected Bus Procurement by Fuel Type, FY2024-FY2038

Fuel Type	FY24–FY28	FY29	FY30–FY38
Compressed Natural Gas Buses Procured	75 per year	50 per year	0 per year
Electric Buses Procured	25 per year	50 per year	100 per year
Total Buses Procured	100 per year	100 per year	100 per year

This schedule will require facility conversion to support electric buses, which includes dedicated charging, systems, and electric utility support. CNG buses emit fewer local air pollutants and greenhouse gases than traditional diesel buses and additional improvements in emissions may be realized through the use of renewable natural gas sources. The estimated greenhouse gas emission impacts of this strategy are shown in Figure E-1.

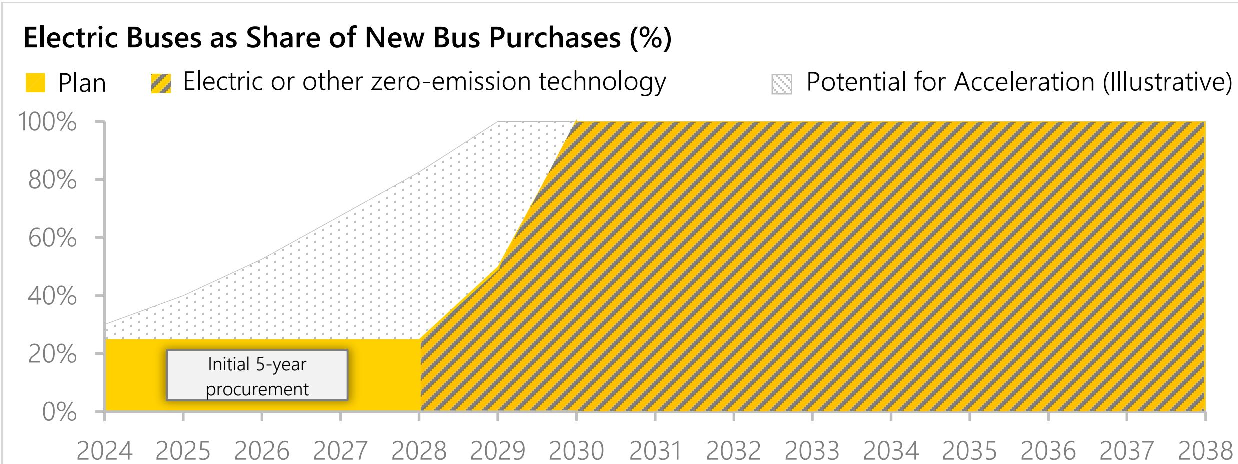
Figure E-1: Estimated Annual Metrobus Fleet Greenhouse Gas Emissions, Selected Years



Metro plans to adapt the pace of its conversion to electric buses in response to the progression and maturity of vehicle technology as well as the availability of the funding sources required to meet anticipated capital costs. If electric or other zero-emission buses demonstrate performance on par with conventional vehicles in terms of annual hours or miles of service, reliability, availability, and range, it may enable a more rapid transition.

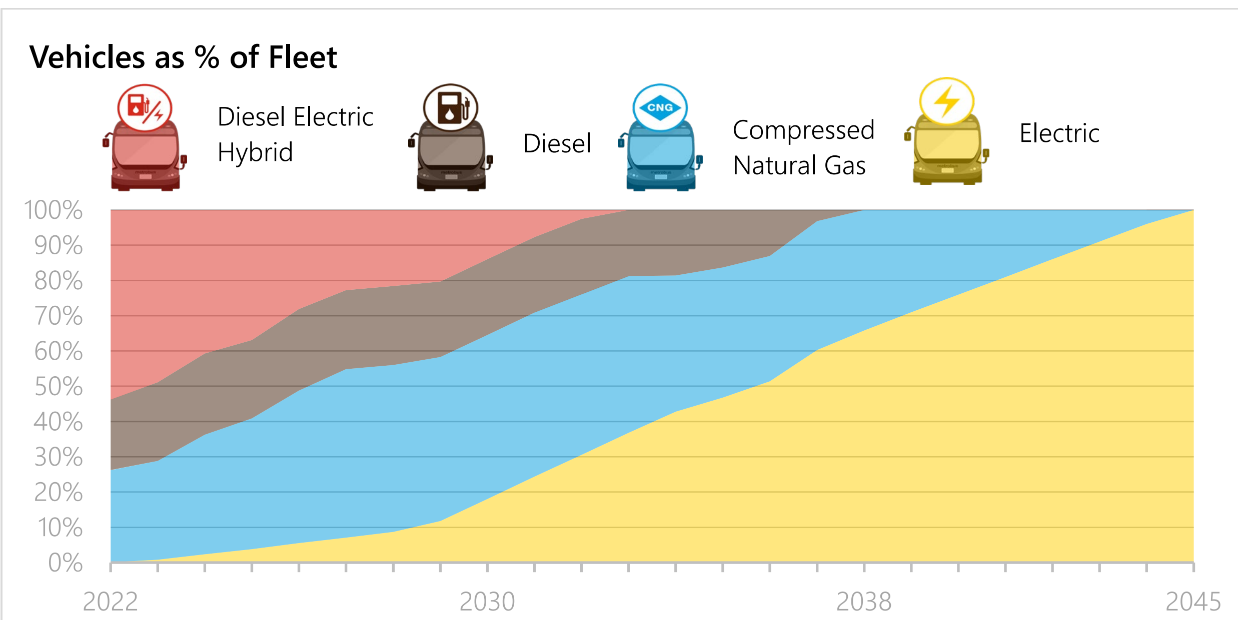
Figure E-2 demonstrates Metro's planned procurement levels as well as an illustrative path for a potential expedited transition to electric or other zero-emission bus technologies.

Figure E-2: Electric Bus Procurement Paths, FY2024–FY2038



The projected long-term composition of the Metrobus fleet is shown in Figure E-3. With fleet procurement transitioning to the purchase of only electric buses by FY2030, the share of electric buses in the Metrobus fleet would increase steadily throughout multiple procurement cycles as other vehicles are retired.

Figure E-3: Projected Share of Vehicles in Metrobus Fleet by Propulsion Technology



Facility Capacity

Metro's existing and programmed facilities will offer sufficient capacity to accommodate the planned increase in the size of the Metrobus articulated fleet—Metro will be able to house 324 articulated buses beginning in FY2027, upon the completion of reconstruction activities at Northern and Bladensburg Divisions. However, current Metrobus facilities and infrastructure are not sufficient to support the anticipated growth of the electric bus fleet. As a result, this plan has identified the facilities gaps expected through FY2038, and estimates the total number of facilities which will require conversion to accommodate these new vehicles. Table E-2 summarizes these capacity needs.

Table E-2: Division Needs, Existing and Planned Vehicle Capacity, Selected Years

	FY25	FY30	FY35	FY38
Electric Bus Storage Capacity	13	163	163	163
Electric Bus Fleet Size	63	288	785	1,048
Electric Bus Capacity Gap	50	125	622	885

In September 2021, Metro announced plans to reopen Northern Bus Garage with the infrastructure and equipment needed to operate 100% electric vehicles.[1] This facility's 150-bus capacity will support the conversion of the Metrobus fleet to fully zero-emission technologies by 2045.

The average Metrobus operating division has a capacity of approximately 165 buses, with the smallest division having a capacity of 83 and the largest a capacity of 263. Starting in FY24 and continuing in FY25, Metro will require at least one additional partial facility conversion to accommodate the storage and fueling of its projected FY25 electric bus fleet size of 63 vehicles. The electric bus fleet will continue to grow over time, requiring the equivalent of five or more facility conversions by FY38.

[1] https://www.wmata.com/about/news/First-all-electric-bus-garage-to-be-built-at-Northern-bus-facility.cfm

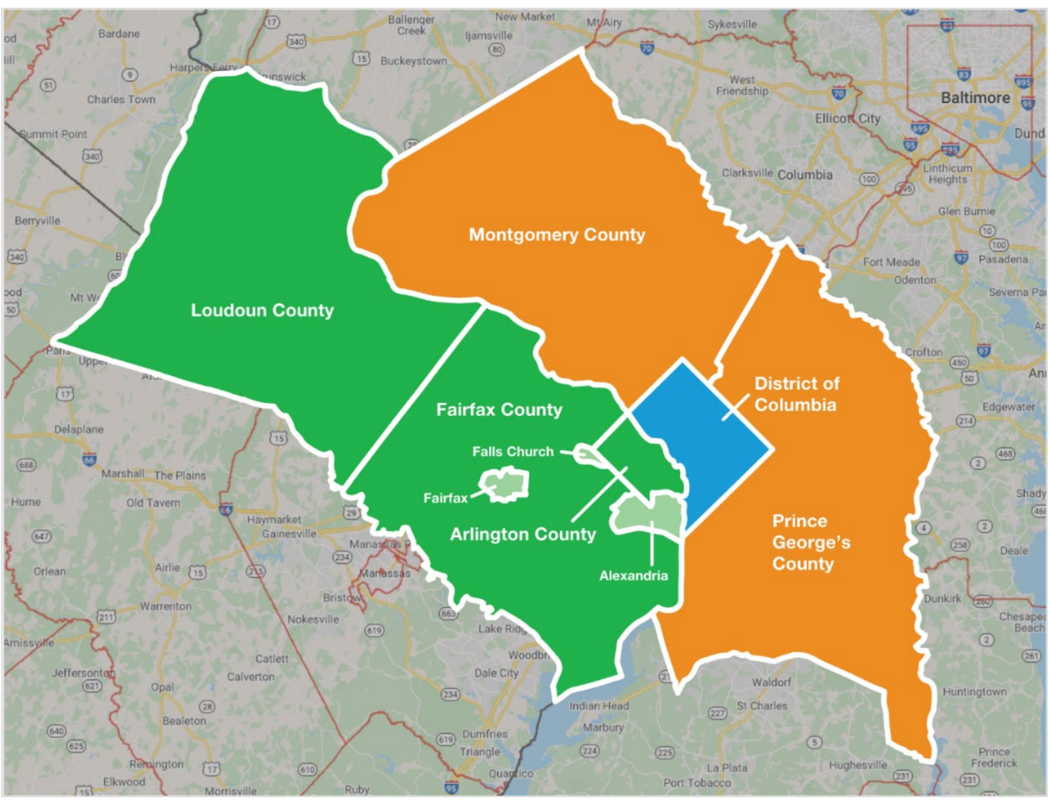
Section 1. Introduction

The Metrobus Fleet Management Plan documents the process and practices by which Metro establishes its current and projected Metrobus revenue vehicle fleet and facilities requirements. This planning document provides a system-wide analysis of Metro's bus fleet size from FY2021 through FY2038, taking into consideration current and future ridership demand, policy goals, fleet supply, and capacities of the Metrobus maintenance programs and facilities.

1.1 System Overview

Metrobus is an essential fixture of the Washington metropolitan region's transportation network. Created in 1973 through the consolidation of four private bus companies, the system now connects 2,417 street miles and a population of 3.9 million residents, carrying large volume ridership through major urban corridors as well as delivering riders to more remote destinations within a service area of 1,500 square miles.

Figure 1-1: WMATA Compact Area



The Metrobus service area encompasses the District of Columbia, Maryland's Montgomery and Prince George's counties, and Northern Virginia's Arlington and Fairfax counties and cities of Alexandria, Fairfax and Falls Church. Figure 1-1 shows the jurisdictions in which Metrobus operates.[2]

Operating 245 routes on 159 lines[3], Metrobus reaches 10,687 bus stops.[4] Many routes connect to Metrorail stations, facilitating transfers between modes. In FY2019[5], Metrorail and Metrobus combined carried 284 million passenger trips, 104 million of which were on Metrobus[6]. As of result of the coronavirus pandemic, Metrorail weekday ridership declined by approximately 85% from December 2019 and December 2020; Metrobus ridership declined by about 50% during that same period, owing to the transit-dependent populations and essential workers that depend on Metrobus service. Within the Metro service area, more than 5% of residents either ride a Metrobus or use another local bus service to commute to work during the morning peak period. More than half the region's jobs are located within a half mile of a Metrorail station or Metrobus stop. Metrobus's reasonably priced, flexible service is accessible to people with disabilities, and all vehicles provide bike racks.

Metro is responsible for 11 operating and maintenance divisions and one maintenance-only division that service the fleet. The four divisions located in the District of Columbia accommodate 38% of all vehicles, while the four in Maryland service 38%, and the three in Virginia service 24%.

Two new operating divisions were recently constructed and opened for Metrobus service. Cinder Bed Road Bus Garage in Northern Virginia was opened to revenue service in 2018, followed by Andrews Federal Center Bus Garage in Prince George's County in 2019. A new Compressed Natural Gas (CNG) fueling facility is also under construction and will open at Shepherd Parkway Division in approximately FY2023.

Northern Division was closed to all operations and maintenance activity in 2019 for a full reconstruction and retrofit. Upon its reopening in approximately FY2026, Northern will have the infrastructure and equipment needed to run 100% electric vehicles. This facility will also have the capacity to support up to 75 articulated buses.

[2] Although Loudoun County has joined the WMATA regional compact in anticipation of the opening of the Silver Line Phase 2 extension to Ashburn, the only Metrobus route to serve the county at this time is Route 5A within Dulles International Airport. Before the B30 route was permanently discontinued in 2020, Metrobus also previously served Arundel Mills and the Baltimore-Washington International Airport in Anne Arundel County, Maryland.

[3] Prior to the coronavirus pandemic.

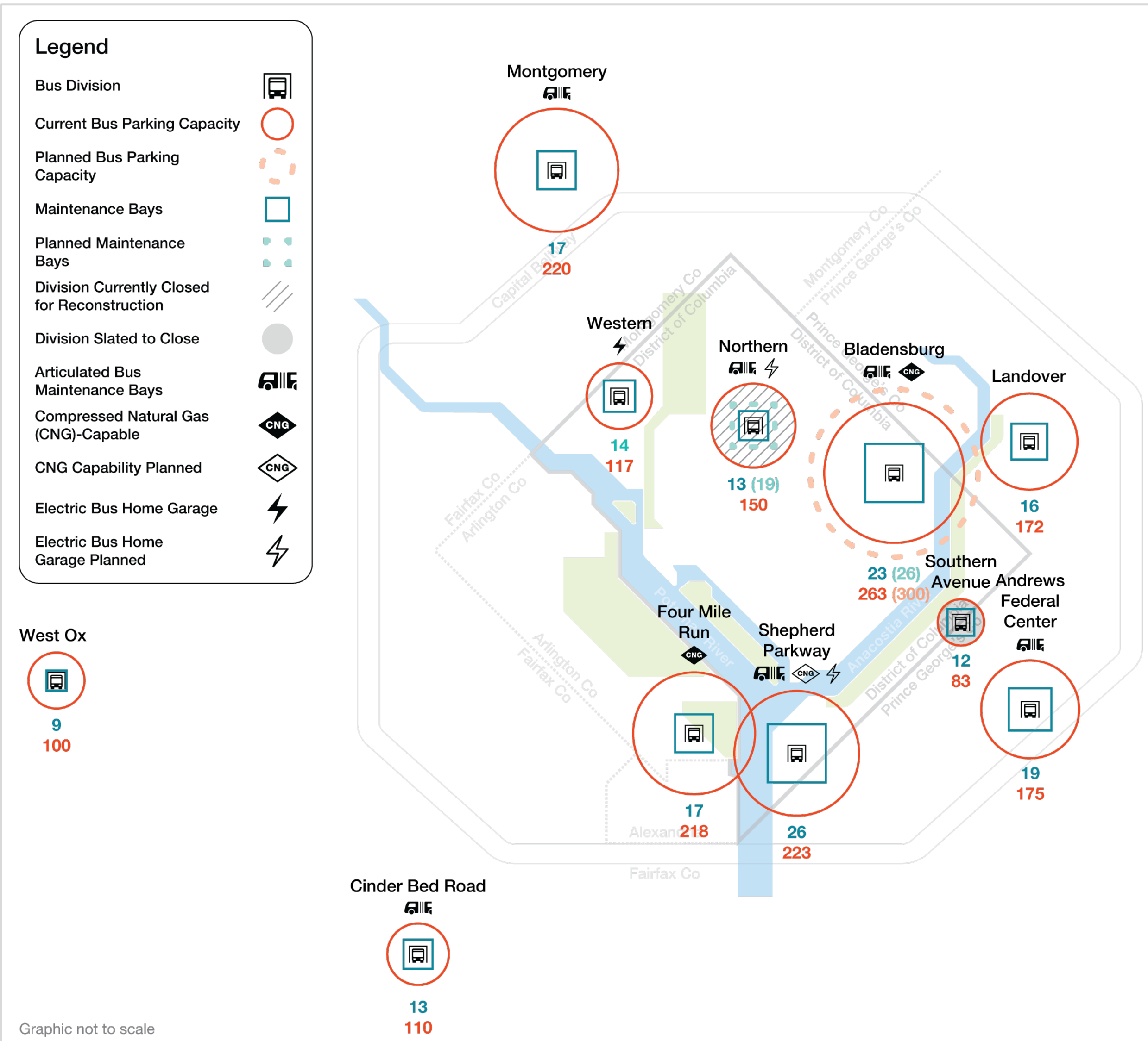
[4] Source: Metro FY2021 Budget https://www.wmata.com/about/records/public_docs/upload/FY2021-Approved-Budget_Final-2.pdf

[5] Metro's fiscal years begin on July 1 and conclude on June 30 of the following calendar year.

[6] Farebox ridership estimates provided from Metrobus Ridership Date Portal on December 15, 2020. https://www.wmata.com/initiatives/ridership-portal/

Bladensburg Division is also undergoing major reconstruction to expand its capacity by approximately FY2027. Unlike Northern, the division has not closed and has maintained operating and maintenance capability during construction. When the reconstruction efforts at Northern are complete, Southern Division is expected to close in approximately FY2026, though these plans have not been finalized. Metro's operating divisions and their respective functions are shown in Figure 1-2.

Figure 1-2: Metrobus Operating Divisions



1.2 Overview of Metrobus Fleet

As of the end of FY2021, the Metrobus fleet consists of 1,557[7] vehicles, as shown in Table 1-1. The total fleet number includes 1,270 buses scheduled for the provision of peak service, with remaining vehicles utilized for maintenance, reserve service and other contingency purposes. The exact size of the Metrobus fleet contracts and grows slightly over time as vehicles undergo maintenance, new vehicles are procured, and older vehicles are retired.

Table 1-1: Metrobus Fleet Count by Facility[8]

Division	Fleet Count
Bladensburg	272
Shepherd Parkway	221
Western	127
Andrews Federal Center	169
Landover	176
Montgomery	215
Southern Avenue	88
Cinder Bed Road	54
Four Mile Run	218
West Ox[9]	-
Carmen Turner Facility[10]	17
Total	1,557

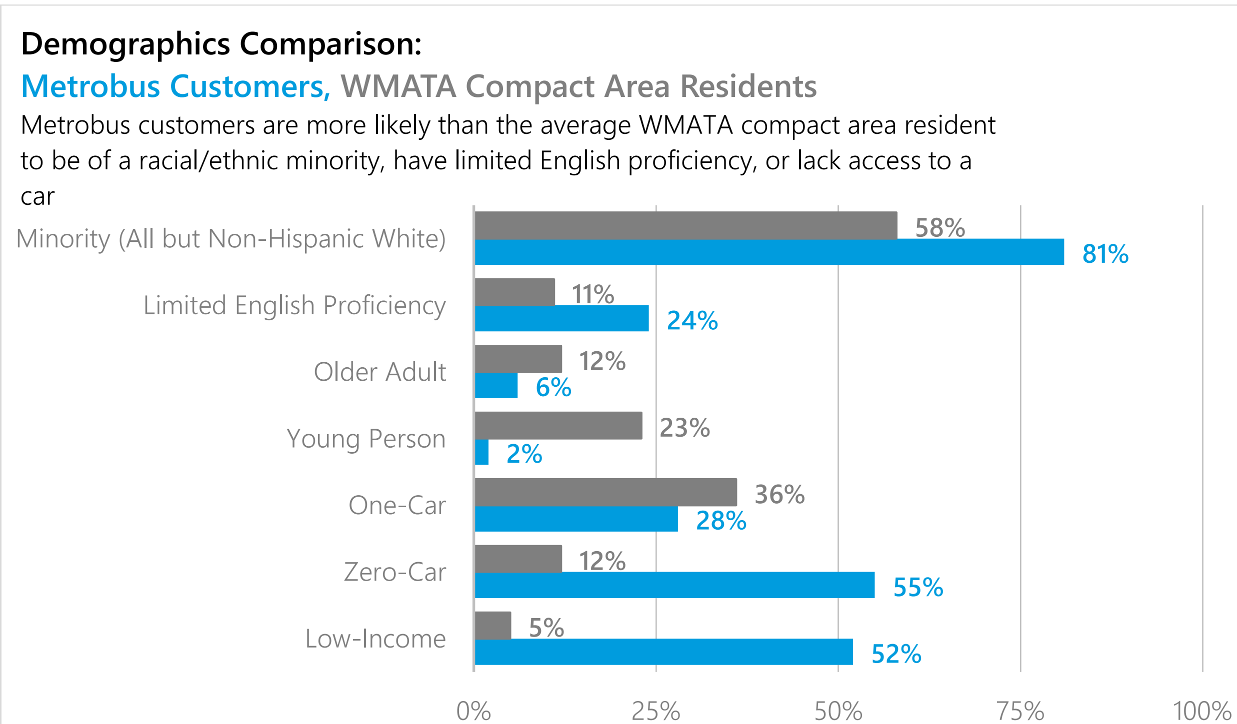
1.3 Bus Transformation Project

The Bus Transformation Project was initiated to prioritize and improve bus service. In September 2018, a task force of strategic planning leaders from Metro and other organizations in the public, private, and nonprofit sectors gathered input from the public and developed a ten-year Action Plan for improving the speed, frequency, reliability, accessibility, and affordability of bus service.

[7] Metro's active fleet size, which includes active buses required for peak service and scheduled headway management, spare buses for operating continuity, maintenance, and special projects.
[8] As of July 1, 2021. Due to operational requirements, divisions may exceed listed capacity in some cases.
[9] In March 2021, Metro announced the temporary closure of its West Ox facility to allow for streamlined operations, reduced costs, and improved efficiency. https://www.wmata.com/about/news/Metrobus-service-changes-March-14-21.cfm
[10] Training vehicles and vehicles undergoing specific maintenance or overhaul activities may be assigned to the Carmen Turner Facility.

Bus ridership has declined and travel speeds have slowed[11] as the region's buses have continued to compete with personal cars and ride-hailing vehicles for road space and curb access. Declining bus speeds have disproportionately impacted low-income and non-white area residents, who comprise the majority of Metrobus customers. Particularly affected by these impacts on bus service are the 55% of Metrobus riders who do not own a car and, therefore, rely on bus service as a primary mode of transportation.

Figure 1-3: Demographic Comparison of Metrobus Customers and WMATA Compact Area Residents[12]



The Bus Transformation Project's Strategy establishes five goals to guide the improvement of bus service: regional connectivity, rider experience, financial stewardship, sustainability, and equity. It recommends 26 tangible actions be taken to achieve these goals. The Action Plan specifies which regional stakeholders will be involved in executing each of the Strategy's actions and plans each initiative's completion over the course of a 2020–2030 timeline.

[11] Source: Washington Area Bus Transformation Project. https://bustransformationproject.com/wp-content/uploads/2018/11/Bus-Transformation-Project-White-Paper-1.pdf

[12] Source: Washington Area Bus Transformation Project. https://bustransformationproject.com/resources/the-bus-system-and-its-riders-today/

Metro's Board officially endorsed the vision of the Bus Transformation Project and resolved to pursue actions, including:

- Directing the incorporation of Bus Transformation Strategy recommendations in Metro's budgeting and planning;
- Directing Metro staff to coordinate bus service with other regional operators to implement these strategic recommendations and improve the unification of regional bus service;
- Recognizing the importance of implementing bus priority interventions such as Bus Rapid Transit (BRT) and bus-only lanes;
- Utilizing project recommendations as guidance for establishing Metrobus service standards, defining cost allocation, and shaping the customer experience.

Some initiatives that align with the priorities articulated in the Bus Transformation Project Strategy are already underway. Metro and the jurisdictions are partnering to improve bus service for riders and the region. In September 2021, Metro implemented more frequent, all day service at 12- to 20-minute headways or better on 36 of the most-used bus lines. Fare changes included free transfers between rail and bus and a cheaper weekly bus pass.

Regional jurisdictions have also partnered with Metro to coordinate implementation of Bus Priority that will improve the speed and reliability for buses. Virginia, the District, and Maryland are all implementing dedicated bus lanes, and working with Metro to implement transit signal priority, queue jumps, and violation detection and enforcement policies.

Mobile fare payments using a virtualized SmarTrip card on Apple (iOS) and Android devices were made available to customers riding Metro and regional transit partner services in 2020 and 2021. The mobile initiative contributes to the Bus Transformation Project's goal of enhancing fare interoperability among regional transit providers, as well as its broader mission of making riding Metrobus easier and more appealing.

1.3.1 Bus Network Redesign

One of the recommendations of the Bus Transformation Project was to redesign the bus network. A growing number of transit agencies around the country have conducted network redesign processes to adapt their service to local land use, economic, and population changes. Many of these agencies have emphasized a high-frequency route network in their redesigns, as well as improved service for suburb-to-suburb trips. Metro has engaged in conversations with a variety of stakeholders on the scope and goals of a redesign of the Metrobus network and expects to initiate an effort in 2022. Any potential impact on fleet requirements is unknown at this time.

1.4 Organization of Report

This report is structured as follows:

Section 1: Introduction – This section briefly summarizes Metrobus operations and describes additional areas of fleet plan context.

Section 2: Ridership Demand – This section summarizes current ridership characteristics and projects ridership growth through 2038.

Section 3: Fleet Requirements – This section provides an analysis of the demand for revenue vehicles and projects the fleet size based on demand. The demand analysis assesses the actual number of buses needed to meet service demand on the current set of bus routes. This section also provides an overview of the performance and design measures Metro applies for network service evaluation and the current system performance and fleet requirements.

Section 4: Fleet Supply – This section addresses the supply of Metrobus revenue vehicles based on planned fleet procurements for the period FY20–FY28. It accounts for total buses to be owned by fiscal year, anticipated procurement, and vehicles available for service. It also outlines the current fleet composition by size, age and fueling technology and summarizes the Metrobus replacement and expansion program.

Section 5: Fleet Maintenance – This section identifies maintenance requirements to support the projected fleet size based on previous sections. It provides an overview of the fleet maintenance program and assesses the performance of the current Metrobus fleet.

Section 6: Facilities Capacity – This section summarizes existing and planned Metrobus facilities and their role in supporting Metrobus service operations. Section 6 also identifies anticipated gaps between existing capacity and future needs.

Appendices – These sections present additional data tables and information to supplement the sections of this document.

Section 2. Ridership Demand

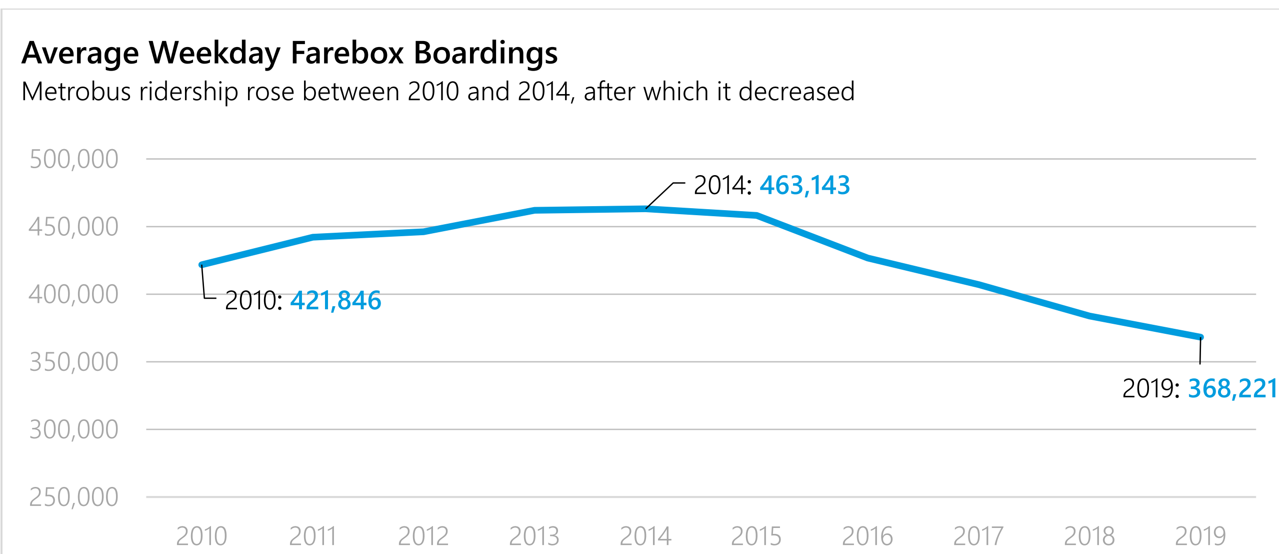
This section documents recent Metrobus ridership trends and Metro's approach to determining future ridership on the Metrobus system. Section 3 will apply this forecast to the calculation of the number of vehicles that will be required to meet the demand.

2.1 Ridership Trends

In the early 2010s, bus ridership at Metro grew steadily, reaching a high point in 2014. After 2014, however, bus ridership began to decline. This trend mirrors others seen across the transit industry in the United States. Falling bus speeds, the growth of ride-hailing companies such as Uber and Lyft, demographic changes, low unemployment, low gas prices, and a rise in wages that has led to growing auto ownership among lower-income people are all factors which may influence these trends. Additional socioeconomic and demographic ridership data is included in the appendix of this document.

Figure 2-1 shows average weekday ridership from 2010 to 2019, including the increases in the first part of the 2010s and the declines in the latter half of the decade.[13]

Figure 2-1: Metrobus Average Weekday Farebox Boardings, May 2010–May 2019



The region—as defined by the Census Bureau—saw its population grow by nearly 12% between 2010 and 2019, during which time employment grew by an even greater rate of 15%. Since 2014, median incomes have increased by 16%, nearly twice the rate of inflation. While the number of households in

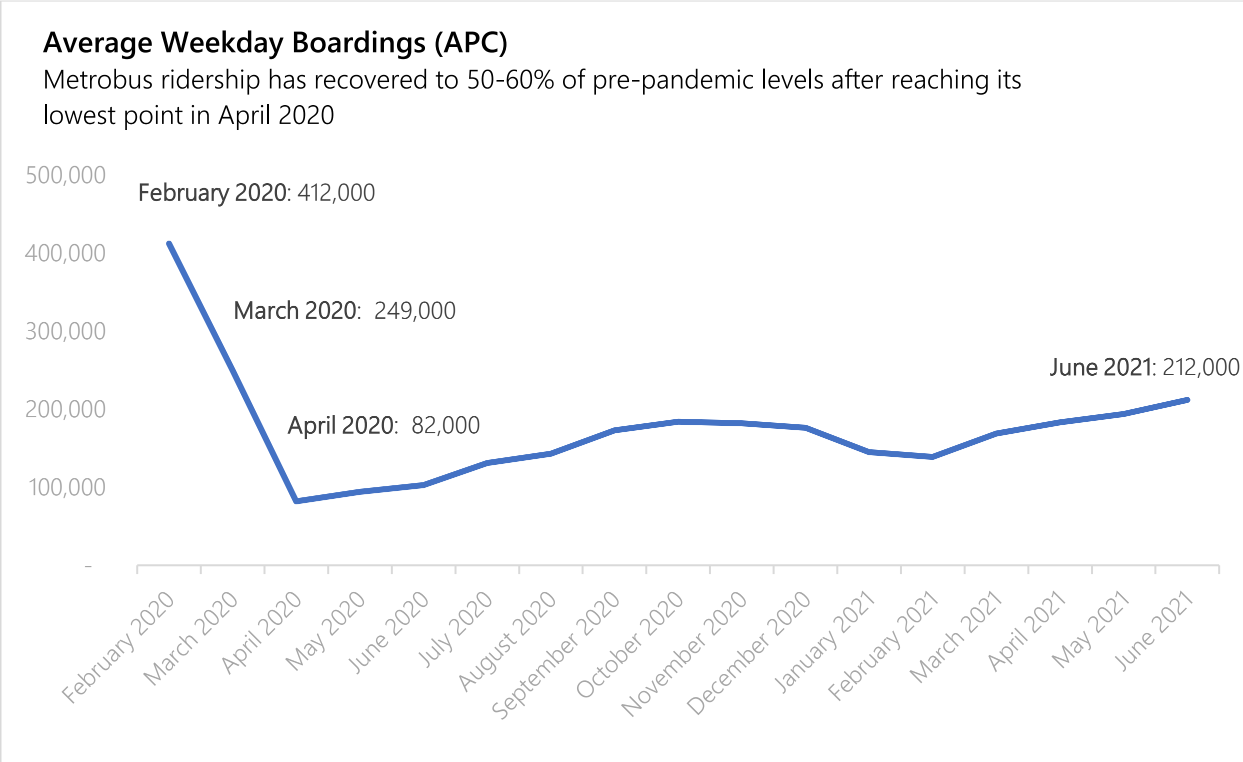
[13] The figure shows farebox-based ridership trends that may not align with other ridership figures in this document as Metro did not obtain automatic passenger counters (APC) systems for the bus fleet until midway through this timeframe.

the region grew by 10%, the number of households with annual incomes of less than $25,000—whose members make up a large portion of Metrobus ridership—fell by more than 14% over that same time period. The number of households with access to at least one vehicle grew faster than the total number of households between 2010 and 2019, and, while the number of "zero-car households" within the region remained around 210,000 throughout the decade, the percentage of households with access to a vehicle grew from 88.9% to 90.1%. These changes in economic conditions may have reduced the number of transit dependent people in the region.

The coronavirus pandemic caused Metrobus ridership to fall significantly in the spring of 2020. Ridership began to grow later in 2020 as businesses around the region re-opened. By December 2020, Metrobus ridership had recovered to about 50% of normal levels, with about 75% of normal service operating.

Figure 2-2 shows the impact of the pandemic on bus ridership. Metrobus ridership levels in January and February 2020 were higher than the same months in 2019, indicating a potential ridership recovery. However, ridership began to decline rapidly in March, with average weekday boardings dropping from 344,000 in February to 111,000 in April. Ridership climbed to 127,000 in May before ridership fell to its lowest level in June. Metrobus service was reduced to 50% or less of regular levels from mid-March through mid-August 2020. Average weekday boardings grew steadily through the summer and early fall, and restoration of bus services to about 75% of pre-pandemic levels in September 2020 supported a noticeable increase in ridership in late August. By fall 2021, Metrobus ridership had recovered to approximately two-thirds of pre-pandemic levels.

Figure 2-2: Average Weekday Boardings (APC), February 2020-June 2021



The ridership changes from the pandemic were uneven, with ridership retention correlated with high proportions of low-income and minority riders. Routes that mainly serve white-collar commuters had very low ridership, while weekend and evening ridership had higher retention rates than the weekday peaks. In general, ridership throughout the day had much less peak-period demand and more consistency through the day.

2.2 Ridership Demand Forecast

The Fleet Plan Forecast provides a basis for evaluating the potential need for changes to the size of the Metrobus fleet based on projected changes to future passenger demand. The methodology and inputs used to develop the forecast, the forecast results and adjustments that were made to the forecast are described in this section. The forecast is a key input to the fleet size estimates developed in Section 3.

2.2.1 Farebox and Automatic Passenger Counters

Metro has two main sources of bus ridership data. The first, farebox data, is recorded by the fare system when passengers pay their fares. In some cases, the bus operator presses a button on the farebox to record a boarding, such as for those who display certain flash passes and those who evade the fare. The button presses are also part of the farebox ridership data.

The other source is from the automatic passenger counters (APCs) at each doorway of the vehicle. These sensors record passengers boarding and alighting using infrared beams or overhead cameras. The sensors are imperfect, however, and the data must be cleaned and processed to produce estimates of the average boardings and alightings at a given stop or on a given trip.

Since 2015, Metro has been transitioning from the use of farebox data to APC data as the system of record for bus ridership. APC ridership estimates tend to run higher than farebox estimates by 15-30%, depending on route. This difference likely is due to unreported fare evasion, malfunctioning farebox equipment, and other factors. Metro's APC estimates have been validated against data collected by human checkers. The fleet plan ridership forecasts are adjusted to align with APC ridership estimates, and all ridership data presented in the plan, either actual past counts or future forecasts, are adjusted to align with APC estimates unless another source is noted.

2.2.2 Short-Term Ridership Forecast

The Short-Term Ridership Forecast (STRF) was developed by Metro's Office of Planning in 2018 to forecast ridership for Metrobus and Metrorail for FY2018-2023. Based on demonstrated ridership drivers such as changes in population, employment, fares, and service levels, the STRF estimates ridership for the AM Peak, PM Peak, Midday, Average Weekday, Saturday, and Sunday time periods for each month of the year. Two forecasts are provided: an upper bound and a lower bound. Bus routes and lines are grouped into corridors for ridership forecasting periods, with forecasts available for each of 91 bus corridors. The STRF is based on historical farebox ridership data and the forecasts are on a farebox basis.

The forecasts were updated with FY2019 data at the conclusion of the fiscal year; no update was made at the end of FY2020 due to the pandemic's impact on FY2020 ridership and data availability.

Due to changes in circumstances and ridership trends since the development of the forecasts, the growth rates in the STRF are overly optimistic for fleet planning purposes. Simply extending the growth rate for the last years of the forecast out to 2038 would generate a forecast of over 550,000 boardings per day. This scenario was deemed unrealistic given recent declines. Other forecasting methods were applied, as described in the next section.

2.2.3 TPB Forecasts and Travel Demand Model

The National Capital Region Transportation Planning Board (TPB) is the Metropolitan Planning Organization for the Washington region. TPB maintains regional long-range forecasts for land use, population, and employment, called the Cooperative Forecast. They also maintain a regional travel demand model. Based on round 9.1A of the Cooperative Forecast, version 2.3.78 of the regional travel demand model, and assumptions about changes in travel from the 2020 amendment of the Visualize 2045 plan, Metrobus ridership was forecasted for 2040. Bus ridership is modeled at the systemwide level.

Transit ridership in the regional travel demand model is usually somewhat higher than actual ridership, which required the steps outlined below for adjustment.

2.2.4 Metrobus Fleet Plan Forecast Approach

A hybrid approach was used to generate ridership forecasts at the corridor level for the bus fleet plan. The forecast was developed as follows:

1. Based on the annual growth rate from FY2019-2023, extend the upper bound Short-Term Ridership Forecast out to 2038 for each corridor and time period.
2. Calculate the annual growth rate implied by the 2020 and 2040 TPB model outputs.
3. Apply the TPB growth rate to the systemwide FY2023 ridership from the STRF, out to 2038.
4. Allocate this systemwide growth among the 91 bus corridors proportionally based on the projected growth on each corridor from step 1.
5. Adjust the forecasted ridership from a farebox to an APC basis.

This method uses the systemwide growth rate forecasted by the TPB regional travel demand model and applies it to a more accurate ridership baseline, while allocating the growth among different corridors based on the STRF model.

2.3 Adjustments to Fleet Plan Forecast

2.3.1 Adjustments for New Projects

Many projects and initiatives may have an impact on bus ridership during the period covered by this fleet plan. They include:

The Silver Line Phase 2 extension, extending the heavy rail line from Wiehle-Reston East to Ashburn via Dulles International Airport, is scheduled to open in 2022. As most local bus service in the area is operated by Fairfax Connector and Loudoun County Transit, little impact on Metrobus ridership is expected.

The Purple Line, owned by the Maryland Department of Transportation Maryland Transit Administration (MDOT MTA), is a light rail line currently under construction from New Carrollton to Bethesda. Metro's Office of Bus Planning is conducting a study on the impact to local bus service; changes are not currently expected to have an impact on fleet expansion or contraction.

Bus priority efforts continue to expand around the region, including transit signal priority, bus stop consolidation, queue jumps, and dedicated bus lanes. These projects may both increase ridership, increasing fleet needs, and decrease running times, potentially reducing fleet needs. At this time, no direct impact to the fleet plan is anticipated from these interventions.

Bus Rapid Transit. Several projects planned for the region aim to add bus rapid transit and other high-quality transit services that are separate from Metrobus service. For example, MCDOT's Flash

BRT service on US 29 in Montgomery County began in the fall of 2020, potentially reducing demand for Metrobus service along the corridor. The impact of these projects will be studied over time.

Adjustments to individual bus routes affected by these projects were reviewed to determine whether they would have any impact either on the number or the composition of the bus fleet. The uncertainty of the status and timing of many of these projects presents challenges in determining whether, when, and to what degree their implementation would impact ridership and demand for vehicles. For this reason, it was determined that the ridership forecasts would not be adjusted to address these projects at this time. Metro will regularly review the potential fleet implication of these and other projects to determine whether they would result in any future impacts in the number, type, and distribution of buses in the system.

2.4 Metrobus Fleet Plan Forecast

Systemwide, the forecast projects that Metrobus ridership will increase by approximately 4.2% from 2019 to 2038, an annual rate of 0.23% annually through 2038. Ridership is projected to increase by about 19,000 daily trips, from about 425,000 weekday boardings in 2019 to 444,000 by 2038. The unaltered Fleet Plan forecast is shown in Table 2-1.

Table 2-1: Average Weekday Ridership for 2015–2019 and Unaltered Ridership Estimate Based on Fleet Plan Forecast for 2020–2038[14]

Year[15]	Weekly Boardings (APC)
2015	549,428
2016	513,450
2017	480,516
2018	411,566
2019	425,104
2020	426,067
2021	427,031
2022	427,998
2023	428,967
2024	429,939
2025	430,912
2026	431,888
2027	432,866
2028	433,846
2029	434,828
2030	435,813
2031	436,800
2032	437,789
2033	438,780
2034	439,773
2035	440,769
2036	441,767
2037	442,767
2038	443,770

[14] 2015–2018 Source: 2015–2018 Spring Pick average weekday. 2019 Source: May 2019 Average Weekday. 2019 Spring Pick average weekday was 403,061. 2020–2038 Source: Estimated average weekday forecast (without coronavirus impacts) based on estimate of annual rate of ridership increase between 2019 and 2038 (0.23%), derived from Fleet Plan Forecast.

[15] 2020–2038 Source: Estimated average weekday forecast (without coronavirus impacts) based on estimate of annual rate of ridership increase between 2019 and 2038 (0.23%), derived from Fleet Plan Forecast.

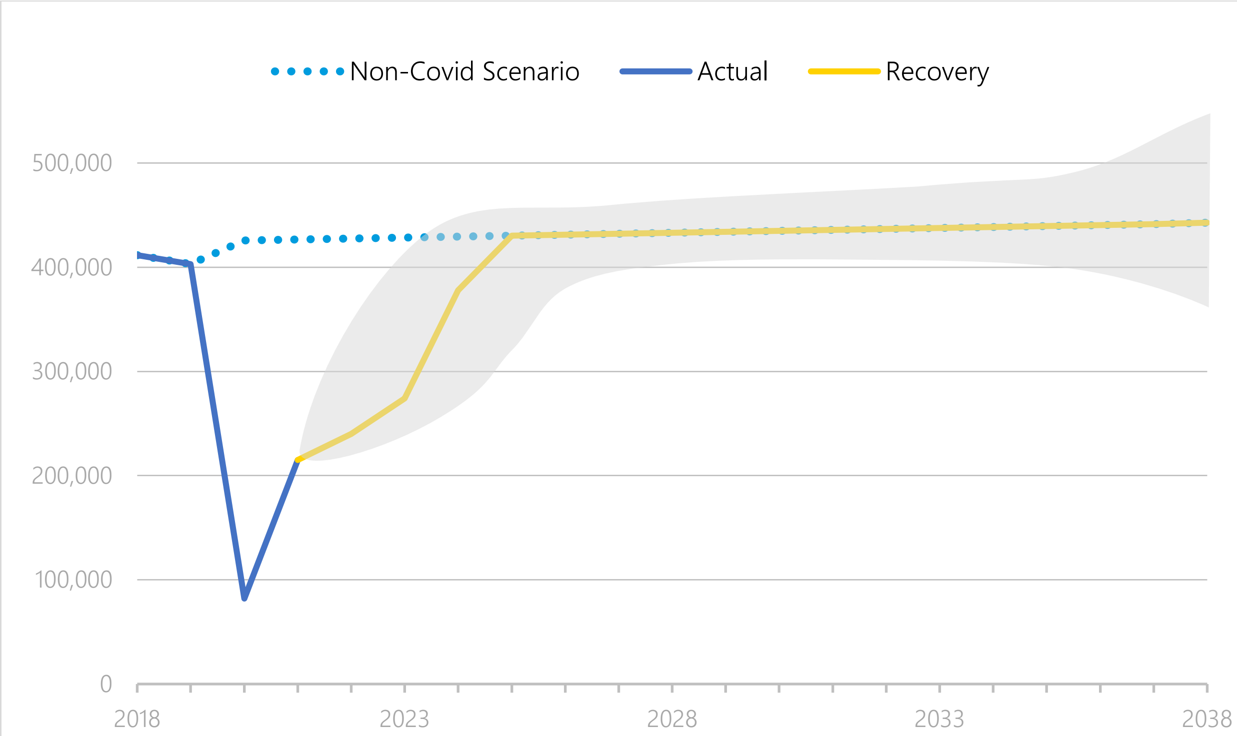
The forecast, adjusted to reflect recovery from the coronavirus pandemic, is shown in Figure 2-3. From a baseline of 2019 levels, ridership is shown having fallen in 2020 due to the pandemic. This figure also illustrates uncertainty in the path to ridership recovery.

The Fleet Plan forecast projects Metrobus network weekday ridership to grow by about 4.4 percent, between 2019 and 2038, but projected ridership changes vary considerably among the corridors. Nineteen corridors are projected to grow by more than 10% over the time period, with Lee Highway routes (3A and 3Y) growing by nearly 42% and Eastern Northern Virginia Routes (8S, 8W, 8Z and 11Y) growing by more than 38 percent. Corridors with the highest growth rates typically have relatively low existing ridership (fewer than 2,000 weekday passenger trips). The projected ridership change and percentage change for each corridor is shown in the appendix. Metro will continue to monitor ridership levels throughout the system, and service planning will not be based exclusively on these forecasts.

2.4.1 Adjustments for Pandemic Recovery

The fleet plan has been developed based on the assumption that ridership eventually will return to the pre-pandemic trajectory, and no adjustment is made for the later years of the forecast to account for long-term ridership impacts of the coronavirus pandemic. In the short term, however, the pace of ridership recovery is uncertain. Figure 2-3 depicts anticipated ridership recovery, with the shaded area intended to illustrate the uncertainty associated with this forecast. Metro's long-term planning assumes eventual recovery but will be revisited in coming years.

Figure 2-3: Metrobus Forecasted Average Weekday Ridership



2.4.2 Long-Term Ridership Forecast Summary

Ridership forecasts at both the system and corridor levels are critical to determining whether ridership change will influence demand for vehicles during the life of the plan. Metro's Fleet Plan Forecast anticipates modest incremental growth in Metrobus ridership through 2038.

The forecast, which was prepared before the coronavirus pandemic, assumes a moderate rate of ridership growth. This projection is supported by recent ridership recovery, forecast growth in population and employment in the Washington metropolitan area, and other transit-supportive trends documented in the forecast model. Increasing fuel prices, environmental regulation, and transit's potential to help address pollution and greenhouse gas emissions are further factors supporting future ridership growth.

Ridership growth is forecast to be uneven across the system, with robust growth in some corridors and minimal growth or ridership loss in others. Changes to ridership patterns in response to the Silver Line Extension, Purple Line project, and other transit corridor improvements and developments in the region, as well as the anticipated transit network redesign project, may impact ridership system wide and in specific corridors in the coming years.

Section 3. Fleet Requirements

Metro's planning efforts involve ensuring the availability of enough buses to meet anticipated ridership demand and service guidelines. Fleet size is determined largely by the headway and travel time on each route during the period of highest passenger demand (the PM peak period on most Metrobus routes). The number of buses required to operate a route is calculated by dividing the round-trip running time (including recovery time) by the headway. However, passenger demand and service guidelines determine where and when Metrobus routes will operate and at what headway. Routes that do not meet minimum service guidelines for crowding, service reliability, or service frequency may require more vehicles to provide sufficient capacity to meet those guidelines. Other guidelines establish the number of spare buses needed to support the fleet's ability to deliver service.

Demand for fleet size has been estimated by applying the ridership forecast from Section 2 and Metro's service guidelines for crowding, service reliability, and maximum headway to Metro's Fall 2019 operations. This section also evaluates the potential for increasing the size of Metro's articulated bus fleet to address crowding on key Metrobus routes, before reviewing the factors considered in evaluating potential Metrobus fleet expansion in the coming years.

3.1 Metrobus Service Guidelines

Metrobus Service Guidelines, adopted by the Metro board in December of 2020[16], provide technical guidance for service planners in evaluating and planning services. The guidelines classify Metrobus routes into five major categories: Bus Rapid Transit (BRT), Framework, Coverage, Commuter, and Gap service. Routes also are classified by activity tier, based on the combined population and employment density of the areas that the route serves. The guideline standards that apply to routes differ according to the route's service classification and activity tier. Some guidelines also differ by time of day (AM and PM peak, mid-day, evening, etc.) and day of week (weekday/Saturday/Sunday). The five classifications are described below.

3.1.1 Bus Rapid Transit (BRT)

BRT involves the strategic application of coordinated strategies for design of routes, services, facilities and technology. BRT systems can include dedicated lanes; high-frequency service; simplified route structure; branded, dedicated, and higher-capacity vehicles; fewer stops than conventional bus routes and improvements at stops; off-vehicle fare collection; and other systems and technologies to improve bus operating speed and reliability.

3.1.2 Framework Service

Framework services are defined as local bus lines that provide direct alignments following key arterial corridors. Framework services also include potential future limited stop Metrobus services. Radial, crosstown and emerging corridor services are included in this category.

[16] https://www.wmata.com/initiatives/plans/upload/Final-MetroBus-Service-Guidelines-2020-12.pdf

3.1.3 Coverage Routes

Coverage routes operate within neighborhoods, connecting to a nearby major routes and modes at a transit hub such as a Metrorail station. Circulating in local neighborhoods and connecting to nearby generators is the main focus of services under this category.

3.1.4 Commuter/Express Service

The services under this category are defined to operate between a residential area or park-and-ride and a business district or Metrorail station, or between a central business district and a peripheral employment area. These routes are designed to have one or more pickup locations in close proximity to each other before operating non-stop, often via a highway, to one or more destinations. Peak direction services connecting park and rides or neighborhoods to major employment center, reverse commute services operating from central areas to suburban employment centers and airport services fall under this category.

3.1.5 Gap Service

Gap service routes are operated for specific purpose to meet specific transit needs that cannot be met by Metro's more general bus and rail services. Examples include routes that serve a school, workplace or other destination with specific, focused demand; a shuttle replacing rail service during overnight hours, when rail service is not operating, or a route with its schedule tied to the operating hours of a specific tourist attraction. Gap service routes are designed to fit the needs of the situation and are not governed by standardized guidelines.

3.1.6 Activity Tiers

Metrobus routes are classified into one of three activity tiers based on the combined population and employment density of the areas served by the route. Combined population and employment density are commonly used as a measure of the accessibility and transit friendliness of development and the capacity of an area to support various levels of transit service. The three activity tiers are ranked by the percentage of bus stops along the route that have a combined population and employment density greater than 25 persons and/or jobs per acre. Tier 1 routes are those on which more than 50% of stops are surrounded by combined population and employment density greater than 25 persons and/or jobs per acre. This level of density surrounds between 15% and 50% of the stops along Tier 2 routes, and less than 15% of stops along Tier 3.

3.2 Peak Vehicle Requirement

Metro's peak vehicle requirement (PVR) is the maximum number of vehicles that Metro regularly deploys in service, excluding spare vehicles and vehicles set aside for other purposes. PVR is driven by Metro's peak level of passenger demand during weekday afternoon periods (Metro's highest demand period). Metro's PVR in December 2019 was 1,270 vehicles. Service volume on most Metrobus routes is demand driven, which requires monitoring and matching of service frequency and capacity to passenger demand. During weekday peak periods on most routes, and during other periods on the system's busiest routes, Metro's service frequencies are calibrated to provide capacity to support passenger loading patterns. This enables Metrobus service to consistently meet passenger demand and ensures passenger comfort. Routes that consistently experience crowded conditions or lateness, as defined by Metro's service guidelines, are evaluated by Metro planners for possible changes to address these issues.

Possible changes to address crowding and late running include adjusting link running times (running times between scheduled time points), converting the route to articulated bus operation (which increases capacity while minimally increasing operating and maintenance costs), reducing the route headways (increasing service frequency) and increasing link travel time. Reducing headways or increasing travel time increases service volume (hours and miles of service) and may increase the number of vehicles required to operate the route. The implementation of additional bus priority corridors and measures by jurisdictions in the region represent an integral component of resolving these items as well.

Service levels during other periods are driven by established maximum headway guidelines. Weekday evening, night, and mid-day service as well as weekend services on many routes have fewer riders and operate policy maximum headways. New service initiatives, such as new routes or route extensions, often also operate policy maximum headways for a trial period as demand develops.

3.2.1 Fleet Sufficiency Analysis

Metro's service planners regularly monitor its performance and make service adjustments to address system deficiencies and enhance efficiency. Adjustments that result in changes to service volume often require increasing or reducing the number of buses on select lines. This can result in changes to the overall size and composition of the bus fleet.

This fleet plan uses the Metrobus Service Guidelines for evaluating services. The guidelines provide revised performance measures and target values for reviewing operations and monitoring service at the route, corridor and network levels. Productivity, reliability and level of crowding are the three key performance measures used by Metro.

> Productivity measures how effectively the resources devoted to route operations are used, typically by calculating the number of boardings per hour, per mile, or per trip. Lines that have high productivity, carrying a relatively large number of boardings per unit of service, are potential candidates for service expansion, which could increase the number of peak vehicles required on that line or route.

> Reliability is a critical service quality measure for customers, reflecting customers' expectation for on-time bus arrival and on-time completion of a bus trip. Bus lines with poor service reliability, particularly ones whose end-to-end travel time is regularly longer than the scheduled travel time during some or all periods, may require additional service volume to increase their scheduled running time. In most cases, this added time could not be provided without adding buses to the line.

Level of crowding is another service quality measure from a customer's perspective, based on the customer's reasonable expectations of comfort and safety on board the bus. Lines that experience regular overcrowding may require additional capacity, provided by operating more buses to provide more frequent service and/or longer running times, and/or the substitution of articulated vehicles on the route. These changes could lead to the need for additional buses, or articulated buses, on the route. Any changes to service volumes or vehicle type across Metro's dozens of bus lines could result in a change in the number of vehicles in the fleet, as well as a change in the number of vehicles of each type in the fleet.

Metro's service guideline for maximum headway ensures that each route provides at least a set service level during each period of the day. The maximum headway guideline is based on the route's service classification and service tier, and varies by time of day, with shorter headways recommended for peak periods.

Each route that operated in Fall 2019 was analyzed to determine the potential need for additional vehicles based on crowding, service reliability, or maximum headway deficiencies during the PM peak period. The analyses determined that 68 Metrobus routes could require one or more additional vehicles to meet deficiencies in meeting Metro's service reliability, crowding, and/or maximum headway guidelines based on their performance in in Fall 2019, with some routes deficient in more than one guideline. Nineteen routes would need one or more additional vehicles to address service reliability (late running) based on 2019 operations and ridership. These routes are listed in Table 3-1.

Table 3-1: Routes with Less than 69% of Departures Early or On-Time ("Not Late") during PM Peak Period, Fall 2019

Route	Percent Not Late (2019)
17B	43.4%
7Y	49.6%
R2	50.6%
W8	51.7%
R1	52.7%
C4	52.8%
17M	52.9%
J4	53.2%
H6	55.5%
B8	55.7%
W6	56.4%
C2	57.9%
T14	58.4%
29N	59.4%
H1	59.7%
P12	60.8%
K6	61.0%
S4	61.3%
S2	63.0%

Eight routes likely would require at least one additional bus to address crowding based on 2019 operations and ridership patterns. These eight routes are listed in Table 3-2.

Table 3-2: Routes Experiencing Crowding (100% Seated Load) During One or More Peak Hour, in One Direction, Fall 2019[17]

Route	Division(s)	Jurisdiction(s)
30S	Andrews	MD
30N	Andrews	MD
V2	Southern	MD, DC
11Y	Four Mile	VA
W1	Shepherd	DC
54	Western	DC
79	Montgomery	DC, MD
S9	Montgomery	DC

Six additional routes would require at least one additional bus to meet crowding requirements by 2038 due to increased ridership. Table 3-3 lists these routes and the year in which the analysis indicated that ridership growth would prompt the need for more capacity on the route.

Table 3-3: Routes Projected to Experience Crowding (100% Seated Load) During One or More Peak Hour, in One Direction, Through 2038[17]

Route	Year	Division(s)	Jurisdiction(s)
42	2035	Western	DC
70	2037	Montgomery	MD
3Y	2038	West Ox	VA
8W	2031	Four Mile	VA
8Z	2026	Four Mile	VA
S4	2036	Montgomery	DC, VA, MD

Forty-three routes would require at least one additional bus to reduce headways to levels below Metrobus peak period maximum headway guidelines for their assigned service class and activity tier. These routes are listed in Table 3-4.

[17] Metro's service guidelines call for a maximum peak load factor of 120% of a seated load on BRT, Framework, and Coverage routes, and 100% on other route classes. A capacity of 100% was applied to simplify the analysis, and because routes that experience 100% loads over an hour in the peak period most likely experience 120% loads for some periods during that hour.

Table 3-4: Routes Operating Greater than Specified Maximum Headway during Fall 2019 PM Peak Period[18]

Route	Division(s)	Jurisdiction(s)
32	Andrews	DC
34	Andrews	DC
36	Andrews	DC
39	Andrews	DC
83	Landover	MD
86	Landover	MD
10A	Four Mile	VA
10B	Four Mile	VA
10E	Four Mile	VA
16A	Four Mile	VA
1A	West Ox	VA
1B	West Ox	VA
1C	West Ox	VA
22A	Four Mile	VA
23B	Four Mile	VA
23T	Four Mile	VA
26A	West Ox	VA
29K	Cinder Bed	VA
29N	Cinder Bed	VA
2B	West Ox	VA
30N	Andrews	DC
30S	Andrews	DC
7A	Four Mile	VA
7F	Four Mile	VA
A7	Shepherd	VA
C4	Montgomery	MD
C8	Montgomery	MD
D12	Andrews	DC
D13	Andrews	DC
D14	Andrews	DC
H2	Bladensburg	DC
H4	Bladensburg	DC

[18] Further analysis at the line level would identify whether service is inadequate on a line by line basis.

Route	Division(s)	Jurisdiction(s)
J4	Montgomery	MD
K9	Bladensburg	DC, MD
NH2	Shepherd	DC
Q4	Montgomery	MD
R1	Bladensburg	DC, MD
R12	Landover	MD
V2	Southern	DC
X9	Bladensburg	DC
Y2	Montgomery	MD
Y8	Montgomery	MD
Z6	Montgomery	MD

Many of these routes could require multiple additional buses to meet Metro's maximum headway guidelines during the PM peak period. Fleet adequacy analysis indicated that the 43 routes requiring additional buses to meet headway guidelines could require as many as 130 additional vehicles, with some routes requiring as many as eight additional buses to meet the maximum headway guidelines during the afternoon peak period.

Assuming the service reliability and crowding issues could be resolved by adding just one vehicle to each route identified in those analyses, 155 additional vehicles would be required (seven of the routes that have deficient headways also are listed among routes that require vehicles to address either service reliability or crowding), in addition to 30 spare vehicles (assuming a spare ratio of 19.5%).

3.2.2 Articulated Bus Fleet Considerations

Converting routes to articulated buses is an effective method of adding frequency to increase capacity on high volume, crowded routes. Articulated buses have 50% more seating and standee capacity than standard buses, but their operating cost is only slightly higher, because the largest part of the operating cost—the cost of the bus operator—is the same for both articulated and standard vehicles. Articulated buses also are helpful for adding capacity on corridors and routes where the headways already are so short that reducing them further is likely to result in bus bunching. Of note, articulated buses are not able to operate on all routes due to their length. Articulated buses do incur higher maintenance costs due to their increased size and mechanical complexity.

At the start of FY21, Metro had approximately 66 articulated vehicles in operation out of a total fleet size of over 1,500, an articulated bus fleet percentage of about 4%. A peer comparison analysis found that many other large urban transit agencies operate a higher percentage of articulated vehicles. Metro had the second lowest number of articulated buses among its peer group of large bus operators in 2018 (Table 3-5). While Metro's decision making is not driven solely through this analysis, this review offers helpful insight into potential expansion levels to study. The larger capacity of articulated buses means that agencies can increase peak and all-day capacity, addressing a significant share of customer crowding, with even a relatively minor increase in the proportion of articulated buses in the fleet.

Table 3-5: Articulated Bus Fleet Share at Metro and Peer Agencies[19]

Peer Agency	% Articulated
King County Metro	55%
New York City Transit	19%
Chicago Transit Authority	16%
Los Angeles County Metropolitan Transit Authority	16%
Southeastern Pennsylvania Transit Authority	13%
Miami Dade Transit	11%
Massachusetts Bay Transit Authority	10%
Maryland Mass Transit Administration	7%
Washington Metropolitan Area Transit Authority	4%
Metro Atlanta Rapid Transit Authority	3%

Five performance metrics were considered when identifying potential routes to be assigned articulated vehicles. The exact number of articulated buses in each considered scenario was partially determined by the number of articulated buses required to deliver service on the routes which most closely met the following criteria:

Completing articulated bus conversion of existing routes: Some routes not fully converted to articulated bus operation due to a shortage of articulated vehicles. Given the risk of unbalanced loads on the routes during peak period, converting these routes to articulated bus operations is a high priority.

Ridership: High passenger volume during peak periods are a key indicator of the desirability of articulated vehicles.

Service Frequency: Average number of trips per hour during the PM and AM peak periods. Routes meeting this criterion were already operating more than six trips per hour (10 minutes or headway or shorter) in 2019.

[19] Source: Peer agency documents and National Transit Database information.

Crowding: Percentage of running time over 100% or 120% of capacity, depending on time of day and route service classification. Adding capacity is the most direct approach to relieving crowding on routes.

Schedule Reliability: Percentage of time points departed "not late" (including on-time and early departures, based on the assumption that Metro's early departure statistics are overstated). Metro's on-time performance guideline is 79% on-time operation. However, the standard was adapted to "not late" to address likely over-counting of early departures. Crowding and load imbalances, which are relieved by adding capacity, often are the cause of late running.

This fleet plan assumes that conversion of standard bus to articulated buses will be on a one-to-one basis and will not result in a reduction of fleet size. The main reason for making a one-to-one conversion is to accommodate existing demand and potential future ridership growth while maintaining approximately the same headways now operated using standard buses. The increased size of the articulated bus fleet is expected to increase related maintenance activities but will allow Metro to address crowding and schedule reliability issues caused by high passenger loads without reducing headways. If crowding or service reliability issues are identified in the future, the conversion of additional routes to articulated bus operation would represent one potential solution.

The following articulated bus fleet size scenarios were developed for purposes of comparison, reflecting pre-pandemic December 2019 service.

Table 3-6: Articulated Bus Fleet Share, Illustrative Scenarios

Scenario	Articulated Bus Fleet Share[20]	Total Articulated Bus Fleet Size	Routes Serviced by Articulated Buses	Incremental Routes Serviced
Scenario 1	4%	66 buses	2 routes full 3 routes partial	70, X2 S1, S2, W4[21]
Scenario 2	12%	180 buses	7 routes full 2 routes partial	79, 90, 92, S9, S1, S2 52/54[22]
Scenario 3	15%	223 buses	13 routes full 1 route partial	A2, A6, A7, A8, 52, 54

[20] Based on Metro's projected active fleet.
[21] In Scenario 1, routes S1, S2, and W4 are operated with mix of articulated and standard buses. Metro is not currently operating route S1.
[22] In Scenario 2, routes S1, S2 are operated fully with articulated buses. Routes 52/54 are operated with a mix of articulated and standard buses. Metro is not currently operating route S1.

To take advantage of the opportunities for adding capacity with limited cost increases[23], Metro plans to pursue a limited expansion of the articulated bus fleet to approximately 12% of the active Metrobus fleet (about 180 vehicles), as outlined in Scenario 2. This strategy, when paired with a stable overall fleet size, enables Metro to respond to crowding and service standards without a notable increase in overall fleet size.

The high ridership, short headway routes that now use articulated buses, and those proposed for conversion to articulated bus operations, mostly operate in dense corridors in the District of Columbia's urban core. To minimize deadhead and make the conversion of these routes cost effective, these additional articulated buses would ideally be assigned to garage facilities located in the core area of the District, such as Northern and Western. Western garage has no facilities for parking or maintaining articulated buses, and Metro does not currently plan to add articulated bus facilities there. Many of Metro's articulated buses were assigned to Northern division before its reconstruction began. These buses were reassigned to other divisions further away from the urban core, mostly Bladensburg and Montgomery, during Northern's reconstruction, which increased deadhead time and mileage on the routes using articulated buses.

Northern garage will have 75 articulated bus parking spaces and twelve articulated bus maintenance bays when it reopens in 2026. This would be enough for all of Metro's 66 articulated buses to be reassigned there, which would reduce deadhead mileage on every route that now uses articulated buses except W4. Bladensburg division is the nearest to the termini of route W4 and second nearest (after Northern) to the termini of both the other routes now assigned articulated buses, and those proposed for conversion in Scenario 2. Improvements at Bladensburg division now under construction will expand articulated parking there to 100 vehicles.

In Metro's previous fleet planning, an anticipated gap in articulated bus maintenance bays was identified. Upon the completion of construction efforts at Bladensburg and Northern operating divisions, the Metrobus system will have a total of 48 maintenance bays capable of servicing articulated buses[24]. These developments enable Metro to support an expansion of to the level of 180 articulated buses, improving Metro's ability to deploy articulated bus service from garages with closer geographic proximity to their routes.

3.2.3 Priority and Emerging Corridor Networks

The previous Metrobus fleet plan recommended expanding Metro's PVR by 147 vehicles to provide increased service volume on Metro's Priority Corridor Network, a plan to expand and improve services in Metro's 24 most productive bus corridors. The previous plan recommended adding an additional 87 vehicles to increase volume on the Emerging Corridor Network, which were the next 18 most productive

[23] Largely driven by additional maintenance requirements.

[24] 9 bays at Andrews Federal Center, 11 bays at Bladensburg, 7 bays at Cinder Bed Road, 3 bays at Montgomery, 12 bays at Northern, and 6 bays at Shepherd Parkway.

corridors in the Metrobus network after those identified as priority corridors. Passenger volumes in most of these corridors had grown rapidly in the years before 2015 (the most recent year for much of the data used in preparing the 2017 plan), and peak period passenger capacity on many of the routes in Priority and Emerging corridors was inadequate, resulting in crowing and service reliability challenges on many routes. Corridor improvements potentially could include reduced peak headways to improve service quality and potentially increase the corridor peak vehicle requirement; conversion of routes to articulated vehicles; or transfer of routes or services from Metro to local jurisdictions, which potentially could reduce the corridor peak vehicle requirement.

Ridership trends in many of these corridors has been much more mixed since 2015, with ridership continuing to grow in some corridors, plateau in others, and decline in still others. Service frequencies were reduced on routes in many of these corridors between 2015 and 2019 due to falling demand. Pandemic-related impacts have further distorted ridership and service patterns since the Priority and Emerging corridors were identified.

Uncertainties about the relative status of each of these corridors given pre-pandemic and more recent ridership and service changes, and the priority and schedule for improvements in these corridors, present challenges in estimating how and when improvements might affect ridership and service in each corridor, or how and these changes might influence vehicle requirements at the corridor or network levels. Future planning may also impact the Metrobus network based on current and forecast demand patterns and agency priorities, especially in the context of the updated Bus Service Guidelines adopted in December 2020 and the bus network redesign.

3.2.4 Fleet Size Planning

Metro's bus PVR, based on PM peak period vehicle requirements for each route, was 1,270 in December 2019, shortly before service was disrupted by the coronavirus pandemic. The fleet sufficiency analysis indicates a potential need for additional vehicles to allow Metro to expand peak period bus service to address forecast ridership growth and to meet existing and future service reliability, crowding, and maximum headway requirements. Crowding could be addressed on some, but not all, Metrobus routes by conversion of routes to articulated vehicles, which increase capacity without requiring an increase in PVR. Completion of rail extension and bus priority improvement projects, the Bus Transformation Project and planned network redesign potentially could support an increased fleet size, as could regional-scale redevelopment projects and the conversion of Metro's bus fleet to electric buses.

However, this plan is being developed in a period of uncertainty which supports a cautious approach when considering fleet expansion. In March 2020, the pandemic caused a drop in ridership which has not yet been recovered. The fleet plan forecasts have assumed that Metrobus ridership will fully recover and match the forecast growth trend in the coming years. However, with ridership still significantly below late 2019 levels, the mid-to long-term impacts of the pandemic on transit ridership – and on regional transportation, development, economic and demographic trends that drive transit ridership –

remain unclear. One potential long-term impact is an increase in remote work. This could make hour-by-hour passenger demand more even throughout the day, reducing the need to increase service volumes to increase capacity during peak periods. It is possible that Metrobus could serve a less peaked future demand pattern with the same number of vehicles or fewer than it operates today, even with the same or higher total passenger demand.

Several additional factors support caution when considering fleet expansion. Before the pandemic, Metrobus ridership had fallen by nearly 150,000 weekday trips between Metro's 2014 bus ridership peak and 2019. Annual vehicle revenue hours fell from 3.97 million in 2014 to 3.78 million in 2019, and vehicle revenue miles from 40.2 million to 37.4 million[25]. Rather than growing its fleet as proposed in the 2017 Metrobus Fleet Plan, Metro has maintained a generally consistent fleet size and paused implementation of Priority and Emerging bus corridor improvements. Metro assumes that service will return to 2019 levels as ridership recovers over the next several years, and continue growing at a modest rate through 2038, as described in Section 2. However, forecast ridership growth through 2038 still would leave Metro's ridership below 2014-2015 levels. The planned bus network redesign project will provide Metro with the opportunity to reallocate service volume and vehicles among routes and corridors based on current public, agency, and jurisdictional priorities and Metro's service guidelines, as well as current ridership patterns. Through the network redesign process and expanded use of articulated buses, Metro may be able to serve forecast ridership growth and meet service guidelines within the existing PVR.

Given these uncertainties and conflicting indicators, the Fleet Plan recommends planning for a steady state fleet based on the 2019 PVR of 1,270 vehicles operated in maximum service, through 2038.[26] This recommendation does not foreclose the possibility of adding vehicles if required based on market, project or technology needs. As noted earlier, the current fleet could accommodate significant demand growth through reallocation of service as part of the bus network redesign project, particularly if demand becomes less peak oriented and growth mostly occurs outside the PM peak period. Should additional vehicles be required to meet demand, the fleet can be expanded in the short term by retaining vehicles scheduled for retirement for an additional 1-2 years. New vehicles typically may be acquired with 2-3 years notice, depending on the technology. Even a modest increase of 3-5 vehicles to each year's annual bus procurement, coupled with retention of vehicles set to be retired, could substantially increase Metro's fleet size. Most of Metro's operating divisions have some latent capacity to accept moderate increases in the fleet size, and storage and maintenance capacity expansion could be explored if needed, including in conjunction with planned electric bus support improvements.

Metro will revisit the potential need for fleet size adjustments in future fleet plans in light of the uncertainty and volatility of potential future demand. The fleet plan does not recommend expanding

[25] Source: WMATA 2019 National Transit Database (NTD) Annual Agency Profile
https://cms7.fta.dot.gov/sites/fta.dot.gov/files/transit_agency_profile_doc/2014/30030.pdf

[26] Including 25 strategic buses, seven headway management buses, and four elevator buses.

the fleet due to the relatively low ridership forecast and recent ridership declines, the potential articulated buses and reallocation of vehicles among routes to address service guidelines, and other factors discussed in this section. However, the fleet plan also does not recommend reducing the size of the Metrobus fleet. Planning for a smaller future fleet would compromise Metro's ability to respond to future demand growth if and when it occurs. Despite recent declines, ridership growth could result from improved destination access, frequency, and travel speed in the bus network redesign and bus priority corridor projects, regional population and employment growth and new regional development projects, and other potential changes to the transit market and operating environment.

3.3 Projection of Fleet Demand

Metro maintains a number of buses to account for maintenance and breakdowns, to allow for buses to be used for training and emergency services, and for other purposes, such as rail replacement shuttles for scheduled maintenance operations. Strategic and Headway Management Buses and Elevator Service buses are in scheduled service and are included in the PVR to form the basis or calculating the spare ratio, as discussed in Section 3.3.3. Ready Reserve buses are older buses that are held in reserve in excess of the 19.5% spare ratio.[27] Each of these categories of buses is described in detail below.

3.3.1 Strategic and Headway Management Buses

Strategic and headway management buses play similar but distinct roles in maintaining schedule/headway adherence. Strategic buses are strategically placed to be available to support a variety of routes in the event of unforeseen delays or disruptions in the provision of service. Headway management buses fill in for late buses on specific headway-managed routes. Metro has continued its headway management strategy that was reported in the last fleet plan update. This strategy has improved service reliability. As of December 2019, Metro uses 25 strategic buses and 7 headway management buses.

3.3.2 Elevator Buses

In addition to strategic and headway management buses, Metro maintains a small number of buses (four in December 2019) to operate elevator shuttle buses, buses required to operate bus bridge service between adjacent Metrorail stations during times when their elevators are out of order.

3.3.3 Spare Buses

Spare buses are vehicles in a fleet expected to remain unused during peak service. These include buses requiring corrective or preventive maintenance, needed for training, removed from service for mid-life overhauls and buses utilized for special projects. This fleet plan proposes a spare ratio of 19.5%, to include:

[27] As described in FTA Circular 5010.1E. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/regulations-and-guidance/fta-circulars/58051/5010-1e-circular-award-management-requirements-7-16-18.pdf

15.6% to support routine day-to-day maintenance issues as well as longer term repair actions (Preventive and Corrective Maintenance);

1.5% to support midlife overhauls; and

2.4% to support training, and special projects (fleet and sub-fleet improvement programs).[28]

Recent operational realities and anticipated future fleet needs inform Metro's projected need for spare vehicles. On two occasions from 2017 to 2018, Metro pulled entire sub-fleets of approximately 100 to 150 buses from service due to significant unexpected vehicle issues. Metro has also undertaken major capital projects, such as the Platform Improvement Project,[29] which require the provision of alternative travel options such as bus shuttle service. In recent years, Metro's spare vehicles were not sufficient for the provision of this shuttle service. The Platform Improvement Project is ongoing.

In addition, articulated buses generally require more maintenance than standard-length buses. The same is true for electric buses in recent demonstrations at other transit agencies. Because Metro expects its articulated and electric bus fleets to grow in the coming years, additional spares available for maintenance purposes will help ensure the continued delivery of Metrobus service.

As the articulated share of the Metrobus fleet increases, and as new propulsion technologies are adopted, further maintenance operations adjustments are anticipated. While standard length vehicles can be stored and maintained at each Metro operation division, articulated buses may only be accommodated at 6 of these facilities. Currently, few divisions have the ability to offer fueling support for CNG buses or charging support for electric buses. Metro expects its future fleet to necessitate operational adjustments as a result of this reduced flexibility.

The proposed spare ratio is supported by extensive fleet operation experience and is deemed sufficient to support the various tasks for which spare buses are assigned. Table 3-7 below shows the fleet requirements by category through FY2038.

The Metrobus spare ratio is calculated in accordance with FTA guidance[30], as outlined below.

Spare Ratio = [Spare Vehicles] / [Peak Vehicle Requirement] = 19.5%

[28] Metro's last fleet plan called for a spare ratio of 18.5%, to include 14.7% to support maintenance needs, 1.5% to support midlife overhauls, and 2.3% to support training and special projects. Additional spares are expected to be required to ensure the quality and reliability of Metrobus operations, but midlife overhauls are not expected to increase.
[29] Source: Metro Platform Improvement Project Site. https://www.wmata.com/service/rail/PlatformProject/
[30] Source: Federal Transit Administration. https://www.transit.dot.gov/funding/procurement/third-party-procurement/spares-ratio

Table 3-7: Metrobus Total Vehicle Requirement

Category	Vehicle Count
Peak Vehicle Requirement[31]	1,270
Spares (19.5% Spare Ratio)	248
Total Scheduled Buses	1,518
Ready Reserve Buses	75
Total Vehicle Requirement	1,593

3.3.4 Ready Reserve Buses

Metro maintains a Ready Reserve Fleet of overage buses, which consisted of 75 vehicles in December 2019. The Ready Reserve Fleet is composed of older vehicles, past their scheduled replacement, that nevertheless would be suitable for passenger service to support regular revenue operations or special events. The primary purpose of the Ready Reserve Fleet is to replace buses that are not economically feasible to repair, accommodate approved temporary service changes, replace buses that are removed from service for fleet failures and provide buses for emergency situations. These vehicles are preserved in stored condition and are ready for service. While Metro expects to maintain a Ready Reserve fleet of up to 75 buses through 2038, the number of vehicles in the Ready Reserve Fleet may vary from year to year depending on the number of accidents, the age of the Metrobus fleet, necessary safety campaigns and other circumstances.

In the future, the availability of a Ready Reserve fleet will enable improved continuity of Metrobus service.[32] The ability to deploy Ready Reserve vehicles utilizing proven propulsion technology is helpful to fleet resilience as Metro begins deploying new technologies, such as electric buses, into the fleet. As these Ready Reserve vehicles are not included in Metro's Total Scheduled Buses, they are added to that figure to calculate Metro's Total Vehicle Requirement.

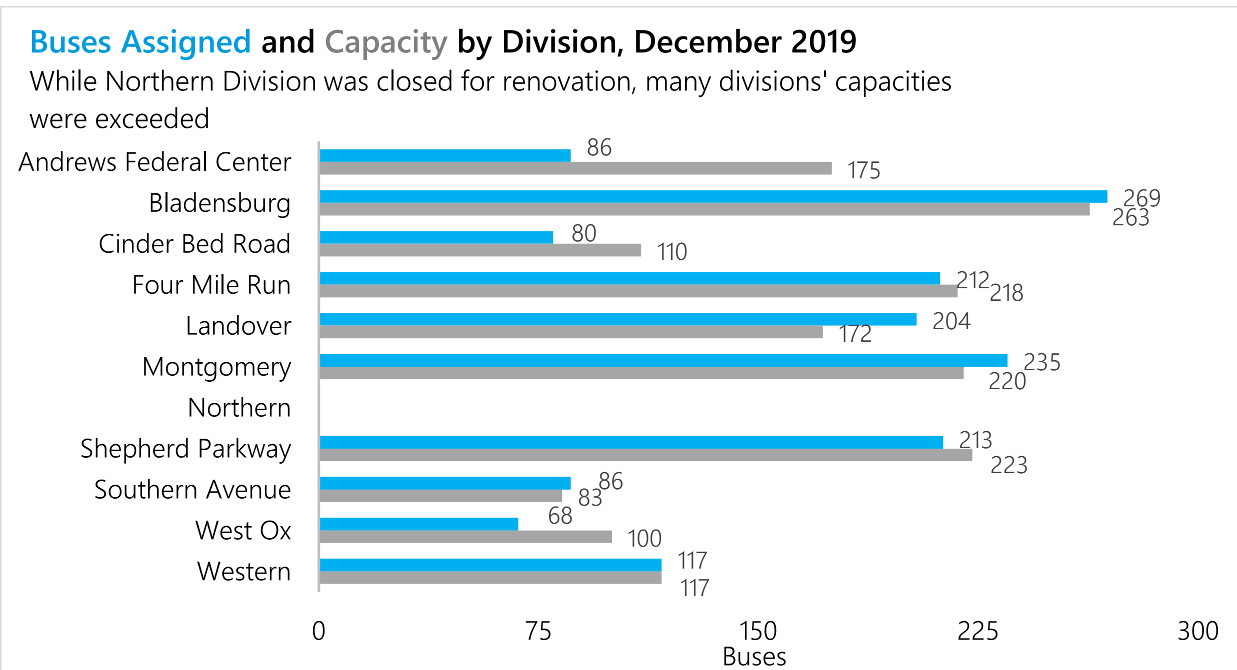
[31] Sometimes defined as vehicles operated in maximum service. This value is used for the calculation of the spare ratio and includes strategic fleet, headway management, and elevator shuttle vehicles.
[32] Ready Reserve vehicles, which will typically be legacy diesel- or CNG-fueled buses, will require continued fuel support at Metro operating divisions. The long-term makeup of the Ready Reserve fleet will require ongoing evaluation as Metro's fleet continues to evolve.

Section 4. Metrobus Fleet Supply

While Metrobus fleet size is driven by the volume and distribution of passenger demand and service requirements, the number of buses required to operate the Metrobus system is greater than the PVR, as described in Section 3. Routine scheduled replacement of the oldest buses is a fundamental component of a bus fleet management plan and helps ensure the quality and reliability of Metrobus services.

Metrobus vehicles have a useful life benchmark of 12 to 15 years,[33] and any temporary reduction in procurement plans would lead to longer-term fluctuations and service delivery challenges. This fleet plan projects the Metrobus PVR to remain constant at 1,270 vehicles through 2038. The total Metrobus fleet includes 248 spare buses, and up to 75 Ready Reserve buses, for a total fleet requirement of 1,593 buses as discussed in Section 3. Figure 4-1 shows how many buses were assigned to each operating division in December 2019, reflecting normal operations before the coronavirus pandemic. Facility capacity is included in this figure as well.

Figure 4-1: Metrobus Assignments and Capacity by Operating Division, December 2019[34]



[33] 12-year useful life benchmark for articulated and electric buses, 15-year useful life benchmark for standard length vehicles.

[34] In December 2019, 13 Ready Reserve vehicles were assigned to Carmen Turner Facility, which is not a standard Metrobus operating division.

Four facilities in December 2019 had capacity of 200 or more vehicles. Several divisions were exceeding their bus capacity in Fall 2019 due to the temporary closure of the Northern Operating Division for reconstruction.

Rehabilitation, replacement and expansion of Metro's existing vehicle fleet are essential to delivering safe, reliable and comfortable service to Metrobus customers. Due to variance in the timing of the procurement and retirement of buses, the precise size of the Metrobus fleet does fluctuate somewhat over time. By planning to procure 100 new buses per year for the duration of this Fleet Plan[35], and retiring buses after they have exceeded their useful life benchmark, the Metrobus fleet will remain a generally constant size for the life of this Fleet Plan. Some buses are expected to be kept past their typical useful life benchmark in order to meet fleet demand requirements. Flexibility in procurement planning will enable Metro to adapt to changes in the size of its articulated bus fleet as well as the pace of advancement in bus propulsion technology, especially in electric buses. For example, the range of electric buses may present route planning or reliability challenges, so it is possible the Metrobus fleet would expand slightly in the future to address those issues while continuing to deliver reliable service.

4.1 Current Fleet Composition

As of July 2021, Metrobus has a total fleet of 1,557 buses. This includes Ready Reserve vehicles and represents the current overall size of the Metrobus fleet, which grows and contracts slightly as vehicles are procured and retired. After FY2021, the Metrobus fleet is expected to remain at or above a total fleet size of 1,593 in order to meet forecasted fleet demand.

The Metrobus fleet consists of buses of three length categories: small, standard, and articulated.[36] A summary of the composition of the Metrobus fleet as of July 2022 is available in this document's appendix.

4.2 Articulated Bus Fleet Procurement Plan

As discussed in Section 3, Metro plans to expand its articulated bus fleet beyond current levels. From the projected end-of-year FY2022 base of 75, Metro will be able to reach 182 articulated buses by 2028 by adding approximately 25 articulated buses to its fleet each year from FY2024 through FY2028. Table 4-1 shows Metro's planned articulated bus fleet expansion through 2028. Two of these articulated buses will be electric vehicles in Metro's upcoming Electric Bus Test & Evaluation Program.

[35] As Metrobus vehicles are generally expected to operate in service for 15 years, procuring 100 new vehicles per year helps ensure a continued steady state fleet size.

[36] Small buses are vehicles with a length of 30-35 feet. Standard buses are 35-42 feet in length. Articulated buses are 60 or more feet in length.

Table 4-1: Articulated Bus Expansion Through FY2028, End-of-Year Totals

Year	Articulated	Standard, Other Types	Total Fleet
2022	75	1518	1593
2023	77	1577	1654
2024	102	1491	1593
2025	127	1528	1655
2026	152	1441	1593
2027	177	1421	1598
2028	182	1411	1593

With this expansion of its articulated bus fleet size, Metro will be able to serve several more high-volume, high-frequency routes with expanded service capacity. This fleet plan assumes a steady articulated bus fleet size after FY2028, though Metro may choose to expand this fleet further as needed to respond to ridership demand patterns and service quality. The articulated fleet will reach a steady-state size of 180 buses after the two 60' test and evaluation electric buses retire.

4.3 Vehicle Lifecycle

4.3.1 Vehicle Useful Life

The Federal Transit Administration establishes standards for vehicle useful life, which begins on the date a vehicle is placed in revenue service and ends when the same vehicle is removed from revenue service. For purposes of grant applications and accounting, transit buses which have been purchased with federal assistance have a minimum useful life of 12 years.[37] Transit providers may also establish a National Transit Asset Management (TAM) Useful Life Benchmark, defined as the "expected lifecycle of a capital asset for a particular transit provider's operating environment, or the acceptable period of use in service for a particular transit provider's operating environment."[38] Useful Life Benchmarks represent the anticipated years of service for a given vehicle type. Metro's useful life benchmarks meet or exceed the minimum useful life standards established by the FTA.

[37] Source: FTA Circular 5010. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/32136/5010-1e-circular-award-management-requirements-7-21-2017.pdf

[38] Source: FTA Final Rule 2132-AB07. https://www.federalregister.gov/documents/2016/07/26/2016-16883/transit-asset-management-national-transit-database

4.3.2 Vehicle Lifecycle Analysis

The lifecycle assessment conducted for the fleet plan reviewed the capital and operating costs of known configurations of transit vehicles on the market. The assessment incorporated vehicle prices paid by major transit agencies in or around FY2020 and Metro operating costs (fuel and maintenance expenses). For propulsion types in which facility investments to expand capacity would be required to accommodate future procurements, construction cost estimates per vehicle were reflected based on recent facility investments by Metro and other major transit properties. These costs were depicted over a 12- or 15-year time frame, based on each vehicle's anticipated Useful Life Benchmark, to show an average annual lifecycle cost for that configuration. While Metro expects standard-length buses to operate in revenue service for 15 years, articulated buses have a Useful Life Benchmark of 12 years. Electric buses are also currently benchmarked to have a 12-year typical useful life, given the lack of available full lifecycle demonstrations for this evolving vehicle technology.

The figures included in this vehicle lifecycle analysis are directional in nature and represent best estimates using presently available information. As technologies develop and Metro's familiarity with new propulsion types grows, it is likely that these assumptions will require review. This analysis shows the potential for increased annual total costs for electric buses, driven largely by the anticipated increased capital costs associated with these vehicles. These capital costs include the significant facility modifications associated with the support of these new vehicles. Additional operating expenses, including the adaptation of Metro's maintenance operations, are also likely to be impacted. A more detailed breakdown of the assumptions of this analysis is available in this document's appendix.

Electric buses, based on present-day purchase costs, have higher capital cost when compared to conventional diesel, CNG, and hybrid vehicles. Because Metro's facilities are also not currently configured to support a large-scale electric bus fleet, significant capital costs associated with facility construction would also be anticipated. In the near-term, operating costs for electric buses are driven in part by issues with vehicle reliability as discussed later in Section 4. Fuel costs for electric and CNG buses are lower than those of other vehicles.

These estimates do not include potential future improvements in vehicle efficiency, costs, reliability or performance. Metro will continue to monitor the advancement of these technologies and the potential impact of their deployment on service delivery. Future vehicle procurements will rely on the improvement of electric bus technologies, which is anticipated based on current industry trends. Other propulsion systems, including hydrogen fuel cell buses, will also be evaluated for potential introduction to the Metrobus fleet in the future.

Figure 4-2: Bus Propulsion Technology Comparison, 40-Foot Buses[39]

Bus Type	Diesel	Diesel Electric Hybrid	Compressed Natural Gas[40]	Battery-Electric	Hydrogen Fuel Cell
Range	300+ miles	300+ miles	300+ miles	150+ miles[41]	250+ miles
Useful Life Benchmark Assumption[42]	15 years	15 years	15 years	12 years	12 years
Existing Garage Capacity, % of Total	100%	100%	28%[43]	<1%	0%
Annual Greenhouse Gas (GHG) Emissions (tons), well-to-wheels[44]	124	99	CNG: 83 RNG: 15[45]	25	74[46]
Total Capital Cost[47]	$710,000	$900,000	$800,000	$1,425,000	$1,475,000
Capital Cost—Vehicle[48]	$710,000	$900,000	$800,000	$1,025,000	$1,375,000
Capital Cost—Facilities & Equipment[49]	No new build cost	No new build cost	No new build cost	$400,000	$100,000
Avg. Annual Operating Cost	$56,832	$55,967	$49,891	$54,436	$81,022
Operating Cost—Maintenance	$38,239	$40,929	$43,251	$46,531	$51,960
Operating Cost— Fuel	$18,594	$15,038	$6,640	$7,905	$29,063
Avg. Annual Total Cost[50]	**$104,165**	**$115,967**	**$103,224**	**$139,853[51]**	**$195,605**
Avg. Annual Total Cost with One-Time Facility Cost	$104,165	$115,967	$103,224	$164,853	$203,939

39 Costs depicted on a per bus basis.
40 Use of renewable natural gas (RNG) would further reduce CNG vehicle emissions.
41 Battery-electric bus range is especially impacted by weather and ambient temperature and can drop below this range under some conditions.
42 Useful life benchmark for standard 40' buses. All articulated 60' buses are assumed to have a 12-year useful life benchmark.
43 Capacity will increase to 43.0% upon completion of active reconstruction work at Shepherd Parkway and Bladensburg Divisions.
44 Information sourced from Argonne National Laboratory's AFLEET analysis, which sources data from the EPA's MOVES emission factor model (for diesel, hybrid, electric and fuel cell buses), and Argonne Lab's GREET Model for CNG.
45 Renewable Natural Gas. Assumed emphasis on landfill gas as an energy source. https://washingtongasdcclimatebusinessplan.com/wp-content/uploads/2020/03/Fact-Sheet_RNG_in_DC_vFINAL.pdf
46 Assumes off-site steam-methane reforming production of gaseous H2.
47 Includes vehicle purchase capital costs and facilities and equipment expansion costs for low-emissions buses.
48 Estimates for standard 40' buses, includes PPA warranty (if not standard for manufacturer inclusion) and midlife overhaul costs.
49 Facility conversion not anticipated for Diesel, Hybrid or CNG buses.
50 Average annual total cost is calculated to include operating and vehicle purchase capital costs. Capital costs are not incurred annually but are included on a per-year basis for purposes of comparison. Facility expansion costs are not included.
51 All new electric and hydrogen fuel cell buses would require facility expansion expenditures if pursued.

4.4 Projection of Fleet Supply

Metro's long-term fleet procurement plans will adopt a level procurement rate of 100 new vehicles per fiscal year. This steady approach will ensure stability in Metro's fleet over time, ultimately reducing variability in the fleet size due to previous years' procurement and retirement schedules. In the near term, some shifts will occur in the size of the Metrobus fleet, as vehicles may be retired at different rates than they are procured. In some cases, especially in the 2030s, vehicles are projected to be kept past their useful life benchmark in order to maintain a sufficient and fleet size to meet demand. The Metrobus fleet size may in some case exceed 1,593 vehicles due to the need to maintain this fleet level in future years.

As Metro evaluates the tradeoffs between various vehicle types, several factors must be taken into consideration. Metro's capacity to support CNG buses is limited to 481 vehicles in FY2021, though that figure grows to 704 in FY2023 with the completion of CNG capacity expansion at Shepherd Parkway. When the Bladensburg Operating Division's construction work is completed, this CNG support capacity will expand further to 741 vehicles. This expansion at Bladensburg is expected in FY2027.

Implementing electric bus capability at Metrobus operating divisions and deploying them in Metrobus operating territory requires extensive coordination within Metro and with other stakeholders. Existing facilities must be evaluated for operational constraints and required electrical capacity enhancements coordinated with local electric utility providers (including feeder extensions from local substations, redistricting and development of a transit rate class).

Given the timeframe needed to plan for and design the facilities—and procure the vehicles—to scale up electric bus service, Metro can reduce the emissions and improve the efficiency of the bus fleet by increasing the share of articulated buses and replacing outgoing diesel and hybrid buses with CNG-powered vehicles. The share of articulated buses in the fleet, which is well below that of most of Metro's peer transit agencies of its size[52], will increase from approximately 4% in FY2021 to approximately 12% by FY2028. Increasing the articulated fleet will allow for capacity to be enhanced on high-density corridors without adding additional vehicles to the fleet.

4.4.1 Emissions

As a part of Metro's emission reduction goals, Metro's fleet procurement strategy will focus on the adoption of an expanded electric bus fleet. One of the key changes recommended in this plan is to use CNG as a transitional strategy to full electric bus implementation. While the long-term goal of Metrobus is to migrate solely to electric buses or other zero-emission technologies, Metro expects to use a period of transition to prepare its facilities and operations to accommodate these new vehicles. This approach can provide significant regional air quality benefits, without the long lead times and technology risks

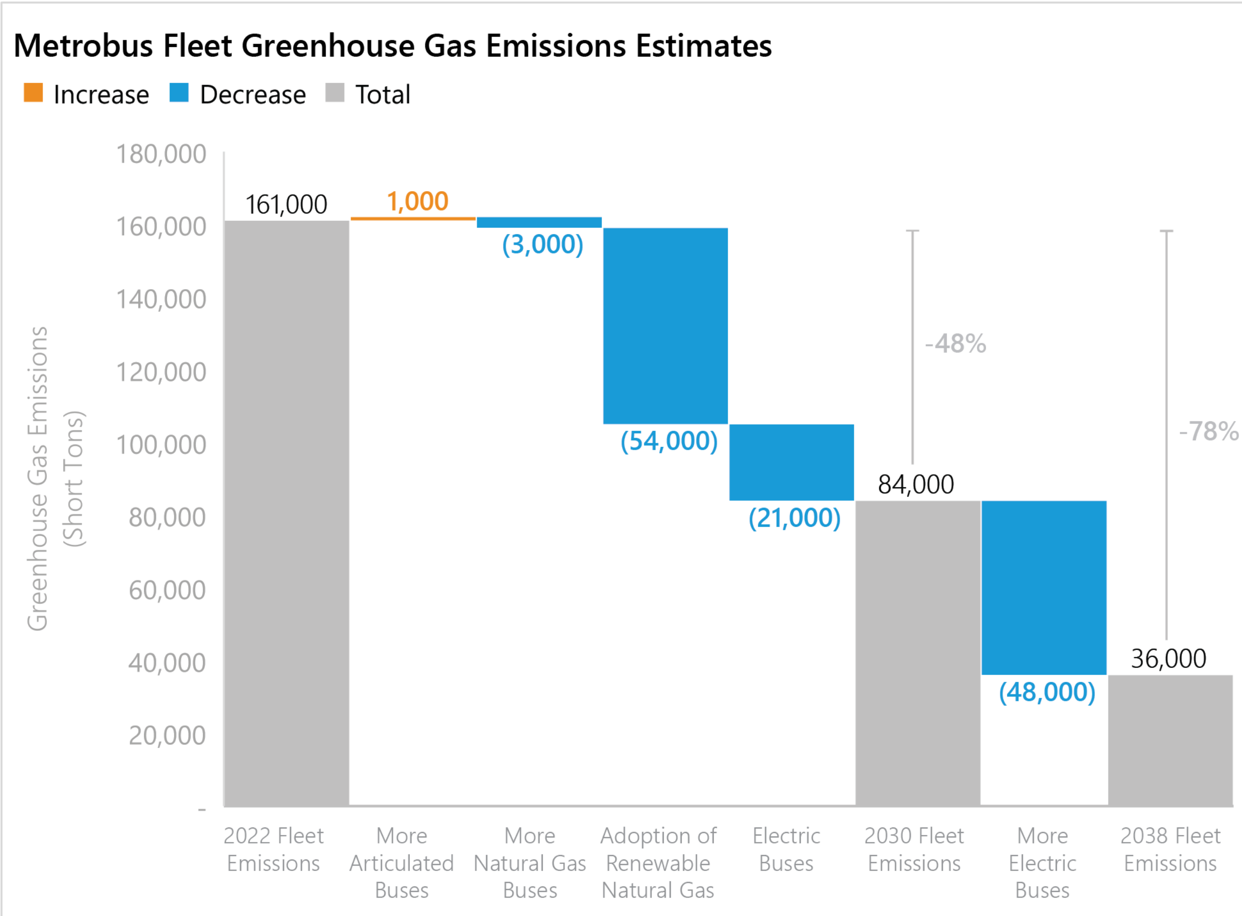
[52] Benchmarking of large transit agencies from National Transit Database.

associated with an accelerated electric bus adoption strategy. The emissions impacts[53] of Metro's planned bus procurement strategy are shown in Figure 4-3. Additional emissions details may be found in this document's appendix.

The use of renewable natural gas as a fuel source for CNG vehicles represents an opportunity for a reduction in fleet emissions as Metro transitions to a 100% electric bus fleet. Renewable natural gas is generated through the capture and processing of biogas, which is produced through the decomposition of organic matter. Potential biogas sources include methane from farming and animal waste, landfills and wastewater treatment facilities.[54] The United States Environmental Protection Agency has cited the potential benefits of the use of RNG, including reductions in upstream greenhouse gas emissions.[55] Metro has already initiated the procurement of renewable natural gas as an energy source.

[53] Figure 4-3 and Figure 4-4 emissions estimates generated through the U.S. Department of Energy's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool, which utilizes emissions data from the U.S. Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES). Articulated bus emissions estimated by comparison of vehicle fuel efficiency.
[54] Source: United States Environmental Protection Agency. https://www.epa.gov/agstar/renewable-natural-gas-agricultural-based-adbiogas-systems
[55] Source: United States Environmental Protection Agency. https://www.epa.gov/lmop/renewable-natural-gas

Figure 4-3: Estimated Annual Metrobus Fleet Greenhouse Gas Emissions, Selected Years



Within Metro operating divisions, existing CNG capacity is currently utilized to nearly the full extent available. Once CNG fueling capacity is implemented at Shepherd Parkway and increased at Bladensburg Division, shifting procurement to predominately CNG acquisition will allow Metro to realize emissions reductions immediately with a proven vehicle configuration. During this time, electric bus procurement will gradually scale up, shifting entire to electric vehicles in 2030 when more Metrobus facilities have been modified to accommodate electric buses and Metro has deeper experience with these vehicles' performance and reliability in the region from the test and evaluation program.

Figure 4-4: Estimated Annual Metrobus Fleet Vehicle Operation Pollutant Emissions, Selected Years

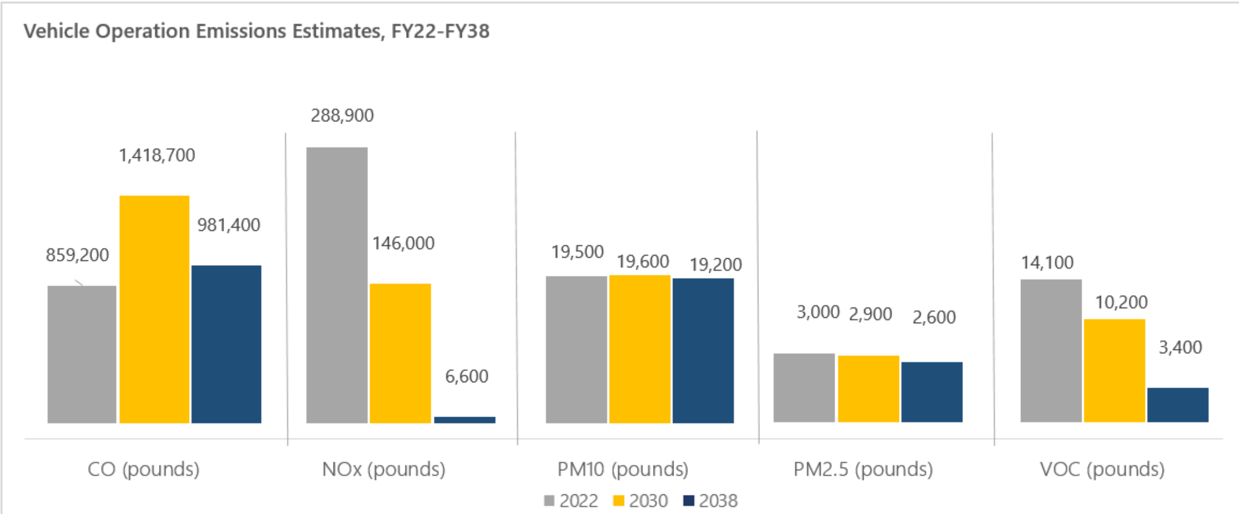


Figure 4-4 summarizes the total annual vehicle operation pollutant emissions estimated for the full Metrobus fleet in FY2022, FY2030, and FY2038.[56] Limiting these vehicle emissions represents an important factor in public health and air quality in the region. The Metropolitan Washington Air Quality Committee (MWACQ) and the National Capital Region Transportation Planning Board (TPB) have highlighted concerns regarding volatile organic compounds (VOCs) and nitrogen oxides (NOx) which combine to form ground-level ozone.[57] Particulate matter smaller than 2.5 micrometers in diameter (PM2.5) is also a noted public health concern.[58]

Metro's planned fleet composition is expected to have meaningful positive effects in these areas – with approximate reductions of up to 98% in NOx emissions, 75% in VOC emissions, and 15% in PM2.5 emissions from vehicle operations by 2038. These improvements are largely driven by the proposed future Metrobus fleet composition, especially the expanded use of CNG and electric buses. More detailed emissions data is available in the appendix of this document.

[56] Y-axes not to scale between charts. While carbon monoxide (CO) emissions in Figure 4-4 were generated using the U.S. Department of Energy's AFLEET Tool, Metro expects to be able to significantly reduce CO emissions through the use of oxidation catalysts and other mitigation strategies.
[57] Source: Metropolitan Washington Council of Governments. https://www.mwcog.org/transportation/data-and-tools/air-quality-forecasts/
[58] While they do not produce tailpipe emissions as conventional vehicles do, electric and hydrogen fuel cell buses, like all transit buses, generate particulate matter emissions during vehicle operation. Sources of this particulate matter include those produced by friction on brakes, tires, and road surfaces, as well as the suspension of road dust.

4.4.2 Electric Bus Planning Considerations

4.4.2.1 Electric Bus Updates and Context

Expanding on the efforts of Metro's first Energy Action Plan in 2019 and the Washington Area Bus Transformation Project, Metro is engaging in planning to integrate electric buses into the Metrobus fleet. The introduction of these buses will reduce regional emissions from Metrobus operations and some operating costs like fuel expenditures while aligning Metro with the sustainability priorities of the region.

Metro's 2020 Zero-emission Bus Update[59] catalogues the actions the agency and region must take to enable adoption of zero-emission buses, including the expansion of energy infrastructure, establishment of regional electric utility policy for transit and a transit-specific energy rate class, and the securing of funding to procure zero-emission buses and convert maintenance and operating divisions to enable the fueling and maintenance of these vehicles.

An Electric Bus Alternatives Assessment study and a Low-or-No Emission Grant from the FTA has enabled the establishment of the test and evaluation program for 12 electric buses at the Shepherd Parkway operating division, which will help assess the functionality and interchangeability of different vehicle and charging brands at Metrobus operating divisions. This pilot will include the purchase of articulated buses, with the introduction of these vehicles into service concluding in FY2023. Situated in Southeast Washington, close to Prince George's County in Maryland and Northern Virginia, Metro will be able to test the pilot fleet on a variety of operating profiles, including variable service block length and topography.

This fleet plan builds upon these assessments of electric buses, outlining pathways to scale the share of electric buses in vehicle procurements and to convert facilities in alignment with programmed construction plans. For the purposes of this report, battery-electric and fuel cell buses were evaluated for zero-emission bus implementation. Battery-electric bus technology has wider demonstrated adoption to date, including at Metro.

Current reconstruction activities at Northern and Bladensburg Divisions enable those facilities to be electric-bus ready, though charging infrastructure planning would still require procurement and installation at Bladensburg. While no additional electric-ready facilities have been identified, Section 6 details the considerations and challenges for each Metrobus division's conversion to support electric buses.

4.4.2.2 State and Local Jurisdiction Standards

Several regional jurisdictions have committed to policy and planning targets to prioritize and scale zero-emission vehicle acquisition in the immediate future. These jurisdictions have expressed these targets

[59] Source: Metro Zero-Emission Bus Update.
https://www.wmata.com/initiatives/sustainability/upload/WMATA_Zero_Emission_Bus_Update-02122020-FINAL.pdf

through signed/pending clean energy legislation, regional "cap and invest" programs, climate action and environmental planning documents recommended for board adoption, and local planning documents.

Metro is coordinating with other regional transit operators and other key stakeholders, such as the Metropolitan Washington Council of Governments (MWCOG) and electric utility companies, to determine a common approach and collaboratively shape regional policy concerning the adoption of zero-emission vehicles and the requisite utility upgrades required, including the development of a transit bus fleet-specific rate class. Opportunities for coordination will increase as transit properties that overlap or are immediately adjacent with the Metrobus operating territory begin deploying zero-emission buses and developing the requisite charging infrastructure.

4.4.2.3 Metrobus Procurement Schedule

Implementing electric bus capability at Metrobus operating divisions and deploying them in Metrobus operating territory requires extensive coordination within Metro and with other stakeholders. Existing facilities must be evaluated for architectural constraints, and Metro must coordinate with local electric utility providers to achieve required electrical capacity enhancements—including feeder extensions from local substations, redistricting and development of a transit rate class. Bus purchases should be aligned with design plans to ensure that Metro does not receive buses it cannot charge and operate.

Although it will take years to scale up electric bus service fully—which entails planning for and designing facilities as well as procuring vehicles—Metro can already begin to reduce its emissions and improve the efficiency of its bus fleet by increasing the share of articulated buses in the fleet and replacing retiring buses with CNG-powered vehicles. The share of articulated buses in the fleet will increase to approximately 12% by FY2028. Increasing the articulated fleet will allow for capacity to be enhanced on high-density corridors without adding additional vehicles to the fleet.

Existing CNG capacity is currently utilized to nearly the fullest extent. In immediate years, diesel bus procurement will occur at a lower capital cost and build a fleet of vehicles that will be on hand during the electric bus deployment. Once CNG fueling capacity is implemented at Shepherd Parkway and increased at Bladensburg Division, shifting procurement to predominately CNG acquisition will allow Metro to realize emissions reductions with a proven vehicle configuration. During this time, electric bus procurement will gradually scale up, increasing in the 2030s when more Metrobus facilities have been configured to accommodate electric buses and Metro has greater awareness of performance and reliability in the region from the test and evaluation program.

4.4.2.4 Electric Bus Adoption Factors

The following factors are crucial components of electric bus technology and infrastructure. These factors are expected to develop over the coming years as electric bus technology matures and more vehicles are deployed.

Bus Range: In FY2021, battery-electric buses are demonstrating typical ranges of approximately 100-150 miles in revenue service. While battery weight is anticipated to decline over the course of the decade, allowing for potential efficiencies of diesel gallon-equivalent fuel economy and range, the advancement in battery range will remain an area to study and evaluate. Battery-electric bus range is a function of battery pack size, vehicle weight, passenger loading, geography, temperature and operating conditions. In recent Altoona testing of electric buses by the FTA[60, 61, 62], energy efficiency has ranged between 1.6-2.5 kWh/mile without accounting for the impact of passengers, HVAC, hills, and traffic.

Electric bus configurations published by several states (including California[63], Maryland, and Washington State[64]) have included battery-electric buses with battery capacity between 440 and 660 kWh. Vehicles with comparable battery capacity are estimated to have range estimates that fall between 2.5kWh/mile and 4.0kWh/mile. A survey of these vehicles currently on the market suggests that battery offerings in FY2021 may allow an operating range as low as 90 miles and as high as over 200 miles, depending on operating conditions. While battery weight is anticipated to decline over the course of the decade, allowing for potential efficiencies of diesel gallon-equivalent fuel economy and range, the advancement in battery range will remain an area to study and evaluate.

Conditions that may cause buses to perform on the lower end of the range include very cold temperatures, maximum HVAC loading and frequent stops and door cycling. Battery systems often need to be warmed before they can commence charging, which shortens available charging windows and may cause other operational impacts. The variable seasonal weather conditions in the Washington metropolitan region will result in cold-weather impacts to electric bus operations on some colder winter days. A 2018-2019 study of District Department of Transportation battery-electric bus performance in Washington, DC found significant variance in vehicle range related to ambient temperature, dropping to as low as 60 to 90 miles per charge in freezing temperatures.[65]

[60] Source: Altoona Test, New Flyer XE40, July 2015
http://apps.altoonabustest.psu.edu/buses/reports/458.pdf?1441118410
[61] Source: Altoona Test, Proterra CAT40DP, September 2020
http://apps.altoonabustest.psu.edu/buses/reports/519.pdf?1602161615
[62] Source: Altoona Test, BYD Electric Bus, 2014
http://apps.altoonabustest.psu.edu/buses/reports/441.pdf?1423598436
[63] Sources: California Department of General Services Price Book
https://www.dgs.ca.gov/-/media/Divisions/OFS/Pricebooks/Current-Year-Price-Book/FY-2020-2021-Price-Book.pdf and Contract Pricing Bulleting
https://www.dgs.ca.gov/-/media/Divisions/PD/PTCS/Broadcast-Bulletins/2019/K-35-19-Zero-Emission-Transit-Buses.pdf
[64] Source: Washington State Bus Price Analysis.
[65] Source: Center for Transportation and the Environment et al. https://cte.tv/wp-content/uploads/2019/12/Four-Season-Analysis.pdf

Reliability: Initial deployments of battery-electric buses were characterized by lower bus availability and higher corrective maintenance. Transit agencies have observed some improvement in terms of reliability, availability and battery storage capacity with newer deployments.[66] These elements are anticipated to improve as the technology matures and more manufacturers enter the market.

For example, the first five battery-electric buses delivered to Los Angeles County Metropolitan Transportation Authority in 2014 experienced approximately 10% of the mean miles before failure of the diesel bus fleet, major issues with door systems and experienced multiple roadcalls from service during most weeks. Some transit agencies, such as Los Angeles County Metropolitan Transportation Authority[67] and Albuquerque Rapid Transit, required manufacturers to repurchase these vehicles due to deficiencies below the contractually agreed standard of performance. Los Angeles utilized trade-in credits to acquire a newer generation fleet of electric buses that offered better performance in service.

Foothill Transit in Southern California was among the first operator to utilize electric buses in service in the United States, beginning in 2009. In the initial analysis period from 2014-2015, miles between roadcalls from service for these electric buses was approximately 20-30% of that of fully-commercialized CNG buses.[68] Foothill subsequently conducted a follow-up analysis of second-generation battery-electric buses in 2015-2016, which exhibited a significant improvement in availability between first-generation and second-generation battery-electric buses, improving from 66% availability to 79% in just one year[69], compared to 90% for CNG buses in that same period. However, a subsequent phase of that evaluation in 2020 depicted comparable miles between roadcalls between first- and second-generation electric buses, suggesting that electric buses still face reliability issues.[70]

More recent fleet deployments demonstrate improvements, but still are not consistently performing at the level of legacy bus configurations. The initial evaluation of electric buses in service with King County Transit in Seattle from 2016-2017 concluded that electric buses were available for service 80.6% of the time, opposed to 90.5% for the hybrid fleet and 86.4% for the diesel fleet, noting that issues resulted

[66] Source: Transit Cooperative Research Program, Battery Electric Buses State of the Practice. https://www.nap.edu/catalog/25061/battery-electric-buses-state-of-the-practice

[67] Source: Los Angeles County Metropolitan Transportation Authority. https://media.metro.net/board/Items/2016/09_september/20160914atvcitem4.pdf

[68] Source: Foothill Transit Battery Electric Bus Demonstration Results, January 2016. https://www.nrel.gov/docs/fy16osti/65274.pdf

[69] Source: Foothill Transit Battery Electric Bus Demonstration Results: Second Report, June 2017. https://www.nrel.gov/docs/fy17osti/67698.pdf

[70] Source: Foothill Transit Agency Battery-Electric Bus Progress Report, March 2020. https://www.nrel.gov/docs/fy20osti/75581.pdf

with the electric drive system.[71] If the electric buses in Metro's fleet were to experience reliability issues at this scale, it would represent a major disruption to Metro's ability to deliver service to the region.

The deployment of limited pilot fleets of electric buses by transit agencies, with data collection and assessment conducted by entities such as the Federal Transit Administration and NREL (National Renewable Energy Laboratory) has allowed manufacturers to improve bus production, in addition to informing electric bus operation to transit agencies. NREL's evaluation of low-voltage batteries at Foothill Transit revealed that electric buses required significantly more service than CNG buses due to the lack of an auto-shutoff feature for bus accessories that continually draw power, such as fareboxes and camera systems. Manufacturers are integrating auto-shutoff features into future designs, and are retrofitting in-service vehicles facing this issue.[72]

AC Transit in Northern California purchased a group of comparable battery-electric and hydrogen-fuel cell buses from the same manufacturer in 2019, with the intention of using the operating performance of these vehicles to inform the subsequent scaling of their zero-emission fleet.[73] The agency concluded electric buses have not yet matured to the point they can "easily replace current diesel and CNG technologies on a large scale" but is expecting further improvement due to continuing advancements.

Battery Degradation: Batteries currently on the market are anticipated to degrade to no less than 80% of their design capacity. Battery manufacturers offer 12-year warranties up to this level, allowing transit properties to mitigate some level of battery degradation risk. Lithium batteries for transit battery-electric buses, excepting early-stage pilots, have only been in service for about 5 years. As a result, there is limited demonstration of full battery lifecycles in this application. Manufacturers suggest that retaining 80% of design capacity through the end of their 12-year life is a reasonable expectation, as stated by their warranty offerings.

Fuel cells, like batteries, also degrade over time, and a mid-life rebuild of a hydrogen fuel cell stack has been anticipated in year 6 or 7 in this fleet plan's analyses.

Energy densities for transit bus batteries continue to evolve at a rapid rate, and corresponding range limitations are likely to continue improving during the analysis period of this fleet plan. Battery energy density, measured in kilowatt hours per kilogram, has been improving by about 10% annually, with vehicles becoming lighter at the same time they demonstrate potential expanded range. The U.S.

[71] Source: FTA Zero-Emission Bus Evaluation with King County Metro. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/115086/zero-emission-bus-evaluation-results-king-county-metro-battery-electric-buses-fta-report-no-0118.pdf

[72] Source: Foothill Transit Agency Battery-Electric Bus Progress Report, March 2020. https://www.nrel.gov/docs/fy20osti/75581.pdf

[73] Source: AC Transit Zero-Emissions Bus Rollout Plan. https://www.actransit.org/website/uploads/AC-Transit-ZEB-Rollout-Plan_06102020.pdf

Department of Energy has established goals for lighter weight batteries with greater energy density at a 15-year lifespan.

Electric Utility Support: Close coordination with local electric utility providers will be needed to make requisite improvements to the grid and connections to Metrobus operating locations. Metro and other regional transit operators may benefit from the establishment of a transit-specific rate class to price appropriately mass transit use of utility capacity.

Training and Development: The maintenance and operation of new propulsion technology will require updated training practices and protocols. Significant training support will be required to support the success of Metro's electric fleet. The scope of these efforts will include charging systems and infrastructure as well as vehicle operation.

Grid Analysis: Charging 100 battery-electric buses requires approximately nine megawatts (MW) of electricity—about the same amount demanded by 6,000 homes. The Capital Grid project in Northwest Washington may enable Northern Division, upon completion of its construction work mid-decade, to accommodate 150 electric buses. Other sites would require build-outs and feeder extensions to increase capacity and connect with nearby substations and may potentially need to be redistricted to a different electric utility provider to accommodate the increased load of electric buses. In other instances, such as where local load growth continues to rise but is already at capacity, the installation of on-site solar power could be considered, along with the parallel incorporation of alternative fuel technology such as CNG.

Facility Layout Planning: Many facilities currently supporting electric buses utilize overhead charging, with pantograph gantries that connect to the bus from a structure above. Plug-in charging, in which the vehicle is plugged into an electrical socket, is also utilized common. Inductive charging, in which the bus connects to an electricity source plate below it, is less common and currently undergoing early evaluations at select agencies. While on-route charging has not been demonstrated on a wide scale, and can be more costly than depot charging due to the utility enhancements and land use acquisition and conversion required to establish it, some transit properties attempt to augment their depot charging capacity by co-locating these facilities with existing power sources and real estate. If Metro implements on-route charging, locations such as Metrorail stations and existing bus terminals may provide adequate electrical capacity and parking space for operators to "fast-charge" the bus in between runs.

Contingency and Resiliency: Retaining diesel fueling capabilities for training and ready reserve purposes in the near term may protect against mechanical failures and grid outages. Gradually scaling up electric bus infrastructure and deployment with low-emission vehicles such as CNG buses will allow Metro to build redundancy and enable flexibility in the forward direction of the fleet. Metro will need to consider the emergency preparedness of its fleet in the event of potential future use of its bus fleet in evacuation scenarios. If an electric or other zero-emission bus were to travel outside the Metro service area in such a situation, re-charging or re-fueling locations would be required.

Route Analysis and Block Assignment: The majority of Metrobus operative blocks assessed are within the current estimated range of a 500-kWh electric bus. Block assignments will need to consider the appropriate threshold at which a battery-electric bus typically returns to the depot for charging—usually around 20%. The impacts of adverse weather conditions on range will also need to be evaluated.

Disadvantaged Communities: Metrobus provides service throughout the Washington metropolitan region and has varying capabilities at its 10 operating divisions in the area. Some divisions only accommodate certain propulsion types, and some do not accommodate articulated buses. Processes such as Title VI will be integrated into Metro's planning for the development of charging infrastructure for zero- and low-emissions infrastructure, as well as for the routing and deployment of newer and cleaner bus fleets. Under Metro's Title VI Program, Metro will continue to monitor vehicle deployment to ensure equity among fleet age and, in the case of zero-emissions, vehicle type. This review is conducted periodically, as rider demographics, the assignments of vehicles to a given route, and capacities and capabilities at facilities change over time. Table 4-2 details the demographics of riders served by each bus division using route assignments as of fall 2019.[74]

Table 4-2: Minority and Low-Income Riders as Share of Riders Served by Bus Division

Division	Minority Riders as Share of Riders Served	Low-Income Riders as Share of Riders Served
Andrews Federal Center	87.3%	47.3%
Bladensburg	81.3%	45.4%
Cinder Bed	66.7%	34.1%
Four Mile Run	65.1%	31.9%
Landover	92.8%	49.6%
Montgomery	81.5%	45.5%
Northern	71.3%	35.3%
Shepherd Parkway	91.9%	57.6%
Southern	91.6%	59.0%
West Ox	65.9%	36.8%
Western	60.2%	30.1%
Weekday Average, System-Wide	80.1%	44.7%

[74] Figures for Northern Division calculated as of Fall 2018, as this facility was closed for rehabilitation in 2019.

4.4.2.5 Electric Bus Considerations Summary

By transitioning to zero-emission buses, Metro will be able to support a clean and sustainable region, reduce greenhouse gas and on-the-road vehicle emissions, decrease vehicle noise, and improve the overall customer experience.

Transitioning beyond Metro's initial test and evaluation to a larger overall electric bus fleet will require close coordination with local, regional, and federal partners. The facility and utility support required to house, maintain, and operate electric buses is significant, and Metro is closely studying advancements in bus technology. Metro is also working to identify the needs, costs and funding sources required to make this transition. Collaboration with regional partners in the development of relevant rate structures and policies represents another key step in this process.

Electric buses involve increased capital costs as manufacturers charge more for these vehicles when compared to CNG, diesel and hybrid buses.[75] Metro's operating facilities are not currently configured to support a larger electric bus fleet. Battery-electric vehicles require dedicated charging equipment and support infrastructure, and often other facility reconfigurations such as parking lane adjustments and ceiling height changes.

Other significant challenges exist to full conversion of the Metrobus fleet to electric or other zero-emission bus technologies, including current industry trends of operating limitations. Existing battery-electric buses do not currently offer the same travel range on a single charge when compared to other propulsion technologies. Reliability is another anticipated hurdle; electric buses are expected to continue to require more frequent corrective maintenance in the near-term. Adjustments to battery life issues are anticipated as electric bus batteries degrade over their lifetime and cold weather has been shown to reduce the longevity of a single charge.

Metro will continue to monitor and evaluate advancements in electric bus technology, performance, reliability, range and costs. The procurement schedule outlined in this plan reflects anticipated developments in these areas as manufacturers and transit agencies improve their familiarity with this technology. If battery-electric or other zero-emission technologies support more rapid adoption and deployment in the future, Metro plans to adjust its procurement approach accordingly.

Metro is working to transition its procurement strategy to focus on electric bus technology in the future. Primary considerations for Metro to evaluate during the scale-up of the electric bus program include:

Battery-Electric Bus Constraints: The rate at which Metro can transition to electric buses will be largely constrained by facility and charging system capacities, and both areas will take a decade or more to build out. A secondary consideration is that even the longest-range battery-electric buses may not be able to operate on some bus routes. Current electric bus range is estimated to be approximately 150 miles, with reduced performance under certain weather conditions. While most current Metro blocks

[75] As do hydrogen fuel cell vehicles.

fall under 150 miles, performance during the test and evaluation program will provide insight on observed range in Metrobus territory.

Flexibility & Anticipated Technology Improvements: This Bus Fleet Management Plan focuses on bus replacement scenarios that were most cost effective, provide the maximum near-term emission benefits to the region, and fit within existing facility plans and constraints.

Bus technologies are evolving rapidly, and are expected to continue evolving in the upcoming years. Metro plans to maintain as much flexibility as possible to adjust its fleet replacement plans, as different technologies and capabilities become available and/or more cost effective in the future.

Near Term Benefits of CNG Fleet Expansion: Given the timeframes anticipated for electric bus adoption, Metro plans to expand its CNG fleet in the near term as a bridging strategy. Currently available Low NOx CNG engines, along with use of renewable natural gas (RNG)[76], can provide immediate air quality and greenhouse gas (GHG) benefits for the DC region.

4.4.3 Fleet Procurement Strategy

The considerations and analyses above inform the approach Metro plans to implement in its future procurement plans, which begin in FY2024.

In June of 2021, the Metro Board of Directors adopted zero-emission fleet goals[77] which inform Metro's strategy for bus procurements in the coming years. In accordance with these goals, Metro plans to purchase only lower-emission and electric buses in its next bus procurement, beginning in FY2024, and transition to the purchase of only zero-emission vehicles beginning in FY2030. By FY2045, these goals direct Metro to be fully transitioned to a zero-emission bus fleet.

In order to provide quality, reliable service while working to reduce greenhouse gas emissions and transition the Metrobus fleet to new technologies, Metro plans to procure a mix of lower-emission and electric buses through a phased approach. This will also allow opportunity for the conversion of Metrobus operating divisions to be able to support electric buses, which are a key identified need in this fleet plan.

While this fleet plan anticipates procurement of lower-emission compressed natural gas buses, Metro may also procure hybrid buses, another lower-emission vehicle technology. Exact procurement plans, fleet composition, and purchase timing will be impacted by facility capacity, bus support infrastructure, maintenance requirements, vehicle technology performance, and other factors. Metro's projected

[76] Additional information available from the US Department of Energy's Alternative Fuels Data Center. https://afdc.energy.gov/fuels/natural_gas_renewable.html

[77] Source: June 10, 2021 Metro Board materials. https://www.wmata.com/about/board/meetings/board-pdfs/upload/3A-Sustainability-Vision-Goals-and-Bus-Fleet.pdf

procurement plans are detailed in the table below and entail a steady procurement of 100 vehicles per fiscal year. Metro will continue to study and evaluate vehicle propulsion technology and performance as it evolves in the coming years and intends to remain flexible in its approach to vehicle acquisition in alignment with Board-established fleet goals.

Table 4-3: Total Projected Bus Procurement by Fuel Type, FY2024-FY2038

Fuel Type	FY24–FY28	FY29	FY30–FY38
Compressed Natural Gas Buses Procured	75 per year	50 per year	0 per year
Electric Buses Procured	25 per year	50 per year	100 per year
Total Buses Procured	100 per year	100 per year	100 per year

Metro plans to procure approximately 75 CNG buses per year from FY2024 through FY2028, along with approximately 25 electric buses in each of these years. These apportionments will shift to an equal split in FY2029. Beginning in FY2030, Metro plans to focus its bus procurement exclusively on electric or other zero-emission vehicles. These plans may adjust or accelerate as technologies develop, and Metro will continue to evaluate advancements in other zero-emission bus technologies such as hydrogen fuel cell vehicles. The projected fleet mix implications of this strategy are shown in Table 4-4 and Table 4-5, as total fleet counts as well as percentages. By the end of FY2038, Metro's fleet would be projected to consist of 34% CNG vehicles and 66% electric buses.

Metro's CNG support capacity is current expected to peak at 741 vehicles after reconstruction efforts at Bladensburg are completed. While Metro's CNG fleet may slightly exceed this programmed capacity in FY2027 and FY2028, Metro expects to be able to accommodate these vehicles through storage at other facilities or adjustments to bus parking configurations. The procurement of hybrid vehicles represents another option if CNG bus support reaches capacity.

Table 4-4: Metrobus Fleet by Propulsion Type, FY2021-FY2038, End-of-Year Totals

FY	Diesel	Hybrid	CNG	Electric	Total Annual Fleet Level
2021	260	861	435	1	1557
2022	318	857	417	1	1593
2023	368	809	464	13	1654
2024	368	648	539	38	1593
2025	368	610	614	63	1655
2026	368	448	689	88	1593
2027	357	364	764	113	1598
2028	357	343	755	138	1593
2029	341	323	741	188	1593
2030	341	223	741	288	1593
2031	341	123	741	388	1593
2032	341	40	725	487	1593
2033	299	0	707	587	1593
2034	299	0	620	687	1606
2035	274	0	620	785	1679
2036	220	0	601	867	1688
2037	50	0	582	961	1593
2038	0	0	545	1048	1593

Table 4-5: Metrobus Fleet by Propulsion Type, FY2021-FY2038, End-of-Year Percentages

FY	Diesel	Hybrid	CNG	Electric
2021	17%	55%	28%	<1%
2022	20%	54%	26%	<1%
2023	22%	49%	28%	1%
2024	23%	41%	34%	2%
2025	22%	37%	37%	4%
2026	23%	28%	43%	6%
2027	22%	23%	48%	7%
2028	22%	22%	47%	9%
2029	21%	20%	47%	12%
2030	21%	14%	47%	18%
2031	21%	8%	47%	24%
2032	21%	3%	46%	31%
2033	19%	-	44%	37%
2034	19%	-	39%	43%
2035	16%	-	37%	47%
2036	13%	-	36%	51%
2037	3%	-	37%	60%
2038	-	-	34%	66%

Figure 4-5: Projected Share of Vehicles in Metrobus Fleet by Propulsion Technology

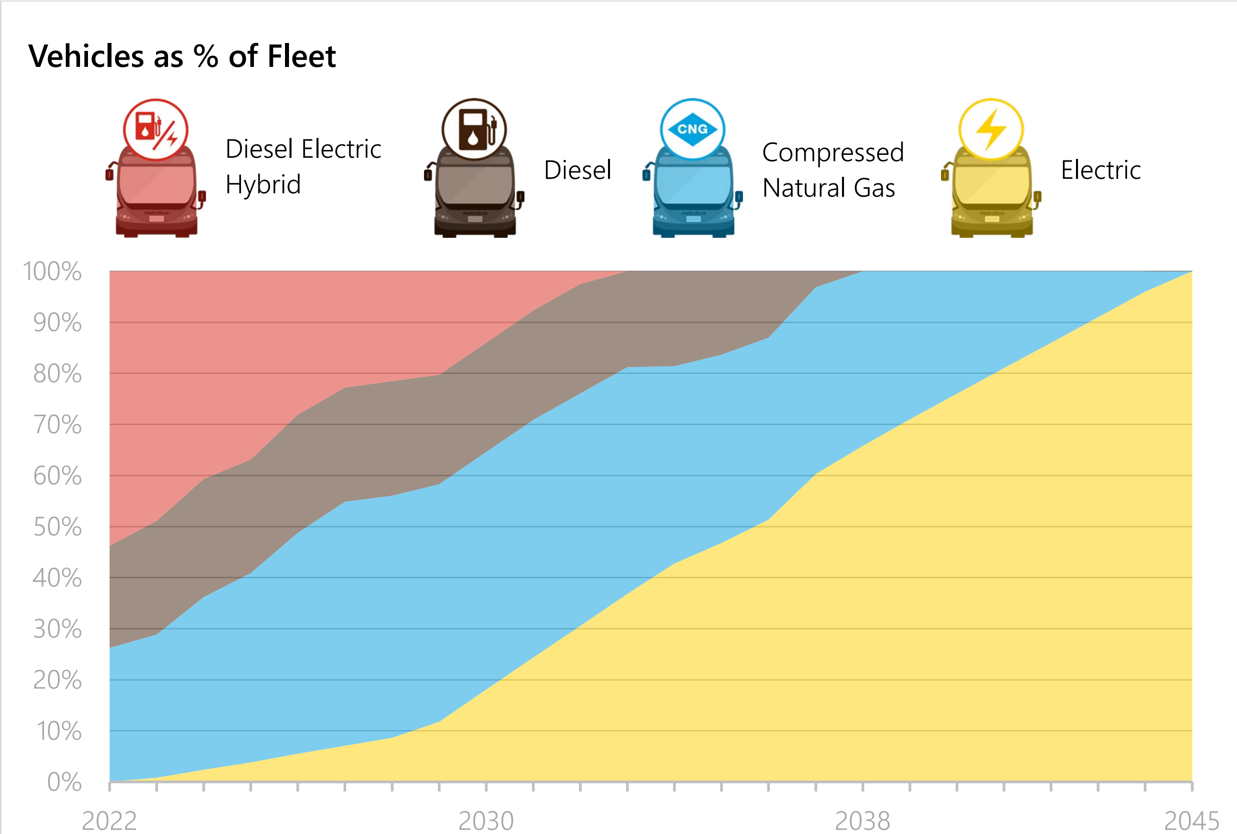
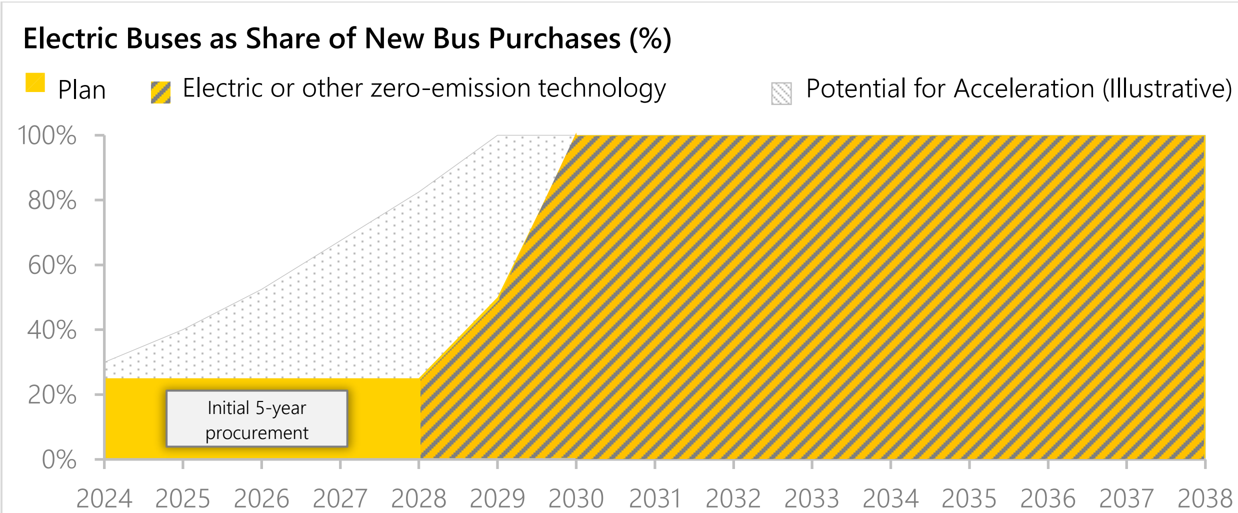


Figure 4-5 charts the share of the Metrobus fleet by propulsion type from FY2022 to FY2045. Metro's current fleet of hybrid buses is expected to be retired by the end of FY2032 as they reach the end of their useful life benchmark. By the end of FY2038, Metro's electric bus fleet is expected to include 1,048 vehicles, approximately 66% of the total fleet. All diesel buses in the fleet are projected to be retired by the end of FY2038. Metro expects to maintain its fleet of small buses (30 to 35 feet) to service specific routes with certain road geometry or turning radius requirements. Adjustments to this plan may be made in the future if these long-term requirements change.

Figure 4-6 demonstrates potential paths for an expedited transition to electric buses in Metro's bus procurement plans.

Figure 4-6: Electric Bus Procurement Paths, FY2024–FY2038



Metro plans to adapt the pace of its conversion to electric buses in response to the progression and maturity of vehicle technology as well as the availability of the funding sources required to meet anticipated capital costs. As electric buses demonstrate the range and reliability required to replace conventional buses on a one-to-one basis, and as requisite funding support is made available, Metro will work to transition to full electric bus procurement as quickly as feasible. While this document assumes a specific schedule for planning purposes, Metro will adjust its approach to fleet management to ensure it reflects available vehicle technology and advancements. Other zero-emission technologies may be procured in addition to electric buses after FY2028.

Table 4-6 outlines the planned procurement and retirement schedule of the Metrobus fleet from FY2021 through FY2038. Due to previous years with variance in procurements and retirements, some fluctuation in the exact size of the Metrobus fleet is anticipated. In some cases, vehicles will be kept past the end of their useful life benchmark in order to meet the projected total vehicle requirement of 1,593 vehicles per year. In some years, the Metrobus fleet may also exceed 1,593 vehicles in order to ensure sufficient fleet size to meet fleet requirements in following years.

Table 4-6: Metrobus Fleet Procurement and Retirement Projection Through FY2038 (Summary)[78]

	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38
Active Fleet (Start of Year)	1576	1557	1593	1654	1593	1655	1593	1598	1593	1593	1593	1593	1593	1593	1606	1679	1688	1593
Deliveries	171	170	112	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Retirements	190	134	51	161	38	162	95	105	100	100	100	100	100	87	27	91	195	100
Active Fleet (end of year)	1557	1593	1654	1593	1655	1593	1598	1593	1593	1593	1593	1593	1593	1606	1679	1688	1593	1593
Diesel as % of Fleet (end of year)	17%	20%	22%	23%	22%	23%	22%	22%	21%	21%	21%	21%	19%	19%	16%	13%	3%	0%
Hybrid as % of Fleet (end of year)	55%	54%	49%	41%	37%	28%	23%	22%	20%	14%	8%	3%	0%	0%	0%	0%	0%	0%
CNG as % of Fleet (end of year)	28%	26%	28%	34%	37%	43%	48%	47%	47%	47%	47%	46%	44%	39%	37%	36%	37%	34%
Electric as % of Fleet (end of year)	<1%	<1%	1%	2%	4%	6%	7%	9%	12%	18%	24%	31%	37%	43%	47%	51%	60%	66%
Average Fleet Age (End of Year)	6.8	6.3	6.6	6.5	6.9	6.7	6.8	7.0	7.2	7.1	7.2	7.2	7.3	7.4	7.8	8.0	7.7	7.8

[78] Projection based on fleet requirements, facility capacity, vehicle age, vehicle useful life benchmarks, and procurement plans. Fleet size expected to grow and contract as a result of past vehicle procurement timing. Assumes no vehicles are retired before the end of their 12-year minimum useful life. In order to maintain total fleet requirement of 1,593, some vehicles are expected to be kept past typical useful life benchmarks. Long-term fleet plans to be updated if electric buses demonstrate viability past currently assumed 12 years.

4.5 Metrobus Technology Strategy

Metro continues evaluate emerging on-board bus technologies and business practices. In the coming years, Metro plans to leverage these technologies as much as possible to provide safe, reliable service to its riders. The collection of accurate real-time data and information represents a significant opportunity to improve the overall Metrobus customer experience. Metro also plans to continue its consideration of other aspects of the rider experience, including adjustments to seat types and layouts, real-time information displays for customers, and fare payment infrastructure.

Targets for improvement include the following areas:

- Offering riders more frequently updated bus schedules
- Comprehensive inclusion of all trips in bus schedules
- Improved application of open source data standards in Metrobus information technology
- Increased share of Metrobus vehicles reporting real-time data and information
- Completely accurate location information for Metrobus stops
- Visible, real-time feedback and information for Metrobus operators
- Real-time access to onboard video footage
- Real-time processing of fare card transactions
- Improved automatic passenger counter data accuracy and availability of data in real-time

Metro is currently exploring changes in its scheduling tools and other software integrations to support the advancement of some of these goals.

4.5.1 Electric Bus Deployment Support

As Metro transitions its fleet to include electric vehicles in the coming years, technology and software to support this transition will be required. Electric buses have many functions and needs distinct from those of conventional vehicles. Software needs will include bus scheduling analysis, charge management and other maintenance-related tools. In advance of and during the upcoming electric bus test and evaluation, Metro will continue to evaluate its technology needs.

4.5.2 Autonomous Vehicle Technology

Metro is monitoring the development of autonomous vehicle technology and engaging on policy issues related to their operation. The nature of automated driving can range from minimal driver assistance to full vehicle automation. Metro expects to pursue collision avoidance technologies in the near term while continuing to evaluate the potential of other opportunities for automation. High or full Metrobus automation advancements are not anticipated in the early portion of this plan, but may have impacts on Metrobus planning and operations in the 2030s or beyond.

Section 5. Fleet Maintenance

Each Metrobus vehicle is a major capital investment which requires proper maintenance in order to maximize its service life and reduce capital and operating expenditures. Proper maintenance of the fleet is also essential to providing safe, reliable service.

However, a portion of the fleet will be out of service at any given moment due to unexpected failures. Transit buses, which operate an average of approximately 30,000 miles a year of high-intensity urban driving for Metrobus, occasionally fail in service, regardless of how well they are maintained. The ripple effect of a bus breakdown can include passenger delay, increased travel time and overcrowded buses. In the past, Metrobus had a large portion of older buses in active service, which increased the possibility of breakdown even despite a rigorous maintenance program.

Metro's maintenance needs and requirements will increase over the next decade due to a mix of different vehicle technologies, including the introduction of electric buses. These new technologies continue to evolve over time, demanding new equipment and best practices. Metro expects to develop additional trainings and protocols as its maintenance practice adapts to these new vehicles.

5.1 Overview of Fleet Maintenance

Metro's in-house maintenance functions include the full scope of normal operating maintenance, complete paint and body work, and full component overhaul. The mission of Metro's Office of Bus Maintenance (BMNT) is to provide safe, clean, reliable buses, service vehicles and support equipment to customers in an equitable and efficient manner. Maintenance procedures and practices are continuously reviewed and adjusted to stay ahead of impending issues that could affect future performance. In addition to regularly scheduled maintenance, risks that impact performance outside of BMNT's domain are also evaluated. BMNT uses a Risk Categorization table which enumerates all issues that may potentially reduce the fleet's performance during current and future years.

Metro's Bus Maintenance department has undertaken several initiatives that have improved the reliability and efficiencies of vehicles. Some of the initiatives include upgrading radiators to a product with better service life, upgrading of coolant level sensors, upgrading the original Energy Storage System provided by BAE to a more reliable Ultra capacitor system, and the installation of upgraded Cummins ECM (Engine Control Modules) on many buses. As a result of these initiatives and other improvements, Metro's fleet reliability has improved significantly.

Metro's maintenance functions follow procedures set forth by bus manufacturers' maintenance manuals and Metrobus standard operating procedures (SOPs). Completed maintenance activities are documented on the pertinent reporting forms, reviewed and certified by a supervisor, and entered into the specified reporting system. Metro has established an extensive support infrastructure and quality control process for the program, which allows crews to exercise control over the process. This helps ensure better body work, mechanical component overhaul and bus rehabilitation.

Metro uses an automated online record keeping system, Maximo, to track bus maintenance functions, parts inventory, and record keeping. Metro has both automated and manual systems for record keeping. The automated system catalogues a complete maintenance history on each vehicle and makes it possible to perform a thorough equipment reliability analysis. Using Maximo, maintenance crews are able to track all preventive and corrective maintenance actions. Metro also uses a manual record-keeping system. The combination of automated and manual systems assures the best possible vehicle maintenance at the lowest cost.

Metro follows its Standard Operating Procedure for Inventory Management to set up and/or modify an item in a storeroom within Maximo.[79] The SOP specifies:

- The responsible section for ensuring the sufficiency of stock levels to meet the operating needs of the divisions.
- Stock out rate shall be less than 5% at all locations.
- Target item availability for preventive maintenance (PM), ADA, bike rack, fare box, and other parts
- Storeroom locations shall not have more than 75 line items of "No Demand Material," defined as items which have not been issued to a work order in the past 24 months, to avoid overstock or excess inventory.
- Slow moving items shall be reviewed monthly and adjust ordering as appropriate.

Metro uses the industry standard "reorder point calculation" in order to optimize the reordering process for inventory items. This method captures the last three years' average of vendor lead times, plus the 45 days for internal administrative lead time as well as the demand (average daily usage) of the item. Reorder Point (ROP) is equal to Lead Time multiplied by Demand.

Metro also sets the economic order quantity (EOQ) to a six-month usage at its main distribution center. This is due to the administrative time and cost to complete more than two procurement actions each year. To maintain an acceptable level of inventory, Metro uses a Maximo report that reflects system-wide inventory usage to actual work orders. The Maximo report allows usage of a particular item across all departments. In addition, if a department is forecasting an increase in usage beyond past usage, the department is advised to notify their inventory planning team. In Bus Maintenance, the inventory planning team works closely with Bus Engineering to determine service levels of the fleet to optimize inventory, and attends relevant meetings to understand upticks in failures. In addition, the Bus Engineering and the inventory planning team collaborate to manage the bus fleet from warranty coverage from the manufacturers to operations and maintenance support.

Metro also stages tow trucks and service trucks throughout the system to respond quickly to vehicles that have failed while in service. Service trucks are equipped with fluids, air compressors, tool kits, jump

[79] This function is supported by Metro's Office of Supply Chain Management.

start equipment and spare parts. If service truck personnel are unable to return a disabled bus to service, it is towed to its home division for more extensive repair, and a replacement bus is put into service.

5.1.1 Future Electric Bus Maintenance

Metro's maintenance systems, policies and procedures continue to undergo further developments and refinements over time. Metro also follows guidelines set forth in manufacturers' manuals, in combination with standard practice.

In the coming years, the increased deployment of electric vehicles in the Metrobus system will lead to adjustments to maintenance practices, protocols, equipment, and training. Electric bus equipment is notably distinct from that of conventional vehicles, especially due to the differences between combustion engines and electric motors. While many aspects of electric bus equipment are similar to those of a conventional vehicle,[80] it is anticipated that maintenance adjustments will be required. Metro's Electric Bus Test and Evaluation will provide valuable experience with and insight into electric bus maintenance requirements and best practices.

5.2 Current Fleet Performance

Overall, Metrobus fleet performance has remained roughly consistent over the past few years. Review and update of the maintenance program is done every two years, but this subject to change with delivery of new buses, as well as when a notice of procedure change is received from the manufacturer. Metro also applies its Standard Operating Procedures (SOP) that establishes the requirements for the development and performance of the preventive and corrective maintenance procedures.

Metro recently conducted an effort to revise the terminology of failures and assesses them as:

- Service Interruption: Mechanical failure on the revenue vehicle that prevents the vehicle from completing a scheduled revenue trip, or from starting the next scheduled revenue trip because actual movement is limited, or safety concerns arise.
- Mechanical Failure: Failure of a mechanical element on the revenue vehicle. Some failures result in inconvenience or discomfort to customers, but do not always result in a service interruption (such as farebox or onboard technology equipment failures). A mechanical failure does require corrective maintenance.

5.2.1. In-Service Failures

Metro tracks bus failures on a daily, weekly, and monthly basis. The in-service failures displayed in Table 5-1 vary among buses using different technologies, though primarily driven by the age of the fleet.

[80] Such as wheels, tires, seats, fare payment systems, onboard technology, windows, windshields, etc.

Table 5-1: Top Causes of In-Service Failure, FY2020

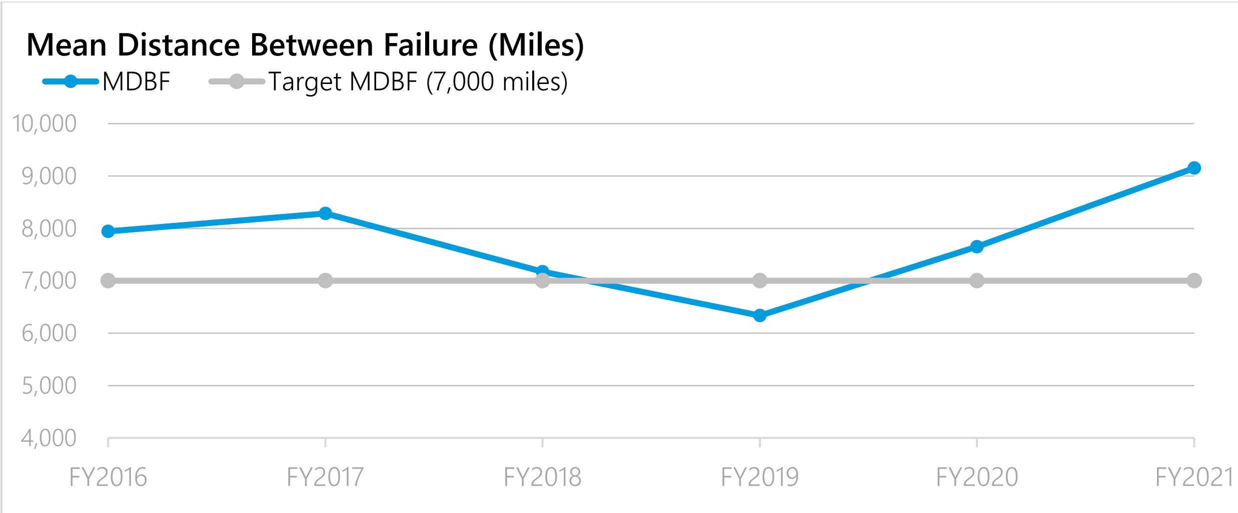
Cause	Counts
Engine/Transmission	784
Body	403
Fluid	359
Air	90
Electrical	76
Exhaust	71
Other	294
Total	2077

5.2.2 Mean Distance Between Failures

Mean Distance Between Failures (MDBF) is defined as the number of chargeable service interruptions during revenue service divided into actual miles. Metro has been able to limit the number of Metrobus failures by applying various operating and maintenance strategies. The replacement of older vehicles, together with standard maintenance practices, has enabled the fleetwide MDBF to remain roughly consistent.

As reported in previous plans, there is a relationship between MDBF, fleet composition, fleet age, and maintenance and operational practices. Metro continues to work to improve the reliability of its fleet through preventive maintenance, mid-life overhauls, fleet management, and other operational practices.

Figure 5-1: Metrobus Mean Distance Between Failures



Metrobus mean distance between failures reached 9,151 miles in FY2021, a 20% improvement compared to the previous fiscal year. This performance was due partly to the reduction in service during the pandemic. Metro was able to operate its most reliable buses on the road and prioritize the maintenance of some older vehicles in the fleet. Additional actions taken to sustain and improve performance included improved failure reporting in Metro's asset management system to allow for more in-depth trend analysis as well as internal quality audits of preventive maintenance programs and service lane activities to identify areas for improvement.[81]

5.3 Types of Maintenance

Two types of maintenance are performed on the Metrobus fleet: Preventive and Corrective maintenance.

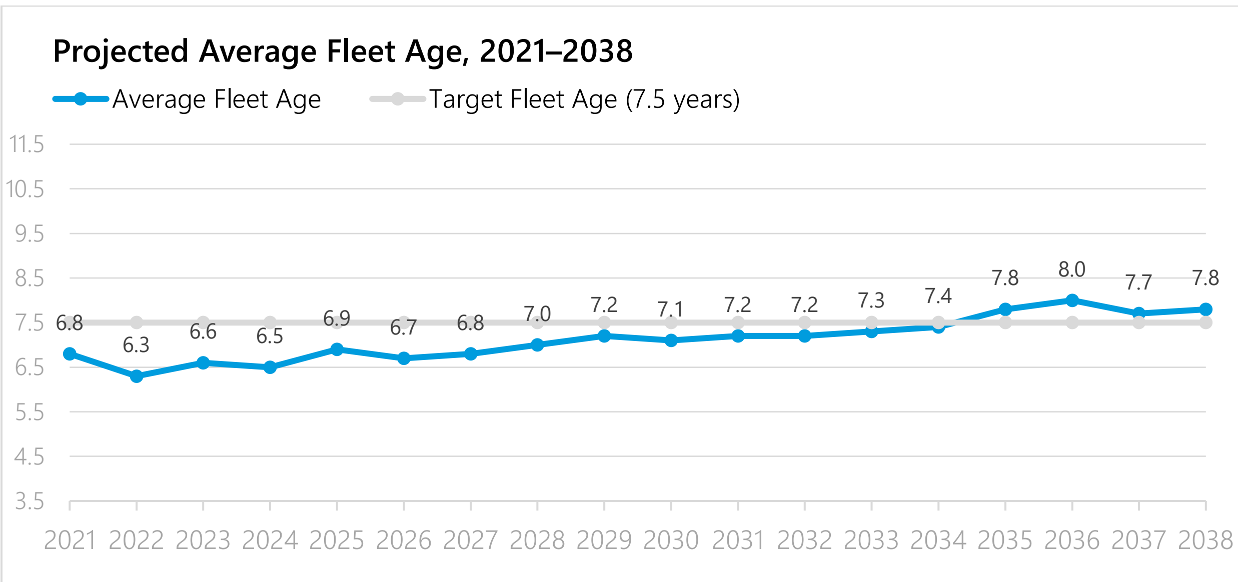
Preventive Maintenance (PM): is a scheduled maintenance program to keep equipment in good working order, prevent in-service failures, and meet certain vehicle regulatory requirements. The mid-life bus overhaul, part of the PM, is critical for maintaining the safety, performance, and reliability of the bus fleet throughout its life. The mid-life overhaul, developed in the 1994, was designed to maintain buses in a state of good repair, reduce in-service breakdowns, improve safety and reliability, and introduce standardization across the fleet as possible.

Corrective Maintenance (CM): is an unscheduled maintenance to respond to unexpected vehicle breakdowns, malfunctions and accidents.

[81] Source: Metro FY2021 Performance Report. https://www.wmata.com/about/records/upload/Q4FY21MetroPerformanceReport.pdf

In recent years, significant improvements in fleet reliability has been made through a combination of bus replacements and a robust maintenance program. As a result, the failure rate of buses has been reduced significantly, thereby improving the reliability of service. This fleet plan projects that Metro will need to keep some vehicles beyond their useful life benchmark in some cases in order to meet fleet requirements. Thus, average fleet age is projected to be slightly above Metro's 7.5 average age target during later points of the analysis period of this plan. If electric vehicle technology demonstrates sustainable useful life beyond Metro's current 12-year benchmark, the fleet's average age may be lowered as older vehicles of other propulsion technologies could be retired sooner. By continuing to operate a fleet with generally consistent average vehicle age of 6 to 7 years in service, Metro anticipates positive ongoing contributions to fleet reliability.

Figure 5-2: Projected Average Fleet Age



5.3.1 Preventive Maintenance (PM)

The Metrobus scheduled PM program sustains bus reliability by detecting and correcting potential defects. Buses are withdrawn from service at regular mileage-based intervals for preventive maintenance actions including inspecting equipment and conducting routine service. The schedule is developed based on manufacturer recommendations and Metro experience. Measures include lubrication, replacing filters, replenishing fluids, making adjustments, cleaning of exterior and interior surfaces, and scheduled replacement of electrical and mechanical equipment. Table 5-2 shows schedules for the preventive maintenance program.

Table 5-2: Preventive Maintenance Schedule

Inspection Type	Inspection Interval	Labor Hours	Buses/Day
ADA Equipment Maintenance	90 days (ramp), 42 days (lift), and annual inspection	3.21	44
A-Inspection	6,000 miles	8.00	36
Bus Interior Cleaning	16 days	4.00	1501
Bus Steam Cleaning	6,000 miles	2.95	36
Camera Maintenance	Biannually	4.00	12
Clever Devices	Annually	2.00	6
Coolant and System Care	Ongoing	0.32	12
Engine Tune Up	36,000 miles	5.10	6
Fire Suppression	Biannually	5.00	12
Fluid Analysis—Various	Varies	0.52	36
GFI Farebox Maintenance	Varies	1.10	7
Heavy Maintenance Overhaul	7.5 years	-	20
HVAC Inspection	90 days/monthly	4.32	24
Interior Cleaning	Monthly	2.00	69
Service Lane Activity	Daily	0.32	1501

A-inspection provides the primary Metrobus vehicle inspection and service, completed every 6,000 miles. It covers the entire vehicle including driver's equipment and controls, passenger interior, vehicle exterior, engine and engine compartment, transmission, battery, chassis, lubrication, and articulation equipment (if pertinent) and culminates with a complete road test.

Each bus goes through daily and bi-weekly regular inspections to ensure day-to-day operations. Service lane activity is a daily cursory inspection concurrent with the routine refueling and service of the vehicle. It includes checking the farebox, fluid levels, lights, doors and interlocks. The interior is also swept, and the exterior is washed.

B-Inspection is done bi-weekly and follows a checklist of bus equipment condition and operation inspection which includes safety and weather-related equipment, passenger seats, stop chimes, doors, floors, windows, wheelchair equipment, brakes, axles, tires, battery, fluid levels, wires and hoses.

5.3.2 Mid-Life Overhaul

Mid-life overhaul, an integral part of the PM program, is another component of the fleet management plan. After reaching its mid-life, a Metrobus will have traveled over 230,000 miles. Many critical parts will wear out and basic overhauls will not be sufficiently able to maintain the expected performance.

Initiated in 1994, the Heavy Maintenance Overhaul Program provides for the rehabilitation of bus mechanical and electrical systems, including overhaul of the engine, transmission, pneumatic equipment, doors, wheelchair lifts, destination signs, suspension, and other structural components. In addition, the interior and exterior of the bus are repainted and all upholstery is replaced.

Heavy overhaul incorporates new technology and safety enhancements, keeps the fleet in compliance with air quality requirements, and permits standardization of configuration across bus fleets of varying ages. Buses undergoing mid-life overhaul is a function of the number of new buses purchased in a given year, available funding and manpower to complete the overhaul, as well as the fleet spare ratio.

On average, Metro plans to replace approximately 100 of its oldest vehicles with new buses each year. Over the years Metro's procurement of buses has varied in numbers – the procurement of over 120 buses per year from 2005 to 2015 has created a residual backup of the mid-life overhaul program, due to demand above the typical capacity of 100 vehicles per year. This backup has caused some mid-life overhauls to occur at least one year beyond the recommended 7.5-year interval.

Currently, 20 buses are in overhaul process at any given time, and each week, the program accepts two in-service buses and releases two buses completing rehabilitation. In some cases, overhauls have been delayed due to previous years with uneven procurement of new vehicles without commensurate expansion of Metro's heavy overhaul capacity. With the transfer of the heavy maintenance overhaul to Andrews Federal Center, it is anticipated that more capacity will be available to address the need for mid-life overhauls in the coming years. Table 5-3 illustrates the mid-life overhaul timing as of FY2020.

Table 5-3: Mid-Life Overhaul Schedule[82]

Year Manufactured	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Quantity	21	147	100	119	105	105	80	246	0	112	100
2020 Rehab	6	4	84								
2021 Rehab			15	85							
2022 Rehab				34	66						
2023 Rehab					38	62					
2024 Rehab						43	57				
2025 Rehab							12	78			
2026 Rehab							11	78			
2027 Rehab								90		10	
2028 Rehab										95	
2029 Rehab										7	86
2030 Rehab											14

[82] Schedule as of FY2020, for existing fleet.

5.3.3 Corrective Maintenance (CM)

With a substantial preventive maintenance program, Metro is able to optimize the corrective maintenance requirement and minimize the accompanying service quality degradation. However, unexpected breakdowns will occur even on new systems and components, and all corrective maintenance is required to be completed within 48 hours, unless awaiting shop repair or deferral for parts acquisition.

5.4 Maintenance Capacity for Fleet

There are four categories of maintenance at Metro as outlined below: warranty, shop, garage and retrofit. The capacity of Metro's operating maintenance is a function of the capacity of the divisions. The following summarizes each of the scheduled maintenance activities.

> Warranty Maintenance: Service and repair of systems and equipment that are still under the manufacturer's warranty. This work is specified by the equipment manufacturer and is required to be accomplished in order to preserve the warranty on the product.
>
> Shop Maintenance: Heavy repair shop work involving activities such as accident repair, scheduled equipment overhaul and unscheduled corrective maintenance (e.g. engine or transmission replacement).
>
> Garage Maintenance: The bulk of Metrobus preventive and corrective maintenance is accomplished at the individual garage level.
>
> Retrofit Maintenance: Activities at this level include manufacturer's recall repairs, and special item retrofits.

On an average weekday, up to 214 buses are expected to undergo different categories of maintenance including heavy overhaul. Since the previous fleet plan, the opening of Andrews Federal Center and Cinder Bed Road Divisions, along with the temporary closure of Northern Division for reconstruction, have led to a total garage storage capacity of 1,681. Metro's daily maintenance capacity is 214 vehicles, as shown in Table 5-4.[83]

[83] This is a standing portion of parking capacity at Metrobus operating divisions which Metro applies as a planning assumption to ensure a balance between vehicles stored and maintenance operation capacity.

Table 5-4: Current Maintenance Capacity

Maintenance Type	Maintenance Capacity (2021)	% of Storage Capacity (2021)
Warranty	17	1.0%
Shop	47	2.8%
Garage	142	8.4%
Retrofit	8	0.5%
Total	214	12.7%
Total Parking Capacity	1,681	100%

5.5 Distribution of Maintenance Functions

Since the 2017 fleet plan, Metrobus has begun utilizing Cinder Bed Road division for heavy overhauls and Andrews Federal Center for both operating maintenance and heavy overhaul. Upon the completion of reconstruction activities at Northern, Southern Avenue Division is expected to close in approximately FY2026. Table 5-5 shows a summary of current Metro maintenance facilities.

Table 5-5: List of Maintenance Facilities

Division	Location	Facility Type
Andrews Federal Center	Prince George's County, MD	Operating Division and Heavy Repair
Bladensburg	District of Columbia	Operating Division
Cinder Bed Road	Fairfax County, VA	Operating Division
Four Mile Run	Arlington County, VA	Operating Division
Landover	Prince George's County, MD	Operating Division
Montgomery	Montgomery County, MD	Operating Division
Northern	District of Columbia	Operating Division
Shepherd Parkway	District of Columbia	Operating Division
Southern Avenue	Prince George's County, MD	Operating Division
West Ox	Fairfax County, VA	Operating Division
Western	District of Columbia	Operating Division
Carmen E. Turner	Prince George's County, MD	Heavy Repair

Currently there are 1,681 vehicle storage spaces in the ten operating divisions, which is above the fleet requirements. This capacity will increase to 1,785 vehicles in approximately FY2027, upon the reopening of Northern Division[84] and the completion of reconstruction activities at Bladensburg Division.[85]

Metrobus currently has 166 maintenance bays available for operating maintenance at the ten operating divisions, 31 of which are capable of servicing articulated buses. With the completion of construction work at Northern in FY2026 and Bladensburg in FY2027, total maintenance bays will number 176, with 48 of those capable of accommodating articulated buses. Standard length buses are able to be serviced in articulated bus maintenance bays as needed.

Table 5-6: Operating Maintenance Bays at Metrobus Divisions, Current and Programmed

Garage	Total Maintenance Bays, FY21	Articulated Maintenance Bays, FY21	Total Maintenance Bays, FY27	Articulated Maintenance Bays, FY27
Andrews Federal Center	19	9	19	9
Bladensburg	23	6	26	11
Cinder Bed Road	13	7	13	7
Four Mile Run	17	0	17	0
Landover	16	0[86]	16	0
Montgomery	17	3	17	3
Northern[87]	-	-	19	12
Shepherd Parkway	26	6	26	6
Southern Avenue	12	0	-	-
West Ox	9	0	9	0
Western	14	0	14	0
Total	166	31	176	48

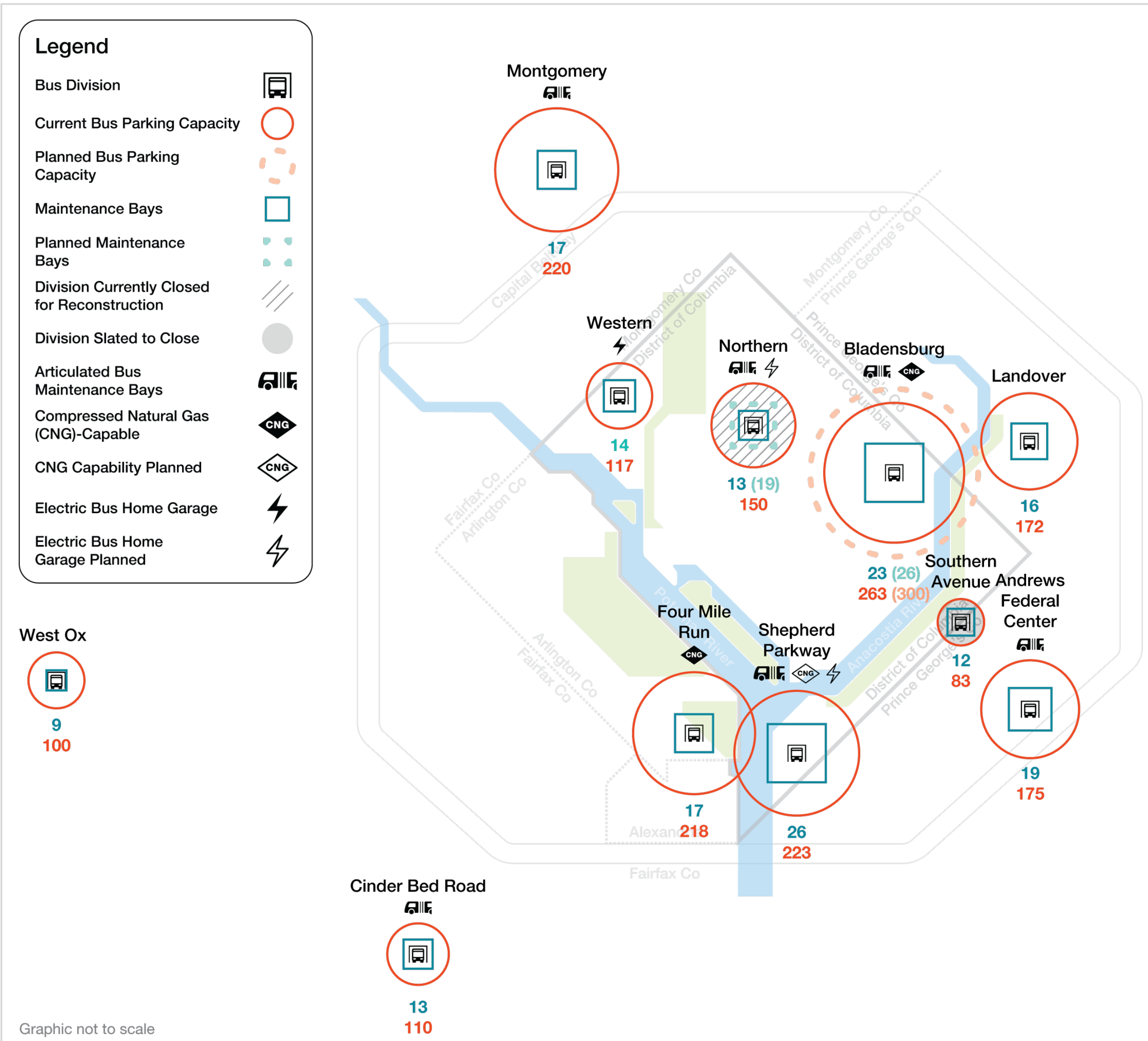
Table 5-6 summarizes current and programmed overall maintenance bay capacity as well as articulated vehicle maintenance bay capacity. As indicated in Section 5.4, the current operating maintenance capacity is 214 buses.

[84] Northern is expected to re-open in FY2026.
[85] Reconstruction activities at Bladensburg are expected to complete in FY2027.
[86] Up to 8 articulated buses could be maintained on a temporary basis at Landover using portable lifts.
[87] Currently closed for reconstruction until FY2026.

Section 6. Facilities

This section documents Metrobus Facilities for operations, maintenance, heavy repair shop, heavy overhaul shop, and training facilities. Figure 6-1 shows the locations and functions of the facilities in the Metrobus system.

Figure 6-1: Metrobus Operating Divisions



6.1 Metrobus Facilities

As of December 2020, Metrobus vehicles are operated and maintained at ten operating and eleven maintenance facilities. Four operating and four maintenance facilities are located in the District of

Columbia, currently four operating and five maintenance facilities in Maryland and currently three operating and maintenance facilities in Virginia. Prior to the temporary closing of Northern Operating Division, Metro's existing parking capacity was 1,831 buses. However, the 150-bus capacity at Northern division is currently unavailable while the facility is undergoing reconstruction, leading to a total existing garage capacity of 1,681. These construction efforts are expected to conclude in FY2026. Metro's Bladensburg Operating Division is currently undergoing construction modifications, and its capacity will expand from 263 buses to 300 buses upon its completion in FY2027. After Northern construction is complete, Metro expects to discontinue operations at its Southern Avenue Operating Division, bringing its total parking capacity to 1,785 buses.[88]

Two new Metrobus operating and maintenance facilities were opened in 2019: Cinder Bed Road, which currently houses 100 standard buses and 10 articulated buses, and Andrews Federal Center, which houses 148 standard buses and 27 articulated buses.

Metro has a compressed natural gas (CNG) capacity of 481 buses, or approximately 29% of the FY2021 fleet capacity, which will grow with the completion of CNG installation at Shepherd Parkway and expansion of CNG capacity at Bladensburg Road. The facility improvements currently programmed will allow up to 741 buses, or approximately 42% of Metro's total fleet parking capacity, to be powered with CNG from approximately FY2027 onward.

Table 6-1: Compressed Natural Gas (CNG) Bus Fueling and Maintenance Capacity, as Programmed in FY2022

Fiscal Years	Facility Change	Total CNG Bus Fueling and Maintenance Capacity	Programmed Total Capacity	CNG as % of Total Capacity
FY20–FY22	None planned	481	1,681	29%
FY23–FY25	Shepherd Parkway CNG conversion completed in FY2023	704	1,681	42%
FY26	Northern re-opens, Southern closes	704	1,748	40%
FY27 onward	Bladensburg construction complete	741	1,785	42%

Two existing support facilities provide specialized maintenance services for the Metrobus System. The Carmen Turner Facility is a heavy maintenance and training facility in Prince George's County in Maryland. Buses in need of major repairs are cycled through Carmen Turner Facility for major body work, paint and maintenance functions. The Andrews Federal Center Heavy Overhaul Shop, collocated

[88] Northern will add 150 spaces, Bladensburg will add 37 spaces, and the closure of Southern Avenue will reduce spaces by 83.

with the Andrews Federal Center Operating Division, is a heavy repair shop that serves as the home of the Metro Heavy Maintenance Overhaul Program.

6.2 Existing Metrobus Facilities

Metrobus divisions currently are designed and organized for a total parking capacity of 1,668 vehicles. In FY2026, Metrobus facilities will be able to accommodate a total of 1,785 vehicles, following the completion of reconstruction activities at Northern and Bladensburg Divisions. While seven Metro facilities are capable to store and maintain articulated buses, Landover Division is not configured to do so on a permanent basis.

Currently, Metro can store 174 articulated buses at six divisions. This capacity will increase to a total of 324 articulated buses upon the completion of reconstruction at Northern and Bladensburg Divisions.

Table 6-2: Parking Capacity by Division, as Programmed in FY2022

Division	Total Parking Capacity, FY22	Articulated Parking Capacity, FY22	Total Parking Capacity, FY27 onward	Articulated Parking Capacity, FY27 onward
Andrews Federal Center	175	27	175	27
Bladensburg	263	25	300	100
Cinder Bed Road	110	10	110	10
Four Mile Run	218	-	218	-
Landover	172	8	172	8
Montgomery	220	24	220	24
Northern	-	-	150	75
Shepherd Parkway	223	80	223	80
Southern Avenue[89]	83	-	-	-
West Ox	100	-	100	-
Western	117	-	117	-
Total	1,681	174	1,785	324

Andrews Federal Center: Andrews Federal Center Bus Garage is located in Forestville, Maryland. Operations began in July 2019, following the rerouting of bus routes that had previously terminated at the Southern Avenue facility. Heavy Overhaul functions, Central Warehouse, Non-Revenue Vehicle Service Shop, Bus Engineering, and the Signs & Shelters Shop that originally operated out of Bladensburg were transferred to this facility.

[89] Southern Avenue Division is expected close in FY26 upon the reopening of Northern Division.

Bladensburg: Bladensburg Bus Division located at 2251 26th Street NE in the District of Columbia. The original division was constructed in 1962 and is currently being reconstructed and replaced with a safe, modern facility built to LEED standards for storage and maintenance of Metro's bus fleet. The new facility will have CNG and diesel support capabilities. During the construction period, CNG fueling capability will become available at the Shepherd Parkway bus division. Bladensburg currently has capacity for 238 standard buses and 25 articulated buses. When the new facility opens in FY27 (the estimated opening date), it will have capacity for 200 standard buses and 100 articulated buses. Metro is working to ensure this facility is electric bus-ready when it re-opens, though additional infrastructure and planning steps would be required.

Carmen Turner Facility: The Carmen Turner Facility is a heavy maintenance and training facility in Prince George's County in Maryland. Buses in need of major repairs are cycled through Carmen Turner Facility for major body work, paint and maintenance functions. While buses used for training or special service are parked at Carmen Turner, which is located directly across Pennsy Drive from Landover Division, there are no plans to expand revenue bus parking and routine maintenance functions to Carmen Turner at this time.

Cinder Bed Road: Cinder Bed Road Division was built as a replacement for the Royal Street Division, which was closed in 2014. This division is located along Cinder Bed Road in the Newington area of Fairfax County. This facility currently has capacity for 110 buses (100 standard buses and 10 articulated buses).

Four Mile Run: Four Mile Run Division is located on South Eads Street between Four Mile Run and 32nd Street South in Arlington County, Virginia. The project site is split by South Glebe Road and the site was reduced in size due to adjacent roadway widening in the 1980s. This division is one of the two divisions where CNG buses can be fueled, stored, and maintained. This Division has a storage capacity of 218 standard buses and 17 maintenance bays.

Landover: Landover Division is located on Pennsy Drive between Landover and New Carrollton Metrorail Stations in Prince George's County, Maryland. Landover Division has capacity for 164 standard and 8 articulated buses and has 16 standard maintenance bays. A major service lane and storage area project was completed in 2016 that improved operations of the facility.

Montgomery: Montgomery Division is located on Marinelli Road between Citadel Avenue and Nebel Street near White Flint Metrorail Station in Montgomery County, Maryland. Montgomery Division has a capacity for 220 buses, including 196 standard and 24 articulated buses. This location also has 17 maintenance bays, 3 of which can accommodate articulated buses.

Northern: Northern Division is located on 14th Street NW between Buchanan Street NW and Decatur Street NW in Washington, DC. After its reconstruction, articulated buses will be stored and maintained at Northern. This division was closed in 2019 and is scheduled to be fully reconstructed – built to LEED standards – with a capacity of 75 standard buses and 75 articulated buses with an anticipated reopening in FY2026. In September 2021, Metro announced plans for Northern to be its first all-electric bus garage upon reopening.[90]

Shepherd Parkway: Shepherd Parkway Division was constructed and opened in 2012 and is located near the intersection of Blue Plains Drive SW and DC Village Lane SW in southwest Washington, DC. Shepherd Parkway Division has a capacity for 223 buses, including 143 standard buses and 80 articulated buses. There is a total of 26 maintenance bays, six of which can be used for articulated buses. A new CNG fueling facility is under construction at Shepherd Parkway which will add new capability to support the CNG fleet. Shepherd Parkway has been chosen to house a test pilot of 12 electric buses.

Southern Avenue: Southern Avenue Division is located near the intersection of Southern Avenue and Marlboro Pike in Prince George's County, Maryland, near the District of Columbia border. Southern Avenue Division has a capacity for 83 standard buses and has 12 maintenance bays. This division was planned for closure upon the opening of the new Andrews Federal Center Division but remains open to maintain the capacity lost from Bladensburg and Northern divisions when their reconstruction work began. Southern Division is expected to close after construction efforts at Northern conclude, but these plans have not been finalized.

West Ox: West Ox Division is located on Alliance Drive between Piney Branch Road and Fairfax County Parkway in Fairfax County, Virginia. This Division has a storage capacity for 100 standard buses, with nine maintenance bays. This location replaced the former Arlington Division. Metro has limited to no ability to initiate reconstruction at this Fairfax County-owned facility.

Western: Western Division is located near the intersection of Jenifer Street NW and 44th Street NW in the Friendship Heights neighborhood of Washington, DC. Western Division has a capacity for 117 standard sized buses and has a total of 14 maintenance bays.

6.3 Maintenance Facilities Requirements

Metro currently has a lower proportion of articulated buses in its fleet compared to nine similar large peer transit agencies, at around 4% of its total fleet. Its ability to house additional articulated buses is constrained by maintenance bay capacity (i.e. maintenance bays that can service 60' three axle buses), which major operators aim to keep at a ratio of 10 vehicles to each bay. Metro currently has 31 articulated-capable maintenance bays and a total parking capacity for 174 articulated buses. While the current fleet of articulated buses can be accommodated by the existing maintenance bays, the suggested capacity ratio would be exceeded if Metro grows the articulated fleet to meet total parking capacity. Tables showing the capacity of each operating division by propulsion type are found in this document's appendix.

[90] https://www.wmata.com/about/news/First-all-electric-bus-garage-to-be-built-at-Northern-bus-facility.cfm

Metro's existing and programmed facilities will offer sufficient capacity to accommodate the planned increase in the size of the Metrobus articulated fleet. However, current Metrobus facilities and infrastructure are not sufficient to support the anticipated growth of the electric bus fleet. As a result, this plan has identified the facilities gaps expected through FY2038, and estimates the total number of facilities which will require conversion to accommodate these new vehicles. Table 6-3 summarizes these capacity gaps.

Table 6-3: Division Needs, Existing and Planned Vehicle Capacity, Selected Years

	FY25	FY30	FY35	FY38
Electric Bus Storage Capacity	13	163	163	163
Electric Bus Fleet Size	63	288	785	1,048
Electric Bus Capacity Gap	50	125	622	885

In September 2021, Metro announced plans to reopen Northern Bus Garage with the infrastructure and equipment needed to operate 100% electric vehicles.[91] This facility's 150-bus capacity will support the conversion of the Metrobus fleet to be fully zero-emission by 2045.

The average Metrobus operating division has a capacity of approximately 165 buses, with the smallest division having a capacity of 83 and the largest a capacity of 263. Starting in FY24 and continuing in FY25, Metro will require at least one additional partial facility conversion to accommodate the storage and fueling of its projected FY25 electric bus fleet size of 63 vehicles. The electric bus fleet will continue to grow over time, requiring the equivalent of five or more facility conversions by FY38.

Due to these identified facilities' needs, significant capital investment will be required to support Metro's transition to an electric fleet. Section 6.5 discusses the extent to which each operating division may be conducive to electric-capable reconstruction.

Metro's existing and programmed CNG support capacity is generally expected to be able to support the anticipated size of the CNG fleet. Depending on ultimate vehicle delivery and retirement dates, some CNG buses may be decommissioned after 12 years in service.[92] The CNG bus fleet's unmet storage and fueling needs will peak in FY27, when the estimated CNG fleet size of 764 vehicles will outstrip programmed system capacity by 23 vehicles. In FY28, the fleet size with outstrip available capacity by 14 vehicles. Metro expects to be able to maintain and fuel its CNG fleet without the

[91] https://www.wmata.com/about/news/First-all-electric-bus-garage-to-be-built-at-Northern-bus-facility.cfm

[92] Metro generally plans to operate standard length vehicles in service for 15 years in accordance with its useful life benchmarks. The Federal Transit Administration establishes a minimum useful life of at least 12 years of service for large, heavy-duty transit buses.

construction of additional CNG facilities beyond programmed work at Shepherd Parkway and Bladensburg.

6.4 Electric Bus Facility Requirements

Metro is initiating an electric bus test and evaluation and is developing a transition plan for zero-emission buses. Metro envisions a scaled approach to the conversion to electric or other zero-emission technologies that will account for future technical advances, costs, scalability, current and future constraints, and all other aspects that can be foreseen and addressed. Metro will work to determine what can be accomplished within current power grid capabilities, as well as with power grid and facility upgrades that would support eventual conversion of the Metrobus fleet to 100% electric or other zero-emission operation at each facility. This plan will outline the key pieces of a coordinated approach across multiple regional agencies and stakeholders to support the successful evolution of the Metrobus fleet.

Metro currently has one electric bus based at Western Division and is planning to commence a 12-bus test and evaluation program at Shepherd Parkway. Upon the completion of construction work, Bladensburg Division is expected to have the potential to house electric buses, pending the completion of design work to install charging infrastructure and support equipment. Northern is planned to open with full electric bus support capabilities.

Metrobus facilities will require adjustments as fleet needs evolve in the coming years. Chargers, conduits, transformers, and other equipment will need to be installed in each garage offering electric bus support. Garage configurations in some cases may require modifications to ceiling height or parking and maintenance area dimensions. Electric bus technology is also expected to introduce new facility needs for parts and materials storage. Safety considerations and protocols must also be taken into account as new equipment is stored or installed at Metro facilities.

6.5 Electric Bus Expansion at Metrobus Facilities

Metro faces varying considerations when evaluating electric bus support at its existing operating divisions. The reconstructed Northern Division is expected to be completed in FY2026 and will reopen as Metro's first operating division capable of full all-electric bus support.[93] Considerations for electric facility conversion at Metrobus divisions include:

Andrews Federal Center: This new facility was not built to accommodate electric service. It may be a candidate for long-term retrofit to support electric vehicles.

Bladensburg: This division is undergoing reconstruction and rehabilitation. Metro expects this facility to be designed to be electric-bus ready, though installation of the required charging infrastructure and other support systems would be required, and continue to support CNG buses.

[93] https://www.wmata.com/about/news/First-all-electric-bus-garage-to-be-built-at-Northern-bus-facility.cfm

Cinder Bed Road: This newer facility is not electric bus-ready and may require a conversion of its parking lot to accommodate overhead charging.

Four Mile Run: While this division is located adjacent to a Dominion Energy substation, recent development in the area suggests it may not have the capacity to support electric bus charging requirements. In addition, space to expand the facility is limited. While it is likely the division will continue to house only CNG vehicles in the near future, it could be modified as part of substation upgrades with storage to accommodate limited electric bus layovers or fast-charging equipment.

Landover: Landover has been identified as a potential location to support electric buses, but a 1.35-mile extension of electric utility capability from a nearby BGE substation, as well as a potential redistricting to Pepco to operate the system's full capacity of electric vehicles, may be required to do so. Landover's location across Pennsy Drive from the Carmen Turner Facility has been identified as a strategic reason to consider prioritizing its conversion to electric bus support.

Montgomery: This division is directly adjacent to a planned upgrade of Pepco's White Flint substation. Connections between the substation and division with feeders may be feasible in the coming years. As the facility may already be a higher priority for renovation in the coming years, it could be considered for future garage electrification.

Shepherd Parkway: Shepherd Parkway has been chosen to house a test pilot of 12 electric buses, in part due to its strategic proximity to Metrobus operating territory in the District of Columbia, Northern Virginia and Prince George's County, Maryland. The implementation of new feeders could potentially be coordinated with any potential expansion of electrical capacity at the District of Columbia Public Schools bus storage site directly to the south of this division.

Southern Avenue: This division is expected to close following the completion of reconstruction efforts at Northern Division, though these plans have not been finalized. It is not currently targeted for upgrades to accommodate electric bus charging.

West Ox: Metro has limited ability to spearhead facility reconstruction at this facility, which is operated in partnership with Fairfax County.

Western: Western Division currently houses Metro's first and only electric bus, and its proximity to a Pepco substation and older condition, poising it for other reconstruction needs, suggest it may be a good site for conversion to accommodate additional electric buses. The facility likely does not have room to expand beyond its current footprint.

Appendix

Appendix A: Additional Materials and Information

Acronyms

ADA	Americans with Disabilities Act
APC	Automatic passenger counter
BMNT	Metro's Office of Bus Maintenance
BRT	Bus rapid transit
BTP	Bus Transformation Project
CM	Corrective maintenance
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
DDOT	District Department of Transportation
FTA	Federal Transit Administration
GHG	Greenhouse gas
MCDOT	Montgomery County Department of Transportation
MDBF	Mean distance between failures
MPDGE	Miles per diesel gallon equivalent
MWCOG	Metropolitan Washington Council of Governments
NOx	Nitrogen Oxide
PCN	Priority Corridor Network
PM	Preventive maintenance
PM_{10}	Particulate matter 10 micrometers or smaller
$PM_{2.5}$	Particulate matter 2.5 micrometers or smaller
PVR	Peak vehicle requirement
RNG	Renewable natural gas
SOP	Standard operating procedure
STRF	Short-term ridership forecast
TPB	Transportation Planning Board
VOC	Volatile Organic Compound
WMATA	Washington Metropolitan Area Transit Authority

Definition of Terms

Articulated Bus – A bus 60 feet or longer, typically with two sections linked together by a pivoting joint.

Authority – The Washington Metropolitan Area Transit Authority.

Corrective Maintenance – Unscheduled maintenance to respond to unexpected vehicle breakdowns, malfunctions and accidents.

Electric Bus – A bus which is powered by one or more on-board electric batteries rather than some other fuel source.

Elevator Bus – Shuttle buses required to operate bus bridge service between adjacent Metrorail stations during times when their elevators are out of order.

Headway Management Bus – Scheduled buses which fill in for late buses on specific headway-managed routes.

Maximo – Metro's enterprise asset management system.

Mean Distance Between Failures – A measure which reports the number of miles between chargeable service interruptions. The higher the mileage for the mean distance between failure, the more reliable the bus fleet.

Mid-Life Overhaul – The rehabilitation of the mechanical and electrical systems of a bus, including overhaul of the engine, transmission, pneumatic equipment, doors, wheelchair lifts, destination signs, suspension, and other structural component overhauls and repairs.

Operating Division – A location where buses are stored, maintained, and serviced.

Peak Vehicle Requirement – The maximum number of vehicles that Metro regularly deploys in service, excluding spare vehicles and vehicles set aside for other purposes.

Preventive Maintenance – A program of scheduled maintenance intended to keep equipment in good working order, prevent in-service failures, and meet certain vehicle regulatory requirements.

Range – The distance a bus is able to travel in revenue service without requiring refueling or recharging.

Ready Reserve Bus – Older vehicles, not scheduled in regular service, which are suitable for passenger service to support regular revenue operations or special events, accommodate approved temporary service changes, replace buses that are removed from service for fleet failures and provide buses for emergency situations.

Spare Ratio – The number of spare vehicles (as defined by subtracting the Peak Vehicle Requirement from the total active fleet) divided by the Peak Vehicle requirement.

Strategic Bus – Scheduled buses which are placed to be available to support a variety of routes in the event of unforeseen delays or disruptions in the provision of service.

Zero-Emission Bus – A bus which does not emit pollutants at the tailpipe in operation.

A1: Socioeconomic and Demographic Changes in the Washington Metropolitan Area, 2010–2019

The following review of socio-economic and demographic changes in the Washington-Arlington-Alexandria, DC-MD-VA-WV Metro Area for the 2010-2019 period supports the discussion of Metrobus ridership in Section 2. The data used in the analysis is drawn from United States Census Bureau and American Community Survey (ACS) data.

As Table A-1 shows, population in the Washington-Arlington-Alexandria, DC-MD-VA-WV Metro Area (which is not coterminous with Metro's service area), grew by nearly 12% between 2010 and 2019. The number of employed persons in the civilian workforce increased by 15% over the same period. The percentage of the population that was employed in the civilian workforce increased from 52.4% to 53.8% from 2010 to 2020.

Table A-1: Population in the Washington-Arlington-Alexandria, DC-MD-VA-WV Metro Area[94]

Year	Population	Civilian Labor Force-Employed	% of Population Employed
2010	5.61	2.94	52.4%
2011	5.70	2.99	52.5%
2012	5.80	3.08	53.1%
2013	5.95	3.14	52.8%
2014	6.03	3.18	52.7%
2015	6.10	3.25	53.3%
2016	6.13	3.27	53.3%
2017	6.22	3.34	53.7%
2018	6.25	3.37	53.9%
2019	6.28	3.38	53.8%
Change, 2010–2019	11.9%	15.0%	
Change, 2014–2019	4.1%	6.3%	

[94] Source: United States Census Bureau American Community Survey (ACS).

Table A-2 shows that median income in the Washington region increased by 25% between 2010 and 2019, and 16% just since 2014. The increase from 2014 to 2019 was, nearly twice the rate of inflation over the same time period.

Table A-2: Median Income in the Washington Metropolitan Region[95]

Year	Median Household Income
2010	$84,523
2011	$86,680
2012	$88,233
2013	$90,146
2014	$91,193
2015	$93,294
2016	$95,843
2017	$99,669
2018	$102,180
2019	$105,659
Change, 2010-2019	25.0%
Change, 2014-2019	15.9%

[95] Source: United States Census Bureau American Community Survey (ACS).

The number of households with incomes below $25,000 per year—households in which a large share of Metrobus customers live—dropped between 2010 and 2019. As shown in Table A-3, the Washington region added nearly 210,000 households from 2010 to 2019—an increase of more than 10%. Over the same time period, the number of households with incomes less than $25,000 declined by more than 14%, with almost all of that decline (13.6%) occurring since 2014. The percentage of households with incomes below $25,000 declined from 12.2% in 2010 and 11.5% in 2014 to 9.5% in 2019.

Table A-3: Washington Metropolitan Region Households and Their Incomes, 2010–2019[96]

Year	Total Households	Income <$25,000	% of Households with an Income <$25,000
2010	2,042,154	249,778	12.2%
2011	2,071,390	250,419	12.1%
2012	2,085,494	240,133	11.5%
2013	2,133,062	246,965	11.6%
2014	2,154,147	248,357	11.5%
2015	2,172,310	236,117	10.9%
2016	2,191,806	251,823	11.5%
2017	2,203,717	229,101	10.4%
2018	2,234,559	231,573	10.4%
2019	2,251,002	214,478	9.5%
Change, 2010–2019	10.2%	-14.1%	
Change, 2014–2019	4.5%	-13.6%	

[96] Source: Census Bureau American Community Survey (ACS).

Table A-4 shows the number of households in the region with access to one, two, and three or more vehicles, for each year between 2010 and 2019. While the number of households in the region increased by 10.2%, the number of households with access to at least one vehicle increased by 11.7% between 2010 and 2019. While the number of "zero-car households" in the region remained around 210,000 throughout the decade, the percentage of zero-car households fell from around 11.1% in 2010 to 9.9% in 2019.

Table A-4: Washington Metropolitan Region Households by Number of Accessible Vehicles, 2010–2019[97]

Year	1 Vehicle	2 Vehicles	3+Vehicles	At Least 1 Vehicle	% of Households
2010	666,634	733,570	415,605	1,815,809	88.9%
2011	695,390	747,294	409,924	1,852,608	89.4%
2012	699,486	745,955	423,844	1,869,285	89.6%
2013	701,047	782,166	436,312	1,919,525	90.0%
2014	726,223	774,708	443,652	1,944,583	90.3%
2015	723,518	784,926	445,395	1,953,839	89.9%
2016	719,214	784,674	465,551	1,969,439	89.9%
2017	725,490	804,757	463,373	1,993,620	90.5%
2018	732,567	804,696	481,843	2,019,106	90.4%
2019	743,339	806,894	478,170	2,028,403	90.1%
Change, 2010–2019	11.5%	10.0%	15.1%	11.7%	
Change, 2014–2019	2.4%	4.2%	7.8%	4.3%	

A2: Current Ridership Characteristics

Within the Metro service area, 5% of residents ride the bus to work during the morning peak period, according to the 2013-2018 American Community Survey 5-Year Estimates. This percentage includes both Metrobus and local bus service ridership. In areas of a quarter-mile walking distance to Metrobus lines, Metrobus commuting mode share reaches 9 percent. Since 2013, the mode share of commuters using bus transit has decreased from 7 to 5%, while the mode share of commuters using any mode of transit has decreased from 19 to 13 percent.

[97] Source: United States Census Bureau American Community Survey (ACS).

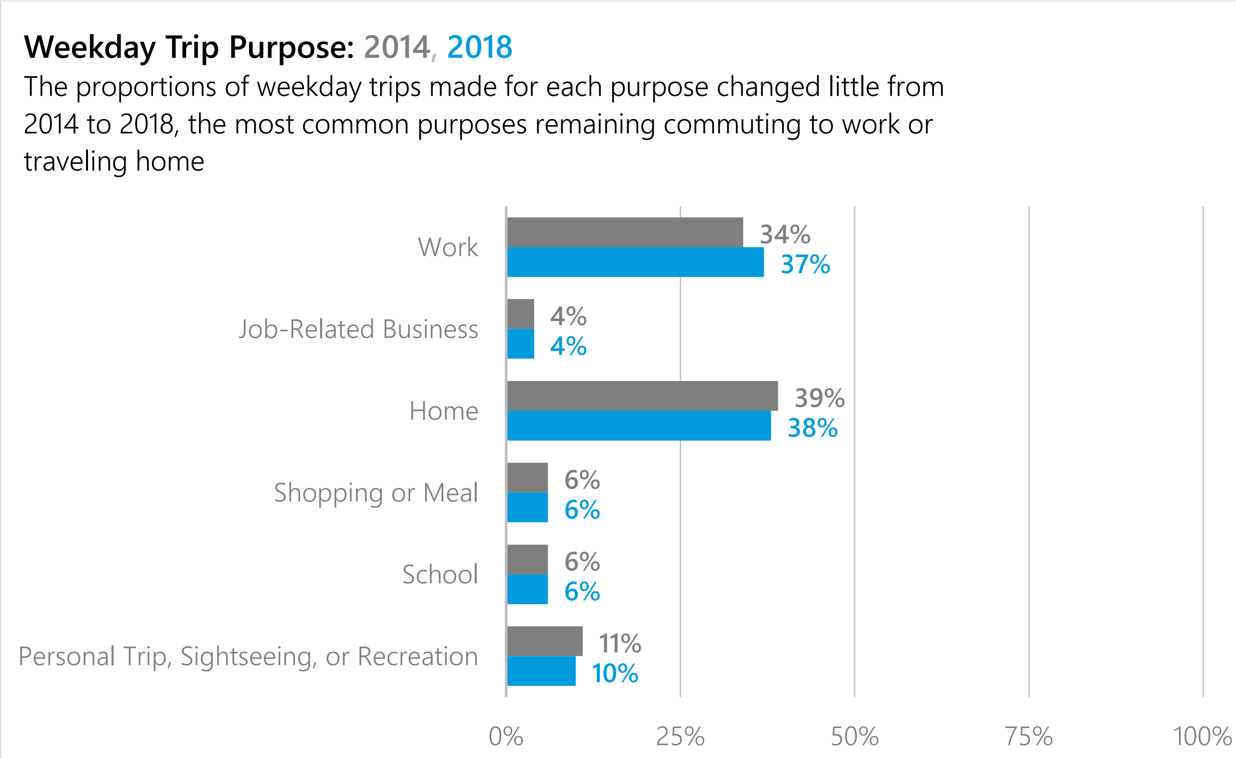
A Metrobus Passenger Survey was conducted in 2018, updating the previous surveys conducted in 2014 and 2008. The results of the survey illuminated many characteristics of Metrobus ridership, as discussed in this section.

In accordance with Metro's survey standardization practice, methodological updates occurred between 2014 and 2018 data reporting to improve comparability of metrics with other data collected by the Authority. Included in this practice is the reporting of valid survey percent instead of percent of total surveys. Unless otherwise specified, average weekday results are reported.

A3: Purpose of Metrobus Trips

The Metrobus Passenger Survey determined trip purpose by stated destination, tabulated into six categories: work, home, shopping or eating, school, job-related business, and personal trips/sightseeing/recreation. Results for 2014 and 2018 are shown in Figure A-2. Trips to work or work-related trips accounted for 41 percent of trips in 2018, or two-thirds of all trips if home-return trips (38 percent of the total in 2018) are eliminated. The percentage of work-related trips increased from 38 percent in 2014 to 41 percent in 2018, possibly reflecting the lower unemployment rate in the latter year. The percentage of personal, sightseeing or recreation trips declined from 11 to 10 percent between 2014 and 2018. The percentages of trips made for other purposes (school and shopping or meals) remained at 6 percent for 2014 and 2018.

Figure A-1: Weekday Trip Purpose, 2014 and 2018[98]



A4: Characteristics of Metrobus Passengers—Ethnicity & Socioeconomic Factors

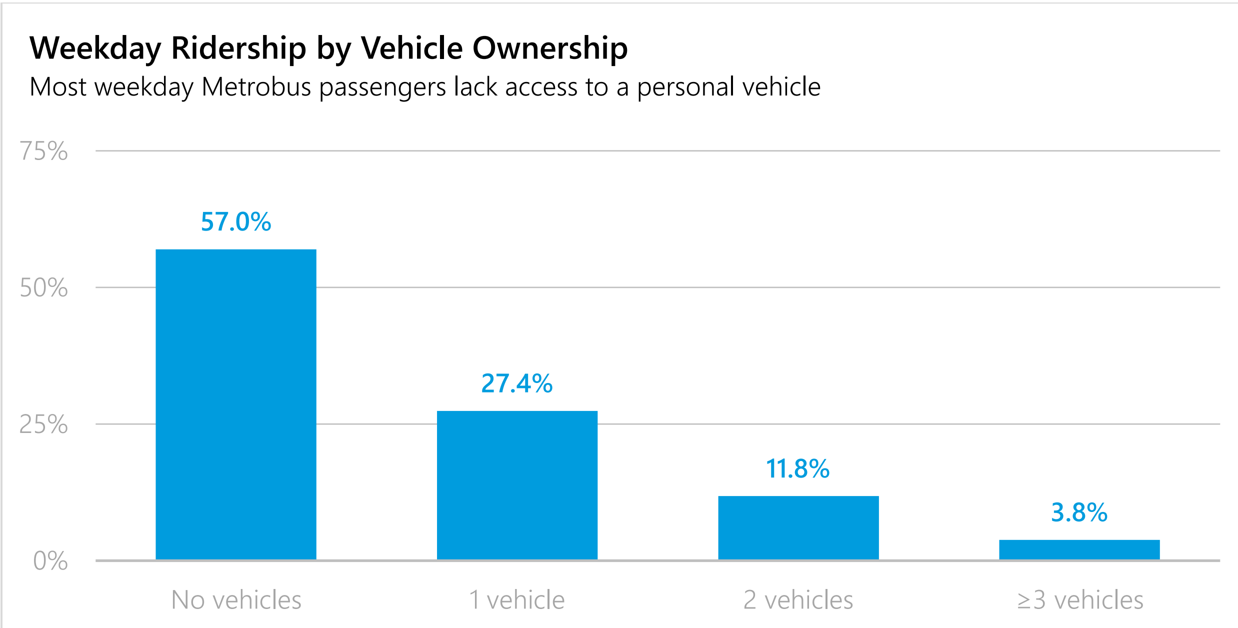
More than half (58%) of Metrobus riders are African American, though the proportion of African Americans fell, and the proportion of Hispanics and whites increased, between the 2014 and 2018 surveys. Metrobus riders span the income spectrum, with twelve percent reporting annual incomes of over $100,000 per year in 2018. However, nearly half (45%) reported household incomes below $30,000 per year. The proportion of riders with incomes below $75,000 per year fell between 2014 and 2018, while the proportion with higher incomes increased.

A5: Vehicle Ownership

According to the 2018 Metrobus Passenger Survey, 43 percent of Metrobus riders are in household with at least one vehicle. Vehicle ownership for Metrobus riders is outlined in Figure A-2.

[98] Source: 2018 Metrobus Passenger Survey.

Figure A-2: Weekday Ridership by Vehicle Ownership[99]



[99] Source: 2018 Metrobus Passenger Survey.

A6: Mode of Access

The 2018 Metrobus Passenger Survey used mode of access evaluate how passengers arrive at Metrobus stops prior to boarding the bus. Responses indicate that 70% of riders walked to Metrobus stops, whereas 27.5% arrived from Metrorail or other public transit service.[100] The remaining respondents used other modes of access to reach their destination, as shown in Table A-5.

Table A-5: Mode of Access for Weekday Ridership[101]

Access Mode	Percentage
Walked	70.0%
Wheelchair	0.7%
Metrorail	13.0%
Other bus service	12.0%
Drove a car and parked	2.0%
Dropped off by someone	2.0%
Ride-hailing service (e.g. Uber, Lyft, Via)	2.0%
Bicycle	0.6%
Rode own bicycle	0.6%
Bikeshare	0.5%
Amtrak, MARC or VRE	0.1%
Taxi	0.5%
Rode with someone who parked	0.5%
HOV or HOT Carpool	0.3%
Scooter-sharing service	0.1%
Vanpool	0.1%

[100] Including Metrobus, another bus service, Amtrak, MARC, or VRE.
[101] Source: 2018 Metrobus Passenger Survey.

A7: Additional Information

Table A-6: Bus Comparison Chart, Lifecycle Cost Analysis[102]

Length	40'	40'	40'	40'	40'
Propulsion Type	Diesel	Hybrid (Diesel)	CNG[103]	Battery-Electric Bus	Fuel Cell Bus
Lifespan (Years)[104]	15	15	15	12	12
Range (Miles)	>300	>300	>300	150[105]	250
2021 Est. Capital Cost (Including Midlife Overhaul)	$710,000	$900,000	$800,000	$1,025,000	$1,375,000
2021 New Facility Costs[106]	N/A	N/A	N/A	$300,000	$100,000
Total Capital Cost[107]	$710,000	$900,000	$800,000	$1,325,000	$1,475,000
2020 Fuel Cost	$2.09	$2.09	$0.72	$0.085	$7.5
Fuel/Energy Unit	gallon	gallon	diesel gallon eq.	kWh	kg
Miles/Fuel Unit (e.g. Miles/Gal)	3.48	4.31	3.36	0.33	8.00
Cost/Mile	$0.60	$0.49	$0.21	$0.26	$0.94
Annual Fuel Cost	$18,594	$15,038	$6,640	$7,905	$29,063

[102] Costs are depicted on a per bus basis.
[103] Metro is currently issuing a procurement for Renewable Natural Gas (RNG), which would further reduce CNG emissions.
[104] Useful life benchmark assumption for standard 40' buses. All articulated 60' buses will have a 12-year assumed useful life benchmark.
[105] Battery-electric bus range is especially impacted by weather and ambient temperature, and can drop below this range under some conditions.
[106] Facility conversion not required for Diesel or Hybrid buses. Expansion of CNG capacity is not anticipated.
[107] Includes vehicle purchase capital costs and facilities and equipment expansion costs for low-emissions buses. Estimates for standard 40' buses, includes PPA warranty (if not standard for manufacturer inclusion) and midlife overhaul costs.

Table A-6: Bus Comparison Chart, Lifecycle Cost Analysis (Continued)[108]

Length	40'	40'	40'	40'	40'
Propulsion Type	Diesel	Hybrid (Diesel)	CNG[109]	Battery-Electric Bus	Fuel Cell Bus
Labor/Mile	$0.59	$0.66	$0.68	$0.90	$0.90
Materials/Mile	$0.30	$0.34	$0.30	$0.30	$0.37
Services/Mile	$0.20	$0.20	$0.31	$0.20	$0.31
Fluids	$0.05	$0.04	$0.03	$0.02	$0.02
Tires	$0.08	$0.08	$0.08	$0.09	$0.09
Annual Maintenance Cost	$38,239	$40,929	$43,251	$46,531	$51,960
Total Annual Operating Cost[110]	$56,832	$55,967	$49,891	$54,436	$81,022
Total Capital Cost[111]	$710,000	$900,000	$800,000	$1,325,000	$1,475,000
12 Year Lifecycle Cost Est.	N/A	N/A	N/A	$1,978,232	$2,447,267
15 Year Lifecycle Cost Est.	$1,562,485	$1,739,511	$1,548,365	N/A	N/A
Average Annual Total Cost[112]	$104,166	$115,967	$103,224	$139,853	$195,606
Average Annual Total Cost with One-Time Facility Cost[113]	$104,166	$115,967	$103,224	$164,853	$203,939
Average Annual Cost Increase over Clean Diesel	N/A	11%	-1%	34%	88%
Average Annual Cost Increase over Clean Diesel (Including Facilities)	N/A	11%	-1%	58%	96%

[108] Costs are depicted on a per bus basis.
[109] Metro is currently issuing a procurement for Renewable Natural Gas (RNG), which would further reduce CNG emissions.
[110] Annual maintenance and fuel cost.
[111] Includes vehicle purchase capital costs and facilities and equipment expansion costs for low-emissions buses. Estimates for standard 40' buses, includes PPA warranty (if not standard for manufacturer inclusion) and midlife overhaul costs.
[112] Average annual total cost is calculated to include operating and vehicle purchase capital costs. Capital costs are not incurred annually, but are included on a per-year basis for purposes of comparison. Facility expansion costs are not included.

Table A-7: Detailed Vehicle Emissions by Fuel Type[114]

Bus Type	Diesel	Diesel Electric Hybrid	Compressed Natural Gas	Renewable Natural Gas[115]	Battery-Electric[116]	Hydrogen Fuel Cell
Annual Total Greenhouse Gases Annual Total Pollutants						
GHG (short tons)	122.2	97.6	87.8	16.5	25.0	63.0
CO (pounds)	186.3	102.9	1861.4	1687.4	21.1	96.4
NOx (pounds)	299.0	287.5	115.5	-11.4	35.3	161.2
PM10 (pounds)	16.0	15.3	14.0	0.4	16.3	32.5
PM2.5 (pounds)	5.1	4.5	3.2	-10.3	3.7	11.6
VOC (pounds)	28.9	25.2	31.8	-57.5	6.0	27.4

[114] Emissions values derived from Argonne National Laboratory's AFLEET analysis, which sources data from the EPA's MOVES emission factor model (for diesel, hybrid, electric and fuel cell buses), and Argonne Lab's GREET Model for CNG.

[115] Renewable Natural Gas. Assumed emphasis on landfill gas, which Washington Gas notes as the most readily available in the region. Link.

[116] Battery-electric and hydrogen fuel cell buses may emit non-exhaust PM2.5 and PM10 through tire wear, brake wear, etc.

Table A-7: Detailed Vehicle Emissions by Fuel Type (Continued)

Bus Type	Diesel	Diesel Electric Hybrid	Compressed Natural Gas	Renewable Natural Gas[117]	Battery-Electric[118]	Hydrogen Fuel Cell
Annual Vehicle Operation Pollutants[119]						
CO (pounds)[120]	154.7	77.4	1779.6	1779.6	0.0	0.0
NOx (pounds)	239.0	239.0	12.0	12.0	0.0	0.0
PM10 (pounds)	12.1	12.1	12.1	12.1	11.7	11.7
PM2.5 (pounds)	1.9	1.9	1.9	1.9	1.5	1.5
VOC (pounds)	9.7	9.7	6.1	6.1	0.0	0.0

[117] Renewable Natural Gas. Assumed emphasis on landfill gas, which Washington Gas notes as the most readily available in the region. https://washingtongasdcclimatebusinessplan.com/wp-content/uploads/2020/03/Fact-Sheet_RNG_in_DC_vFINAL.pdf

[118] Battery-electric and hydrogen fuel cell buses may emit non-exhaust PM2.5 and PM10 through tire wear, brake wear, etc.

[119] Battery-electric and hydrogen fuel cell buses may emit non-exhaust PM2.5 and PM10 through tire wear, brake wear, etc.

[120] Past Altoona Bus Research and Testing Center evaluation (https://mjbradley.com/sites/default/files/CNG%20Diesel%20Hybrid%20Comparison%20FINAL%2005nov13.pdf) has suggested CNG buses have annual CO emissions of approximately 350-950 pounds per year, depending on make, model, average vehicle speed and other operating conditions. Past testing of Metrobus vehicles (https://www.nrel.gov/docs/fy03osti/33280.pdf) with enhanced CO mitigation technology suggested the potential for improvements in this area.

Table A-7: Detailed Vehicle Emissions by Fuel Type[121] (Continued)

Bus Type	Diesel	Diesel Electric Hybrid	Compressed Natural Gas	Renewable Natural Gas[122]	Battery-Electric[123]	Hydrogen Fuel Cell
Annual Upstream Pollutants						
CO (pounds)	31.6	25.5	81.8	-92.2	21.1	96.4
NOx (pounds)	60.0	48.5	103.5	-23.3	35.3	161.2
PM10 (pounds)	3.8	3.1	1.9	-11.7	4.6	20.8
PM2.5 (pounds)	3.2	2.6	1.3	-12.2	2.2	10.1
VOC (pounds)	19.2	15.5	25.7	-63.7	6.0	27.4

[121] Emissions values derived from Argonne National Laboratory's AFLEET analysis, which sources data from the EPA's MOVES emission factor model (for diesel, hybrid, electric and fuel cell buses), and Argonne Lab's GREET Model for CNG.

[122] Renewable Natural Gas. Assumed emphasis on landfill gas, which Washington Gas notes as the most readily available in the region. https://washingtongasdcclimatebusinessplan.com/wp-content/uploads/2020/03/Fact-Sheet_RNG_in_DC_vFINAL.pdf

[123] Battery-electric and hydrogen fuel cell buses may emit non-exhaust PM2.5 and PM10 through tire wear, brake wear, etc.

Table A-8: Facility Capacity by Propulsion Type, FY2021-FY2038

Garage	Fuel Type	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38
Andrews	Diesel	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175
Andrews	Hybrid	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175
Andrews	CNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andrews	Electric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bladensburg	Diesel	263	263	263	263	263	263	300	300	300	300	300	300	300	300	300	300	300	300
Bladensburg	Hybrid	263	263	263	263	263	263	300	300	300	300	300	300	300	300	300	300	300	300
Bladensburg	CNG	263	263	263	263	263	263	300	300	300	300	300	300	300	300	300	300	300	300
Bladensburg	Electric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cinder Bed	Diesel	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110
Cinder Bed	Hybrid	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110
Cinder Bed	CNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cinder Bed	Electric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Four Mile Run	Diesel	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218
Four Mile Run	Hybrid	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218
Four Mile Run	CNG	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218
Four Mile Run	Electric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Landover	Diesel	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172
Landover	Hybrid	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172
Landover	CNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Landover	Electric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A-8: Facility Capacity by Propulsion Type, FY2021-FY2038 (Continued)

Garage	Fuel Type	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38
Montgomery	Diesel	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
Montgomery	Hybrid	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
Montgomery	CNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Montgomery	Electric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern	Diesel	0	0	0	0	0	150	150	150	150	150	150	150	150	150	150	150	150	150
Northern	Hybrid	0	0	0	0	0	150	150	150	150	150	150	150	150	150	150	150	150	150
Northern	CNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern	Electric	0	0	0	0	0	150	150	150	150	150	150	150	150	150	150	150	150	150
Shepherd	Diesel	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223
Shepherd	Hybrid	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223
Shepherd	CNG	0	0	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223
Shepherd[124]	Electric	0	0	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Southern	Diesel	83	83	83	83	83	0	0	0	0	0	0	0	0	0	0	0	0	0
Southern	Hybrid	83	83	83	83	83	0	0	0	0	0	0	0	0	0	0	0	0	0
Southern	CNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Southern	Electric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West Ox	Diesel	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
West Ox	Hybrid	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
West Ox	CNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West Ox	Electric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[124] The impact of the electric bus test and evaluation on overall garage capacity is to be determined.

Table A-9: Total Capacity and Gaps by Propulsion Type, FY2021–FY2038

Garage	Fuel Type	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38
Total Capacity	Diesel	1681	1681	1681	1681	1681	1748	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785
Total Capacity	Hybrid	1681	1681	1681	1681	1681	1748	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785
Total Capacity	CNG	481	481	704	704	704	704	741	741	741	741	741	741	741	741	741	741	741	741
Total Capacity	Electric	1	1	13	13	13	163	163	163	163	163	163	163	163	163	163	163	163	163
Total Fleet Level	Diesel	260	318	368	368	368	368	357	357	341	341	341	341	299	299	274	220	50	0
Total Fleet Level	Hybrid	861	857	809	648	610	448	364	343	323	223	123	40	0	0	0	0	0	0
Total Fleet Level	CNG	435	417	464	539	614	689	764	755	741	741	741	725	707	620	620	601	582	545
Total Fleet Level	Electric	1	1	13	38	63	88	113	138	188	288	388	487	587	687	785	867	961	1048
Capacity Gap	Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capacity Gap	Hybrid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capacity Gap	CNG	0	0	0	0	0	0	-23	-14	0	0	0	0	0	0	0	0	0	0
Capacity Gap	Electric	0	0	0	-25	-50	0	0	0	-25	-125	-225	-324	-424	-524	-622	-704	-798	-885

Table A-10: Garage Capacity by Bus Length, FY2021–FY2038

Garage	Fuel Type	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38
Andrews	Standard	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148
Andrews	Artic	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Andrews	Total	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175
Bladensburg	Standard	238	238	238	238	238	238	200	200	200	200	200	200	200	200	200	200	200	200
Bladensburg	Artic	25	25	25	25	25	25	100	100	100	100	100	100	100	100	100	100	100	100
Bladensburg	Total	263	263	263	263	263	263	300	300	300	300	300	300	300	300	300	300	300	300
Cinder Bed	Standard	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Cinder Bed	Artic	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Cinder Bed	Total	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110
Four Mile Run	Standard	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218
Four Mile Run	Artic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Four Mile Run	Total	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218	218
Landover	Standard	164	164	164	164	164	164	164	164	164	164	164	164	164	164	164	164	164	164
Landover	Artic	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Landover	Total	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172
Montgomery	Standard	196	196	196	196	196	196	196	196	196	196	196	196	196	196	196	196	196	196
Montgomery	Artic	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Montgomery	Total	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
Northern	Standard	0	0	0	0	0	75	75	75	75	75	75	75	75	75	75	75	75	75
Northern	Artic	0	0	0	0	0	75	75	75	75	75	75	75	75	75	75	75	75	75
Northern	Total	0	0	0	0	0	150	150	150	150	150	150	150	150	150	150	150	150	150

Table A-10: Garage Capacity Table by Bus Length, FY2021–FY2038 (Continued)

Garage	Fuel Type	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38
Shepherd	Standard	143	143	143	143	143	143	143	143	143	143	143	143	143	143	143	143	143	143
Shepherd	Artic	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
Shepherd	Total	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223
Southern	Standard	83	83	83	83	83	0	0	0	0	0	0	0	0	0	0	0	0	0
Southern	Artic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Southern	Total	83	83	83	83	83	0	0	0	0	0	0	0	0	0	0	0	0	0
West Ox	Standard	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
West Ox	Artic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West Ox	Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Western	Standard	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117
Western	Artic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Western	Total	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117
All	Total	1681	1681	1681	1681	1681	1748	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785	1785

Table A-11: 2019 and 2038 APC Adjusted Weekday Ridership and Ridership Change by Corridor

Corridor ID	Corridor Name	APC Adjusted Weekday Ridership May 2019	APC Adjusted Weekday Ridership 2038 Forecast	Ridership Change 2019–2038
1	Columbia Pike	12,193	12,544	2.9%
2	Richmond Hwy Express	2,588	2,327	-10.1%
3	Crystal City / Potomac Yard	2,867	2,633	-8.2%
4	Georgia Ave / 7th St (DC)	21,498	23,244	8.1%
5	National Harbor	2,578	2,412	-6.4%
6	Route 410 West	5,765	6,412	11.2%
7	Pennsylvania Ave / Wisconsin Ave	21,854	22,811	4.4%
8	Sixteenth St	15,553	16,492	6.0%
9	Leesburg Pike	5,227	5,519	5.6%
10	Veirs Mill Rd	6,078	6,806	12.0%
11	H St / Benning Rd	16,286	16,713	2.6%
12	New Hampshire Ave-MD	6,458	6,520	1.0%
13	U St / Garfield	13,612	13,712	0.7%
14	Georgia Ave (MD)	7,046	6,850	-2.8%
15	Anacostia / Congress Heights	19,227	19,169	-0.3%
17	Route 410 East	7,113	7,827	10.0%
18	Little River Turnpike / Duke St	3,275	3,308	1.0%
19	Rhode Island Ave (Metro to Laurel)	5,130	5,368	4.6%
20	Rhode Island Ave (DC)	4,717	5,150	9.2%
21	Eastover / Addison	6,085	5,992	-1.5%
22	Colesville Rd / Columbia Pike (MD US 29)	7,413	7,233	-2.4%
23	Fourteenth St	13,950	14,916	6.9%

Corridor ID	Corridor Name	APC Adjusted Weekday Ridership May 2019	APC Adjusted Weekday Ridership 2038 Forecast	Ridership Change 2019–2038
24	North Capitol St	6,845	7,508	9.7%
25	MacArthur Blvd / K St / Trinidad	12,642	13,920	10.1%
26	Tysons	378	424	12.1%
27	Brookland	7,247	7,793	7.5%
28	Maryland Ave	1,139	1,418	24.4%
29	Fort Washington	1,893	1,721	-9.1%
30	Central Ave	1,868	2,183	16.8%
31	Kings Park	1,281	1,351	5.5%
32	Springfield	2,048	1,928	-5.8%
33	Wilson Blvd	3,851	4,369	13.5%
34	Landmark	643	647	0.6%
35	Ballston / Pentagon	4,653	4,619	-0.7%
36	Petworth	8,894	9,021	1.4%
37	Lincolnia	5,838	6,068	3.9%
38	Bowie	2,232	2,263	1.4%
39	Connecticut Ave (DC)	4,434	4,674	5.4%
40	Connecticut Ave (MD)	2,022	2,036	0.7%
41	Greenbelt	3,019	3,135	3.9%
43	Hunting Point	4,169	4,229	1.4%
44	Chain Bridge Rd	288	267	-7.3%
45	Washington Blvd	2,937	3,464	17.9%
46	Lee Hwy	1,049	1,490	42.0%
48	Capitol Heights / Marshall Heights / Benning Heights	1,096	1,270	15.9%
49	Bladensburg Road-Anacostia	9,366	9,668	3.2%

Corridor ID	Corridor Name	APC Adjusted Weekday Ridership May 2019	APC Adjusted Weekday Ridership 2038 Forecast	Ridership Change 2019–2038
50	Anacostia-Eckington	4,672	4,702	0.7%
51	District Heights	3,081	3,608	17.1%
52	Riggs Rd	5,219	5,220	0.0%
53	Fairfax Village	0	0	0.0%
54	Shipley Terrace-Ft. Drum	2,070	1,893	-8.6%
55	United Medical Ctr / Anacostia	3,844	3,747	-2.5%
56	Alabama Ave	8,306	8,013	-3.5%
57	Garfield / Anacostia	3,073	3,022	-1.7%
58	P Street-LeDroit Park	1,613	1,932	19.7%
59	Park Rd / Brookland	4,008	4,208	5.0%
60	Clinton	2,281	2,541	11.4%
61	Forestville	3,392	3,507	3.4%
62	270 / Twinbrook / Silver Spring	0	0	0.0%
63	Mt Pleasant	5,780	6,335	9.6%
64	East Capitol	5,855	6,097	4.1%
65	Oxon Hill	4,266	4,671	9.5%
66	Military Rd	4,772	4,429	-7.2%
67	Annapolis Rd	5,656	5,956	5.3%
68	Minnesota Ave / M St	19,129	19,460	1.7%
69	Massachusetts Ave	3,475	3,457	-0.5%
70	MLK Hwy-DC	2,476	2,750	11.0%
71	Takoma-Fort Totten	663	694	4.6%
72	Central NOVA	1,665	2,056	23.5%
73	Central PGC	3,175	3,552	11.9%
74	College Park-White Flint	2,626	2,738	4.3%

Corridor ID	Corridor Name	APC Adjusted Weekday Ridership May 2019	APC Adjusted Weekday Ridership 2038 Forecast	Ridership Change 2019–2038
75	Eastern NOVA	1,681	2,327	38.4%
76	Fort Lincoln / Brookland	2,312	2,364	2.2%
77	Northern PGC	4,144	4,517	9.0%
78	Stanton Road	0	0	0.0%
79	Western DC	1,650	1,632	-1.1%
80	River Road	1,195	1,127	-5.7%
81	Western NOVA	4,694	4,963	5.7%
82	South Dakota/18th St NE	1,433	1,514	5.6%
100	University Blvd	9,151	9,888	8.0%
400	Airport	1,401	1,597	14.0%
600	Special	0	0	0.0%
	Total	425,104	443,770	4.4%

Table A-12: Metrobus Fleet Procurement and Retirement Schedule Through FY2038 (Standard Length Buses)

Vehicle Type		FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38
Standard Diesel	Fleet Owned by Metro (Start of Year)	168	218	276	326	326	326	326	315	315	299	299	299	299	299	299	274	220	50
Standard Diesel	Retirements	4	112	0	0	0	0	11	0	16	0	0	0	0	0	25	54	170	50
Standard Diesel	Deliveries	54	170	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Standard Diesel	Vehicles on Site (End of Year)	218	276	326	326	326	326	315	315	299	299	299	299	299	299	274	220	50	0
Standard Hybrid	Fleet Owned by Metro (Start of Year)	888	824	824	776	615	577	415	331	331	311	211	123	40	0	0	0	0	0
Standard Hybrid	Retirements	64	0	48	161	38	162	84	0	20	100	88	83	40	0	0	0	0	0
Standard Hybrid	Deliveries	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Standard Hybrid	Vehicles on Site (End of Year)	824	824	776	615	577	415	331	331	311	211	123	40	0	0	0	0	0	0
Standard CNG	Fleet Owned by Metro (Start of Year)	443	435	417	464	520	576	632	666	625	611	611	611	595	577	490	490	490	490
Standard CNG	Retirements	83	18	3	0	0	0	0	84	64	0	0	16	18	87	0	0	0	18
Standard CNG	Deliveries	75	0	50	56	56	56	34	43	50	0	0	0	0	0	0	0	0	0
Standard CNG	Vehicles on Site (End of Year)	435	417	464	520	576	632	666	625	611	611	611	595	577	490	490	490	490	472
Standard Electric	Fleet Owned by Metro (Start of Year)	1	1	1	11	30	49	68	80	94	144	244	332	431	489	589	689	752	827
Standard Electric	Retirements	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	12	0	7
Standard Electric	Deliveries	0	0	10	19	19	19	12	14	50	100	88	100	58	100	100	75	75	75
Standard Electric	Vehicles on Site	1	1	11	30	49	68	80	94	144	244	332	431	489	589	689	752	827	895

Table A-13: Metrobus Fleet Procurement and Retirement Schedule Through FY2038 (Articulated Buses)

Vehicle Type		FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38
Articulated Diesel	Fleet Owned by Metro (Start of Year)	0	42	42	42	42	42	42	42	42	42	42	42	42	0	0	0	0	0
Articulated Diesel	Retirement	0	0	0	0	0	0	0	0	0	0	0	0	42	0	0	0	0	0
Articulated Diesel	Deliveries	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Articulated Diesel	Vehicles on Site (End of Year)	42	42	42	42	42	42	42	42	42	42	42	42	0	0	0	0	0	0
Articulated Hybrid	Fleet Owned by Metro (Start of Year)	54	37	33	33	33	33	33	33	12	12	12	0	0	0	0	0	0	0
Articulated Hybrid	Retirement	17	4	0	0	0	0	0	21	0	0	12	0	0	0	0	0	0	0
Articulated Hybrid	Deliveries	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Articulated Hybrid	Vehicles on Site (End of Year)	37	33	33	33	33	33	33	12	12	12	0	0	0	0	0	0	0	0
Articulated CNG	Fleet Owned by Metro (Start of Year)	22	0	0	0	19	38	57	76	95	95	95	95	95	95	95	95	76	57
Articulated CNG	Retirement	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	19	19
Articulated CNG	Deliveries	0	0	0	19	19	19	19	19	0	0	0	0	0	0	0	0	0	0
Articulated CNG	Vehicles on Site (End of Year)	0	0	0	19	38	57	76	95	95	95	95	95	95	95	95	76	57	38
Articulated Electric	Fleet Owned by Metro (Start of Year)	0	0	0	2	8	14	20	26	33	33	33	45	45	87	87	85	104	123
Articulated Electric	Retirement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6	6	6
Articulated Electric	Deliveries	0	0	2	6	6	6	6	7	0	0	12	0	42	0	0	25	25	25
Articulated Electric	Vehicles on Site (End of Year)	0	0	2	8	14	20	26	33	33	33	45	45	87	87	85	104	123	142

Table A-14: Metrobus Fleet Procurement and Retirement Schedule Through FY2038 (Small Buses)

Vehicle Type		FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38
Small Diesel	Fleet Owned by Metro (Start of Year)	27	27	27	27	27	27	27	5	0	0	0	0	0	0	0	0	0	0
Small Diesel	Retirements	0	0	0	0	0	0	22	5	0	0	0	0	0	0	0	0	0	0
Small Diesel	Deliveries	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small Diesel	Vehicles on Site (End of Year)	27	27	27	27	27	27	5	0	0	0	0	0	0	0	0	0	0	0
Small Hybrid	Fleet Owned by Metro (Start of Year)	19	19	19	19	19	19	19	12	0	0	0	0	0	0	0	0	0	0
Small Hybrid	Retirements	0	0	0	0	0	0	7	12	0	0	0	0	0	0	0	0	0	0
Small Hybrid	Deliveries	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small Hybrid	Vehicles on Site (End of Year)	19	19	19	19	19	19	12	0	0	0	0	0	0	0	0	0	0	0
Small CNG	Fleet Owned by Metro (Start of Year)	6	6	0	0	0	0	0	22	35	35	35	35	35	35	35	35	35	35
Small CNG	Retirements	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small CNG	Deliveries	0	0	0	0	0	0	22	13	0	0	0	0	0	0	0	0	0	0
Small CNG	Vehicles on Site (End of Year)	6	0	0	0	0	0	22	35	35	35	35	35	35	35	35	35	35	35
Small Electric	Fleet Owned by Metro (Start of Year)	0	0	0	0	0	0	0	7	11	11	11	11	11	11	11	11	11	11
Small Electric	Retirements	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small Electric	Deliveries	0	0	0	0	0	0	7	4	0	0	0	0	0	0	0	0	0	0
Small Electric	Vehicles on Site (End of Year)	0	0	0	0	0	0	7	11	11	11	11	11	11	11	11	11	11	11

Table A-15: Composition of Metrobus Fleet, Start of FY2022[125]

Manufacturer	Model Year	Fuel Type	Length	Fleet Code	Buses in Fleet
Orion	2005	CNG	Small	Fleet 32	6
New Flyer	2006	Diesel	Standard	Fleet 37	112
New Flyer	2007	CNG	Standard	Fleet 38	15
New Flyer	2009	Hybrid	Standard	Fleet 42	20
New Flyer	2008-2009	Hybrid	Standard	Fleet 43	160
New Flyer	2009	Hybrid	Articulated	Fleet 44	4
New Flyer	2010	Hybrid	Standard	Fleet 45	140
New Flyer	2011-2013	Hybrid	Standard	Fleet 46	210
New Flyer	2012	Hybrid	Standard	Fleet 47	52
Orion	2012	Diesel	Small	Fleet 48	27
Orion	2012	Hybrid	Small	Fleet 49	19
New Flyer	2013	Hybrid	Standard	Fleet 50	9
NABI	2014	Hybrid	Standard	Fleet 52	94
NABI	2014	Hybrid	Standard	Fleet 53	10
New Flyer	2015	Hybrid	Articulated	Fleet 54	21
New Flyer	2015-2016	CNG	Standard	Fleet 55	164
New Flyer	2015-2016	Hybrid	Standard	Fleet 56	56
New Flyer	2016	Hybrid	Standard	Fleet 57	54
New Flyer	2016	Electric	Standard	Fleet 58	1
New Flyer	2018	CNG	Standard	Fleet 59	100
New Flyer	2018	Hybrid	Articulated	Fleet 60	12
New Flyer	2019	CNG	Standard	Fleet 61	75
New Flyer	2019	Diesel	Standard	Fleet 62	25
New Flyer	2020	Diesel	Standard	Fleet 63	25
New Flyer	2020	CNG	Standard	Fleet 64	75
New Flyer	2020	Diesel	Articulated	Fleet 65	10
New Flyer	2021	Diesel	Articulated	Fleet 66	32
New Flyer	2021	Diesel	Standard	Fleet 67	29
Total					1,557

[125] Includes training and Ready Reserve buses.

Appendix B: Fleet Demand Estimates, Additional Detail

B1: Productivity

Metro tracks four productivity measures: minimum passengers per revenue hour, mile, bus trip, and minimum percentage of unique ridership. Productivity guidelines differ by service type and service Tier 2, but not by time period. Lines or routes that fail to meet productivity guidelines may be modified to improve productivity. Changes could include the reduction of frequencies, which could reduce the number of buses required to operate the line or route.

Tables C-1 and C-2 show the guidelines for minimum passengers (boardings) per revenue hour and mile. These guidelines are the same for all time periods and thus are applicable to the PM Peak period, when Metro operates its highest number of vehicles.

Table B-1: Metrobus Minimum Passengers per Revenue Hour Target[126]

Zone	BRT	Framework	Coverage
Tier 1	35	30	20
Tier 2	25	20	15
Tier 3	20	15	10

Table B-2: Minimum Passengers per Revenue Mile Target[127]

Zone	BRT	Framework	Coverage	Commuter
Tier 1	5.0	4.0	4.0	1.5
Tier 2	2.0	2.0	2.0	1.0
Tier 3	2.0	1.0	1.0	1.0

Based on these guidelines, of the routes that operated in Fall 2019, about 29 routes fell below their assigned minimum passengers per revenue hour guideline, and 48 were below the minimum passengers per mile guideline.

B2: Reliability

Reliability of bus operations is defined by the difference between actual travel time and the scheduled travel time at the trip-link level. Routes are considered to have poor reliability if they fail to meet Metro's

[126] Source: Metrobus Service Guidelines December 2020. https://www.wmata.com/about/board/meetings/board-pdfs/upload/4A-Metrobus-Service-Guidelines-CORR.pdf
[127] Source: Metrobus Service Guidelines December 2020. https://www.wmata.com/about/board/meetings/board-pdfs/upload/4A-Metrobus-Service-Guidelines-CORR.pdf

service reliability guideline, departing from the time point no more than two minutes early or seven minutes late from the scheduled departure time. For headway-based service, reliability is measured as the percentage of timepoint pull-outs that are no greater than the scheduled service headway plus three-minutes after the pull-out time of the bus ahead. The current guideline is for the bus to depart on time 79% of the time. This guideline percentage applies for all Metrobus line classifications and all time periods.

Late running can be caused by many factors including unbalanced passenger loading, irregular headways, misallocated link travel time—that is, too much time on some links and not enough on others—and inadequate recovery time at the ends of each run. Usually, late running is caused by inadequate scheduled end-to-end running time. Several strategies exist for correcting late running that do not require adding service volume, such as correcting headway or link running time imbalances and improving travel speed by consolidating and moving bus stops or implementing bus signal priority along the bus route. Often, though, the only effective option for addressing late running is adding service volume to increase link running times and recovery time, in which case additional buses usually are required to operate the route.

Planners regularly assess whether routes have adequate travel time and address travel time using several operational strategies including monitoring the service by Service Operation Managers, reducing route length, and adding running time—which usually requires adding buses to the route.

Based on performance analysis on Fall 2019 Metro operations. For this analysis, routes that operated less than 69% of departures "not late" during the PM period were identified as potentially requiring an additional bus to provide reliable service. This more relaxed standard was used to account for potential over-counting of early departures, and the potential to address the late running using approaches that do not require additional vehicles. Based on this analysis, 19 routes potentially would require an additional bus to meet service reliability guidelines. The routes are listed in Table B-3.

Table B-3: Routes with Less than 69% of Departures Early or On-Time ("Not Late") during PM Peak Period, Fall 2019

Rank	Route	Percent Not Late (2019)
1	17B	43.4%
2	7Y	49.6%
3	R2	50.6%
4	W8	51.7%
5	R1	52.7%
6	C4	52.8%
7	17M	52.9%
8	J4	53.2%
9	H6	55.5%
10	B8	55.7%
11	W6	56.4%
12	C2	57.9%
13	T14	58.4%
14	29N	59.4%
15	H1	59.7%
16	P12	60.8%
17	K6	61.0%
18	S4	61.3%
19	S2	63.0%

B3: Level of Crowding

Vehicle load factor is a performance measure used to determine crowding on a specific bus route and trip. Vehicles are considered "crowded" when they are running over 100-120% of their seated capacity. Excessive crowding onboard buses is unpleasant and potentially dangerous for passengers, and can slow the route, making it less reliable. The load factor is the number of people on the bus at the maximum load point divided by the vehicle capacity, usually expressed as a percentage of the number of seats on the buses used to operate the route. The load factor for service and vehicle adjustments in the current service guidelines varies by vehicle classification, headway and time period. Most routes, at most times, are considered over-crowded when passenger volume exceeds 100% of the seats on the bus (i.e., 40 passengers aboard a 40-foot bus, which typically has 40 seats) for more than 15% of their running time. This means that a bus operating on a route with a 60-minute end-to-end trip running time would exceed the guideline if it carried more than 40 passengers for more than nine minutes.

Buses operating headways less than 20 minutes have a more lenient crowding guideline of 120% (48 passengers aboard a 40-seat bus) for more than 15% of the trip running time. All commuter bus routes have a load target of no more than 100% of the seats due to the danger to passengers of standing while the bus operates at higher speeds.

Crowding is caused by a shortage of capacity at the bus routes peak load location and time period. However, crowding can occur even if sufficient capacity is being operated if delays are preventing sufficient capacity reaching the peak load point at the proper time. As with late running, schedule and stop location adjustments can be considered to address crowding before adding capacity. However, crowding usually only can be addressed by adding capacity during the peak time period, either by reducing headways or adding travel time to the routes. This usually requires adding buses to the route to operate the additional capacity.

Passenger crowding is a component of service quality that receives significant attention from Metro planners. They continuously monitor passenger feedback on this issue and regularly review data to determine the degree of crowding throughout the system. Lines that have a relatively large number of boardings per unit of service, are candidates for service expansion, which requires adding vehicles to the route.

A more detailed analysis and a stricter standard was applied in which routes were identified whose average peak load exceeded the average available seats during any PM peak hour, in any direction, in the Fall 2019. To avoid the variability of different route classes having different load factors, and to provide a stricter standard, a 100% load factor was applied to all routes. Eight routes were identified as having insufficient seats during at least PM peak hour. These routes are identified in Table B-4.

Table B-4: Routes Experiencing Crowding (100% Seated Load) During One or More Peak Hour, in One Direction, Fall 2019

Rank	Route	Division(s)	Jurisdiction(s)
1	30S	Andrews	MD
2	30N	Andrews	MD
3	V2	Southern	MD, DC
4	11Y	Four Mile	VA
5	W1	Shepherd	DC
6	54	Western	DC
7	79	Montgomery	DC, MD
8	S9	Montgomery	DC

Forecasts percentages of annual ridership increase were applied to the peak average peak loads by PM peak hour and direction to determine whether additional routes would experience crowding due to forecast ridership increases during the 2020-2038 period. Six additional routes were identified as potentially requiring additional buses to address crowding through 2038: Table B-5 lists the routes and the year in which the route likely would begin experiencing crowding based on ridership increase.

Table B-5: Routes Experiencing Crowding (100% Seated Load) During One or More Peak Hour, in One Direction, Through 2038

Route	Year	Division(s)	Jurisdiction(s)
42	2035	Western	DC
70	2037	Montgomery	MD
3Y	2038	West Ox	VA
8W	2031	Four Mile	VA
8Z	2026	Four Mile	VA
S4	2036	Montgomery	DC, VA, MD

B4: Service Design Measures

Service frequency or headway is used as the primary service design measurer, together with span of service and duplication of service. Service frequency, or headway, is the service interval between buses on a bus route. For demand-driven routes carrying high ridership, headway is determined by the number of vehicles required to provide enough capacity to serve demand during peak, and in many cases during mid-day periods. For policy driven routes with lower ridership, frequency is determined based on the service guidelines that correspond to the route's classification, service tier, and the time period during which it is operating. Weekday maximum headway guidelines are shown in Table B-6.

Table B-6 Maximum Weekday Service Headway (Minutes)[128]

Zone	BRT Peak	BRT Off-Peak	Frame-work Peak	Frame-work Off-Peak	Frame-work Premium	Coverage Peak	Coverage Off-Peak	Commuter
Tier 1	10	15	15	15	12	30	60	Varies based on demand
Tier 2	15	20	20	20	15	30	60	Varies based on demand
Tier 3	30	30	30	60	30	60	60	Varies based on demand

Headway directly determines the number of vehicles required to operate a bus route (the number of buses required to operate a route can be calculated by dividing the running time, including of layover or recovery time, by the headway). Thus, headway has a direct impact on the fleet size, and even minor changes to Metro's peak period headway guidelines, when extended across Metro's more than 200 bus routes, can profoundly influence the number of buses that would be required to operate the Metrobus network.

Metro has 43 routes that operate longer peak period headways than indicated by the relevant service guideline, based on the routes' service classification and activity tier. These routes are listed in Table B-7.

Table B-7: Routes Operating Greater than Specified Maximum Headway during Fall 2019 PM Peak Period

Route	Division(s)	Jurisdiction(s)
32	Andrews	DC
34	Andrews	DC
36	Andrews	DC
39	Andrews	DC
83	Landover	MD
86	Landover	MD
10A	Four Mile	VA
10B	Four Mile	VA
10E	Four Mile	VA

[128] Source: Metrobus Service Guidelines December 2020. https://www.wmata.com/about/board/meetings/board-pdfs/upload/4A-Metrobus-Service-Guidelines-CORR.pdf

Route	Division(s)	Jurisdiction(s)
16A	Four Mile	VA
1A	West Ox	VA
1B	West Ox	VA
1C	West Ox	VA
22A	Four Mile	VA
23B	Four Mile	VA
23T	Four Mile	VA
26A	West Ox	VA
29K	Cinder Bed	VA
29N	Cinder Bed	VA
2B	West Ox	VA
30N	Andrews	DC
30S	Andrews	DC
7A	Four Mile	VA
7F	Four Mile	VA
A7	Shepherd	VA
C4	Montgomery	MD
C8	Montgomery	MD
D12	Andrews	DC
D13	Andrews	DC
D14	Andrews	DC
H2	Bladensburg	DC
H4	Bladensburg	DC
J4	Montgomery	MD
K9	Bladensburg	DC, MD
NH2	Shepherd	DC
Q4	Montgomery	MD
R1	Bladensburg	DC, MD
R12	Landover	MD
V2	Southern	DC
X9	Bladensburg	DC
Y2	Montgomery	MD
Y8	Montgomery	MD
Z6	Montgomery	MD

B5: Summary of Network Performance and Fleet Requirements

As of December 2019, Metrobus' Peak Vehicle Requirement (PVR) for weekday roll-out was 1,270 buses.

Table B-8 shows the PVR by bus division and the system total as of December 16, 2020. PVR is calculated on the division level because many routes require a different number of buses in the AM and PM peak period service. When different routes with different AM and PM bus requirements are housed in the same bus division, buses that serve one route in the AM peak can be repurposed to serve another route in the PM peak. Balancing the supply and demand of buses at the division level reduces the actual total number of buses required to maintain an adequate level of revenue service.

Table B-8: Peak Vehicle Requirement (PVR) by Division, December 2019

Division	PVR
Bladensburg	216
Shepherd Parkway	166
Southern Ave	72
Andrews	71
Landover	148
Four Mile Run	178
West Ox	59
Cinder Bed	69
Montgomery	190
Northern[129]	0
Western	101
System Total	1,270

The PVR column shows the peak vehicle requirement for scheduled buses per operating division, which is the greater of the AM or PM peak vehicle requirement. Strategic fleet and headway management buses provide operational redundancy to assist in schedule/headway adherence, while elevator buses provide bus bridge service for Metrorail stations with elevator outages to serve riders who require elevators to access the stations.

Spares are calculated by multiplying the Total Maximum Scheduled Vehicle Count of 1,270 by 19.5%. This adds 248 vehicles to the fleet, bringing the total scheduled bus count to 1,518. To this total, Metro

[129] Northern Division closed for reconstruction until FY2026.

adds additional vehicles in ready reserve to the 1,270 Total PVR and 248 spares brings the total fleet need to 1,593.

B6: Estimate of Fleet Adequacy

The estimate of fleet adequacy analyzed the performance of Metrobus routes operating in Fall 2019 to determine whether the routes were meeting service guidelines for reliability, crowding, and maximum headway during the PM peak period, whether additional buses might be required for routes to meet the guidelines, and the number of buses that might be required to meet the guidelines. Service reliability, passenger crowding, and maximum headways considerations inform Metro's long-term planning of estimated total fleet demand. Through the deployment of an expanded articulated bus fleet, Metro expects to be able to respond to ridership demand and continue providing quality bus service to the region.

Appendix C: Cost Comparisons of Fleet Procurement Scenarios

C1: Procurement Approach Considerations

Metro's procurement approach must balance several factors: the capital costs of purchasing vehicles, the operating costs of fueling and maintaining those vehicles, the costs and time needed to upgrade existing operating divisions to accommodate new propulsion technologies (with temporary capacity loss during those reconstruction activities), the social cost of emissions to the Washington metropolitan region, as well as the challenges associated with utilizing emerging technologies.

Hybrid diesel-electric buses are not expected to be prioritized in future Metrobus procurements due high capital costs and the development of cleaner alternatives. Diesel buses, while the least expensive to purchase, emit the highest level of pollutants, which runs counter to Metro's sustainability goals and those of other transit operators in the District of Columbia, Maryland and Virginia. The incorporation of new low NOx engines will also allow for reduced emissions from conventional levels. Compressed Natural Gas (CNG) buses have been proven to be a reliable vehicle for Metrobus, which offers moderate capital and operating costs with significantly reduced emissions from conventional diesel. Latest generation "Low NOx" CNG engines reduce Oxides of Nitrogen (NOx) emissions by 90% compared to existing diesel and hybrid buses. Metrobus is planning to incorporate Renewable Natural Gas (RNG) fueling into its fleet in the near future, which offers additional emissions reductions, particularly for carbon dioxide (CO_2). RNG, when made from waste that would usually emit methane, is in some cases considered "carbon negative" because the emissions that are avoided from the waste's conversion to RNG outweigh any emissions that would be caused from fuel production, transportation and use in a transit vehicle[130].

While zero-emission buses, such as those operating with battery-electric or hydrogen fuel cell power, entail the highest capital costs for Metro to purchase and require facility investments to be accommodated, operating cost savings and reduction of fleet emissions are possible with the incorporation of these vehicles, especially as the powertrain and battery technology continues to mature.

C2: Procurement Scenario Methodology

In comparing potential procurement paths, Metro evaluated several potential future fleet procurement, retirement, and composition scenarios. Metro's previous Board-adopted fleet procurement strategy called for even 50/50 procurement of diesel and CNG vehicles. For analysis purposes, this appendix compares that baseline scenario against the strategy adopted in this plan, which calls for the procurement approach described in Section 4 of this document.

[130] Source: US EPA AgSTAR. https://www.epa.gov/agstar/renewable-natural-gas-agricultural-based-adbiogas-systems

Vehicles are generally expected to be retired according to their useful life benchmark: 15 years of service for non-electric 40’ buses, and 12 years of service for electric buses and all 60’ (articulated) buses. In some instances, bus retirements may be delayed beyond the Useful Life Benchmark to ensure the fleet maintains a level size at or above the total fleet requirement of 1,593 vehicles.

After FY2023, when 112 buses are procured to account for the 12 additional electric buses dedicated to the Shepherd Parkway Test and Evaluation Program, vehicle deliveries remain smooth at 100 buses per year. The intention of this constant delivery schedule is to avoid instances in which a surplus of buses will retire in one year, followed by a shortage of retirements in a subsequent year, which causes fleet age, reliability, availability and spare availability to be inconsistent over time. The delayed retirements of some vehicles beyond their useful life benchmarks reduces unevenness in retirements, and thus the total fleet level.

All scenarios include procurement of 60’ (articulated) buses that increase the size of the articulated bus fleet to 180 buses from FY2028 onwards. This recommendation, which will scale the articulated bus fleet to comprise approximately 12% of the active Metrobus fleet, is consistent with the analysis in Section 3 of this report.

From FY2024 onwards, the distribution of the 100 deliveries per year varies based on that scenario’s chosen fuel mix proportion. Table C-1 depicts procurements by propulsion type for each scenario. The two scenarios discussed will be referred to as the “Baseline” scenario and the “2021 Metrobus Fleet Management Plan” scenario.

Table C-1: Bus Procurement Scenarios Summary, by Fiscal Year

Scenario	Fuel Type	FY24–FY28	FY29	FY30–FY33	FY34–FY38
Baseline	Diesel	50	50	50	50
	CNG	50	50	50	50
	Electric	0	0	0	0
2021 Metrobus Fleet Management Plan	Diesel	0	0	0	0
	CNG	75	50	0	0
	Electric	25	50	100	100

Tables C-2 through C-4 depict the comparative cost impacts of the analyzed scenarios.

Table C-2: Bus Fleet Propulsion Technology Scenario Comparison, Summary

	Baseline Scenario	2021 Metrobus Fleet Management Plan
Scenario Procurement Timeline	FY24-FY38 50% diesel / 50% CNG	FY24-28 75% CNG / 25% Electric FY29 50% CNG / 50% Electric FY30-38 100% Electric
Capital Cost (Vehicles)—Variance from Baseline Scenario[131]	N/A	$398M
Capital Cost (Facilities and Equipment)—Variance from Baseline Scenario[132]	N/A	$579M
Operating Cost—Variance from Baseline Scenario[133]	N/A	($37M)
Total Cost—Variance from Baseline Scenario[134]	N/A	$940M
Facility Conversion Needs[135]	N/A	6 or more electric bus facilities
Final Diesel Procurement/ Retirement	N/A N/A	FY2023 FY2038
First Year Full Electric Procurement	N/A	FY2030

[131] Includes initial vehicle purchase and midlife vehicle overhaul. Inflated on 2% per annum basis, per Federal Reserve Guidelines.
[132] Rough order of magnitude estimates for facility conversion costs per bus sourced from peer agency depot conversion assessments in California, Maryland and New Jersey.
[133] Includes fuel and maintenance costs, derived from Metrobus observed cost per mile data in FY 2019 and FY 2020.
[134] Sum of capital (vehicle acquisition and facilities expansion) and operating cost.
[135] Base CNG capacity, per current facility planning, is 741 vehicles beginning in FY2024. Base electric bus capacity is assumed to be 13 buses, including the Shepherd Parkway test and evaluation program, beginning in FY2023.

Table C-3: Metrobus Fleet Management Plan Annual Incremental Cost from Baseline Fuel Mix Scenario (USD $000)

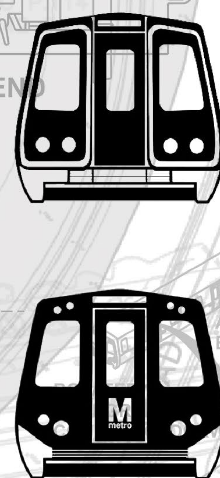
Value	FY2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Operating Costs	-	-	(396)	(807)	(1,235)	(1,679)	(2,164)	(2,351)	(2,267)	(2,462)	(2,375)	(3,315)	(3,240)	(2,293)	(3,480)	(3,800)	(4,675)
Capital Costs - Vehicles	-	-	14,459	14,496	14,531	14,564	14,840	16,007	31,998	35,104	27,168	38,674	26,091	32,970	52,064	39,185	25,709
Capital Costs - Facilities	5,100	10,404	10,612	10,824	11,041	16,892	34,461	46,866	47,206	46,850	48,409	49,757	44,500	43,191	46,208	51,754	54,983
Capital Costs - Total	5,100	10,404	25,071	25,320	25,572	31,457	49,301	62,873	79,205	81,954	75,577	88,431	70,591	76,161	98,272	90,939	80,692
Total Incremental Cost in Year	5,100	10,404	24,676	24,513	24,337	29,778	47,137	60,523	76,938	79,492	73,202	85,116	67,351	73,868	94,791	87,139	76,017

Table C-4: Metrobus Fleet Management Plan Cumulative Incremental Cost from Baseline Fuel Mix Scenario (USD $000)

Value	FY2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Operating Costs	-	-	(396)	(1,202)	(2,437)	(4,116)	(6,280)	(8,631)	(10,897)	(13,359)	(15,734)	(19,049)	(22,289)	(24,582)	(28,062)	(31,862)	(36,537)
Capital Costs - Vehicles	-	-	14,459	28,955	43,486	58,050	72,890	88,897	120,896	155,999	183,167	221,841	247,932	280,902	332,966	372,150	397,860
Capital Costs - Facilities	5,100	15,504	26,116	36,940	47,981	64,874	99,334	146,201	193,407	240,257	288,665	338,423	382,923	426,114	472,322	524,076	579,059
Capital Costs - Total	5,100	15,504	40,575	65,895	91,467	122,924	172,225	235,098	314,302	396,256	471,833	560,264	630,854	707,016	805,288	896,226	976,918
Total Cumulative Incremental Cost	5,100	15,504	40,180	64,693	89,030	118,808	165,944	226,467	303,405	382,897	456,099	541,215	608,566	682,434	777,225	864,364	940,381

Metrorail

Fleet Management Plan



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REVISION HISTORY

Version	Date	Change Description
Draft 1	February 2010	
Revision 1	September 2010	To address FTA and PMOC comments
Revision 2	January 2011	To address FTA and PMOC comments
Revision 3B	July 2011	To address FTA and PMOC comments
Revision 3C	July 2011	To address WMATA comments
Revision 3D	July 2011	To address WMATA comments
Revision 4A	September 2011	To address FTA and PMOC comments
Revision 4B	October 2011	To address WMATA comments
Revision 4C	January 2012	To address FTA and PMOC comments
Revision 4D	March 2012	To address FTA and PMOC comments
Revision 4E	March 2012	To address WMATA comments
Revision 4F	April 2012	To address FTA and PMOC comments
Revision 4G	August 2012	To address FTA comments
Revision 4H	June 2013	New Silver Line Operating Plan Changes
Revision 4I	July 2013	To address FTA comments
Revision 4J	August 2013	To address FTA comments
Revision 5	January 2016	Revise plan timeframe from 2010-2025 to 2015-2030
Revision 5A	May 2016	Updated: ridership/service projections, spare ratio calculations, vehicle procurement plans, maintenance & reliability data
Revision 6	December 2021	Revise plan timeframe from 2015-2030 to 2020-2040 and update to reflect fleet retirements and procurement plans, ridership/service projections, changes to maintenance programs, and systems and facilities needs analysis

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Executive Summary

The Metrorail Fleet Management Plan details how Metro will modernize and grow its rail fleet and supporting systems and facilities to meet service demands between 2020 and 2040.

Metro Overview

Metro operates rail service over six lines totaling 117 two-track miles serving 91 stations throughout the Washington metropolitan area. Service delivery is made possible by a network of track infrastructure and systems for train control and traction power as well as facilities for railcar storage and maintenance. Two system expansion projects are currently underway. Silver Line Phase 2 extends service 11-miles along the Dulles corridor and will include six new stations. The Potomac Yard Station adds an infill station in the city of Alexandria, Virginia on the Blue and Yellow Lines.

Ridership and Service Projections

Metrorail ridership has traditionally grown with system expansion and regional population and job growth. Beginning in 2010, rail ridership declined due to changes in travel markets with the growth of telework and ride-hailing alternatives as well as declining reliability of Metrorail service. Ridership began to stabilize and, by 2019, return to growth with improved service reliability following system renewal investments and replacement of the oldest and least reliable railcars. Pre-pandemic peak service ran on an 8-minute system headway pattern[1] with a mix of six-car and eight-car trains. The early months of the coronavirus pandemic saw a sharp drop in Metrorail ridership as customers were urged to stay home and limit travel to essential trips. A prolonged and uncertain recovery period is expected but it is not currently anticipated to alter capacity demand projections in this plan's 2030 and 2040 milestone years.

Metro considers a range of factors to develop system and line-level ridership projections, including the pace and location of regional population and job growth. Metro anticipates approximately one percent annual growth over the plan's 20-year timeframe with a higher initial growth rate in the years following the opening of Silver Line Phase 2. Rail service standards target average peak hour loads at or below 100 passengers per railcar. Applying the standard to the ridership forecasts, Metro has identified a need to increase rail service to operate all eight-car trains and increase train frequencies to a 7-minute headway level by 2030. Increased service will be phased in based on demand by line and fleet acquisition schedules.

Vehicle Requirements

Following the completion of 7000-Series railcar deliveries in 2020, Metro has 1,278 railcars in its revenue fleet, consisting of 2000-Series, 3000-Series, 6000-Series, and 7000-Series cars.[2] Since 2015, Metro has decommissioned the 1000-Series, 4000-Series, and 5000-Series vehicles due to age and reliability issues.

[1] Metro's Red Line operates at half the system headway and interlined segments, where two or more lines overlap, have lower effective headways. An 8-minute system headway, for example, is a system service pattern where trains leave end-of-line terminals every 8-minutes except on the Red Line, where trains depart every 4 minutes. On interlined segments, the combined headway is 2.6 to 4 minutes.

[2] In addition to railcars used for revenue service, Metro operates and maintains a fleet of 186 maintenance of way vehicles and four revenue collection vehicles.

Based on projected service level requirements, Metro calculates the number of railcars needed to operate peak period service. Metro adds a spare factor at a ratio of 20% of peak vehicles, equivalent to approximately 17% of the total fleet, to account for maintenance and rehabilitation activities.

Meeting the demands for all eight-car train operations and 7-minute service frequencies requires a total fleet of 1,528 railcars by the conclusion of the 8000-Series delivery period:

- 2020 (8-minute headway with mixed six- and eight-car trains): 1,278 cars
- 2030 (7-minute headway with 100% eight-car trains): 1,528 cars

The procurement of 8000-Series railcars is underway to replace the 2000-Series and 3000-Series vehicles and enable fleet expansion. The procurement will enable acquisition of up to 800 railcars with a base and four options. Precise option quantities can be adjusted before execution to ensure flexibility to meet Metro's needs. The number of railcars needed to meet replacement and potential capacity expansion milestones is summarized in Table E-1.

TABLE E-1: METRO 8000-SERIES PROCUREMENT PURPOSES

Procurement Purpose	Incremental Railcars	Total Railcars
2000-Series and 3000-Series replacement	366	366
8-Minute Headway, 100% Eight-Car Trains	70	436
7-Minute Headway, 100% Eight-Car Trains	164	600
6-Minute Headway, 100% Eight-Car Trains or early 6000-Series replacement	184	784
Contingency railcars	16	800

By 2030, if Metro exercises the base procurement as well as option quantities sufficient to support 100% eight-car trains at a 7-minute system headway, the railcar fleet will consist of 1,528 railcars:

- 6000-Series: 180 railcars[3]
- 7000-Series: 748 railcars
- 8000-Series: 600 railcars

Beyond 2040, Metro projects there may be a need to run trains at 6-minute frequencies. Following the 8000-Series, the next railcar procurement is anticipated to align with the retirement of the 6000-Series railcars beginning in 2045. An accelerated timetable could be pursued to meet faster than anticipated ridership growth, acquire railcars compatible with a next-generation train control system, or pursue early retirement of existing vehicles.

[3] A total of four revenue collection vehicles are expected to be converted 6000-Series railcars by 2030 (out of 184 total).

Maintenance and Reliability

Since 2015, Metro has made changes to its maintenance practices and seen improvement in railcar reliability measures. There are three types of railcar maintenance used to ensure a state of good repair throughout the lifecycles of these vehicles: Scheduled Maintenance Program (SMP), Preventive Maintenance & Inspection (PMI) and Corrective Maintenance (CM). Metro is improving its railcar rehabilitation program by implementing the SMP to overhaul railcar systems and components on a six-year cycle in lieu of the midlife overhaul program. Metro also modified the timing and tasks associated with the PMI program. These changes, coupled with the replacement of older and less reliable railcars, has improved fleet reliability. Metro recorded an improvement across vehicle series in Mean Distance Between Delays (MDBD) from 2015 to 2019, including a 75 percent decrease in customer offloads.

System and Facilities Capacity

An assessment of existing and planned systems and facilities reveals gaps Metro will need to address to meet projected service levels. Railcar storage and shop space are also not optimally configured for eight-car train operations and maintenance and further efficiency and reliability improvements will be explored.

- Yard Capacity: Metro's railyards do not currently have sufficient railcar storage capacity in all locations it will be needed to support a 7-minute system headway with 100% eight-car trains. Additional storage capacity will be needed on the Red Line and Blue, Orange & Silver Lines, especially at New Carrollton Yard, by 2030 when the fleet is projected to grow to 1,528 railcars.
- Shop Capacity: Metro's current railcar maintenance shop capacity is not adequate to meet demand at 7-minute headway service with 100% eight-car trains (2030). Construction of the new Heavy Repair & Overhaul (HR&O) facility in Landover, Maryland addresses current and future needs for railcar rehabilitation and meets Red Line shop capacity needs by enabling conversion of existing heavy repair shop bays at Brentwood Yard to service and inspection (S&I) bays. Additional shop expansions at New Carrollton and Branch Avenue Yards are needed to address shop capacity constraints on the Blue, Orange & Silver Lines and Green & Yellow Lines.
- Traction Power: Existing traction power capacity allows operation of 100% eight-car trains at 8-minute headways and current projects underway or planned will meet requirements for up to a 6-minute headway.
- Throughput: While core throughput capacity of 26 trains per hour is sufficient on all lines to operate a 7-minute headway, Metro's current operating standard for train turning capacity at terminals is 15 trains per hour and will require operational adjustments for 7-minute headway operation (approximately 17 trains per hour) at terminals with the most frequent service – Shady Grove, Glenmont, Greenbelt, and Largo.

Figure E-1 summarizes the requirements and gaps Metro needs to address to deliver service at 8-minute, 7-minute, and 6-minute system headways. The 7-minute headway capability is expected to be sufficient to meet service demand for the 20-year timeframe of this fleet plan.

FIGURE E-1: SYSTEM CAPACITY CAPABILITIES TO DELIVER 100% 8-CAR TRAIN SERVICE BY HEADWAY

Key:
- Current capabilities meet requirements
- Current & planned major projects, operational changes meet requirements
- Additional capacity needed, currently unplanned

	8-Minute Headway	7-Minute Headway (2030)	6-Minute Headway (Beyond 2040)
Fleet Size	**1,364 railcars** 7000-Series delivery complete Delivery of **434** 8000-Series cars (Options 1 & 2)	**1,528 railcars** 7000-Series delivery complete Delivery of **600** 8000-Series railcars (Options 1, 2, & 3)	**1,712 railcars** Delivery of **784** 8000-Series railcars (Options 1, 2, 3, & 4)
Yard Capacity	**56** spaces New Carrollton	**112** spaces at New Carrollton **52** spaces at Red Line yards	**112** spaces at New Carrollton **132** spaces at Red Line yards **60** spaces at Dulles
Shop Capacity	**40** bays in Heavy Repair & Overhaul Facility **8** bays at New Carrollton **8** bays at Branch Avenue	**40** bays in Heavy Repair & Overhaul Facility **16** bays at New Carrollton **8** bays at Branch Avenue	**40** bays in Heavy Repair & Overhaul Facility **16** bays at New Carrollton **8** bays at Branch Avenue **8** additional bays at Branch Avenue or Greenbelt **8** bays at Dulles
Traction Power	**Completed** power upgrades sufficient on all lines	**BL/OR/SV** lines by **FY2022** **RD** line by **FY2026** **YL/GR** lines by **FY2030**	**BL/OR/SV** lines by **FY2022** **RD** line by **FY2026** **YL/GR** lines by **FY2030**
Throughput			
Core	**22.5** trains per hour on **BL/OR/SV** lines; **<26** trains per hour standard	**<26** trains per hour on **BL/OR/SV** lines; within standard	Requires capacity to run **30** trains per hour on **BL/OR/SV** lines or frequency reduction on at least one line
Terminal	**15** trains per hour at **4** terminals; at current maximum standard	**>17** trains per hour or turnbacks; operating changes required	**20** trains per hour or turnbacks; operating changes required

1 Introduction

The Metrorail Fleet Management Plan is a statement of the processes and practices by which the Washington Metropolitan Area Transit Authority (Metro) establishes its current and projected Metrorail fleet requirements. It explains how service goals are applied to ridership projections to develop peak vehicle requirements, how vehicle maintenance needs inform the target spare ratio, how these requirements are impacted by Metrorail system expansions and other factors, and describes implications for supporting systems and facilities.

1.1. Overview of Plan

The Metrorail Fleet Management Plan is organized as follows:

- Chapter 1: Introduction. Provides a plan overview and system context to understand later content.
- Chapter 2: Demand for Revenue Vehicles. 2A documents Metrorail's projected peak ridership demand and how much service is required to meet the demand. 2B provides the number of vehicles required to provide that service and supporting methodology and context.
- Chapter 3: Supply of Revenue Vehicles. Details how Metro will meet the projected vehicle demand through long-term vehicle procurement, rehabilitation, and retirement plans as well as what the fleet composition will be over the next 20 years.
- Chapter 4: Maintenance and Reliability. Explains how Metro maintains and stores the fleet on an ongoing basis, detailed information on maintenance practices and programs, and updates on reliability metrics.
- Chapter 5: System and Facilities Capacity. Describes gaps in the current system and facilities capacity and how Metro will address with underway and planned investments.
- Appendix. Defines acronyms and terms. Details additional tables, figures, and methodologies for analysis and findings found in the Plan.

1.2. Plan Timeframe

The Plan covers fleet requirements for a 20-year timeframe, from 2020 to 2040. This timeframe captures all existing and committed improvements to the Metrorail system and provides adequate lead time to adjust operating, maintenance, and procurement strategies to accommodate anticipated changes in revenue fleet supply and demand. The Plan is a living document that is based on current realities and assumptions, and it is therefore subject to future revision. It has been developed to be consistent with the guidelines established for fleet management plans by the Federal Transit Administration (FTA) in their 1999 *Dear Colleague* letter and in FTA's *Oversight Procedure 37 – Fleet Management Plan Review*.

1.3. Description of Current System

1.3.1 Operating Characteristics

The Metrorail system opened in 1976 and has grown to 91 passenger stations along 117 two-way route-miles of heavy rail rapid transit, serving the District of Columbia and adjoining areas of Maryland and Virginia. With the completion of the Silver Line Phase 2 and the addition of the Potomac Yard station, this will increase to 98 stations and 128 two-way route-miles. Most Metrorail stations provide multimodal transfer facilities, including Park-and-Ride and connections to the following transit services: Metrobus services operated by Metro, bus services operated by local jurisdictions, Amtrak, the MARC commuter rail service and the Virginia Railway Express (VRE). All station platforms are 600 feet long, and each platform can accommodate trains up to eight-cars in length.

The system operates along six double-tracked rail lines (Red, Yellow, Green, Blue, Orange, and Silver). Table 1-1 summarizes the key characteristics of each line. The service patterns and fleet requirements of each line are described in Section 2.

TABLE 1-1: SUMMARY OF METRORAIL LINES, 2020

Line	Length (mi.)	Number of Stations	Peak Period Headway (min.)	Total Peak Trains (incl. gap and tripper)
Red	31.9	27	4	40
Yellow	15.1	17	8	16
Green	23.0	21	8	18
Blue	30.3	27	8	20
Orange	26.4	26	8	21
Silver	29.6	28	8	21
System Total	**117**	**91**	**8**	**136**

Figure 1-1 illustrates the existing system and its stations. The Blue, Orange, and Silver Lines share tracks through the core area of the region, as do the Yellow and Green Lines. The Blue and Yellow Lines also share tracks in Alexandria, Arlington, and Fairfax Counties. The Orange and Silver Lines share tracks in Arlington and Fairfax Counties. Similarly, the Green and Yellow lines share track in Maryland, as do the Blue and Silver. These shared segments of track offer Metro flexibility in structuring service patterns to meet operational needs. The Red Line does not share track segments with other lines.

FIGURE 1-1: METRORAIL SYSTEM MAP

1.3.2 System Infrastructure and Non-Revenue Facilities

Metrorail also relies on an interconnected network of system infrastructure and non-revenue facilities to deliver service and maintain fleet reliability. Elements include:

- Automatic Train Control
- Traction Power
- Terminals
- Pocket Tracks
- Junctions
- Railcar Storage Yards and Tail Tracks
- Railcar Maintenance and Overhaul Facilities

1.3.2.1 Automatic Train Control

An automatic train control (ATC) system regulates train speed and spacing to ensure safe and efficient operations. The ATC system combines automated and manual elements located on the train, along the track, in stations, and at remote central facilities. The system includes several subsystems which work in tandem to manage and regulate train movements: automatic train protection (prevention of collisions and derailments), automatic train operation (control of train movement and stopping at stations), and automatic train supervision (monitoring and control of train schedule):

- *Automatic Train Protection (ATP)*. ATP assists in enforcement of safe operation of the system by imposing speed limits and ensuring train separation. At interlockings, ATP ensures that train movement is permitted only when a clear, uncontested route is available and the track switches are locked in position. In all cases where two or more trains are competing for the use of a common segment of track, the system allocates the track to one train at a time and locks out all others.
- *Automatic Train Operation (ATO)*. ATO performs many of the functions normally performed by the operator. Those functions are smooth acceleration of the train to running speed, regulation of that speed, and stopping the train smoothly at the proper position in the station. Trains are currently operated in manual mode.
- *Automatic Train Supervision (ATS)*. ATS controls and monitors train routing and scheduling. The subsystem supplies operating data to the Rail Operations Control Center and automatically makes minor scheduling adjustments to maintain traffic flow. ATS communication with the trains is provided by the Train-To-Wayside Communication (TWC) system.

1.3.2.2 Traction Power

The 750 Volts Direct Current (VDC) Traction Power System provides the power source for vehicle propulsion. The traction power system includes contact and running rails, associated conductor system, power substations and tie-breaker stations including transformers, rectifiers and switchgear for conversion and supply of power to the contact rail system. Each segment of contact third rail can be supplied by adjacent power substations and are supplied by separate power company substations wherever practicable for additional reliability.

1.3.2.3 Terminals

Metro has ten terminals where train lines originate and terminate service.[4] Trains generally reverse direction at terminals and the time it takes to reverse train operation represents a capacity constraint in the Metrorail system. All terminals have crossovers, allowing trains to move from one track to another on the revenue side of the platforms and most also have crossovers on the non-revenue side. Five of the terminals have yard leads that continue past the terminal tracks.

1.3.2.4 Pocket Tracks

The Metrorail system has eight pocket tracks, each of which is configured as a third track between the two

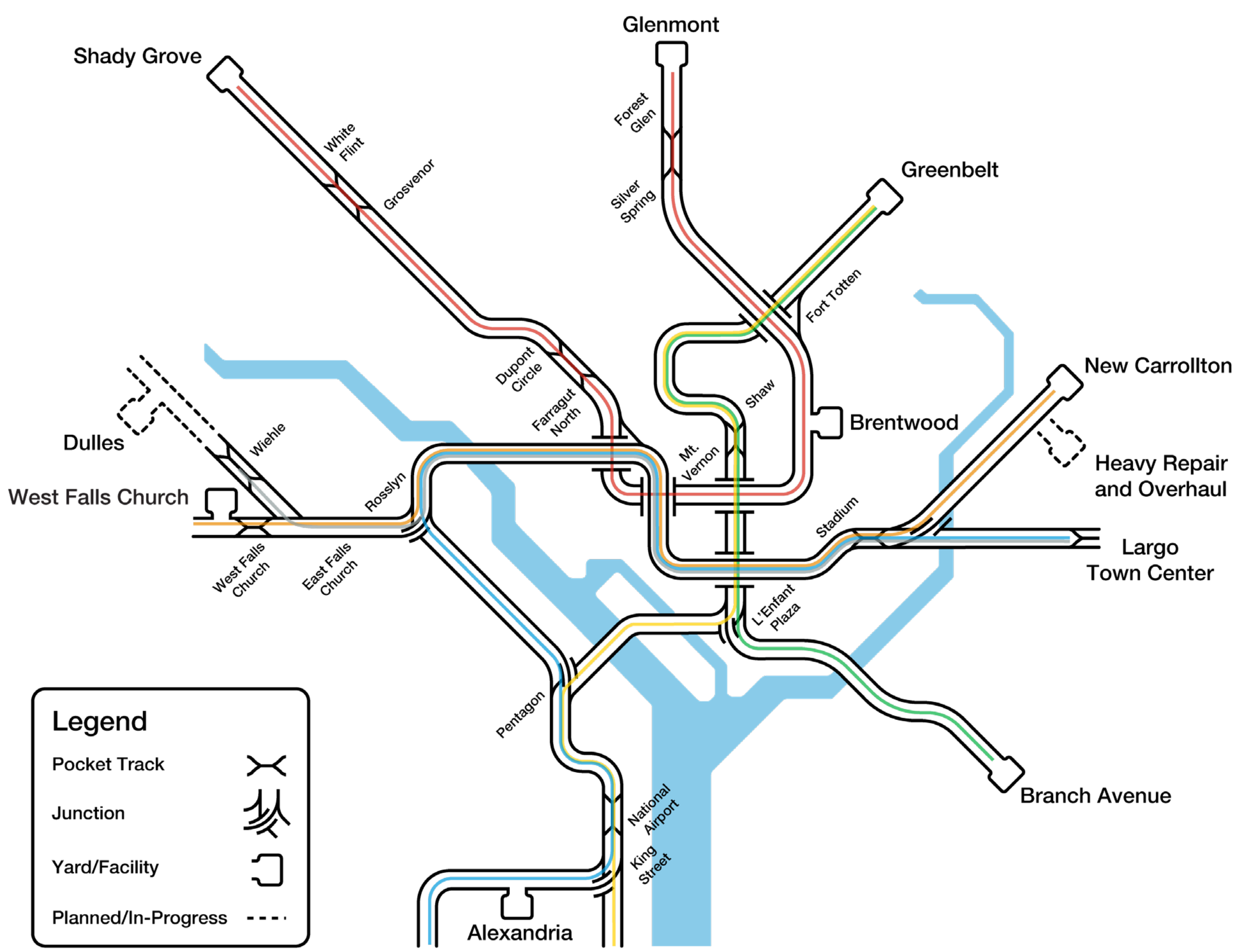
[4] Ashburn will replace Wiehle as the western terminal on the Silver Line with the opening of Silver Line Phase 2.

mainline tracks capable of storing an eight-car train.[5] These pocket tracks were incorporated into the design of the system for operational flexibility, such as to move disabled trains off the mainline and to allow for "short-lining", wherein certain scheduled trains turn back along the line rather than continuing service to the terminal station. Short-lining allows Metro to concentrate service capacity in the core of the system where demand is highest and to reduce service impacts from maintenance activities.

1.3.2.5 Junctions

Metrorail has junctions where lines meet to allow two rail lines to merge into one or trains to move from one line to another. Metro's Blue, Orange, and Silver Lines as well as Yellow and Green lines all merge into trunk lines and operate as interlined service. Junction configurations constrain system capacity because each merge point is a potential delay location. All three Metrorail capacity-critical junctions (Rosslyn, L'Enfant Plaza and Stadium-Armory) are "flying junctions" – configured with flyover track that avoids movement conflicts between trains moving in opposite directions.

FIGURE 1-2: LOCATION OF KEY SYSTEM INFRASTRUCTURE AND NON-REVENUE FACILITIES



[5] Pocket tracks are located at or near Wiehle, West Falls Church, Grosvenor, Silver Spring, Mt. Vernon Square, Stadium-Armory, and Reagan National Airport.

1.3.2.6 Railcar Storage and Maintenance

Metro has nine railcar storage locations and seven maintenance facilities across the system to house its revenue and non-revenue fleets when not in service. These yards are equipped with electrified third rail track to store and maneuver vehicles as well as non-electrified track to store Maintenance of Way (MoW) equipment. Size and capacity vary by yard based on the available real estate and needs of the system at the time of construction. The facilities are summarized in Table 1-2.

TABLE 1-2: CURRENT RAILCAR MAINTENANCE AND STORAGE FACILITIES[6]

Name	Line(s)	Revenue Storage	Maintenance Bays	Year opened	Functions
Alexandria	Blue and Yellow Lines	176	20	1981	Railcar storage, scheduled inspections, corrective maintenance
Branch Avenue	Green Line	174	8	2002	Railcar storage, corrective maintenance
Brentwood	Red Line	90	42	1974 (expanded 2007)	Railcar storage, corrective maintenance, heavy repair and overhaul
Glenmont	Red Line	132	0	1998	Railcar storage (no shops)
Greenbelt	Green and Yellow Lines	270	20	1995 (expanded 2007)	Railcar storage, scheduled inspections, corrective maintenance, heavy repair and overhaul, commissioning
Largo	Blue and Silver Lines	38	0	2004	Railcar storage (no shops)
New Carrollton	Orange Line	120	16	1978 (expanded 2006)	Railcar storage, scheduled inspections, corrective maintenance
Shady Grove	Red Line	166	36	1983 (expanded 2007)	Railcar storage, scheduled inspections, corrective maintenance
West Falls Church	Orange and Silver Lines	188	28	1986 (expanded 2014)	Railcar storage, scheduled inspections, corrective maintenance
Total		**1,354**	**170**		

All locations provide railcar storage and are a base of operations for daily rail service. The maintenance facilities perform a variety of functions but can be split into three overarching groups: Service and Inspection, Heavy Repair and Overhaul, and Car Track Equipment Maintenance.

[6] Table does not include Dulles Yard or the Heavy Repair & Overhaul Facility, which have not yet opened.

- Service and Inspection (S&I) shops perform routine preventive maintenance and carry out the inspection schedule for the railcar fleet
- Heavy Repair and Overhaul facilities triage and service railcars that require extensive repair as well as perform railcar overhauls on a six-year cycle
- Car Track Equipment Maintenance (CTEM) facilities perform all Maintenance of Way equipment repairs and maintenance.

Additionally, two new facilities are planned to increase storage and maintenance capacity. Dulles Yard includes a railcar S&I shop and a CTEM facility and will open with Silver Line Phase 2. The construction of the Heavy Repair and Overhaul Facility in Landover, Maryland will consolidate most heavy repair and overhaul operations currently performed at Brentwood and Greenbelt Yards and enable Metro to meet current and future fleet overhaul needs.

1.4. Vehicle Inventory

Metro maintains two types of vehicle fleets: revenue and non-revenue. Following the delivery of the final 7000-Series railcars, Metro's revenue fleet consists of 1,278 vehicles used for passenger service. The non-revenue fleet provides operational support as revenue collection vehicles and maintenance of way equipment.

1.4.1 Revenue Vehicle Inventory

Metrorail's fleet of revenue vehicles consists of 1,278 railcars. All railcars are configured in permanently married pairs, consisting of an A-car and a B-car. All car series except for the 7000-Series have an operating cab at each end of each married pair, while on the 7000-Series only A-cars have a full operating cab.

Metro acquired seven car fleets through a series of procurements from 1974 to the present. The first six series of cars were fully compatible and interoperable with one another and could be coupled both mechanically and electrically for operations. Meanwhile, the new 7000-Series have all new control systems, meaning they cannot be operated in a trainline with the older car series. Since 2015, Metro has decommissioned the 1000-Series, 4000-Series, and 5000-Series as 7000-Series cars have arrived and entered service. Additionally, Metro's 8000-Series base procurement of 256 railcars, along with an optional expansion of an additional 100 railcars, will deliver 366 cars to replace the 2000-Series and 3000-Series cars. An additional three options delivering up to 434 cars will be available for potential expansion of the fleet.

All cars are capable of operating on all lines within the Metrorail system; older car series can operate in train consists composed of two, four, six, or eight cars, while the new 7000-Series operate in four or eight car consists. All Metrorail vehicles are compliant with the Americans with Disabilities Act (ADA). Table 1-3 summarizes the key characteristics of each car series; further discussion of each may be found in Section 3.

TABLE 1-3: CURRENT METRORAIL FLEET [7, 8]

Manufacturer	Series	Seats Available	Years Entered Service	Years Overhauled	# Purchased	# in Service
Rohr Industries	1000	80	1976-1981	1994-1997	300	No longer in service
Breda Construzioni Ferroviarie	2000	68	1984-1985	2003-2004	76	74
	3000	68	1985-1989	2004-2008	290	276
	4000	68	1992-1994		100	No longer in service
Construcciones y Auxiliar de Ferrocarriles, S.A. (AAI/CAF)	5000	68	2002-2005		192	No longer in service
Alstom	6000	64 (A-car) 66 (B-car)	2007-2009		184	180
Kawasaki	7000	62 (A-car) 68 (B-car)	2015-2020		748	748
Total					**1,890**	**1,278**

1.4.2 Non-Revenue Inventory

Much like Metro has support facilities in its network to support operations, it also maintains a non-revenue rail vehicle fleet to maintain infrastructure and collect fares. Currently Metro has 186 Maintenance of Way fleet vehicles and four revenue collection cars that operate on its lines.

1.5. System Expansion Plans

Two major Metrorail system expansion projects are committed for implementation during the 20-year timeframe of the Metrorail Fleet Management Plan: Silver Phase 2 serving Dulles Airport, and the Potomac Yard Metrorail Station, a new infill station serving the Blue and Yellow Lines between the existing National Airport and Braddock Road stations. In 2019, Metro launched the Blue/Orange/Silver Corridor Capacity and Reliability Study to identify potential solutions to address capacity, reliability, and customer needs on the Blue, Orange, and Silver lines. Alternatives under evaluation include system expansion concepts and a locally preferred alternative may be selected in 2022.

1.5.1 Silver Line Phase 2

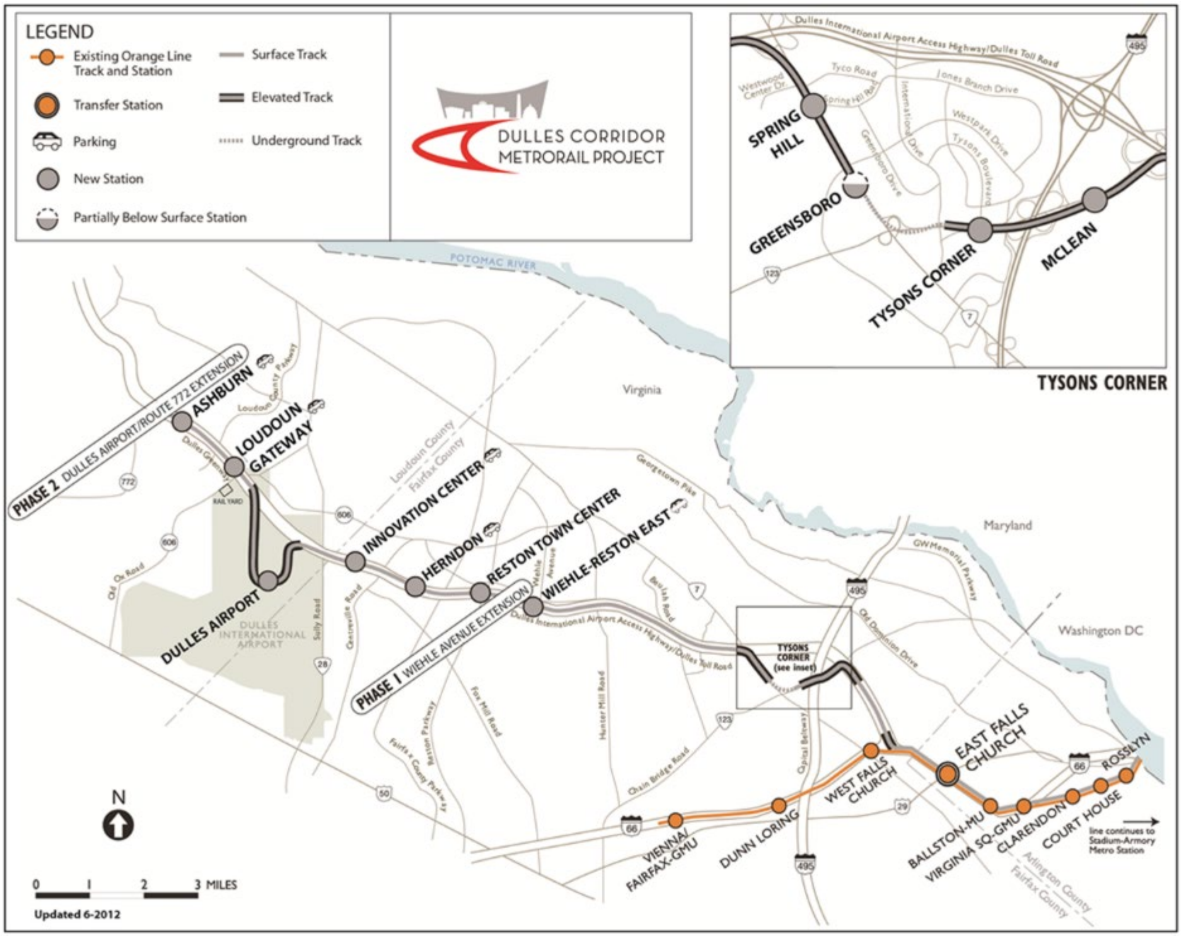
Phase 1 of the Silver Line Expansion, comprising a new branch off the Orange Line near West Falls Church and extending roughly 12 miles through Tysons Corner to Wiehle-Reston East in Reston, Virginia, commenced operations in July 2014 as the new Silver Line. Phase 2 of the project, extending an additional 11 miles beyond Wiehle, through Herndon, Dulles Airport, and beyond to Ashburn in Loudoun County, is expected to begin operations in 2022. Phase 2 includes a new rail yard and maintenance facility west of

[7] Reflects completion of 7000-Series procurement in early 2020 and usage of two 2000-Series railcars and two 6000-Series railcars as revenue collection vehicles.

[8] Table includes retired vehicles series.

Dulles Airport. Figure 1-3 provides a map of the Dulles Corridor rail extension.

FIGURE 1-3: DULLES CORRIDOR METRORAIL EXTENSION [9, 10]



The opening of Silver Line Phase 2 will have three major impacts on the Metrorail system:

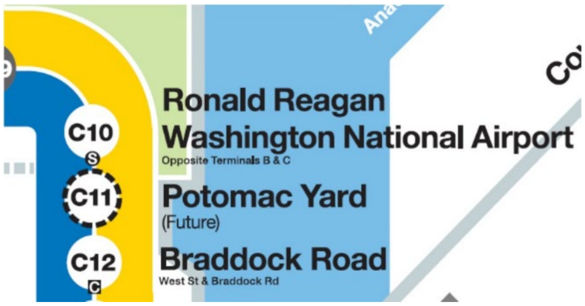
- Increased ridership. The opening of new stations will increase ridership and crowding as Silver Line trains enter the core of the system near Rosslyn.
- Increased fleet requirements. The route extension will add 21 minutes to the one-way running time of the Silver Line, thereby increasing the required number of trains. Likewise, ridership growth will warrant increasing deployment of eight-car trains.
- Increased railcar maintenance and storage requirements. The increased number of peak vehicles and increase in total service mileage will necessitate a commensurate increase in maintenance activities. An annex to the West Falls Church S&I facility was constructed as part of Silver Line Phase 1. A new maintenance and storage facility to the west of the Dulles Airport Station, Dulles Yard, will deliver an additional 168 storage spaces and 20 maintenance bays once completed.

[9] From Metropolitan Washington Airport Authority (MWAA).
[10] Referred to alternatively as the Silver Line Expansion.

1.5.2 Potomac Yard Station

Starting in 2011, the City of Alexandria, in cooperation with the Federal Transit Administration (FTA), Metro, and the National Park Service, sponsored an Environmental Impact Statement for the construction of "infill" station on Metro's Yellow and Blue Lines, serving the Potomac Yard area, a former railroad yard and now mixed-use neighborhood located between the existing Braddock Road and National Airport stations.

FIGURE 1-4: LOCATION OF NEW POTOMAC YARD STATION



Metro's Board of Directors approved the addition of the Potomac Yard station to the adopted regional system in 2015. In April 2018 the City of Alexandria and the Metro Board both approved the design-build construction project. Construction is underway and the new station is projected to open in 2022. The station is expected to add one minute of running time to the one-way travel times of Blue and Yellow Line services due to the additional station stop.

2 Demand for Revenue Vehicles

This section documents Metro's approach to determining demand for revenue vehicles. First, peak passenger demand is projected and service standards are used to determine service requirements. Second, a total vehicle requirement is determined by calculating the vehicles required for peak service and accounting for spares.

As of this document's publication, the coronavirus pandemic was ongoing, leading Metro to initially ramp down service in spring 2020 in response to decreased travel demand and to protect the health of Metro employees and later realign service levels to provide improved all day frequencies in fall 2021. While the ridership implications of this pandemic remain uncertain, the forecasts discussed within this document are long-term, reflecting anticipated trends over 5-year, 10-year, and 20-year periods. Metro's previous Rail Fleet Management Plan projected that ridership demand would support a 6-minute system headway and 100% eight-car trains by 2030. In light of revised forecasts, this document has been updated reflect the anticipated need for a 7-minute system headway with 100% eight-car trains by 2030.

As a result of the pandemic, it is possible that travel behavior and demand will be affected for a sustained period. The implications of these changes are not yet known and have the potential to alter ridership trends in multiple ways. Rider expectations of public transit capacity and tolerance for crowding may also shift over time. The impacts of these potential changes will be revisited in the coming years.

2A Passenger Demand and Service Levels

2.1. Peak Passenger Demand

Current and future peak ridership levels are the primary driver of fleet requirements. Capacity requirements of a rail line are driven by the number of riders traversing the busiest segment during its busiest hour of the day, known as maximum load points. Metro projects ridership at key maximum load points and applies service standards for passenger loads to determine future service level requirements.

2.1.1 Ridership Trends

Currently, of the 20 million trips taken in the Washington, DC metro area each weekday, 1.3 million are taken by Metrorail, bus, or commuter rail, accounting for 20% of commute trips and 3% of non-commute trips. Metrobus serves approximately 70% of bus trips in the region and other local agencies serve the remaining bus and all commuter rail trips.

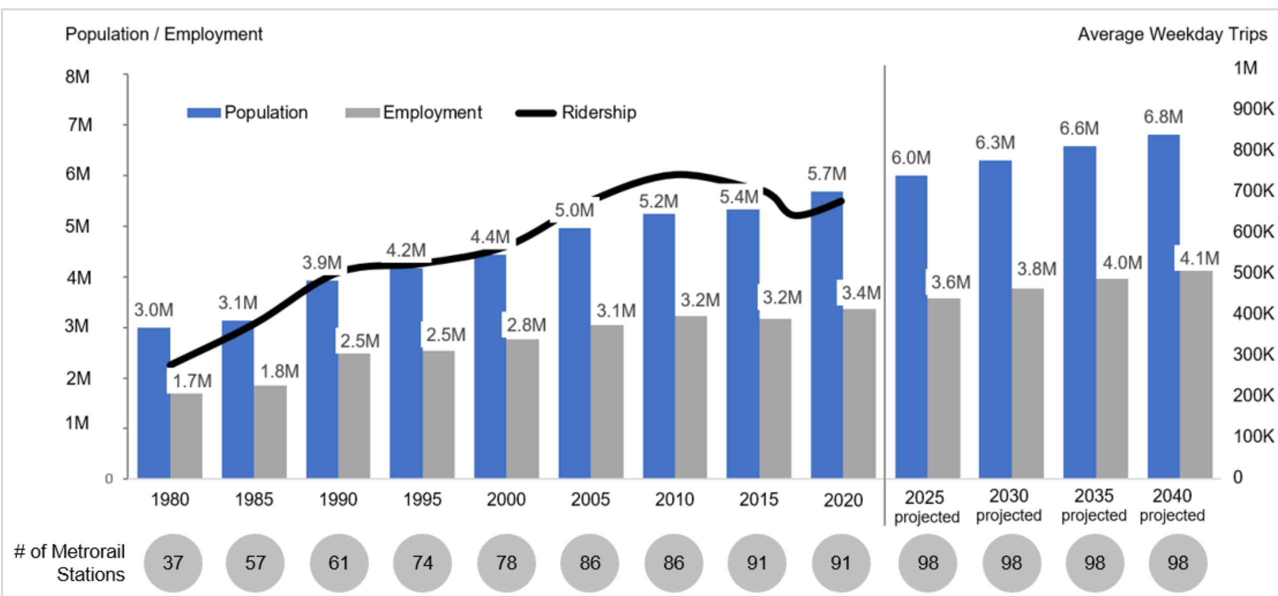
TABLE 2-1: WASHINGTON METROPOLITAN AREA DAILY TRIPS BY TRAVEL MODE, 2019[11]

Trip type	Total	Car	Transit	Walk	Bike	Ride-hailing	Telework	School bus
Commute	**4 million**	66%	20%	2%	1%	1%	10%	-
Non-commute	**16 million**	81%	3%	9%	<1%	2%	-	5%

Long-term Metrorail ridership is largely driven by population and job growth in the service area the level of mobility provided by the transit network. Metrorail ridership grew with the build-out of the originally planned 103-mile regional system, which was completed in 2001, and sustained growth of population and jobs in the Washington metropolitan region. Over the last 30 years, Metrorail ridership has grown at an average annual rate of approximately 1%, including as high as 3% in the 2000s and -2% in the past decade.

The past decade's ridership decline, beginning with modest decreases and escalating to significant drops in 2015 and 2016, was driven in part by changes in the regional travel market. These changes included the introduction of competing ride-hailing options and the growth of telework. Declines in Metrorail service reliability and increased planned service disruptions for system renewal also impacted ridership. Peak rail ridership, where work commutes make up a larger share of trips, experienced a lesser decline than off-peak ridership. Rail ridership began to stabilize in 2017 as service reliability improved and by 2019 was returning to growth, increasing approximately 7% over the prior year.

FIGURE 2-1: RIDERSHIP IN RELATION TO POPULATION AND EMPLOYMENT GROWTH, 1980-2020[12]



[11] Metro analysis; data from Metropolitan Washington Council of Governments (MWCOG), Regional Travel Survey and State of the Commute survey.
[12] Ridership data from Metro Office of Planning. Population and employment data from MWCOG, reflects Round 9.2 update published September 2020. https://www.mwcog.org/documents/2018/10/17/cooperative-forecasts-employment-population-and-household-forecasts-by-transportation-analysis-zone-cooperative-forecast-demographics-housing-population/.

In the last several years, safety and state of good repair investments including track rehabilitation and railcar replacement have led to improvements in service reliability. In 2016, Metro launched SafeTrack, a 13-month system-wide renewal initiative that required weekday service disruptions to accommodate multi-week surges of repair and renewal work. Since the conclusion of SafeTrack, major capital work requiring weekday service disruptions has continued to occur episodically, including the Platform Improvement Project's closure of six stations on the Blue and Yellow Lines in 2019 and four stations on the Orange Line in 2020. These major events usually cause immediate declines in ridership at affected stations and may also have residual impacts.

As commute trips are a major driver in transit ridership, employment trends including the number and location of jobs are important. The Washington metropolitan region continues to see growth in households and jobs, particularly in areas served by Metrorail such as the District of Columbia and Arlington County, and in several major transit-served areas such as Tysons Corner in Fairfax County, Eisenhower Avenue in Alexandria, and Bethesda and New Carrollton in Maryland. Silver Line Phase 2 is planned to open in 2022, which will add six new stations and bring additional connectivity to the Metrorail system. Figure 2-1 tracks ridership with historic population and employment growth. Regional population is forecast to grow to 6.8 million by 2040 with 4.1 million jobs, an increase of over one million residents and 750,000 jobs.

2.1.2 Metrorail Ridership Forecasts

Metro uses two models to develop its ridership forecast. For near-term forecasting, Metro uses a Short-Term Ridership Forecast (STRF) model based on demonstrated ridership drivers. For longer-term forecasts, Metro applies forecast growth rates from the travel demand model maintained by the National Capital Region Transportation Planning Board (TPB), the region's Metropolitan Planning Organization. This approach ensures Metro is using the best data about baseline ridership levels (up to fiscal year 2019) and applying common assumptions about future growth and development consistent with other local and federal agencies in the region.

Ridership methodology and assumptions

To estimate ridership for this Plan, Metro begins with the FY2017-2023 Short Term Ridership Forecast (STRF). In 2018, Metro developed the Short-Term Ridership Forecast model to project passenger demand through 2023. This forecast model was developed by analyzing previous years' data through a regression model. A set of machine-based learning and data mining procedures (e.g., regression trees and random forests) were used to inform the selection of variables to account for non-linear relationships within the data. The modeling determined the most important variables were population within walking distance of a station, service reliability at a given station, the number of hotel rooms, and employment. Regional forecasts of growth in households and jobs were used as inputs to Metro's in-house transit forecasting model. The modeling process considers major transportation improvements, such as the opening of Phase 2 of the Silver Line to Dulles Airport and Ashburn, and the new Potomac Yard station on the Blue and Yellow Lines.

Metro extends the short-term forecasts by applying the growth rates implied in from the TPB travel demand model's ridership growth outputs. To estimate ridership beyond fiscal year 2023, Metro begins at the end of the STRF, and applies station-level compound annual growth rates to the years through 2040. These figures are derived from the forecasted rail ridership of the regional travel demand model maintained by the TPB. The growth rates consider how projected changes in population and employment across the region will affect regional travel patterns and transit ridership.

Line and segment-specific growth projections are then developed and applied to the LineLoad application, a network assignment program that collects origin-to-destination data from Metro's farebox, creates a scheduled representation of the Metrorail network, and accurately reflects station-to-station ridership and direction of travel. The tool makes assumptions about the specifics of when, and to what destination, passengers will travel in the future, to develop link-load forecasts.

Metrorail system-wide passenger demand is generally projected to grow at an average annual rate of 1.4% from 2020 to 2025 and 0.7% from 2025 to 2030 with differences by line. Ridership is expected to grow more rapidly in the early years of the plan primarily due to the openings of the Silver Line Phase 2 and Potomac Yard Station, which will add a combined seven stations to the Metrorail System.

As peak hour, peak direction line specific forecasts determine future fleet requirements, Table 2-2 translates and summarizes the system-wide forecasts into ridership growth rates for peak hour, peak-direction segments of the Metrorail system. These rates are consistent with long-term historical growth rates and assumes the short-term trends and annual fluctuations may be higher or lower than the average rate. All lines are assumed, in this analysis, to see their maximum passenger flow in the AM peak hour. As such, Metro uses the AM peak hour to define maximum service requirements and as the basis for projected future peak demand.

TABLE 2-2: FORECAST ANNUAL GROWTH RATES FOR PEAK HOUR RIDERSHIP AT MAX LOAD POINTS

Line	Segment (From-To)	Forecast Average Annual Growth Rates 2020-2025	2025-2030	2030-2040
Red	Judiciary Square - Gallery Place/Chinatown	2.2%	0.8%	0.7%
	Dupont Circle - Farragut North	1.3%	0.6%	0.4%
	Gallery Place/Chinatown - Metro Center	1.2%	0.7%	0.6%
Yellow	Pentagon - L'Enfant Plaza	1.7%	0.5%	0.7%
Green	Waterfront - L'Enfant Plaza	2.5%	1.2%	1.2%
	Shaw-Howard - Mt. Vernon Square	1.1%	0.8%	0.5%
Blue	Rosslyn - Foggy Bottom-GWU	2.2%	1.0%	0.6%
	L'Enfant – Smithsonian	0.6%	1.6%	1.2%
	Pentagon - Arlington Cemetery	2.5%	0.9%	0.9%
Orange	Courthouse – Rosslyn	1.8%	0.6%	0.5%
	L'Enfant – Smithsonian	2.4%	0.7%	0.8%
Silver	Courthouse – Rosslyn	1.1%	0.2%	0.4%
	L'Enfant – Smithsonian	1.7%	0.2%	1.0%
All	**System-Wide Average**	**1.4%**	**0.7%**	**0.7%**

Appendix Table A-4 shows the projected peak hour maximum passenger flow for each line in Metro's system from 2020 through 2040.

2.2. Service Levels to Meet Demand

Ridership demand drives the scheduling of peak headways and train lengths. Headways are the departure frequencies of trains originating from a given terminal and are not defined by overlapping lines. Given the interwoven, "spoke-and-wheel," system design of Metrorail, all lines except the Red Line must operate at compatible frequencies to ensure that trains can merge and diverge from interlined segments on schedule.

2.2.1 Metrorail Service Standards

To ensure that Metrorail remains a desirable choice for existing and future passengers, Metro places a premium on providing high quality service and meeting the needs of the Washington metropolitan region. Providing sufficient service to meet service standards is critical to Metro's success and fulfillment of its mission to move the region.

Metro's target revenue vehicle load for service planning purposes is at or below 100 passengers per car, which is calculated as the average passenger load over the course of one hour. 100 passengers approximately represent all seats occupied with an additional half as many standing. Metro applies the passenger load standard to the busiest segment of each route during the peak hour. The Metro Board of Directors codified this standard in adopted resolution 2012-29 on October 25, 2012 (Table 2-3):

TABLE 2-3: METRORAIL RUSH PERIOD SERVICE STANDARD

Rush Period Service Standard	Location
Passenger loads below an average of **100** passengers per car (PPC) and shall not exceed 120 PPC or fall below 80 PPC	At locations in the system where vehicle passenger loads are the greatest

Where passengers per car (PPC) exceeds an average of 100 passengers per hour across one or more maximum load points, Metro looks to provide more capacity. Consistently offering service exceeding passenger loading guidelines results in deterioration of customer satisfaction and customers foregoing trips, less reliable service as crowded trains have longer and less predictable station dwell times, and potential safety issues.

2.2.2 Service Level Requirements

Applying the 100-passenger per car service standard to the ridership forecast, Metro can estimate when additional service will be needed to meet demand. Additional capacity can be provided by increasing train lengths (up to eight cars), increasing the standard service frequency, or scheduling supplemental "tripper" trains at specific times and locations. Train frequency and system capacity impact Metro's ability to serve riders as well as the overall customer experience. With increased capacity, riders are likely to experience shorter wait times, less crowding, have a better chance of boarding, and have the option to sit more often. Over the long term, the level and quality of service customers experience also affects ridership demand.

Operating more eight-car trains, delivering more car-capacity per scheduled train, is generally preferred before increasing frequency, as explained below in section 2.3.1. Reducing headway (i.e., reduce time between trains arriving at a platform during peak service) increases the trains per hour serving a line and changes must be compatible across interconnected lines. Additionally, Metro may deploy up to two tripper trains per line to temporarily increase capacity but doing so on more than two lines is generally less practical and efficient than increasing the overall scheduled peak frequency. The crowding relief provided is uneven, only affecting a narrow window between trains in the regular schedule, and operating more than a limited number of supplemental trains can interfere with delivering reliable service due to the interconnected nature of the Metrorail network and need for compatible frequencies at system merge points.

The designated system headway level (i.e. 8-minute, 7-minute, 6-minute) is shorthand, referencing the headway for most single line segments but is not the uniform headway for all parts of the system. Notably, the Red Line operates at half the system headway and interlined segments of the Yellow, Green, Blue, Orange and Silver Lines, where two or more lines overlap, have lower effective headways. An 8-minute system headway, for example, is a system service pattern where trains leave end-of-line terminals every 8-minutes except on the Red Line, where trains depart every 4 minutes. On interlined segments, the combined headway is 2.6 to 4 minutes.

For long-term planning purposes, capacity is assumed to progress in lockstep with changes to the overall system headway. In practice, system-wide changes could be phased in over multiple years (e.g., Red Line implementation in a different year than the rest of the system) so long as compatibility is ensured between the interconnected elements of the system on the Blue, Orange, and Silver and Yellow and Green Lines.

Table 2-4 details the hourly capacity for each considered headway for two-line patterns and one-line patterns. Appendix Table A-4 shows the expected growth in hourly ridership demand from 2020 to 2040 at each maximum load point. Analyzing the forecast demand against capacity levels of different system service patterns is the basis for determining the level of service required.

TABLE 2-4: SERVICE PATTERN CAPACITY PER LINE, PASSENGERS PER HOUR

	System Headway, 100% 8-Car Trains		
Service pattern	**8-minute**	**7-minute**	**6-minute**
Two-line pattern	12,000	13,714	16,000
With 2 added trippers	*15,200*	*16,914*	*19,200*
One-line pattern	6,000	6,857	8,000
With 2 added trippers	*7,600*	*8,457*	*9,600*

Projected Metrorail ridership from 2020 through 2040 indicate the implementation of a 7-minute headway with 100% eight-car trains is needed by 2030. It enables Metro to meet demand requirements and maintain service standards while making efficient use of assets and capital investments. The 7-minute peak headway keeps all lines near 100 passengers per car and within the bounds of Metro's service standards, with limited use of trippers, through 2040. Table 2-5 summarizes historical and projected peak hour passenger flow on each trunk segment.

TABLE 2-5: PEAK HOUR PASSENGER FLOW AT MAXIMUM LOAD POINTS BY TRUNK SEGMENT, 2000-2040

Trunk Segment [13]	2000 (actual)	2005 (actual)	2010 (actual)	2015 (actual)	2020 (actual) [14]	2025 (forecast)	2030 (forecast)	2035 (forecast)	2040 (forecast)
Gallery Place – Red	12,900	12,700	12,100	11,600	12,765	13,200	13,720	14,190	14,660
L'Enfant Plaza – Yellow/Green	8,900	13,600	13,000	13,700	12,390	12,400	12,820	13,400	14,050
Rosslyn – Blue/Orange/Silver	15,500	16,100	16,800	15,400	15,375	20,910	21,530	22,075	22,620

[13] Exact maximum load points by trunk segment have shifted over time but in recent history have been located at Gallery Place, L'Enfant Plaza, and Rosslyn.
[14] Fiscal year 2020 actual ridership is based on weekday ridership in October 2019.

Even with 100% eight-car trains, demand begins to outgrow the 8-minute headway by 2027 and all lines exceed 100 passengers per car by 2030, making the transition to a 7-minute headway necessary. Developing capacity for a 6-minute headway would ensure the ability to meet levels through 2040 and beyond. Although this level of service would ensure no trippers would be needed until at least 2037, it would incur capital investment and operating costs beyond what the service standard indicates is necessary. Metro currently intends to plan capital investments to the 7-minute headway capacity level but develop options to meet a future need for 6-minute headway capacity and not take any actions that would preclude a future decision to advance it. Metro will have an opportunity to re-evaluate ridership forecasts and service needs before decisions on exercising 8000-Series expansion options must be made.

In Table 2-6, the anticipated passengers per car at the maximum load point on each line are summarized for 8-minute, 7-minute, and 6-minute headway service scenarios, with and without tripper trains. The projections use the peak hour maximum passenger flow figures for the highest volume segment on each line. Actual 2020 passenger loads are included for comparative purposes.

TABLE 2-6: FORECAST PEAK HOUR PASSENGERS PER CAR AT MAXIMUM LOAD POINTS, 2020-2040

Line	System-wide headway pattern and train lengths	2020 Actual [15]	2025 Forecast	2030 Forecast	2035 Forecast	2040 Forecast
Red	8-min headways, 6- and 8-car trains (2020 conditions)	121	127	132	136	141
	8-min headways, 100% 8-car trains		110	114	118	122
	8-min headways, 100% 8-car trains, with 2 trippers		87	90	93	96
	7-min headways, 100% 8-car trains		96	100	103	107
	7-min headways, 100% 8-car trains, with 2 trippers		78	81	84	87
	6-min headways, 100% 8-car trains		83	86	89	92
	6-min headways, 100% 8-car trains, with 2 trippers		69	71	74	76
Yellow	8-min headways, 100% 8-car trains (2020 conditions)	107	99	102	105	109
	8-min headways, 100% 8-car trains		99	102	105	109
	8-min headways, 100% 8-car trains, with 2 trippers		78	80	83	86
	7-min headways, 100% 8-car trains		87	89	92	95
	7-min headways, 100% 8-car trains, with 2 trippers		70	72	75	77
	6-min headways, 100% 8-car trains		74	76	79	82
	6-min headways, 100% 8-car trains, with 2 trippers		62	63	66	68
Green	8-min headways, 100% 8-car trains (2020 conditions)	105	108	112	118	125
	8-min headways, 100% 8-car trains		108	112	118	125
	8-min headways, 100% 8-car trains, with 2 trippers		85	89	93	99
	7-min headways, 100% 8-car trains		94	98	103	110
	7-min headways, 100% 8-car trains, with 2 trippers		76	80	84	89
	6-min headways, 100% 8-car trains		81	84	89	94
	6-min headways, 100% 8-car trains, with 2 trippers		67	70	74	78
Blue	8-min headways, 6- and 8-car trains (2020 conditions)	89	114	119	123	127
	8-min headways, 100% 8-car trains		96	101	104	107
	8-min headways, 100% 8-car trains, with 2 trippers		76	79	82	84
	7-min headways, 100% 8-car trains		84	88	91	93
	7-min headways, 100% 8-car trains, with 2 trippers		68	71	74	76
	6-min headways, 100% 8-car trains		72	76	78	80
	6-min headways, 100% 8-car trains, with 2 trippers		60	63	65	67
Orange	8-min headways, 6- and 8-car trains (2020 conditions)	109	154	158	163	167
	8-min headways, 100% 8-car trains		138	142	146	150
	8-min headways, 100% 8-car trains, with 2 trippers		109	112	115	119
	7-min headways, 100% 8-car trains		121	125	128	131
	7-min headways, 100% 8-car trains, with 2 trippers		98	101	104	107
	6-min headways, 100% 8-car trains		104	107	110	113
	6-min headways, 100% 8-car trains, with 2 trippers		86	89	91	94
Silver	8-min headways, 6- and 8-car trains (2020 conditions)	107	141	143	145	148
	8-min headways, 100% 8-car trains		115	116	118	120
	8-min headways, 100% 8-car trains, with 2 trippers		90	91	93	95
	7-min headways, 100% 8-car trains		100	101	103	105
	7-min headways, 100% 8-car trains, with 2 trippers		81	82	84	85
	6-min headways, 100% 8-car trains		86	87	89	90
	6-min headways, 100% 8-car trains, with 2 trippers		72	72	74	75

PPC < 100 PPC 100-120 PPC > 120

[15] Fiscal year 2020 actual ridership is based on weekday ridership in October 2019 and was higher than forecast levels on some lines as ridership overall increased 7% year-over-year.

2B Total Vehicle Requirements

Metro calculates the peak vehicle requirements (PVR) necessary to meet the service levels identified as necessary in future milestone years, deriving the number of trains and railcars necessary to provide a given level of service aligned with ridership demand and accepted service standards. This requirement is then used to guide decisions for fleet size, service patterns, maintenance, and infrastructure.

2.3. Peak Vehicle Requirements

Metro's Peak Vehicle Requirement (PVR) is defined as the total number of revenue vehicles required for scheduled service plus revenue vehicles required to serve as gap trains.

The total scheduled vehicle requirements for each line are a result of:

1. The scheduled train headways and number of cars per train operating on the line
2. The end-to-end running time of the line, including recovery time;
3. Allocation of vehicles for strategic gap or standby trains.

2.3.1 System Headway and Train Length Operating Plan

Metrorail service standards, the physical layout of the Metrorail System, and operational considerations largely define the operating plan by line. Metro can reliably schedule a minimum operable headway of 2.3 minutes, or a maximum of 26 trains per hour over any one segment. In practice, headways are impacted by several operating factors including junction and terminal capacity constraints, vehicle availability, station dwell times and end-of-line recovery time. Additionally, where multiple routes converge and diverge through junctions, their headways must be coordinated to ensure efficient operations.

Metro operates two types of route patterns across its six colored lines:

- Primary routes on Metrorail lines are operated from one terminal of the line to the other, stopping at all stations in between.
- Tripper trains are used where there is a sharp imbalance in passenger volumes in the peak and off-peak directions of a line, and an additional train is needed in one direction only at specific times to accommodate a regular surge in demand.

Metro previously operated short line routes to take advantage of the mid-route turnbacks (i.e. pocket tracks) built along a line to provide a higher level of service closer to the core of the system where passenger capacity is generally highest. These included short-line Red Line trips between Grosvenor and Silver Spring and using Mt. Vernon Square as a northern terminal on the Yellow Line. The short turns at Grosvenor were eliminated in January 2019 and the Silver Spring and Mt. Vernon Square turnbacks eliminated in July 2019 with service continuing to end-of-line terminals. Metro continues to operate short-line routes in certain circumstances to accommodate track work or supplement service for special events.

Metrorail service currently includes a mix of six- car and eight-car trains, varying by route, as Metro progresses to 100% eight-car train operations. The current fleet is sufficient for operation of approximately

75% eight-car trains until the 8000-Series acquisition enables fleet expansion. As peak headways already provide reasonably frequent service, increasing train lengths is preferred as the first option for adding incremental capacity before shortening the system headway, considering the following factors:

1. **System design.** The Metrorail system was designed to ultimately operate with eight-car trains – each station platform is 600 feet long, allowing a maximum of eight, 75-foot cars to berth at each station platform. Additionally, a number of the busiest stations, including Farragut North, Gallery Place, and Union Station, have platforms configured with entrances at the far ends. This leaves some customers more than 150 feet away from the closest rear six-car train door once on the platform, creating frustrating and potentially hazardous situations as customers hurry to try to catch trains.
2. **Cost effectiveness.** Lengthening trains is a cost-effective way to increase capacity as train operators account for a large share of the marginal cost of train operations. The incremental cost of adding more cars in service is lower with fewer, longer trains. For example, 24 railcars could be operated as four six-car trains or three eight-car trains; operating the cars as eight-car trains increases operator productivity and enables delivery of a higher amount of overall passenger service volume given a specific funding level.
3. **Reliability and incident recovery**. Prioritizing increasing train length at a given car-capacity level enables maintaining wider train spacing, allowing for more incident recovery time and a reduction in cascading delays.
4. **Predictability and comfort for customers**. Customers consistently respond favorably to the prospect of eight-car train operations, associating longer cars with reduced crowding. Metro has found this is more than just perception. When mixed train lengths are operated on a line, the last two cars of eight-car trains are underused as customers choose to wait on parts of platforms where they know a train will come.
5. **Railcar configuration**. The newest 7000-Series and forthcoming 8000-Series railcars are configured for quad operations with operator cabs only located on one end of each married pair. This complicates building consists in non-quad configurations, increasing the operational preference for eight-car train operations.

Table 2-7 shows the current scheduled and projected percentage of eight-car trains on each line. While the completion of 7000-Series deliveries will enable increases in eight-car train operations up to at least 75%, full eight-car train deployment will require additional investments in fleet, facilities and infrastructure; these improvements are discussed in further detail in Chapter 5.

TABLE 2-7: CARS PER TRAIN CONSIST

	% 8-Car Trains	
Line	**2020**	**2025-2040**
Red	47%	100%
Yellow	100%	100%
Green	100%	100%
Blue	37%	100%
Orange	60%	100%
Silver	25%	100%

Table 2-8 summarizes the current and projected operating plan for the milestone years of the Plan to reflect planned expansions and adherence to the current service standards. The table demonstrates the service changes projected to occur with the opening of Silver Line Phase 2.

TABLE 2-8: CURRENT AND PROJECTED SYSTEM PEAK HEADWAYS

Line	Terminal 1	Terminal 2	Pattern	# Peak Hour Peak Dir. Trips		Peak Hour Avg. Headway (min)	
				2020, 2025	**2030, 2040**	**2020, 2025**	**2030, 2040**
Red	Shady Grove	Glenmont	Red	15	17.1	4	3.5
	Shady Grove	Glenmont	Red Tripper	n/a	1	n/a	60
			Combined Red	15	18.1	4	33
Yellow	Huntington	Greenbelt	Yellow	7.5	8.6	8	7
Green	Greenbelt	Branch Avenue	Green	7.5	8.6	8	7
	Greenbelt	Branch Avenue	Green tripper	1	1	60	60
			Combined Green	8.5	9.6	7.1	6.3
			Combined Yellow + Green through L'Enfant Junction	16	18	3.5	3.3
Blue	Franconia	Largo	Blue	7.5	8.6	8	7
Orange	Vienna	New Carrollton	Orange A	7.5	8.6	8	7
	Vienna	New Carrollton	Orange Tripper	2	1	30	60
			Combined Orange	9.5	9.6	6.3	6.3
Silver	Wiehle	Largo	Silver Phase 1	7.5	n/a	8	n/a
	Ashburn	Largo	Silver Phase 2	7.5	8.6	8	7
			Combined Blue + Orange + Silver through Rosslyn Junction	24.5	26.7	2.4	2.2

The associated capacity, expressed in trunk segment railcars per hour during the peak hour at maximum load points, is summarized in Table 2-9.

TABLE 2-9: PEAK HOUR CAPACITY DELIVERED BY TRUNK SEGMENT AT MAXIMUM LOAD POINTS, RAILCARS PER HOUR, 2000-2040

Trunk Segment	2000 (actual)	2005 (actual)	2010 (actual)	2015 (actual)	2020 (actual) [16]	2025 (forecast)	2030 (forecast)	2035 (forecast)	2040 (forecast)
Gallery Place – Red	126	141	140	128	105	128	145	145	145
L'Enfant Plaza – Yellow/Green	80	138	141	166	116	128	145	145	145
Rosslyn – Blue/Orange/Silver	142	170	173	155	150	188	214	214	214

Table 2-10 outlines historical and projected average passengers per car by trunk segment at maximum load points, assuming Metro were to adopt 100% eight-car trains by 2025 and a 7-minute system headway by 2030.

TABLE 2-10: PEAK HOUR PASSENGERS PER CAR AT MAXIMUM LOAD POINTS BY TRUNK SEGMENT, 2000-2040

Trunk Segment	2000 (actual)	2005 (actual)	2010 (actual)	2015 (actual)	2020 (actual) [17]	2025 (forecast)	2030 (forecast)	2035 (forecast)	2040 (forecast)
Gallery Place – Red	102	90	86	91	121	103	95	98	101
L'Enfant Plaza – Yellow/Green	113	99	92	83	107	97	88	92	97
Rosslyn – Blue/Orange/Silver	109	95	98	103	103	111	101	103	106

2.3.2 Vehicle Run Times

The time required to run a route from end to end, including recovery time at each terminal, determines how many trains are required to operate a certain service frequency. Table 2-11 lists one-way travel times:

[16] Fiscal year 2020 actual capacity is based on weekday ridership in October 2019.
[17] Fiscal year 2020 actual passengers per car is based on weekday ridership in October 2019.

TABLE 2-11: ONE WAY TRAVEL TIMES OF METRORAIL ROUTES[18]

			Travel Time (minutes)		
Terminal 1	**Terminal 2**	**Line**	**Pre-Silver Line Phase 2**	**Post-Silver Line Phase 2**	**Post-Potomac Yard opening**
Red					
Shady Grove	Glenmont	Red	70	70	70
L'Enfant Junction Routes					
Huntington	Greenbelt	Yellow	51	51	52
Greenbelt	Branch Avenue	Green	51	51	51
Rosslyn/Stadium-Armory Junction Routes					
Franconia	Largo	Blue	68	68	69
Vienna	New Carrollton	Orange	62	62	62
Wiehle	Largo	Silver Line (Ph. 1)	70	n/a	n/a
Ashburn	Largo	Silver Line (Ph. 2)	n/a	93	93

2.3.3 Gap Trains

Metro stages gap trains at strategic locations in rail yards and pocket tracks for rapid deployment as needed to maintain service quality. Gap trains mitigate the impact of trains removed from service, filling "gaps" in scheduled service to avoid missed trips, or address unanticipated crowding. The trains are scheduled with assigned operators, staged ready for service, and considered part of Metrorail's peak vehicle requirement.

The majority of gap train deployments are to replace trains with in-service failures, which include mechanical problems and vandalism. Gap trains are also deployed for non-mechanical problems, including to relieve occasional unanticipated platform overcrowding and to maintain scheduled headways under degraded operation conditions, especially those that sometimes remain even after a malfunctioning train has been replaced.

Because of the later-than-expected delivery of the 7000-Series railcars, Metro reduced the number of gap trains in 2014 with the start of the Silver Line from five to three. Combined with other factors, including a reduced spare ratio, the lack of gap trains contributed to decreased service reliability during this period. As new 7000-Series railcars were placed into service from 2016 to 2020, Metro increased the number of gap trains to seven to allow for sufficient distribution across the system.

For this plan's milestone years, Metro expects to operate a combined total of ten gap and tripper trains. This is currently projected to consist of seven gap trains and three tripper trains but the allocation could change depending on the balance of needs between providing supplemental capacity (tripper trains) and supporting service reliability (gaps trains). Gap trains currently operate as a mix of six-car and eight-car trains. By 2025, all gap trains are expected to be eight-car consists, as shown in Table 2-12.

[18] Recovery time is not included in the run-time calculation.

TABLE 2-12: GAP TRAIN REQUIREMENTS, ALL LINES

	2020	2025	2030	2040
Scheduled Gap Trains	7	7	7	7
Gap Train Vehicle Requirements	44	56	56	56

2.3.4 Peak Vehicle Calculations

Total peak period vehicle requirements are developed from peak hour, peak direction vehicle requirements, considering each route's running time, train consist requirements, and use of trippers to accommodate imbalanced peak demand. Table 2-13 summarizes, for each milestone year from 2020 to 2040, the total scheduled peak vehicle requirements by line:

TABLE 2-13: PEAK VEHICLE REQUIREMENTS, ALL LINES

Type of Service	Peak Vehicles Required for Service							
	2020		2025		2030		2040	
	Trains	Cars	Trains	Cars	Trains	Cars	Trains	Cars
Red Line Scheduled	38	264	38	304	43	344	43	344
Red Line Tripper	n/a	n/a	1	8	1	8	1	8
Gap Train	2	12	2	16	2	16	2	16
Subtotal: Red Line	**40**	**276**	**41**	**328**	**46**	**368**	**46**	**368**
Yellow Line Scheduled	15	120	15	120	17	136	17	136
Yellow Line Tripper	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Gap Train	1	6	1	8	1	8	1	8
Subtotal: Yellow Line	**16**	**126**	**16**	**128**	**18**	**144**	**18**	**144**
Green Line Scheduled	15	120	15	136	17	136	17	136
Green Line Tripper	2	16	1	8	1	8	1	8
Gap Train	1	8	1	8	1	8	1	8
Subtotal: Green Line	**18**	**144**	**17**	**152**	**19**	**152**	**19**	**152**
Blue Line Scheduled	19	128	19	152	22	176	22	176
Blue Line Tripper	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Gap Train	1	6	1	8	1	8	1	8
Subtotal: Blue Line	**20**	**134**	**20**	**160**	**23**	**184**	**23**	**184**
Orange Line Scheduled	18	132	19	152	21	168	21	168
Orange Line Tripper	2	12	1	8	1	8	1	8
Gap Train	1	6	1	8	1	8	1	8
Subtotal: Orange Line	**21**	**150**	**21**	**168**	**23**	**184**	**23**	**184**
Silver Line Scheduled	20	130	26	208	29	232	29	232
Silver Line Tripper	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Gap Train	1	6	1	8	1	8	1	8
Subtotal: Silver Line	**21**	**136**	**27**	**216**	**30**	**240**	**30**	**240**
Total: All Lines	**136**	**966**	**142**	**1,136**	**159**	**1,272**	**159**	**1,272**
With 20% Operating Spares Ratio	*164*	*1,162*	*170.5*	*1,364*	*191*	*1,528*	*191*	*1,528*

2.4. Provision of Spare Vehicles

The operating spares ratio (OSR) is defined by the Federal Transit Administration as:

$$OSR = \frac{[TAF]-[PVR]}{PVR}$$

Where:

OSR is the Operating Spares Ratio

TAF is the Total Active Fleet

PVR is the Peak Vehicle Requirement

Providing for a sufficient quantity of spare vehicles is essential to delivering reliable service and performing a cost-effective maintenance program; meanwhile, providing too many spare vehicles would mean underutilization of high-value, long lived capital assets and suboptimal resource allocation.

The FTA establishes no formal OSR goal for rail transit fleets, allowing individual agencies to tailor their fleet requirements to meet the unique operational characteristics and service goals of each agency's environment. Metro calculates its target spare ratio based on an analysis of the vehicle requirements for various maintenance activities over the course of a typical year, and a target of meeting the full peak vehicle requirement, including gap trains, on a minimum of 95% of weekdays.

2.4.1 Requirements for Maintenance

Since 2015, Metro has made significant changes to its maintenance operations and fleet to improve service reliability and reduce unscheduled maintenance. As a result, the share of cars out of service for corrective maintenance decreased more than 30% between September 2016 and September 2019. Metro's target operating spares ratio is 20%, which is equivalent to approximately 17% of the total fleet. This target is based on the full procurement of the 8000-Series trains and continued maintenance practices improvement. The target operating spares ratio can be separated into components, expressed here as target percentages of scheduled peak vehicles based on historic rates and anticipated need.

- Out of service for Rehabilitation under the Scheduled Maintenance Program (SMP) – Allow for 1.5% of peak vehicles

  In following industry best practice, Metro has implemented a new Scheduled Maintenance Program (SMP) in its Railcar Rehabilitation Program. This is a continual overhaul program based on 6-year cycles for each fleet series as opposed to a traditional mid-life overhaul. At times, rehabilitation activities with overlap with legacy fleet vehicles undergoing SMP during the same years as 7000-Series railcars.

- Out of service for Periodic Maintenance and Inspection (PMI) – Allow for 2% of peak vehicles

  Vehicles out of service for periodic maintenance and inspections are steady and predictable due to the scheduled nature of the preventive maintenance program, and scale directly with the number of vehicles in the fleet and how much they are being operated.

- Out of service for Engineering – <u>Allow for 1% of peak vehicles</u>

  Metro removes cars from service to complete analysis or campaign-based modifications to correct defects and improve reliability. Although much of this activity is planned in advance to limit the impact on overall fleet availability, unpredictable systemic defects that occur throughout a car series can cause this number to shoot up significantly.

- Out of service for Parts – <u>Allow for 2% of peak vehicles</u>

  Metro must hold a certain number of vehicles out of service awaiting delivery of necessary parts for repair. This number fluctuates over time and does not show a cyclical or seasonal pattern. Potential spikes are considered areas for consistent management attention rather than accommodation through the spare ratio.

- Out of service for Corrective Maintenance (Repair) – <u>Allow for 12.5% of peak vehicles</u>

  Although Metro has reduced the number of vehicles held out of peak service for repairs, this remains the largest category of out of service vehicles. This target anticipates continued improvements in fleet availability due improvements in preventive maintenance and the railcar rehabilitation program and ongoing benefits of the replacement of the least reliable legacy railcars.

- Out of service for Miscellaneous Issues – <u>Allow for 1% of peak vehicles</u>

  Vehicles are held out of service for a variety of other reasons, many of which affect the availability of vehicles during peak periods due to either the urgency of the issue or the length of time needed to complete the task. Examples include downloading video footage following an onboard incident and installing advertising wraps.

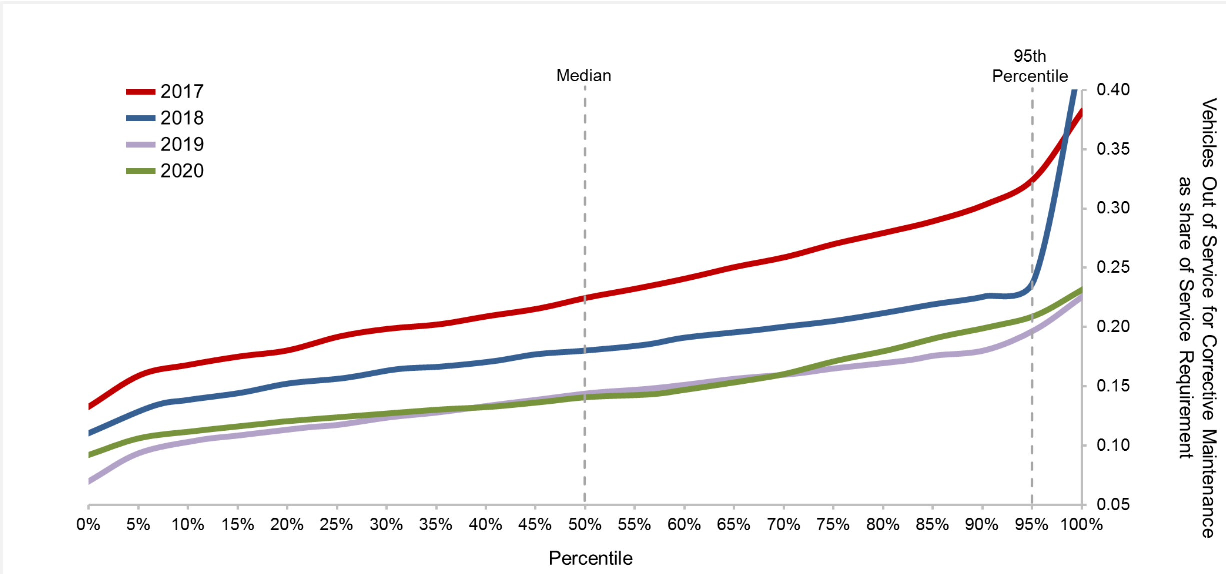
To monitor vehicle availability, Metro tracks vehicle status daily using reports from its enterprise asset management system, Maximo. This provides a source of historical data for the typical vehicle requirements for various maintenance activities during AM Peak periods. Analysis of actual AM Peak vehicle status data covering multiple years shows Metro's continued improvement in corrective maintenance levels and variability. Reliability trends are described in more detail in Chapter 4.

Trainline compatibility is an additional factor affecting the operating spare ratio as 7000-Series cars cannot be mixed with other car series in a single train consist and Metro prefers to operate other cars in single-series consists due to increased reliability. This can result in having quantities of spares cleared for service that are not sufficient to assemble a full trainset of a single-series.

Figure 2-2 shows the share of revenue vehicles out of service for corrective maintenance as a share of the total vehicles required for daily service.

FIGURE 2-2: REVENUE VEHICLES OUT OF SERVICE FOR CORRECTIVE MAINTENANCE AS SHARE OF

DAILY SERVICE REQUIREMENT, FY2017-FY2020[19]



As shown in this figure, there is a sharp increase in the number of vehicles required to meet peak vehicle service requirements more than 95% of weekdays. To achieve a fleet size sufficient to meet these service requirements while accounting for vehicles out of service for corrective maintenance, Metro seeks to balance efficient use of resources while providing reliable service the vast majority of days throughout the year. These considerations inform Metro's target operating spares ratio of 20% of vehicles required for peak service.

2.4.2 Total Projected Fleet Demand

The total fleet demand is calculated by combining projected peak service requirements, maintenance requirements (according to the above OSR component ratios and rounded where appropriate to reflect that railcars are permanently mated married pairs). This is provided for major milestone years from 2020 through 2040 in Table 2-14.

[19] Data shown for non-holiday weekdays with daily service requirement equal to or greater than 800 vehicles. Figure does not include vehicles out of service for parts, engineering, or periodic maintenance and inspection.

TABLE 2-14: TOTAL PROJECTED FLEET DEMAND AND SUPPLY/DEMAND BALANCE

	Total Fleet Requirements by Milestone Year			
Vehicle Requirement	**2020**	**2025**	**2030**	**2040**
Peak Vehicle Requirement (Service)	**966**	**1,136**	**1,272**	**1,272**
Out of Service for Rehabilitation (1.5%)	14	18	20	20
Out of Service for Periodic Maintenance and Inspection (2%)	20	22	26	26
Out of Service for Engineering (1%)	10	12	12	12
Out of Service for Parts (2%)	20	22	26	26
Out of Service for Miscellaneous (1%)	10	12	12	12
Out of Service for Corrective Maintenance (12.5%)	122	142	160	160
Total Maintenance Requirement	**196**	**228**	**256**	**256**
Total Fleet Demand	**1,162**	**1,364**	**1,528**	**1,528**
Projected Out of Service Ratio (% of total fleet demand)	*17%*	*17%*	*17%*	*17%*
Projected Operating Spares Ratio (% of peak vehicles)	*20%*	*20%*	*20%*	*20%*
Projected Vehicle Supply	**1,278**	**1,418**	**1,528**	**1,528**
Supply/Demand Balance [20]	116	54	0	0

[20] The surplus vehicles at the end of FY2020 include expansion vehicles to operate Silver Line Phase 2 and increase the share of trains operated as eight-car trainsets to 75% in subsequent years. A surplus is also expected at year-end 2025 as 8000-Series will be entering service during the buffer, or contingency, period before 2000-Series and 3000-Series railcars are decommissioned to account for burn in issues and the potential need for modifications.

3 Supply of Revenue Vehicles

Meeting the projected demand for revenue vehicles requires an assessment of the existing vehicle fleet to meet demand and identify potential gaps requiring resolution over the 20-year horizon of the Plan. Following the entry into service of the final 7000-Series railcars in May 2020 and the earlier retirement of the 1000-Series, 4000-Series, and 5000-Series vehicles, Metro's fleet consists of 1,278 revenue units and 190 non-revenue units (186 Maintenance of Way units and 4 revenue collection cars).

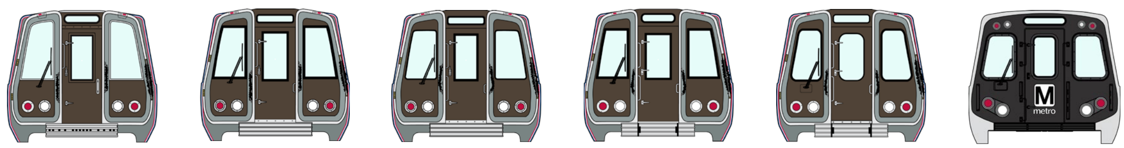
The 1000-Series through 6000-Series were designed to be fully compatible with one another, maximizing the flexibility Metro has in deploying vehicles for service. The 7000-Series represents a significant advancement in technology and cannot be fully electrically coupled with older cars for operations; rather they can only be mechanically coupled with older cars. All Metrorail vehicles are compliant with the Americans with Disabilities Act (ADA) and can operate on all revenue and non- revenue track throughout the Metrorail system.

The Federal Transit Administration establishes standards for vehicle useful life, which begins on the date a vehicle is placed in revenue service and ends when the same vehicle is removed from revenue service. For purposes of grant applications and accounting, railcars which have been purchased with federal assistance have a minimum useful life of 25 years.[21] Transit providers may also establish a National Transit Asset Management (TAM) Useful Life Benchmark, defined as the "expected lifecycle of a capital asset for a particular transit provider's operating environment, or the acceptable period of use in service for a particular transit provider's operating environment."[22] Useful life benchmarks represent the anticipated years of service for a given vehicle. Metrorail cars are considered to have a useful life benchmark of 40 years.

The actual years of service to be obtained from each railcar series varies depending on the most cost-effective strategy available to maximize their reliable service lives.[23] Figure 3-1 summarizes key characteristics of each vehicle series and further discussion of each series is provided in the following paragraphs.

[21] Source: FTA Circular 5010 https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/32136/5010-1e-circular-award-management-requirements-7-21-2017.pdf
[22] Source: FTA Final Rule 2132-AB07 https://www.federalregister.gov/documents/2016/07/26/2016-16883/transit-asset-management-national-transit-database
[23] The vehicle specifications for the 1000-, 2000/3000-, 4000-, and 5000-Series called for a design life of 35 years; the specifications for the 6000- and 7000-Series called for a design life of 40 years. 1000-Series railcars remained in service for their full 40-year useful life, including a midlife overhaul. The 4000-Series and 5000-Series railcars were retired in lieu of midlife overhauls due to cost and reliability considerations. Following mid-life overhauls between 2003 and 2005, the 2000-Series and 3000-Series railcars are projected to have a 40-year average useful lifespan.

FIGURE 3-1: METRO VEHICLE SERIES COMPARISON [24]



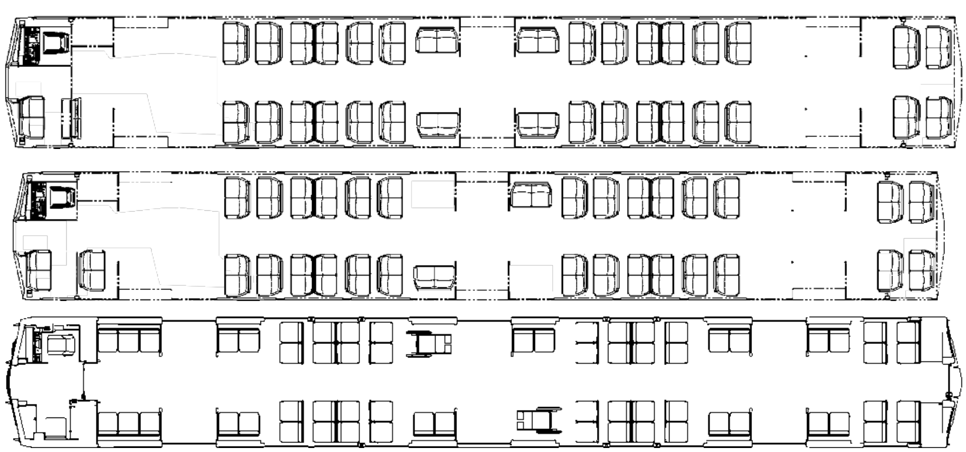
Series	1000	2000 & 3000	4000	5000	6000	7000
# Purchased	300	76; 290	100	192	184	748
Entered Service	1976-1981	1984-1985; 1985-1989	1992-1994	2002-2005	2007-2009	2015-2020
Status	Retired (2016-2018)	74 in service; 276 in service	Retired (2017-2018)	Retired (2019-2020)	180 in service	748 in service
Builder	Rohr	Breda-Alstom	Breda	CAF	Alstom	Kawasaki
Dimensions: Length	75’ 0”	75’ 0”	75’ 0”	75’ 0”	75’ 0”	75’ 0”
Dimensions: Width	10’ 1.75”	10’ 1.75”	10’ 1.75”	10’ 1.75”	10’ 1.75”	10’ 1.75”
Dimensions: Height	10’ 10”	10’ 10”	10’ 10”	10’ 10”	10’ 10”	10’ 10”
Seats	80	68	68	68	A Car 64; B Car 66	A Car 62; B Car 68

FIGURE 3-2: ACTIVE VEHICLE SERIES SEATING CHARTS

2000-Series
3000-Series

6000-Series
(A Car)

7000-Series
(A Car)



[24] 8000-Series in active procurement.

3.1. Current Revenue Vehicle Fleet

Metro's fleet of revenue vehicles consists of 1,278 railcars. These cars were acquired through a series of procurements and entered service from 1976 through 2020.

3.1.1 2000/3000-Series

Seventy-six 2000-Series and 290 3000-Series railcars entered service from 1983 to 1988 after being received from Breda Construzioni Ferroviarie (Breda). The 2000/3000-Series have 68 seats per car. The series were rehabilitated by Alstom between 2003 and 2005. During the mid-life overhaul the vehicles were stripped to the bare shell and underwent comprehensive structural and mechanical inspections and evaluation. The car braking, communications, truck, and Automatic Train Operation (ATO) systems underwent mid-life overhauls. The interior liners, train-line wiring and HVAC systems were replaced, the propulsion system was converted to AC drive, and upgrades were made to the draw, couplers, auxiliary power, and air supply systems.

The 2000/3000-Series is expected to have a useful life of 40 years, with replacement anticipated to be completed by the end of FY2028. Reliability of the 2000/3000-Series improved following their 20-year mid-life rehabilitation, and Metro plans to keep them in service for their full-rehabilitated lifespan.

3.1.2 6000-Series

The 6000-Series vehicles were manufactured by Alstom. A total of 184 6000-Series railcars entered service from 2006 to 2008. The 6000-Series incorporate substantial structural and mechanical improvements when compared to previous series, informed by Metro's accumulated experience with the performance of each of these vehicle sub-systems. 6000-Series includes an advanced Vehicle Monitoring System (VMS) that is compatible with those in the 2000-, 3000-, and 5000-Series. As of 2020, the 6000-Series continues to have a strong reliability record.

The 6000-Series vehicles were designed with a 40-year lifespan and initiated heavy maintenance through the Scheduled Maintenance Program in FY2020, which will be repeated on a six-year cycle.

3.1.3 7000-Series

The 7000-Series was manufactured by Kawasaki. A total of 748 7000-series railcars entered service between 2015 and 2020. The production schedule for the 7000-Series was delayed by supply chain issues primarily associated with the 2011 Tōhoku earthquake and tsunami in Japan, resulting in vehicles not arriving in time to support Silver Line Phase 1 opening as planned. The 7000-Series cars were received in 6 phases to meet varying demands:

- Silver Line Phase 1: 64 cars
- Replacements for the 1000-Series: 300 cars
- Replacements for the 4000-Series: 100 cars
- Replacements for the 5000-Series (1): 130 cars
- Replacements for the 5000-Series (2) + Growth for eight-car trains: 90 cars
- Silver Line Phase 2: 64 cars

The new 7000-Series cars are maintained as married pairs and operated in sets of two married pairs (quads).

Only A-cars of the 7000-Series contain full operating cabs, which enables greater total passenger capacity. "Quads" are arranged in an A-B-B-A orientation, and two quads can be combined to form an eight-car train consist. The 7000-Series vehicles incorporate state-of-the-art crash energy management design features, and shift to roof-mounted HVAC modules (in lieu of the split system in use on older car series) to ease maintenance.

The 7000-Series cannot be fully electrically coupled for interoperability with earlier car series (rather, they can only be mechanically coupled to facilitate emergency train movements if needed). This limitation allows Metro to take advantage of modern, state-of-the-art trainline technology, rather than mandating compatibility with the 1970s-1980s standard in use on the older car series. This new technology offers dramatically enhanced communications capabilities, includes improved car mechanical diagnostics, and wireless car health data transfer.

3.2. Retired Revenue Vehicle Fleet

Starting in 2016, Metro began to retire several vehicles from its revenue fleet in order to improve reliability and operations. As the 7000-Series units were delivered, commissioned, and proved reliable Metro retired the 1000-Series, 4000-Series, and 5000-Series. The 1000-Series had reached and exceeded their useful life benchmark of 40 years while the 4000-Series and 5000-Series vehicles were retired early due to excessive reliability issues. Metro retained the first two cars of each series for historical and educational purposes.

3.2.1 1000-Series

The Rohr cars (1000-Series) were the first revenue rail fleet vehicles acquired by Metro, and were first put into operation with the opening of the Red Line in 1976. Each car had 80 seats. The 1000-Series vehicles underwent a major overhaul between 1994 and 1997, which was designed to improve their reliability and modernize key car components. The 1000-Series were projected to have a useful life of approximately 40 years. Metro began the retirement of the 1000-Series in 2016 and completed their retirement in 2018.

1000-Series vehicles were involved in incidents in which their passenger compartments suffered significant damage as a result of the railcars "telescoping" when impacted. Following the Ft. Totten accident in 2009, Metro instituted a policy to only operate the 1000-Series vehicles within the middle of train consists (otherwise known as the "belly" position) until their eventual replacement in 2016. These vehicles were decommissioned as the 7000-Series cars were received and commissioned for service. Of the 300 purchased, 298 have been decommissioned to date, and the remaining two are maintained for historical significance.

3.2.2 4000-Series

Breda was also the supplier for the 100 4000-Series vehicles which entered service between 1992 and 1993. The 4000-Series were originally intended to have a lifespan of 35 years. As such, they would normally have been expected to receive a mid-life overhaul around 2012. However, Metro retired these cars in 2017 and 2018, replacing them with new 7000-Series cars in lieu of a mid-life overhaul.

This car series experienced the lowest reliability performance in the Metro fleet. Because of the relatively small size of the fleet (100 cars), the cost-per-car to perform a major mid-life rehabilitation would have been relatively high, while the marginal cost of purchasing an additional 100 railcars on the 7000-Series contract was comparatively low, due to the amortization of startup and engineering costs.

The 7000-Series cars have a projected lifespan of 40 years, whereas overhauled 4000-Series cars would only have an expected remaining lifespan of perhaps 15 years. For these reasons, the 4000-Series cars were decommissioned. Two of these cars remain as part of the non-revenue fleet for historic preservation purposes.

3.2.3 5000-Series

The 5000-Series was constructed by Construcciones y Auxiliar de Ferrocarriles S.A. (CAF) and entered service between 2001 and 2004. A total of 192 5000-Series vehicles were constructed. This series was delivered with several unique design features such as an all-aluminum structure and the first on-board diagnostic system (though the 2000/3000-Series received such a system as part of their mid-life overhaul). The addition of these vehicles to the fleet coincided with the opening of the central portion of the Green Line and the extension of the Green Line to Branch Avenue.

In subsequent years, the 5000-Series displayed below average reliability and required greater than expected engineering and maintenance effort to maintain acceptable performance. Metro undertook an analysis in 2014-2015 to evaluate the expected costs and benefits of performing a major mid-life rehabilitation of the 5000-Series cars, which would have been due by approximately 2020. The costs and benefits of multiple overhaul approaches were compared against two avenues of replacing the 5000-Series in lieu of rehabilitation: exercising two contract options on the ongoing 7000-Series procurement of new cars, or initiating a new railcar procurement for a base order of 192 cars.

This analysis indicated that the optimal choice on the basis of capital cost per car, expected operating costs, and expected service reliability was to replace the 5000-Series by exercising the final two contract options for new 7000-Series cars. In spring 2015, Metro reached agreement with its member jurisdictions and the Federal Transit Administration to adopt this strategy. Delivery and acceptance of the replacement cars took place in 2019 which allowed the retirement of all 5000-Series cars. Two cars remain in Metro's non-revenue fleet for historic preservation purposes.

3.3. Adjustments to Vehicle Supply

From 1974 to the present, Metro has purchased 1,890 railcars. Through FY2020, 600 of these cars have been decommissioned, generally as part of the fleet replacement strategy outlined previously in Section 3.2. All 1000-Series, 4000-Series and 5000-Series railcars have been decommissioned through this approach, totaling 592 total vehicles no longer in service. A small number of vehicles have been decommissioned outside of these series-wide retirements, typically as a result of irreparable damage. Most of these 600 decommissioned vehicles were disposed of, although a handful now serve other functions (such as first-responder training). At the completion of the 7000-Series delivery, the Metrorail fleet is comprised of 1,278 railcars. Vehicles not available for service are subtracted from the fleet size before calculating the fleet spare ratio. Vehicles decommissioned, converted to another purpose, or not available for service use fall into the following categories:

3.3.1 Damaged and Disposition-Pending Vehicles

Eight 3000-Series vehicles have sustained irreparable damage and have been decommissioned[25]. These vehicles were decommissioned following the conclusion of investigations by the National Transportation Safety Board (NTSB) and Metro's insurance carrier.

Of these eight vehicles, six have been decommissioned and disposed of, and two are used for safety training purposes at Metro's Carmen Turner Facility.[26] Six other 3000-Series vehicles were involved in a collision on October 7, 2019 and are likely to be decommissioned due to the age of the cars and the prohibitive cost of potential repairs.[27] Two 6000-Series vehicles sustained major damage after a derailment in a storage yard, but are currently undergoing repairs and are expected to return to revenue service.[28]

3.3.2 Revenue Collection Vehicles

The Metrorail system is designed such that transporting money and fare media between passenger stations and the Treasury facilities is best accomplished by train. The Treasury facilities are directly accessible by train, and the money carts (wheeled vaults) in each station are stored in lockers at the platform level for easy access by money collection trains. Because money distribution and collection are performed during off-peak revenue hours when passenger trains are still in service, safety and operating considerations dictate that the money trains must have the same operating characteristics as the passenger trains among which they must run.

Revenue collection vehicles are modified so that seats, carpets, windscreens, and stanchion bars are removed; steel plates with tie-down rings are fitted over the floors. Bump rails are also installed to keep carts away from interior liners, and shotgun racks are installed for the use of security personnel.

As of the conclusion of FY2020, Metro has a total of four vehicles designated for revenue collection: two such vehicles converted from 2000-Series trains, and two such vehicles converted from 6000-Series trains. As the time approaches, if more revenue collection vehicles are required, Metro will review the matter and conduct another cost-benefit analysis of all options, including purpose-built vehicles and modifying existing passenger railcars for revenue collection purposes.

3.3.3 Overhaul Float

In the past, Metro would have to plan vehicle supply schedules to accommodate a "float" of vehicles out of service for midlife overhauls. The new Scheduled Maintenance Program has replaced midlife overhauls, rehabilitating vehicles on an ongoing basis and eliminating the need for one-time adjustments to accommodate these activities.

3.3.4 Not Ready for Service

[25] The eight decommissioned 3000-Series vehicles are railcars 3191, 3216, 3217, 3252, 3256, 3257, 3036 and 3037. Railcars 3191 and 3252 were involved in a collision on January 6, 1996. Railcars 3256, 3257, 3036 and 3037 were involved in a collision on June 22, 2009. Railcars 3216 and 3217 were involved in a collision on November 29, 2009.

[26] Railcars 3191 and 3252.

[27] Railcars 3008-3009, 3206-3207, and 3120-3121.

[28] Railcars 6050-6051.

As new railcars are received, the cars undergo a series of tests and procedures to determine if the car is fit for service or requires minor issues to be addressed before going into service. In rare instances, vehicles may be returned to the manufacturer for major defects or significant damage during shipping and delivery. As these cars move through evaluation, they are deemed "not ready for service", but are counted in the overall fleet allotment.

3.3.5 Historical Significance

Metro maintains ownership of the first two cars of each series for historical significance and reference. Metro intends to continue this practice for each series as they are retired. Other decommissioned vehicles are used by public and private organizations for historical purposes or adaptive uses.

3.4. Existing and Planned Procurements

The projection of Metrorail vehicle supply considers the projected revenue vehicle demand and vehicle retirement plan. During the 2020 to 2040 Plan horizon, Metro will initiate one new rail vehicle procurement (referred to here as the 8000-Series) and begin preparation for additional replacements and expansions (referred to here as the 9000-Series).

3.4.1 8000-Series Railcar Procurement Program

Metro is in the process of procuring its next series of vehicles, known as the 8000-Series. The procurement will enable the replacement of the 366 originally purchased 2000-Series and 3000-Series railcars and the acquisition of additional railcars to accommodate fleet growth due to increased service requirements. Although not currently planned, the acquisition could also enable the early retirement of 6000-Series vehicles, which would most likely be undertaken to acquire vehicles compatible with a next generation train control system in lieu of retrofitting the 6000-Series vehicles. The procurement is structured with a base level and four options, with the potential to adjust option quantities prior to execution, to provide flexibility to meet Metro's needs.

The 8000-Series base order and initial option quantities will comprise up to 800 railcars:

- Base (256 cars)
- Option 1 (104)
- Option 2 (104)
- Option 3 (120)
- Option 4 (216)

The current long-term operating plan could be accommodated as follows with slight adjustments to the quantities of the option levels. Metro will need to exercise the base and Option 1 as planned to replace the 2000-Series and 3000-Series railcars (366). Options 2 and 3 would be exercised to achieve the capability for 7-minute headways (234). Option 4 would provide enough railcars for 6-minute headway operations or replacement of the 6000-Series railcars (184). The maximum order of 800 could also accommodate acquisition of 16 contingency railcars in addition to the other categories.

3.4.2 9000-Series Railcar Procurement Program

After the 8000-Series procurement, the next potential railcar procurement in the 20-year time horizon of the fleet plan is the 9000-Series. The 9000-Series procurement could be timed to replace the 6000-Series at the end of their 40-year lifespan between 2046 and 2048 and provide additional fleet expansion capabilities beyond 2040, if warranted. Alternatively, an accelerated schedule could be considered in the 2030s for a combination of fleet expansion, early retirement of existing vehicles, or replacement for compatibility with a potential next generation train control system.

3.4.3 Contingency Fleets, Retirements, and Procurement

Metro recognizes that newly-procured vehicles may require up to two years after their acceptance and entry into regular service to be "burned in", allowing maintenance staff and operators to identify and react to vehicle performance issues that may arise during revenue operations. Because of this, Metro phases its car replacement programs such that the older cars being replaced are not immediately retired on a one-to-one basis with the arrival of new cars; rather, the one-for-one retirement of older cars commences once the replacement cars have been in service long enough to establish their reliability. In some cases, this approach may result in apparent short-term increases in the size of the total fleet above the level needed to meet peak vehicle demand or impact the target operating spares ratio. However, beyond delaying retirement of old cars during a new car delivery, Metro does not plan to maintain any long-term "contingency fleets" of older vehicles beyond their useful life benchmark.

3.5. Summary of Vehicle Supply Plan

Table 3-1 presents a summary of the expected service lifespan of each vehicle series, including a summary of whether and when a series had or will receive a major mid-life rehabilitation. Table 3-2 presents a summary schedule of the proposed vehicle acquisitions, fleet adjustments, and retirements by year for FY2015-FY2040.

TABLE 3-1: VEHICLE LIFE EXPECTANCY BY FISCAL YEAR

Vehicle Series	Vehicle manufacturer	Number of vehicles	Fiscal Year Entered Service	Approx. Mid-life Overhaul Year	Useful Life Benchmark (years)	Expected End of Useful Life [29]
2000	Breda	70	1984	2004	40	2024
2000	Breda	6	1985	2005	40	2025
3000	Breda	84	1985	2005	40	2025
3000	Breda	90	1986	2006	40	2026
3000	Breda	48	1987	2007	40	2027
3000	Breda	62	1988	2008	40	2028
3000	Breda	6	1989	2009	40	2029
6000	Alstom	82	2007	-	40	2047
6000	Alstom	98	2008	-	40	2048
6000	Alstom	4	2009	-	40	2049
7000	Kawasaki	24	2015	-	40	2055
7000	Kawasaki	116	2016	-	40	2056
7000	Kawasaki	216	2017	-	40	2057
7000	Kawasaki	192	2018	-	40	2058
7000	Kawasaki	128	2019	-	40	2059
7000	Kawasaki	72	2020	-	40	2060
8000	Hitachi	256-800	2025-	-	40	2065-

[29] Actual year of retirement may vary from the useful life benchmark depending on fleet demands, lags between delivery and entrance to service, and other factors. In some cases, there may be a year or more gap between the delivery of a vehicle and its entrance into revenue service.

TABLE 3-2: SUMMARY OF PROPOSED RAILCAR ACQUISITIONS, ADJUSTMENTS, AND RETIREMENTS BY FISCAL YEAR [30, 31]

Car Series		FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024	FY2025	FY2026	FY2027	FY2028	FY2029	FY2030	FY2031	FY2032	FY2033	FY2034	FY2035	FY2036	FY2037	FY2038	FY2039	FY2040
1000-Series	1000-series fleet owned by WMATA (start of year)	288	285	242	65	6	6	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	1000-series adjustments for revenue collection	-4	-4	-6	-6	-4	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1000-series adjustments for historical preservation	0	0	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
	1000-series revenue vehicles (start of year)	284	281	234	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1000-series retirements	3	43	177	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1000-series retirements (vehicles not in revenue service)	0	0	0	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1000-series revenue vehicles on-site (end of year)	281	238	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000-Series	2000-series fleet owned by WMATA (start of year)	76	76	76	76	76	76	76	76	76	76	76	76	4	4	4	2	2	2	2	2	2	2	2	2	2	2
	2000-series adjustments for revenue collection	0	0	0	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	0	0	0	0	0	0	0	0	0	0	0
	2000-series adjustments for historical preservation	0	0	0	0	0	0	0	0	0	0	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
	2000-series revenue vehicles (start of year)	76	76	76	74	74	74	74	74	74	74	72	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2000-series retirements	0	0	0	0	0	0	0	0	0	0	0	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2000-series retirements (vehicles not in revenue service)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	2000-series revenue vehicles on-site (end of year)	76	76	76	74	74	74	74	74	74	74	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3000-Series	3000-series fleet owned by WMATA (start of year)	288	282	282	282	282	282	282	276	276	276	276	276	204	60	2	2	2	2	2	2	2	2	2	2	2	2
	3000-series adjustments for revenue collection	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3000-series adjustments for historical preservation	0	0	0	0	0	0	0	0	0	0	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
	3000-series adjustments for disposition-pending vehicles	0	0	0	0	0	-6	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3000-series revenue vehicles (start of year)	288	282	282	282	282	276	276	276	276	276	274	274	202	58	0	0	0	0	0	0	0	0	0	0	0	0
	3000-series retirements	6	0	0	0	0	0	0	0	0	0	0	72	144	58	0	0	0	0	0	0	0	0	0	0	0	0
	3000-series retirements (vehicles not in revenue service)	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3000-series revenue vehicles on-site (end of year)	282	282	282	282	282	276	276	276	276	276	274	202	58	0	0	0	0	0	0	0	0	0	0	0	0	0
4000-Series	4000-series fleet owned by WMATA (start of year)	100	100	100	74	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	4000-series adjustments for revenue collection	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4000-series adjustments for historical preservation	0	0	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
	4000-series revenue vehicles (start of year)	100	100	98	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4000-series retirements	0	0	26	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4000-series revenue vehicles on-site (end of year)	100	100	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5000-Series	5000-series fleet owned by WMATA (start of year)	192	192	192	192	192	10	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	5000-series adjustments for revenue collection	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5000-series adjustments for historical preservation	0	0	0	0	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
	5000-series revenue vehicles (start of year)	192	192	192	192	190	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5000-series retirements	0	0	0	0	182	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5000-series revenue vehicles on-site (end of year)	192	192	192	192	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6000-Series	6000-series fleet owned by WMATA (start of year)	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
	6000-series adjustments for revenue collection	0	0	0	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
	6000-series temporary adjustments for damaged vehicles	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	0	0	0	0	0	0	0	0	0	0	0	0
	6000-series revenue vehicles (start of year)	182	182	182	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
	6000-series retirements	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6000-series revenue vehicles on-site (end of year)	182	182	182	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
7000-Series	7000-series fleet owned by WMATA (start of year)	0	24	140	356	548	676	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748
	7000-series revenue vehicles (start of year)	0	24	140	356	548	676	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748
	7000-series deliveries	24	116	216	192	128	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7000-series revenue vehicles on-site (end of year)	24	140	356	548	676	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748	748
8000-Series	8000-series fleet owned by WMATA (start of year)	0	0	0	0	0	0	0	0	0	0	0	144	288	432	576	600	600	600	600	600	600	600	600	600	600	600
	8000-series revenue vehicles (start of year)	0	0	0	0	0	0	0	0	0	0	0	144	288	432	576	600	600	600	600	600	600	600	600	600	600	600
	8000-series deliveries	0	0	0	0	0	0	0	0	0	0	144	144	144	144	24	0	0	0	0	0	0	0	0	0	0	0
	8000-series revenue vehicles on-site (end of year)	0	0	0	0	0	0	0	0	0	0	144	288	432	576	600	600	600	600	600	600	600	600	600	600	600	600
Total Fleet All Series	Fleet owned by WMATA (start of year)	1128	1143	1216	1229	1290	1236	1296	1290	1290	1290	1290	1434	1434	1434	1520	1542	1542	1542	1542	1542	1542	1542	1542	1542	1542	1542
	Est. annual adjustments	-6	-6	-12	-16	-16	-22	-18	-12	-12	-12	-16	-16	-16	-16	-16	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14
	Revenue vehicles (start of year)	1122	1137	1204	1213	1274	1214	1278	1278	1278	1278	1274	1418	1418	1418	1504	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528
	Deliveries	24	116	216	192	128	72	0	0	0	0	144	144	144	144	24	0	0	0	0	0	0	0	0	0	0	0
	Retirements	9	43	203	129	182	8	0	0	0	0	0	144	144	58	0	0	0	0	0	0	0	0	0	0	0	0
	Retirements (vehicles not in revenue service)	0	0	0	2	0	4	6	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	Revenue vehicles (end of year)	**1137**	**1210**	**1217**	**1276**	**1220**	**1278**	**1278**	**1278**	**1278**	**1278**	**1418**	**1418**	**1418**	**1504**	**1528**	**1528**	**1528**	**1528**	**1528**	**1528**	**1528**	**1528**	**1528**	**1528**	**1528**	**1528**
	% of revenue vehicles past useful life (end of year)	**0.0%**	**1.7%**	**2.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**5.3%**	**10.4%**	**6.6%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
	Average revenue fleet age (end of year)	23.6	21.7	16.2	13.1	12.3	12.5	13.4	14.3	15.3	16.2	15.3	12.1	8.9	7.8	8.6	9.5	10.5	11.4	12.4	13.4	14.3	15.3	16.2	17.2	18.1	19.1

[30] Based on delivery schedules for 8000-Series, retirement of 2000-Series and 3000-Series vehicles, and completion of 7000-Series delivery in FY2020. Forecast assumes retirement of older vehicles in coordination with delivery of new vehicles, while growing fleet to meet ridership demand. Deliveries reflect the fiscal year vehicles entered revenue service.

[31] In FY2020, four 1000-Series railcars were retired and removed from the fleet inventory after having served as revenue collection vehicles. Those vehicles were cars 8002, 8003, 8004 and 8005 and were removed as of May 20, 2020.

4 Maintenance and Reliability

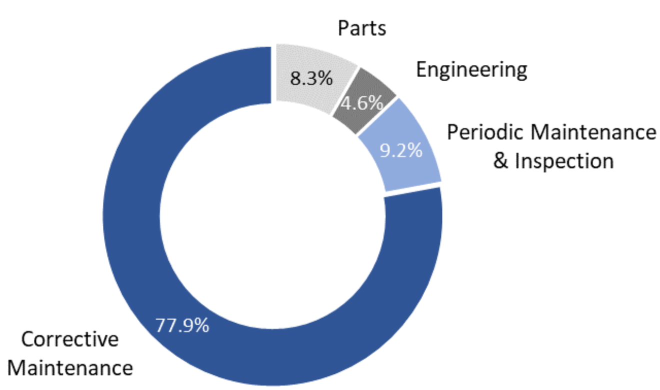
This section provides greater detail regarding the approach to railcar maintenance and rehabilitation to sustain a reliable fleet that underpins the target spare ratio.

Each day, in the same manner that a given number of vehicles is required to provide service to passengers, a given number of vehicles is required by Metro's railcar maintenance staff to maintain a reliable fleet. Metro car maintenance staff track vehicles out of service in real-time according to the following high-level categories:

- Vehicles out of service for rehabilitation under the Scheduled Maintenance Program (SMP)
- Vehicles out of service for corrective maintenance
- Vehicles out of service undergoing Periodic Maintenance & Inspections
- Vehicles out of service for engineering analysis or campaign-based modifications
- Vehicles out of service awaiting the delivery of parts

While Metro car maintenance works around the clock, the most critical aspect of car availability for the purposes of the fleet management plan is the extent to which vehicles are not available to operate during peak periods. On a typical weekday at 07:00 AM, the reasons for vehicles out of service break out as follows:

FIGURE 4-1: TYPICAL WEEKDAY PEAK OUT OF SERVICE REQUIREMENT[32]



[32] Source: 7AM non-holiday weekday "RCAR" Maximo Report, May 2016-September 2019. Overall non-holiday weekday percent out-of-service average is 18.51% for the same timeframe. Corrective Maintenance otherwise referred to as "repairs." Vehicles undergoing SMP are included within total for vehicles out of service for Periodic Maintenance & Inspection.

The following subsections describe Metro's Preventive Maintenance & Inspection (PMI) program, the Scheduled Maintenance Program, its approach to Corrective Maintenance, its engineering campaign strategy, and other reliability-centered initiatives.

4.1. Preventive Maintenance

The Preventive Maintenance and Inspection (PMI) Program constitutes the core strategy in maximizing the reliability of vehicles in revenue service and reducing the maintenance spares requirement. The PMI Program comprises all periodic (scheduled) progressive inspection, servicing and cleaning activities needed to meet the inspection requirements defined by the vehicle manufacturer.

4.1.1 Inspections

Scheduled inspections are the basis of Metro's PMI Program. An inspection of the vehicle includes a visual and mechanical inspection, system tests and servicing of mechanical components. Inspections also include replacement of components based on the recommendations of respective manufacturers. Defects identified during this inspection are corrected prior to the release of the vehicle from maintenance.

The Metro PMI Program contains four inspection types performed on each car at varying intervals, as summarized in the table below.

TABLE 4-1: OVERVIEW OF PREVENTIVE MAINTENANCE INSPECTIONS [33]

Inspection Type	Scheduled Inspection Interval	Average Interval (Mileage)	Standard Inspection Time (Hours)	Standard Inspection Labor Time (Hours)
Daily	24 hours	166	0.5	0.5
A	60 days / 90 days*	10,000 / 15,000*	24	30
B	Semi-Annual	30,000	24	46
C	Annual	60,000	36	60

** - 7000-Series trains*

In past inspection schedules, vehicles were scheduled for inspections to occur at various intervals: every 24 hours (daily); every 30 days (intermediate); every 90 days (type A inspection); semi-annually (type B inspection); and annually (type C inspection). In an update to the Metro PMI Program, the intermediate inspection has been eliminated and the type A inspection – which previously occurred every 90 days – now occurs every 60 days for 2000-Series, 3000-Series, and 6000-Series vehicles. Type A inspections continue to occur every 90 days for 7000-Series trains.

Daily inspections occur each day on vehicles released for service. These inspections are typically performed

[33] Some variability exists in the exact tasks and requirements related to inspections of each different car series.

after PM peak service concludes and prior to the time the system begins revenue operations again the next morning. Given the scope and time requirements of the Type A, B and C inspections, vehicles undergoing these preventive maintenance tasks are withheld from peak service for one to two days. These inspections typically occur Monday through Friday over the course of four working shifts.

A brief summary of periodic maintenance activities follows:

> Daily Inspection: The Daily inspection consists of a safety test of the car-borne automatic train control equipment, visual inspection of the interior and exterior of the car, and a functional test of safety-critical and passenger convenience-related components such as lighting, the public address system and emergency evacuation equipment. Defects are addressed prior to releasing the car for service. Graffiti removal is a top priority: Metro aims to never release a car for service with graffiti or vandalize equipment. Daily inspections are typically performed in the yard as opposed to inside the shop facility.
>
> Type A Inspection: Prior to technical inspection, under-car equipment is cleaned to enhance the quality of the inspection. Blow pits with compressed air hoses are provided at each service and inspection facility to blow carbon dust out of traction motors and generators. Blow pits also have hot water wash equipment to remove grease and dirt from mechanical components such as air conditioning condenser coils, couplers and wheel trucks. Following the cleaning process, designated system components are inspected for serviceability and are functionally tested.
>
> Type B Inspection: This includes all the requirements of the Type A inspection. Additional tasks include but are not limited to: a detailed door inspection and adjustment check, a detailed coupler and draft gear inspection, and other servicing and adjustments not required as frequently as in the previous inspections.
>
> Type C Inspection: This encompasses all the requirements of previous inspections and adds routine overhaul of selected electrical and mechanical components. The equipment to be overhauled is removed and replaced in compliance with the inspection procedure published by the Office of Chief Engineer, Vehicles (CENV). Removed components are sent to the appropriate overhaul shop (either Greenbelt or Brentwood).

The specific inspection and preventive maintenance requirements differ somewhat by car series, which results in each car series having unique PMI mechanic training, equipment, and materials requirements. In the interest of efficiency and to minimize duplicative resources not to duplicate vehicle specific resources, Metro assigns each car series to a specific “home” Service & Inspection (S&I) shop for A, B, and C inspections, as shown in Table 4-2:

TABLE 4-2: PERIODIC INSPECTION BLOCK ASSIGNMENT BY S&I SHOP [34]

S&I Shop	2000-Series	3000-Series	6000-Series	7000-Series	Total
Shady Grove	30	-	182	174	386
Alexandria	12	98	2	68	180
West Falls Church	14	120	-	56	190
New Carrollton	10	64	-	116	190
Greenbelt	10	-	-	334	344
Total	**76**	**282**	**184**	**748**	**1,290** [35]

In this context, the "home" shop does not describe a physical location the vehicle returns to each night, but instead describes the locations for periodic inspections to be performed on a given vehicle series. Each shop typically performs from one to three periodic inspections a day.

4.1.2 Cleaning

Most cleaning is performed during off-peak and non-revenue hours, although some is done while the vehicle is out of service for other inspections.

There are three levels of interior cleaning, as well as an exterior cleaning. When possible given schedule constraints and train wash availability, exterior washing is accomplished by train operators taking their trains through the automatic train wash as they return to the yard following passenger service. Cars with serious graffiti or other vandalism are removed from service immediately. Metro has experienced only a few incidents of major graffiti on railcars in service, and its removal requires a major effort that is outside the scope of this routine cleaning program. Additionally, Metro performs a monthly disinfection of railcars which includes the wiping down of all frequently touched surfaces[36].

The three types of interior cleaning are performed as follows:

Terminal cleaning: Basic cleaning performed on a train when it reaches a terminal, before re-entering service. This cleaning includes the removal of trash and newspaper. Train cleaning personnel are assigned to terminal stations to perform this task. They also provide emergency spot cleaning and alert the Terminal Supervisor to more extensive cleaning requirements that may warrant removing the train from service temporarily. This cleaning occurs from 7:00am to 11:00pm, Monday through Friday.

[34] Figures shown reflect point-in-time information from Reliability Centered Maintenance Planning (RCMP) as of May 29, 2020. Periodic inspection block assignments change over time with operational requirements and fleet size.
[35] Metro's active revenue fleet consists of 1,278 railcars. Two 2000-Series vehicles and two 6000-Series vehicles are currently designated for revenue collection purposes, and are assigned to Alexandria. Two 6000-Series vehicles are out for long-term repair and will be assigned to track inspection. Six 3000-Series railcars are pending decommission.
[36] At the time of this document's publication, Metro's disinfection techniques and schedules have been adapted to respond to the ongoing COVID-19 pandemic. Every railcar is disinfected daily before entering revenue service, and electrostatic sprayers are used to disburse the approved disinfectant. The operator's cab is also disinfected in the course of this cleaning.

Midday Layover Cleaning: This cleaning includes sweeping, the wiping of surfaces and the mopping of 192 railcars during weekday mid-day layovers.

Heavy Duty Cleaning: This task is performed in conjunction with the Type A inspection, every 60 days for 2000-Series, 3000-Series and 6000-Series vehicles and every 90 days for 7000-Series vehicles. The interior of the car is thoroughly cleaned. The walls, ceiling, windows, light fixtures, and seats are hand washed with detergent, and the carpet is shampooed.

4.2. Railcar Rehabilitation

Metro utilizes a Scheduled Maintenance Program (SMP) for railcar rehabilitation, wherein railcars are rehabilitated on a recurring six-year cycle. In previous maintenance practices, specific sub-systems and components were replaced during periodic inspections or in accordance with manufacturer recommendations. As a result, railcars underwent this type of maintenance over the course of multiple separate occasions. By consolidating all major sub-system replacement under a single scheduled maintenance operation, Metro achieves gains in efficiency and ensures that all sub-systems are maintained in a state of good repair.

Previously, railcars were not comprehensively overhauled until their estimated mid-life point of 20 years. Through the SMP, railcars will be maintained in a state of good repair throughout their anticipated useful life benchmark. Additionally, Metro will utilize the SMP to introduce targeted improvements to achieve enhanced reliability, maintainability and a positive customer experience. For example, 6000-Series vehicles will undergo seat replacement and the introduction of LED interior lighting, while 7000-Series vehicles will undergo the installation of improved video camera systems.

In the past, 20-year mid-life railcar overhauls cost approximately 70% of the cost of an entirely new railcar. With newly instituted six-year SMP cycles, railcar rehabilitation will become more frequent, improving reliability and reducing rehabilitation costs. With the installation of more energy efficient sub-systems and components, energy consumption will also be reduced. The planned opening of the HR&O facility will expand Metro's capacity to perform the railcar rehabilitation activities associated with the SMP. Other periodic inspections and repairs will continue as outlined in Section 4.1.1.

With an established and coordinated railcar rehabilitation process, Metro is able to drive process improvements and better maintain the overall appearance of cars in service. It is anticipated that this approach will also allow for increased railcar rehabilitation throughput and efficiency gains by creating predictability in material acquisition. The SMP also utilizes railcar-specific performance measures to support a process of continued improvement.

4.2.1 Current Scheduled Maintenance Program (SMP) Rehabilitation Status by Series

As Metro transitions its overhaul process to the approach outlined above, rehabilitation schedules and scope within the SMP vary by vehicle series. Older vehicles within Metro's fleet are currently in the process of being rehabilitated, and this work will recur within six-year cycles.

- 2000/3000-Series

  Vehicles in the 2000-Series and 3000-Series began to undergo rehabilitation within the SMP starting in FY2018. Specific efforts include overhauling air compressors, HVAC systems and truck assemblies.

- 6000-Series

  From FY2019 to FY2021, all 6000-Series railcars are planned to be rehabilitated as part of the SMP. Vehicles that have undergone SMP have seen notably improved performance as measured by MDBF.

- 7000-Series

  As they are the newest vehicles in the fleet, 7000-Series railcars have not yet undergone rehabilitation within the SMP. Metro forecasts 7000-Series railcars to begin rehabilitation in FY2022. Due to the size of the 7000-Series fleet, these rehabilitation efforts are anticipated to take six years to complete. The first round of 7000-Series rehabilitations will conclude in FY2026, and the SMP will run continuously for the life of this series of vehicles. Material and equipment requirements will be defined in advance, and planning efforts for this round of rehabilitation are currently underway.

4.3. Corrective Maintenance and Fleet Reliability

Metro's preventive maintenance and railcar rehabilitation programs aim to reduce failures and minimize the impact of unscheduled corrective maintenance on vehicle availability. Unscheduled maintenance is triggered by failures identified on out of service vehicles, such as during daily safety inspections, as well as vehicles that are removed from service due to an in-service failure. Unscheduled maintenance activity accounts for roughly three quarters of the railcars out of service at any given time. Significant improvements in Mean Distance Between Delays (MDBD) and fleet availability are further detailed below.

When failures occur, Metro's goals are: 1) to make sure no unsafe vehicle is deployed for service; 2) to return a repaired vehicle to service as quickly as possible; and 3) to identify the root cause of the failure and properly address it to avoid recurrence. Most corrective maintenance activities are performed in maintenance shops. Metro also positions Road Mechanics in the system to intercept problem trains in service to minimize the impact of a failure on service. Road Mechanics work to quickly assess the reported failure, perform any appropriate minor mechanical repairs, and determine whether it is safe for the railcar to remain in service.

4.3.1 Fleet Reliability

It is the responsibility of Metro's Office of Reliability Engineering and Performance Analysis (REPA) to track service delays and mechanical failures that cause unscheduled maintenance. Through careful record keeping, Metro can identify trends that can either be addressed through engineering campaigns or incorporated into scheduled maintenance routines, thereby increasing vehicle availability and performance over the long run.

Mean Distance Between Delays (MDBD) is Metro's primary reported fleet reliability measure. MDBD includes failures during revenue service resulting in delays of four or more minutes. Metro also tracks Mean Distance

Between Failures (MDBF), including all mechanical failures, monthly by car series to facilitate performance management and trend analysis. Table 4-3 summarizes in-service reliability trends at the car series and fleet-widelevel from FY2015 through FY2019:

TABLE 4-3: ANNUAL MEAN DISTANCE BETWEEN DELAYS BY CAR SERIES, FY2015-FY2019 [37, 38]

Fiscal Year	1000-Series	2000-Series	3000-Series	4000-Series	5000-Series	6000-Series	7000-Series	Fleet Avg
2015	60,441	89,242		24,689	48,802	100,683	46,294	**63,015**
2016	64,583	76,227		24,082	41,301	115,969	60,932	**60,105**
2017	69,708	81,472		43,372	54,140	100,407	126,241	**79,656**
2018	-	94,070	70,988	-	50,589	85,312	141,914	**92,657**
2019	-	137,469	92,242	-	46,621	116,166	268,899	**160,985**

The rail fleet MDBD performance has increased in recent years, reaching over 160,000 miles between delays in FY2019. These trends illustrate the reliability challenges that were presented by the 1000-Series, 4000-Series, and 5000-Series cars which performed below the fleet-wide average for in-service reliability. The 1000-Series and 4000-Series railcars were retired from the fleet in FY2017; the 5000-Series railcars were retired in FY2019. In contrast, the latest additions to the railcar fleet, the 6000-Series and 7000-Series railcars, have been consistent high-performers in recent years.

The reduction in the frequency of vehicle-related delays correlates with an improvement in the percentage of the fleet that is out of service for unscheduled maintenance. This reduction in vehicles out of service for maintenance allows for a lower total operating spare ratio (OSR), with typical weekdays now showing a roughly 12.5% fleet requirement for unscheduled maintenance with only outlying days upwards of 20% (in contrast to a typical day of 20% as in 2010). These prior improvements, combined with replacement of the oldest and least reliable cars in the fleet, allow Metro to plan for a minimized OSR.

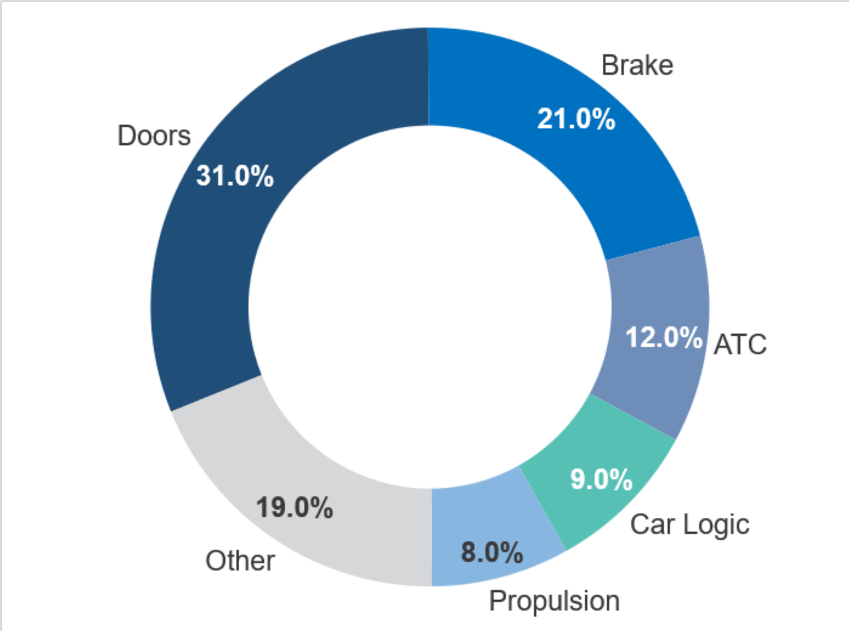
4.3.1.1 Sub-System Delays

Metro also keeps significant statistics on the sub-systems that fail, a practice which helps to identify trends in failures by component and supplier at the fleet-wide or car series level, as needed.

Figure 4-2 shows the rate of delays caused by each of the major individual car-borne sub-systems per million miles across all cars in the fleet during the period from July 2018 through June 2019. The data indicate that Doors, Brake, Automatic Train Control, Car Logic and Propulsion are the top five sub-systems responsible for in-service delays.

[37] From Metro Office of Transit Performance Management.
[38] Mean Distance Between Delay values for 2000-Series and 3000-Series trains were measured as a combined measure until FY2018.

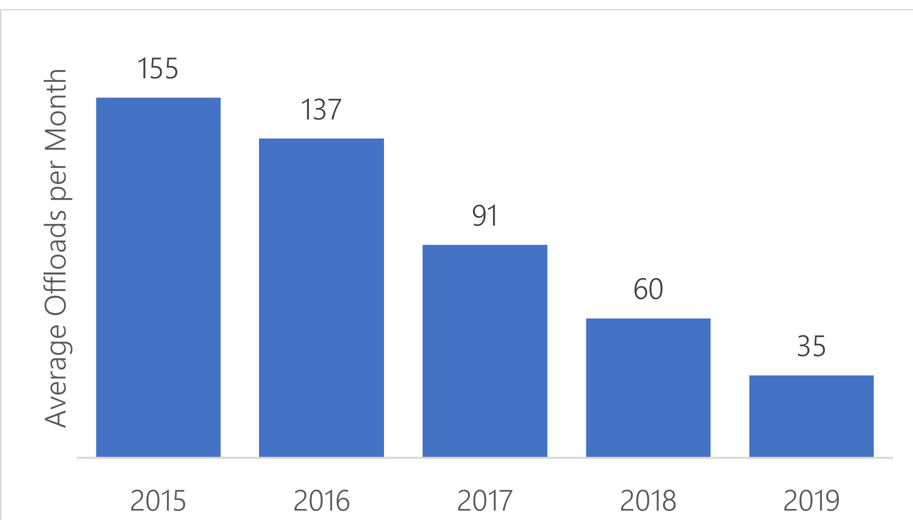
FIGURE 4-2: SUB-SYSTEM DELAYS (4 OR MORE MINUTES) PER MILLION MILES [39]



4.3.1.2 Railcar Offloads [40]

Metro measures and reports the offload metric so that management is able to prioritize critical failures that impact customers. Over the last five fiscal years, there has been a drastic decline in the number of railcar offloads experienced, as shown in Figure 4-3 The improved offload performance is due in large part to the retirement of older fleets as well as a concentrated effort in reducing failures that cause offloads.

FIGURE 4-3: AVERAGE OFFLOADS PER MONTH (2015-2019) [41]



[39] From Office of Reliability Centered Maintenance Planning (RCMP) sub-system delay rolling 12-month report, October 2019.
[40] A railcar offload is a significant consequence of a railcar failure that requires passengers to be removed from an affected railcar. These figures do not include offloads caused by other purposes, such as a track fire.
[41] From Metro Office of Transit Performance Management.

4.4. Engineering Campaigns

When a recurring defect on a particular car series is identified, one or more cars may be held out of service for detailed engineering evaluation. If a defect is identified as presenting an on-going issue throughout a subset of cars in the fleet, the Office of the Chief Engineer-Vehicles (CENV) will prepare an Engineering Test Plan (ETP), with potential components and requirements to correct or prevent the identified problem. An ETP is followed up by an Engineering Test Report (ETR) to validate a technical solution, and subsequently an engineering campaign is initiated to apply the solution to all vehicles affected by the issue.

The engineering campaign process is important for maximizing in-service reliability and vehicle availability. However, performing engineering campaign work requires the availability of cars on which to perform the modifications, and as such if the OSR is too low, campaigns will take longer to complete and the performance benefits will be deferred or delayed. Metro has been working to instill industry best practices in scheduled maintenance and rehabilitation programs and coordinating engineering activities with scheduled maintenance to reduce the number of cars unavailable for peak service at any one time due to engineering requirements.

4.5. Reliability Initiatives

Metro has employed several ongoing efforts to improve fleet availability and reliability.

4.5.1 Dedicated Consists and Dedicated Yards

Metro has implemented a practice of running trains in dedicated single-series consists and scheduling trains to return to dedicated yards. Starting in fiscal year 2018 following the retirement of 1000-Series railcars, Metro has operated trains in dedicated consists of a single railcar series. It previously operated 1000-Series railcars only in the "belly" position of train consists between other series vehicles following the 2009 Fort Totten collision. Although designed for interoperability, the railcars perform best when operated as trains within a single series.

Starting in fiscal year 2019, railcars are scheduled to return to dedicated yards each night allowing most scheduled and unscheduled maintenance on vehicles to be performed in the same shops. This practice enables maintenance teams to develop familiarity and greater pride of ownership with specific assets. As railcar mechanics must be specifically trained in each series, it also improves the efficiency of maintenance by allowing staff assignments to be better aligned with the specific car series serviced in each shop.

4.5.2 Reliability Centered Maintenance and Performance Management

Metro uses asset performance, condition, and failure data, enabled by information technology systems, to adjust maintenance programs and inform performance management. Metro is implementing a reliability centered maintenance approach to developing maintenance programs for assets based on a data-driven understanding of the characteristics of each asset, accounting for the operating context and risk profile. As a part of this approach, Metro works to ensure that every asset is maintained properly through an effective maintenance program. Metro also uses data to investigate root causes of failures and design appropriate maintenance and engineering solutions.

Reliability centered maintenance is a key element in how Metro develops its asset management strategy, encompassing inspections and maintenance (both preventive and corrective) as well as planned capital renewal. In this way, Metro is able to examine the effectiveness of its asset management strategies. Metro regularly monitors and sets targets for a range of performance measures, tracked on a monthly basis for internal management and published quarterly in the *Metro Performance Report*.

4.5.3 Quality Assurance

As a part of its quality assurance processes, Metro's Office of Quality Assurance, Internal Compliance & Oversight (QICO) monitors and assesses compliance with quality requirements for rolling stock maintenance, operations and engineering. QICO also monitors the performance of new fleet vehicles and the quality of maintenance work performed on all vehicles to ensure that practices and procedures are effectively supporting the goal to provide the best in safe, reliable, cost effective and attractive rail transit services.

The Office of the Chief Mechanical Officer, Rail (CMOR) also monitor failures and documents trends for quality assurance purposes. Daily audits are performed within the various maintenance shops and on revenue lines to measure the quality of maintenance performed. The results of the audits are reported to the respective maintenance managers. Procedural problems and failure trends are reported to the Office of Chief Engineering Vehicles for further evaluation and corrective action.

4.5.4 Parts Availability

Metro's Office of Supply Chain Management (SCM) was established in fiscal year 2018 to modernize management of the supply and distribution of parts and materials. The office is responsible for inventory planning and operations of a central supply warehouse and on-site storerooms at major operations facilities including rail yards. SCM is working to centralize and improve inventory planning, standardize data, and reduce inefficient spending on parts and materials. Through its supply chain management efforts, Metro expects to order and receive parts faster, increase asset availability, and improve operational cost efficiency.

As a part of this effort, Metro established the Office of Supply Chain Planning and Analytics (SCPA) within SCM. This office works to improve forecasting accuracy, coordinate planning and analytics, and increase planning effectiveness through data-driven decisions. Metro is also planning to implement a Vendor Managed Inventory program (VMI), a collaborative approach between Metro and a vendor which is expected to reduce wait time for parts from suppliers and allow those parts to be purchased at a lower cost.

4.6. Test Track and Commissioning Facility

Extensive testing is necessary on each train delivered to Metro before it is accepted and placed into service. The testing and commissioning period for a pair of railcars is typically sixty days. All on-board systems are tested, including the car's interface with the Automatic Train Control system. The tests are performed under a variety of operating conditions that examine performance both within the normal operating range and at the limits of that range, including tests on acceleration and braking performance, communications, heating and cooling systems, lighting, signage and door controls.

Prior to 2015, the acceptance testing process was conducted primarily during the brief overnight periods, during which time track usage would also have to be coordinated with maintenance crews, contractors, and non-revenue train movements. This significantly limited the number of cars per month that Metro could test and commission. As part of the 7000-Series Program, Metro constructed a test track and commissioning facility at the Greenbelt rail yard, both fully complete by 2016. This facility accommodates the testing and commissioning of up to 20 railcars per month. The facility also houses office space for Rail Engineering personnel and will be used for ongoing engineering analysis of the entire rail fleet.

4.7. Heavy Repair and Overhaul Facility

Metro is constructing a consolidated Heavy Repair and Overhaul (HR&O) facility to meet the needs of the current fleet and accommodate future growth. This facility will be dedicated to railcar rehabilitation work, component overhaul and extensive repair projects. The facility will have space for 40 railcars in the shop space and serve as the central hub for the railcar rehabilitation program. Additionally, shop space will be reserved for unscheduled heavy maintenance. The opening of the HR&O facility will replace most heavy repair and overhaul functions at the Brentwood Shop. Brentwood's 42 car-bays will be reallocated to service and inspection and car track equipment maintenance (CTEM) while retaining capacity to perform overflow heavy repair work.

5 System and Facilities Capacity

5.1. Gaps in Current System

To properly and accurately assess Metro's capability to meet future demand, Metro combines ridership forecasts and with assessments of the system's infrastructure. Beyond the railcar fleet itself, system gaps are driven by storage and maintenance capacity, core and terminal throughput, traction power, and station capacity. Understanding the constraints of the current system allows Metro to identify what areas of the system will need improvement to meet 8, 7, and ultimately 6-minute headways. This allows Metro to plan and prioritize improvements needed for the system to reliably deliver higher service levels.

In addition to projects already underway, including Dulles Yard, the Heavy Repair & Overhaul Facility, and traction power upgrades, Metro needs to plan for and begin execution of several projects to deliver 100% eight-car train service at 7-minute headways by 2030. These include addressing storage capacity constraints on the Blue, Orange, and Silver Lines and the Red Line and maintenance shop capacity constraints on the Green Line and corresponding with storage expansion on the Blue, Orange, and Silver Lines. In addition, terminal capacity is a constraint under Metro's current operational standard of 15 trains per hour. More frequent service requires reducing scheduled recovery time at terminals and may require operational changes, such as increased use of drop-back operators.

Long-term planning and investments require decisions made years in advance in order to ensure system capacity and infrastructure are sufficient to meet demand in the future. Table 5-1 summarizes the approximate lead time required for major capital investment decisions.

TABLE 5-1: RAIL SYSTEM CAPITAL INVESTMENT DECISION LEAD TIME REQUIREMENTS

Category	Capital Investment	Approximate Lead Time Required
Railcars	Initiating new railcar procurement	5 to 8 years
Railcars	Exercising railcar procurement option	1 or more years
Yards & Shops	Expanding rail yard or shop capacity	2 to 6 years
Yards & Shops	Building new rail yard or shop facility	5 to 10 years
System Expansion	Opening new rail line	20 or more years

5.2. Railcar Storage

5.2.1 Current Railcar Storage

Revenue vehicles are currently stored at nine locations throughout the Metrorail system and will expand to ten with the opening of Dulles Yard. As summarized in Table 5-2, the total capacity will be 1552 spaces for revenue vehicle storage.[42] One space is equivalent to one revenue vehicle or approximately 75 feet of electrified track. Non-revenue storage track is predominately non-electrified track allocated to diesel operated Maintenance of Way (MoW) operations and storage. Electrified non-revenue storage track is also allocated to treasury trains and specialized testing and maintenance equipment.

Metro's current yard footprint has two primary challenges as Metro implements 100% eight-car trains and more frequent service, including internal yard configurations not optimized for full length train consists, requiring a greater number of yard movements to fully utilize available storage, and a structural imbalance between western and eastern yards on the Blue, Orange, and Silver Lines, which constrains capacity and drives operational inefficiency due to the need to operate non-revenue trips to stage trains for service and return trains to yards afterwards, adding operating cost and encroaching on the overnight track maintenance window.

Table 5-2 summarizes the storage and maintenance capacity of each yard as well as the share of storage capacity that can be used by eight-car trains.

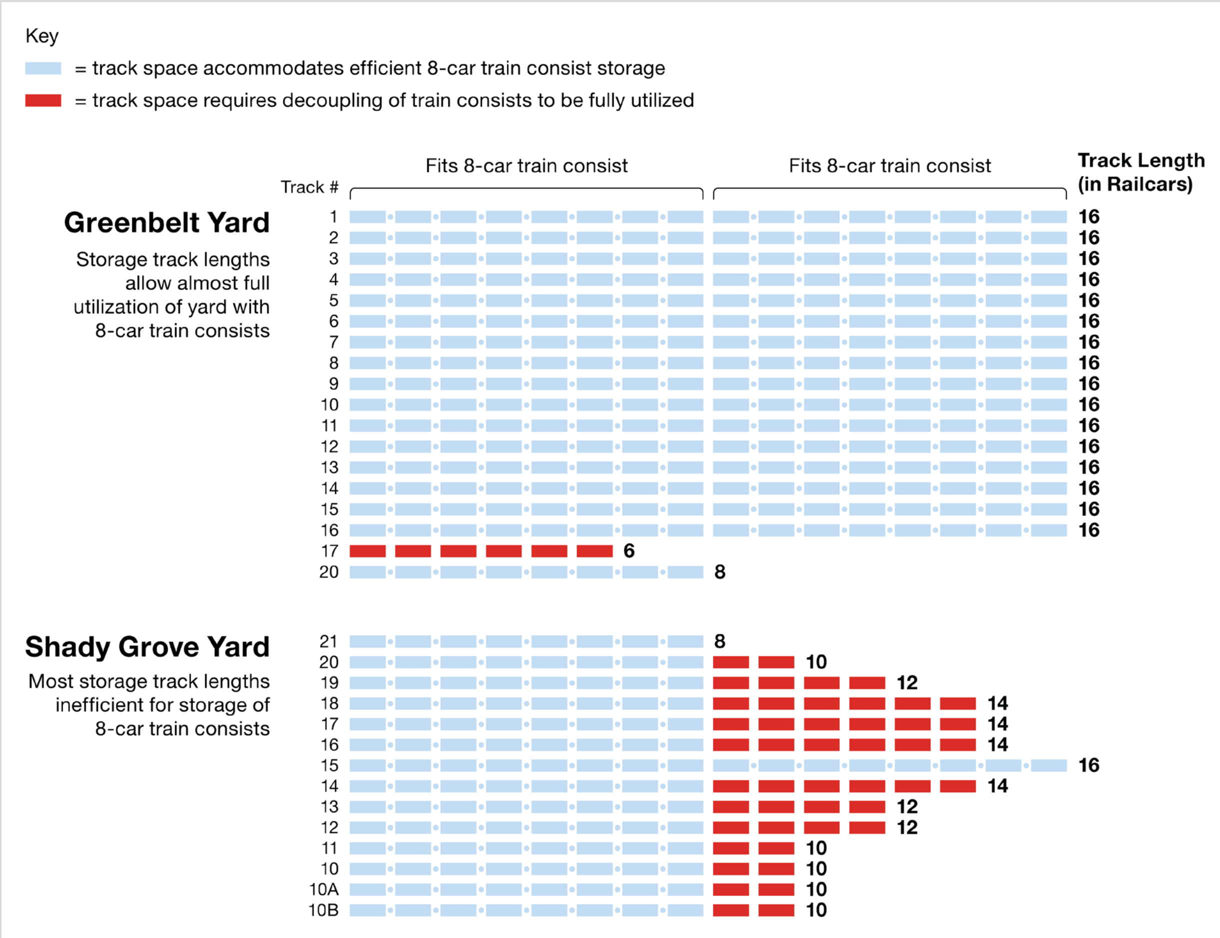
TABLE 5-2: RAILCAR STORAGE LOCATIONS

Yard	Location	Revenue Storage Track Spaces	Railcars Storable as 8-Car Trains	Percent Stored as 8-Car Trains	Non-Revenue Storage Track	Maintenance Bays
A99	Shady Grove	166	120	72%	28	36
B98	Glenmont	132	88	67%	20	0
B99	Brentwood	90	72	80%	0	42
C99	Alexandria	176	136	77%	50	20
D99	New Carrollton	120	88	73%	54	16
E99	Greenbelt	270	264	98%	38	20
F99	Branch Avenue	174	120	69%	16	8
G05	Largo	38	32	84%	0	0
K99	West Falls Church	188	144	77%	24	28
N99	Dulles [43]	168	128	76%	16	20
Total		**1522**	**1192**	**78%**	**246**	**190**

Metro can only utilize 78% of its total storage capacity with eight-car trains as many storage tracks lengths do not translate to multiples of eight. For example, a revenue vehicle track segment may store 14 revenue cars and therefore may only store one complete eight-car train. As a result, either six spaces must be left vacant or a train must be separated and redistributed in reduced consists to vacant track segments. This does not make the space unusable but increases the cost in time and resources required to make use of the space. Figure 5-1 compares the revenue storage layout of Greenbelt Yard to that of Shady Grove Yard.

[42] This total includes the completion of the Dulles Yard, which adds 168 revenue vehicle storage spaces.
[43] Dulles Yard is scheduled to open with Silver Line Phase 2.

FIGURE 5-1: REVENUE VEHICLE STORAGE TRACK EFFICIENCY COMPARISON, 8-CAR TRAIN CONSISTS



While Greenbelt is optimally designed to accommodate eight-car train consists, many of Shady Grove's storage tracks are of lengths which require decoupling of train consists if they are to be fully utilized. As a result of the layout implications shown in Figure 5-1, 98% of Greenbelt's storage spaces can accommodate eight-car trains, while only 72% of Shady Grove's may be utilized before decoupling of consists is required.

The revenue vehicle storage track is configured to store trains as married pairs, the base unit for Metrorail's legacy fleet. The base unit of two was the determinate for revenue storage track segment length. However, the 7000-Series fleet operates a base consist of four cars (a "quad"), and trains for service at eight-cars. Greenbelt is the only yard designed to store eight-car trains with almost all storage tracks 16-cars in length.

The distribution of yard revenue vehicle storage capacity across the east-west axis of the Metrorail system is as follows (see Table 5-2):

1. Red Line: 388 revenue storage spaces dedicated to the Red Line. Red Line operations are physically separated from other lines. The Red Line's three dedicated yards are Shady Grove, Brentwood, and Glenmont.

2. **Blue, Orange, and Silver Lines (Western axis):** 444 spaces in yards at or near the western termini of the Blue, Orange, and Silver lines. These yards are Alexandria,[44] West Falls Church, and Dulles.
3. **Blue, Orange, and Silver Lines (Eastern axis):** 158 revenue storage spaces in yards at the eastern termini of the Blue, Orange and Silver Lines. These yards are New Carrollton and Largo.
4. **Green and Yellow Lines**: 532 revenue storage spaces in yards on the Green and Yellow Lines. These yards are Greenbelt, Branch Avenue, and Alexandria.[45]

FIGURE 5-2: YARD AND SHOP CAPACITY SYSTEM MAP

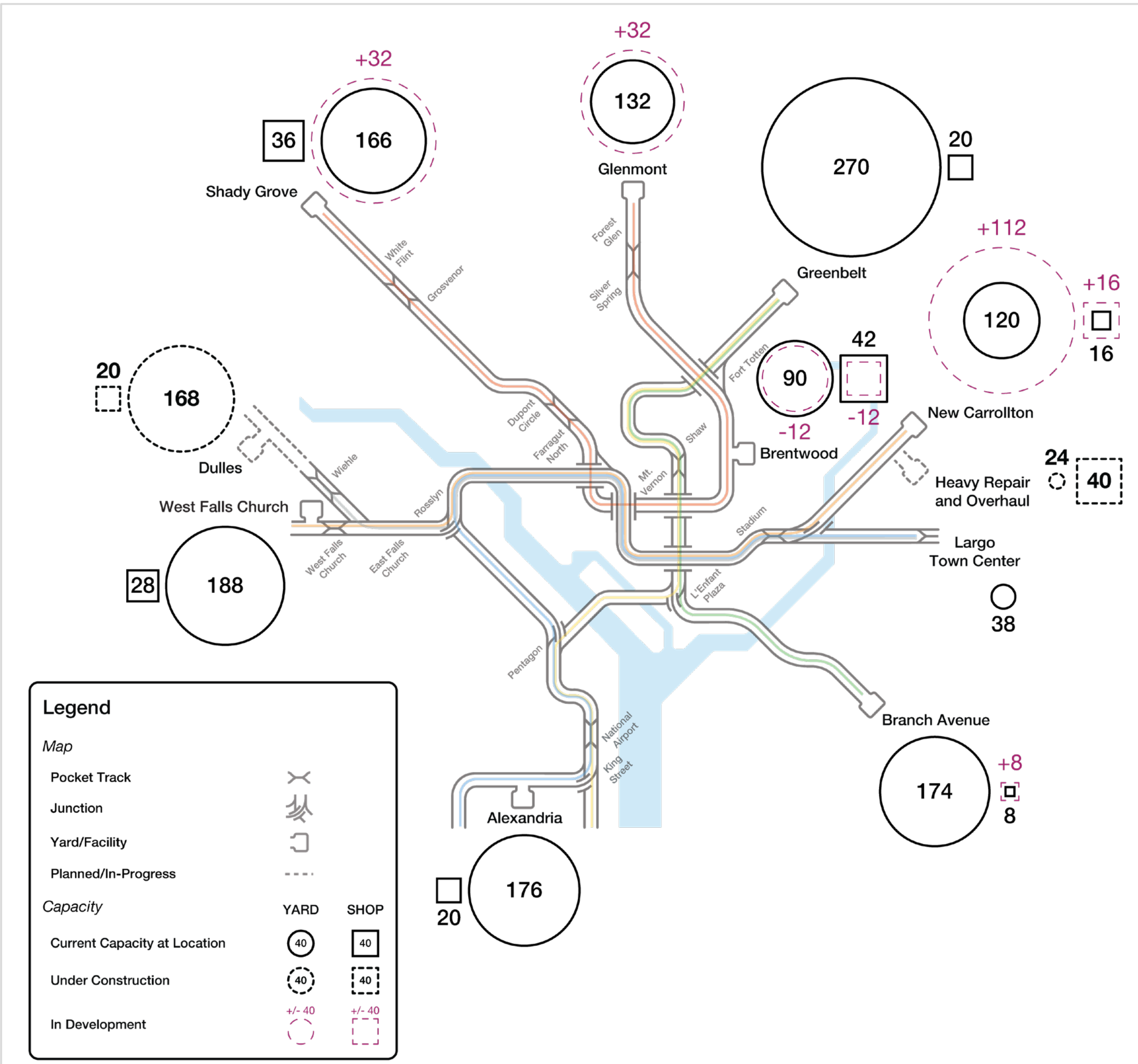


Figure 5-2 displays the distribution of storage capacity across the system. Storage imbalances along the Blue, Silver, and Orange lines generate operations and maintenance challenges on those lines which impact the entire system. For example, the storage of Blue line trains at Alexandria may compel the reallocation

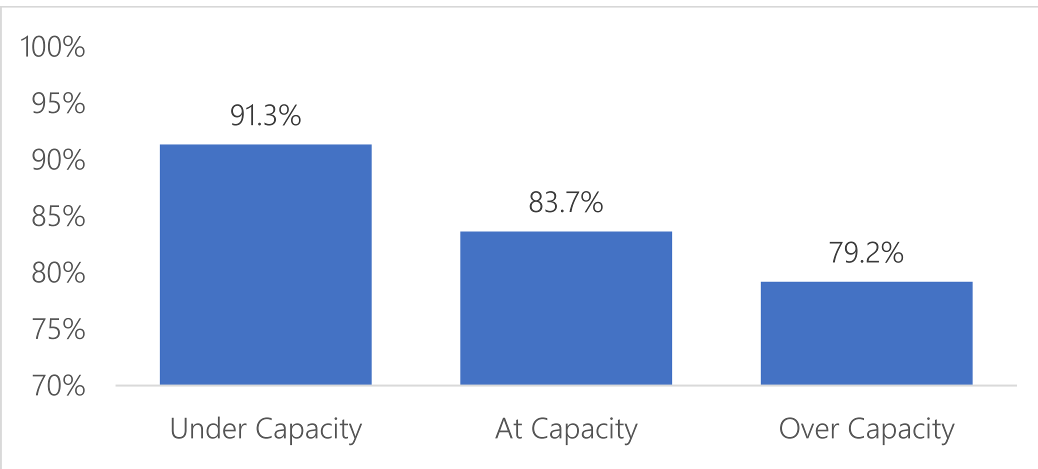
[44] Assumes 50% of Alexandria storage is allocated to Blue and 50% allocated to Yellow Line.
[45] Assumes 50% of Alexandria storage is allocated to Blue and 50% allocated to Yellow Line.

of Yellow Line trains to Greenbelt. The result is an increase in revenue vehicles operating non-revenue trips ("deadhead") at the beginning or end of revenue service. Deadhead trips add operating costs to provide service and may impact the time available to perform overnight maintenance.

Loop tracks are track segments that circumvent a given yard or storage area and connect yard operations to the main service line. They allow for greater freedom of movement for trains and consists within yards. Loop tracks provide a means for service dispatch and staging, assembly, disassembly, storage, and maintenance. Revenue vehicles operating in a yard without a loop track will require more yard movements for assembly and disassembly. Glenmont, Branch Avenue, and Largo are the only yards that are not serviced by a loop track.

Yard capacity and utilization levels also affect service reliability with less capacity-constrained yards generally performing better. As shown in Figure 5-3, rail yards with a higher capacity utilization generally meet service requirements less frequently. Storage imbalances between lines, inconsistent revenue storage track length and yard configurations also present risks to timely service and increased instances of coupling and uncoupling of trains.

FIGURE 5-3: PERCENT OF DAYS MEETING SERVICE REQUIREMENTS BY YARD CAPACITY UTILIZATION, 2019[46]



5.2.2 Additional Yard Infrastructure

In addition to revenue vehicle storage, maintenance of way vehicle storage, and maintenance facilities, yards contain facilities dedicated to supporting Metro's operations. These facilities include train washes, police stations, communications equipment, office space, and revenue collection operations.

Metro currently operates five train washes, located at the Shady Grove, Glenmont, Alexandria, Greenbelt and West Falls Church yards. There are three train washes currently not in use at Branch Avenue,

[46] Yards under capacity in 2019 were Greenbelt and Branch Avenue. Yards at capacity were Shady Grove and Glenmont. Yards over capacity were Alexandria, New Carrollton, and West Falls Church. Figure excludes Brentwood and Largo, rail storage facilities with unique functions.

Brentwood and New Carrollton,[47] while others need improvements. A train wash improvement program is in development to assess and address train wash needs throughout the system.

5.2.3 Future Railcar Storage

Metro plans to grow its yard storage with a planned expansion at New Carrollton Yard and is developing options to expand storage at other yards. To accommodate anticipated future railcar storage needs, Table 5-3 shows the locations of needed storage increases in the rail yards within the system.

TABLE 5-3: FUTURE YARD STORAGE CAPACITY AND SHOP CAPACITY NEEDS TO ACHIEVE ALL 8-CAR TRAINS AT 7-MINUTE HEADWAYS

		Revenue Storage Capacity			Shop Capacity		
Yard	Location	Existing/Under Construction Spaces	Additional Spaces Needed	New Total	Existing/Under Construction Spaces	Additional Spaces Needed	New Total
A99	Shady Grove	166	52 [48]	218	36	-	36
B98	Glenmont	132	-	132	-	-	0
B99	Brentwood	90	-	90	42	-	42
C99	Alexandria	176	-	176	20	-	20
D99	New Carrollton	120	112 [49]	232	16	16 [50]	32
E99	Greenbelt	270	-	270	20	-	20
F99	Branch Avenue	174	-	174	8	8 [51]	16
G05	Largo	38	-	38	-	-	0
K99	West Falls Church	188	-	188	28	-	28
N99	Dulles [52]	168	-	168	20	-	20
	Heavy Repair & Overhaul [53]	-	-	--	40	-	40
Total		**1522**	**164**	**1,686**	**230**	**24**	**254**

[47] The train wash facilities at Brentwood and New Carrollton are inoperable for environmental reasons. The Brentwood train wash facility has been inoperative for many years and consists of some track-level equipment.
[48] Need for 52 spaces listed at Shady Grove, but need could be met at other rail yards on the Red Line: Glenmont and Brentwood.
[49] For purposes of system balancing, most operationally ideal outcome is expansion of New Carrollton by 112 revenue storage spaces. If full expansion at New Carrollton is not possible, expansion at Dulles yard may be potential alternative outcome.
[50] At New Carrollton, 16 additional shop spaces are needed to accommodate a 112-car revenue storage space expansion. If only 56 revenue storage spaces are added at New Carrollton, only 8 additional shop spaces will be required. If all 16 shop spaces cannot be added at New Carrollton, half could be added to another shop serving the Blue, Orange, or Silver Lines – Alexandria, West Falls Church, or Dulles.
[51] The shop expansion is needed on the Green Line between Branch Avenue and Greenbelt and assigned here at Branch Avenue.
[52] Assumes completion of Dulles Yard and Silver Line Phase 2.
[53] The Heavy Repair and Overhaul facility will include three eight-car storage racks to accommodate trains awaiting repair and overhaul and will not be available for regular storage of trains for revenue service.

Table 5-3 shows the additional revenue storage spaces and shop capacity that will be needed to accommodate the forecasted fleet size associated with operation of all eight-car trains running at 7-minute headways. This table does not show the planned expansion of New Carrollton's revenue storage by 56 spaces, which would reduce the additional spaces needed to 56.

Planned expansion projects:

1. Heavy Repair & Overhaul Facility: The HR&O facility will largely consolidate Metro's heavy repair operations into one facility (Greenbelt will retain four HR&O slots for truck repair) with 40 dedicated slots. Half of the slots will be dedicated to major rehabilitative repairs, which require separation of the vehicle chassis from trucks and movement by crane, and the other half to heavy repairs of shorter durations. The HR&O facility will also hold 24 storage spaces for revenue cars. Plans include capacity for expansion to include twelve maintenance bays for Maintenance of Way (MoW) repair and seven track segments for MoW storage. The MoW storage and maintenance bay would be located in a self-contained area of the HR&O Facility grounds and include a non-electrified loop track, which allows for greater efficiency in vehicle yard movements.

2. New Carrollton Northwest: The planned expansion of the northwest of the New Carrollton yard will add 56 revenue storage spaces to the existing capacity of 120 revenue storage spaces, for a total of 176 revenue storage spaces.

Metro is developing plans to achieve 100% eight-car trains at 7-minute headways by 2030, with exploration of future potential 6-minute headways. However, yard space becomes constrained as service requirements increase, Table 5-4 reflects the relationship between the minimum fleet size needed to meet planned headways, the projected Peak Vehicle Requirement (PVR), and the currently planned storage capacity.

TABLE 5-4: PEAK VEHICLE REQUIREMENT, MINIMUM REQUIRED FLEET AND STORAGE CAPACITY COMPARISON [54]

Anticipated Year	Headway	PVR	Fleet Size Needed to Meet HW	Storage Capacity	Storage Capacity Utilization
2020	Current	966	1166	1522	77%
2025	8-Min HW, 100% 8-car	1136	1364	1602	85%
2030	7-Min HW, 100% 8-car	1272	1528	1602	95%
2040	7-Min HW, 100% 8-car	1272	1528	1602	95%
Future year	6-Min HW, 100% 8-car	1424	1712	1602	107%

Storage capacity along lines that span the east-west axis of the system become increasingly constrained as service demand increases. Notably, New Carrollton and Dulles reach or exceed capacity thresholds at increased headways. Additionally, revenue vehicle storage requirements within the Red Line yards at Shady

[54] Includes rounding up to account for married pair requirements. Operations and fleet size in 2020 are not in line with 20% Operating Spare Ratio due to higher levels of corrective maintenance.

Grove, Brentwood, and Glenmont, reach full utilization at the 8-minute headway level and require expansion for 7-minute and 6-minute headway operations.

Metro is developing options to meet the remaining identified railyard storage and maintenance capacity needs.

5.2.4 Maintenance of Way Fleet Storage

The MoW fleet performs maintenance primarily on Metro’s track and facilities. The vehicles are diesel-powered and stored primarily on non-electrified track at each yard. Largo is the only storage facility without dedicated MoW storage. A small allocation of electrified track is dedicated to revenue collection vehicle storage. Treasury trains are former revenue vehicles converted for the collection and transport of fares (alternatively referred to as “money trains” or “revenue collection vehicles”).

The maintenance of way fleet consists of 186 vehicles across many distinct functions. For the purposes of this document, those functions are organized into five categories: prime movers, work cars, tie replacement and surfacing equipment, heavy construction equipment, and miscellaneous equipment.

TABLE 5-5: MAINTENANCE OF WAY FLEET COMPOSITION [55]

Vehicle Type	Count
Work Cars	**71**
Flat Cars	66
Ballast Cars	5
Tie Replacement and Surfacing Equipment	**45**
Swing Loaders	12
Tie Remover/Inserter Machines	4
Tie Cranes	4
Spike Drivers	4
Ballast Regulators	4
Spot Tampers	4
Tampers	3
Quad Drill Equipment	2
Spike Pullers	2
Rotary Scarifiers	2
On/Off-Track Cranes	2
Tie Shears	1
Track Stabilizers	1
Prime Movers	**42**
Utility Vehicles	34
Locomotives	3
Aerial Lifts	2
Jet Rodders	2
Welders	1
Miscellaneous Equipment	**28**
Rail Tie Carts	6
Vacuum Trucks	4
Scissor Lift Trucks	3
High Rail Flatbeds	2
Bridge Inspection Equipment	2
CTEM Track Geometry Vehicles	1
Ballast Vacuum Excavators	1
Pick-Up, Crew Cabs	1
Switch Maintenance Trucks	1
Rail Trains	1
Crane Trucks	1
High Rail Excavators	1
High Rail Crane Trucks	1
Mobile Maintenance Units	1
Locomotives [56]	1
Lube Trucks	1
Total	**186**

[55] For purposes of this document, Metro's Maintenance of Way fleet of 186 vehicles includes vehicles which are not included in the list of 78 vehicles Metro reports to the National Transit Database (NTD). The NTD reporting requirement calls for the exclusion of vehicles which have rubber tires or which are not self-propelled. Of the 186 MoW vehicles included in this report, 108 either have rubber tires or are not self-propelled.

[56] This vehicle is distinct from the Prime Mover Locomotive listed above as it does not serve a prime mover function. It is used exclusively for the purpose of moving other maintenance vehicles, and cannot be equipped with other specialized equipment.

The MoW fleet includes vehicles with various purposes and specialties. Most vehicles categorized as work cars are flat cars, which are towable units used for the transport of materials and equipment. Tie replacement and surfacing equipment vehicles are used to replace railroad ties (or cross ties) and perform other maintenance activities affecting tracks and surfaces. Prime movers serve as the primary source of propulsion for MoW trains and may be equipped with cranes and other specialized equipment. Heavy construction equipment vehicles are generally used for excavation and loading functions. The miscellaneous equipment category includes vehicles serving other distinct functions.

TABLE 5-6: MAINTENANCE EQUIPMENT STORAGE TRACK CAPACITY [57]

Yard	Location	Unelectrified Storage Track (50' Vehicle Spaces)
A99	Shady Grove	30
B98	Glenmont	12
B99	Brentwood	6
C99	Alexandria	33
D99	New Carrollton	28
E99	Greenbelt	62
F99	Branch Avenue	22
G05	Largo	0
K99	West Falls Church	16
N99	Dulles	18
Total		**227**

For the purposes of determining MoW storage requirements in this document, one space of MoW storage is equivalent to 50 feet of track, the average length of a MoW vehicle. Due to the diversity of equipment within of the MoW fleet, a standard vehicle length does not exist. Contractor-owned vehicles also occupy space in yards to support system renewal programs.

The design and placement of non-electrified track may complicate yard movements. For example, fuel pumps for MoW vehicles are often placed along dead-end siding track as opposed to loops. The design requires vehicles pull in and reverse out, which increases yard movements.

Track maintenance often requires vehicles to concentrate on specific points within the system in need of repairs. Maintenance of way vehicles, including specialized equipment, are often staged at yards near planned work zones away from home yards, requiring all yards to have capacity to accommodate an increased number of vehicles.

[57] Analysis performed July 1, 2019 – October 31, 2019, reconciled with Metro's yard management software (RPM) and Car Track Equipment Maintenance (CTEM) data, provided August 13, 2019 and October 31, 2019. Dulles Yard totals are approximate for three MoW tracks in the assembly area.

5.2.5 Future Maintenance of Way Storage

The construction of the HR&O facility will include future capacity to add storage space for 38 vehicles to the existing 247 spaces of MoW storage enclosed within a dedicated yard, complete with a non-electrified loop track. The "yard within a yard" design—to include a loop track, the only non-electrified loop track in the Metrorail system—allows for ease of yard operations, fueling, and throughput.

5.3. Railcar Maintenance Shops

Revenue vehicles are maintained at shops located at seven of the nine yards in the Metrorail system, increasing to eight of ten with a total of 190 maintenance shop spaces once Dulles Yard opens. One maintenance shop space is equivalent to one 75-foot railcar and spaces are configured to support maintenance of married-pairs. All shop spaces are non-electrified track, covered and enclosed within a maintenance facility.

Metro maintains a shop capacity standard of 15%, meaning enough shop spaces must be available to accommodate 15% of the revenue fleet. This standard includes decentralized service and inspection and running repair and centralized heavy repair and overhaul at a three to one ratio (11.25% to 3.75%). The need for service and inspection and running repair capacity is localized to individual yards or lines as capacity is necessary to meet ongoing daily needs for scheduled preventive maintenance and inspection and corrective maintenance. Heavy repair and overhaul needs are best met at specialized central facilities serving the whole fleet. Metro's shop capacity standard is somewhat less than the total share of maintenance spares in the fleet as some out of service vehicles, including those awaiting parts, do not need to occupy shop space, and some corrective maintenance activities can be completed in less than a day, allowing shop bays to turnover.

TABLE 5-7: RAIL MAINTENANCE SHOP CAPACITY

Yard	Location	Maintenance Bays				Blow Pits	Wheel Lathes
		Lifts	Posted Rail	Flat Track	Total		
A99	Shady Grove	14	20	2	36	4	1
B98	Glenmont	0	0	0	0	0	0
B99	Brentwood	34	6	2	42	0	1
C99	Alexandria	6	10	4	20	2	1
D99	New Carrollton	8	6	2	16	4	1
E99	Greenbelt	16	2	2	20	4	1
F99	Branch Avenue	8	0	0	8	0	0
G05	Largo	0	0	0	0	0	0
K99	West Falls Church	10	10	8	28	2	1
N99	Dulles	18	0	2	20	2	2
Total		**114**	**54**	**22**	**190**	**18**	**8**

Maintenance shop spaces are distributed into three categories: Lifts, posted rail, and flat track.

1. **Lifts:** A hydraulic system that elevates train cars to allow for undercarriage and truck maintenance work. Some lifts are equipped with body jacks, a function that allows for the removal of trucks from the train undercarriage.
2. **Posted rail:** Posted rail is a shop track segment fixed on posts spanning the length of a dugout, this allows for rapid undercarriage maintenance work without the need to elevate the train.
3. **Flat track:** Shop track not on posted rail or equipped with a lift. Flat track is often positioned near wheel lathes.

Furthermore, Wheel lathes, blow pits, and cleaning tanks are critical track spaces and functions within maintenance bays, but not considered as dedicated maintenance space.

1. **Wheel lathe**: a deep pit dedicated to wheel maintenance with dimensions adequate for two standing workers.
2. **Blow pit:** a track segment leading into a maintenance bay where the undercarriage of a revenue vehicle is pressure washed with compressed air and hot water to remove debris prior to inspection. Blow pits are critical to the conduct of timely periodic inspections.
3. **Cleaning tank:** An electrified track segment in an enclosed bay dedicated to the deep cleaning of trains following an inspection. Due to the electrified track, no undercarriage work may be performed on a train inside of a cleaning tank. Cleaning Tanks are occasionally used for internal car repairs.

Maintenance work is distributed into two categories: Service and Inspections and Heavy Repair and Overhaul.

1. **Service and Inspection and running repair (S&I);** servicing and periodic inspections as part of the planned maintenance and upkeep of the revenue vehicle fleet as well as unplanned maintenance.

2. **Heavy Repair & Overhaul (HR&O):** Major and lengthy repairs to vehicles, often requiring substantial assembly and disassembly.

S&I is the predominate use of shop space. Of Metro's 190 shop spaces,[58] 144 are dedicated to S&I and 46 are dedicated to HR&O. The latter is conducted at two facilities, Brentwood and Greenbelt, with Brentwood scheduled to revert to S&I and MoW maintenance after the HR&O facility opens. S&I is distributed by car block, with shops dedicated to servicing specific lines. For example, Shady Grove serves as the Red Line's dedicated S&I shop.

Shop throughput is critical to maintaining high service standards and effectiveness. Under current shop configurations, the maintenance of revenue vehicles requires hours of prepositioning, decoupling, and preparation. To achieve greater efficiency in operations, maximizing "wrench" time and increasing throughput, Metro seeks to develop the ability to conduct maintenance of full trainsets by constructing

[58] Including the 20 maintenance bays added by the completion of Dulles Yard.

capacity expansions as eight-car posted rail maintenance track segments.

TABLE 5-8: EXAMPLE MAINTENANCE SCENARIO: CORRECTIVE MAINTENANCE (BRAKES)

Maintenance Scenario	Duration (Hours)				Daily Throughput (Cars)
	Yard Movements	Staging/Lifts*	Wrench Time**	Total	
Standard configuration: train decoupled, split into 4 pairs	8 (8 moves, 1 hour/move)	0.25	4	12.25	16
8-car posted rail: train coupled, intact	2 (2 moves, 1 hour/move)	0	4	6	32

**Raising and lowering cars on lifts*
***Direct work on railcars*

Posted rail track segments require only limited maintenance, whereas the hydraulic system on a lift track segment requires a dedicated maintenance program. Repairs must be contracted and lifts can be out of service for weeks or months, rendering the shop bays usable for only limited maintenance activities.

Metro operates one commissioning facility at Greenbelt yard, enclosed within a two-track maintenance bay, and equipped with six segments of flat track, two segments of posted rail, and 12 segments of lead track. The facility prepares new trains for service and serves as the primary facility for maintenance engineering campaigns.

TABLE 5-9: PROJECTED FLEET GROWTH AND SHOP CAPACITY

	2020	2025	2030	2040
Fleet Size	1278	1364	1528	1528
Shop Capacity	190	218	218	218
Percent	15%	16%	14%	14%

5.3.1 Future Railcar Maintenance Shops

The system-wide shop-to-revenue storage ratio is only a starting point and must be examined with respect to specific locations within the system. Shop space is constrained in present operations with deficiencies in space at the Green Line yards, Greenbelt and Branch Avenue. Projected fleet growth will further constrain shop capacity and poses a risk to future service reliability. Projects to increase shop capacity must accompany yard storage expansions or significant planned increases in yard storage utilization where it creates a deficiency in the shop capacity standard. Notably, shop capacity expansion needs to accompany storage expansion at New Carrollton to ensure reliable service delivery as the yard grows to meet increased demand.

The construction of the Dulles Yard maintenance shop and HR&O facility—along with the associated shop realignment at Brentwood—are the sole planned expansions of Metro's maintenance shop space. Other needs are under development and evaluation in a system-wide yard improvement study and will be considered for inclusion as projects in future capital planning cycles.

5.3.2 Car Track Equipment Maintenance (CTEM) Facilities

The Maintenance of Way vehicle fleet is assigned shop space and a maintained by Car Track Equipment Maintenance (CTEM). CTEM shop facilities are in four of the nine yards. Dedicated CTEM shop facilities are located at Alexandria, New Carrollton, Greenbelt, and Branch Avenue. Additional facilities at New Carrollton, Shady Grove, West Falls Church serve maintenance field base functions, supporting the operations of work equipment, which are distinct from the activities performed by CTEM. CTEM Shops are shops dedicated to the performance of maintenance on work equipment itself, whereas maintenance field bases serve other purposes and are run by maintenance departments including the Office of Track and Structures (TRST).[59]

TABLE 5-10: MAINTENANCE OF WAY FACILITY CAPACITY

Yard	Location	Function	Maintenance Bays			
			Lifts	Posted Rail	Flat Track	Total
A99	Shady Grove	Maintenance Field Base	0	0	1	1
C99	Alexandria	CTEM Shop / Maintenance Field Base	0	1	5	6
D99	New Carrollton	CTEM Shop / Maintenance Field Base	0	0	8 CTEM 4 Maint. Field Base	8 CTEM 4 Maint. Field Base
E99	Greenbelt	CTEM Shop / Maintenance Field Base	0	1	3	4
F99	Branch Avenue	CTEM Shop / Maintenance Field Base	0	1	3	4
K99	West Falls Church	Maintenance Field Base	0	0	1	1
N99	Dulles[60]	-	0	2	4	6
Total			**0**	**5**	**29**	**34**

The shop facilities are not equipped with lifts; however, shop facilities are frequently equipped with mobile lifts for undercarriage work, and future shop facility space at Brentwood may contain hydraulic lifts.

5.3.3 Future Car Track Equipment Maintenance (CTEM) Shops

Future shop expansions are planned at the HR&O facility and Brentwood Yard. The construction of the HR&O facility for railcars enables the realignment of three shop tracks, currently with capacity for 12 railcar

[59] The Office of Track and Structures (TRST) is responsible for inspecting, maintaining and rehabilitating all revenue and yard tracks as well as all aerials, bridges, retaining walls and tunnels.

[60] Dulles Yard facilities to begin operations with opening of Silver Line Phase 2.

spaces, at Brentwood to CTEM. Additionally, the planned HR&O facility includes a planned but currently unfunded Car Track Equipment Maintenance shop and a Maintenance of Way yard that would include one lift, two inspection pits, and one dedicated wash track (not included in the total shop space count).

TABLE 5-11: FUTURE CAR TRACK EQUIPMENT MAINTENANCE SHOP FACILITY CAPACITY

Shop Capacity	Yard	Location	Maintenance Bays			
			Lifts	**Posted Rail**	**Flat Track**	**Total**
Current	**Total**		**0**	**5**	**29**	**34**
Future	B99	Brentwood	8	0	4	12
	Z99	HR&O	1	2	9	12
	Total		**9**	**2**	**13**	**24**
Total			**9**	**7**	**42**	**58**

5.4. Train Throughput

5.4.1 Core Capacity

Train throughput is defined as the number of trains traversing a given point in the Metrorail System over a period of time, typically described as trains per hour. This is a critical factor in meeting demand at peak times, as it governs the number of trains available to passengers during the highest periods of service to meet requirements and operate safely. Metrorail's core throughput is constrained to a practical maximum of 26 trains per hour, while terminal throughput, the number of trains that can be turned around and redeployed at end-of-line stations, is 15 trains per hour under current operating conditions.

Maximum train throughput is defined as the maximum number of trains that can be reliably operated per hour, also expressed as the minimum sustainable headway. Maximum train throughput is driven by three components:

1. Minimum train separation: Train separation is determined primarily by a train's ability to accelerate quickly up to its maximum speed and brake safely to a stop (managed by the Automatic Train Control system), the train's length, and the configuration of stations and tracks.

2. Governing dwell time: The governing dwell time is the maximum time that a train is stopped at a station and is determined primarily by the number and width of railcar door openings and the passenger volumes at major stations on each line.

3. Operating margin: The operating margin is an amount of time between successive trains that is inserted into a timetable to accommodate minor delays to maintain schedule adherence without significantly impacting following trains.

As determined by prior Metro studies, these various infrastructure, fleet, and operational factors yield a minimum sustained headway of approximately 135 seconds (or 2.3 minutes) between trains, or a maximum of approximately 26 trains per hour. Metro's train control system was designed to accommodate headways as short as 90 seconds. As a result, in certain instances, successive trains may travel past a given point fewer than 135 seconds apart. However, this typically occurs in certain core track segments during short periods of time and cannot be reliably sustained over an entire rush period on a regular basis.

The Blue-Orange-Silver trunk line has the highest core train throughput in the Metrorail System at 22.5 trains per hour, with each service operating at an 8-minute headway. If headways along the Blue-Orange-Silver lines were reduced to 7-minutes, the maximum throughput on that same section would increase to the system-wide throughput capacity limit of about 26 trains per hour. In order to achieve 6-minute headways on the Blue-Orange-Silver Line trunk line, substantial capital investments are required, to be determined by ongoing studies as shown in Table 5-13. Table 5-12 illustrates the progression of throughput needs and gaps (in red) at the milestone service levels (8-minute, 7-minute, and 6-minute headways).

TABLE 5-12: TRAINS PER HOUR CAPACITY STANDARDS AND MAXIMUM NEEDS AT VARIOUS HEADWAYS

		8-minute headways	7-minute headways	6-minute headways
System segment	**Capacity standard**	**Maximum need**		
Terminal	15 trains per hour	15	17.14	20
Core	26 trains per hour	22.5	25.71	30

5.4.2 Terminal Capacity

Metro's current capacity standard for turning around trains at terminals is 15 trains per hour, or every four minutes, based on current operational practices and infrastructure. Metrorail service changes in recent years have ended Red Line turnbacks at Grosvenor and Silver Spring, and Yellow line turnbacks at Mt. Vernon Square. As a result of this increase in service, Red Line terminals at Shady Grove and Glenmont, and the combined Green-Yellow Line terminal at Greenbelt must accommodate twice the frequency of trains compared to the period before the service changes, increasing throughput from 7.5 train per hour (8-minute headways) to 15 trains per hour (4-minute headways). The Blue-Silver Line terminal at Largo accommodates the same number of trains.

More frequent service at the Shady Grove, Glenmont, Greenbelt and Largo terminals – at a 7-minute system headway, or 3.5 minutes between trains (17.14 trains per hour) – requires reducing scheduled recovery time at terminals and may require operational changes, such as increased use of drop-back operators. In addition, potential infrastructure improvements, including construction of new pocket tracks, could further support reliable terminal operations.

5.4.2.1 Automatic Train Control (ATC)

The Automatic Train Control (ATC) system provides for the safe and efficient movement of trains through a series of track circuits and integrated logic for routing controls and speed controls. Metro is studying next generation train control to determine whether to modernize the existing system or transition to

Communication-Based Train Control (CBTC) technology. CBTC systems can improve the accuracy of train positions by allowing trains to communicate to one another, allowing them to operate closer together. This newer technology provides enhanced Roadway Worker Protection, the potential for increased throughput capacity, and other benefits.

5.4.3 Future Rail System Service and Capacity Studies

Metro has studies underway to prepare for future service needs and develop solutions to identified operational and infrastructure challenges and core capacity constraints. Table 5-13 details these studies and their expected outcomes.

TABLE 5-13: FUTURE RAIL SYSTEM SERVICE AND CAPACITY STUDIES

Study	Scope	Est. Completion Date
Next Generation Automatic Train Control	This study considers options for making significant long-term investments to modernize or replace Metro's train control system.	2022
Blue/Orange/Silver	This study evaluates alternatives to identify the best solutions to address future ridership, service, and reliability needs on the Blue, Orange, and Silver lines.	2022

5.5. Traction Power

Metro has completed upgrades to its traction power system, including substations, tiebreaker stations, and cables, to enable operation of 100% eight-car trains at an 8-minute system headway. Ongoing work is underway to rehabilitate existing systems to a state of good repair and complete further upgrades to enable eight-car train operations with higher service frequencies. Planned traction power upgrades meet the needs at the 6-minute system headway level, supporting eight-car train operation at up to two-minute frequencies, by 2030. The line-by-line schedule for these upgrades is shown in Table 5-14. Blue, Orange, and Silver Line upgrades are fully funded in the current program. The schedule and completion of the remaining planned system segments is contingent on future funding availability.

TABLE 5-14: PLANNED SCHEDULE FOR TRACTION POWER UPGRADES

Line(s)	Year of Upgrade Completion
Red	FY2026
Yellow/Green	FY2030
Blue/Orange/Silver	FY2022

5.6. Stations

Station capacity drives system gaps in two ways:

1. **Platform length.** It restricts the number of cars per station to eight due to layout and vertical circulation (the movement of customers outside of trains while within the faregates). The layout of each station allows for a maximum of eight-car trains which makes the option of expanding service to 10-car trains at maintained scheduled headway infeasible due to capital requirements to modify each of the 91 stations.
2. **Limitations to station infrastructure.** As passenger volumes increase, station stairs, escalators, elevators, platforms and faregates can constrain the movement of riders moving through the rail system, thereby causing platform crowding and potentially unsafe conditions. Figure 5-4 below shows the volume-to-capacity ratio for each station's most crowded vertical circulation element in 2020 at the 5pm-5:30pm half hour time period.

FIGURE 5-4: VERTICAL CIRCULATION VOLUME-TO-CAPACITY UTILIZATION, PEAK HALF-HOUR

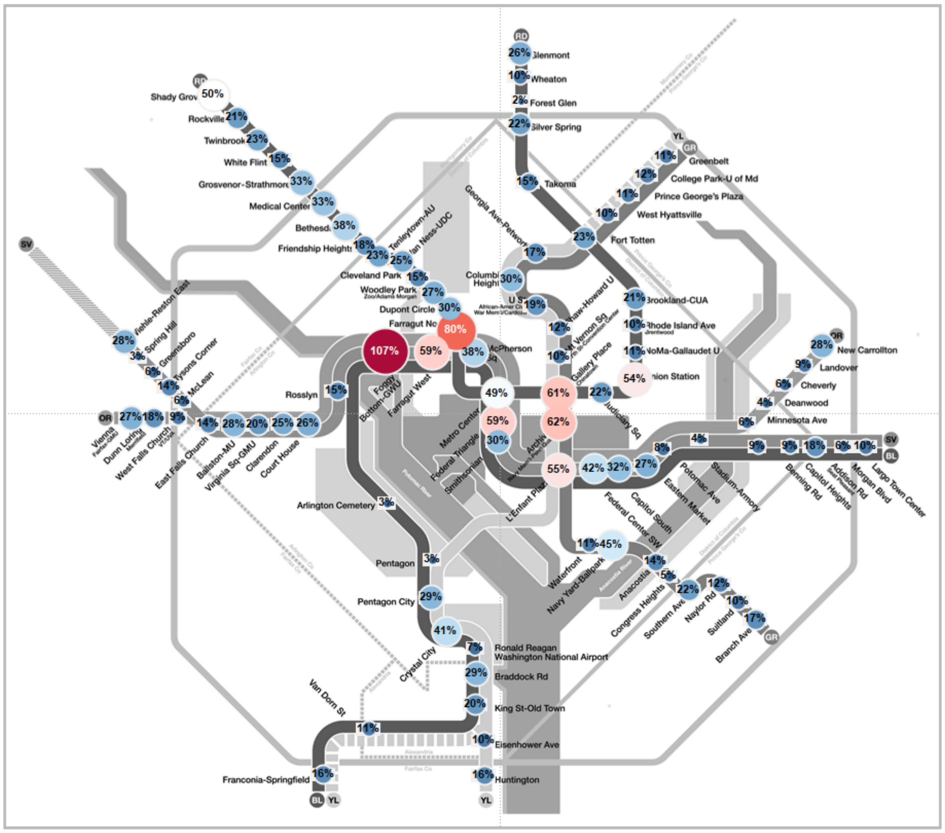


Table 5-15 shows the increase of vertical circulation crowding for each milestone service level by year for the ten most impacted stations.

TABLE 5-15: VERTICAL CIRCULATION USAGE BY YEAR [61]

Station	2020	2030	2040
Foggy Bottom	107%	116%	120%
Farragut North	80%	87%	90%
Archives-Navy Memorial	62%	68%	71%
Gallery Place-Chinatown	61%	67%	70%
Farragut West	59%	64%	66%
Federal Triangle	59%	65%	68%
L'Enfant Plaza	55%	60%	62%
Union Station	54%	63%	68%
Shady Grove	50%	57%	60%
Metro Center	49%	56%	60%

Metro is evaluating several projects to address vertical circulation constraints across the system which includes faregates, continued improvement on escalator and elevator reliability, and station operations generally. These projects are summarized in Table 5-16.

[61] Volume-to-capacity ratio shown for most crowded vertical circulation element. Metro's capacity standard is 50%, implying that a platform would clear in approximately half the time between train arrivals at that station platform.

TABLE 5-16: VERTICAL CIRCULATION IMPROVEMENT PROJECT LIST [62]

Station	New Asset	Status
Archives	Entrance, Mezzanine, Vertical Circulation Elements	Development & Evaluation Complete
Ballston*	Entrance	35% Design in Progress
Courthouse*	Street Elevators	Development & Evaluation Complete
Crystal City*	Entrance	Development & Evaluation Complete, Preliminary Engineering Pending
Bethesda	Entrance	Design
Farragut North and Farragut West	Station Improvements and New Passageway	Development & Evaluation Complete
Foggy Bottom	Mezzanine, Stairs, and Elevators	Development & Evaluation Complete
Huntington	Entrance	Design
L'Enfant Plaza	Elevator and Stairs	Design in Progress
McPherson Square	Elevators	Development & Evaluation Complete
Medical Center*	Entrance	Construction
Metro Center	Elevator and Stairs	Design In Progress
Pentagon City	Street Elevators	Design
Potomac Yard [63]	Entrance	Design
Shady Grove	Stairs	Design
Silver Spring	Entrance	Design
Smithsonian	Elevators	Development & Evaluation in Progress
Union Station	Entrance Relocation	Design

[62] * - Denotes project not being delivered by Metro.

[63] Potomac Yard Station to open in 2022.

Appendix

A.1. Definition of Acronyms and Terms

A.1.1 Acronyms

ADA	Americans with Disabilities Act
ATC	Automatic Train Control
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
ATO	Automatic Train Operation
CAF	Construcciones y Auxilar de Ferrocarriles, S.A., a Spanish railcar manufacturer
CBTC	Communication-Based Train Control
CM	Corrective Maintenance
CTEM	Car Track Equipment Maintenance
FTA	Federal Transit Administration, United States Department of Transportation
HR&O	Heavy Repair and Overhaul
HVAC	Heating, Ventilation and Air Conditioning
MDBD	Mean Distance between Delays
MDBF	Mean Distance between Failures
MoW	Maintenance of Way
MWAA	Metropolitan Washington Airports Authority
MWCOG	Metropolitan Washington Council of Governments
OSR	Operating Spares Ratio
PMI	Preventive Maintenance and Inspection
PMOC	Project Management Oversight Contractor
PPC	Passengers per Car
PVR	Peak Vehicle Requirement
S&I	Service and Inspection Shop
SMP	Scheduled Maintenance Program
STRF	Short-Term Ridership Forecast
TPB	National Capital Region Transportation Planning Board
TWC	Train-to-Wayside Communication
VDC	Volts Direct Current
VMS	Vehicle Monitoring System
WMATA	Washington Metropolitan Area Transit Authority

A.1.2 Terms

"A" CAR – The even-numbered car of a married pair that houses the Automatic Train Control apparatus.

AUTHORITY – The Washington Metropolitan Area Transit Authority.

AUTOMATIC TRAIN CONTROL – The system for automatically controlling train movement, enforcing train safety, and directing train operations.

BAY – Space in a shop where railcars maintenance may be performed.

"B" CAR – The odd-numbered car of a married pair.

BELLY CAR – A revenue vehicles used in the center position of a six- or eight-car train.

COMMUNICATION-BASED TRAIN CONTROL – A train control system that enables the continuous communication between trains and equipment, allowing trains to operate closer together.

CONSIST – The quantity and specific identity of vehicles that make up a train.

CONTACT RAILS – These rails (often referred to as Third Rails) provide electrical power to trains.

CROSSOVERS – Switches allowing trains to move from one track to another.

DEADHEAD – When revenue vehicles perform non-revenue trips to reposition before or after revenue service.

FAILURE RATE – The frequency of failure, expressed as failures per million miles.

FISCAL YEAR – The budget or financial year, beginning July 1 and ending June 30, denoted in the calendar year in which it ends (e.g., July 1, 2019 is part of the 2020 fiscal year).

GAP TRAIN – A ready train stored for immediate deployment in the event a train must be taken out of service.

HEADWAY – The time between consecutive trains operating on the same route.

INFILL STATION – A station that is constructed on an existing rail line, between existing stations.

INTERLOCKING – An arrangement of special track work and signals to prevent conflicting movements through a rail junction, crossover, or crossing.

JUNCTION – A point at which two rail lines merge into one. Junctions can be grade-separated at stations to allow passengers to transfer from one line to another.

MAINTENANCE OF WAY – Referring to assets involved in the repair and maintenance of the rail system.

MARRIED PAIR (Two-Car Unit) – The combination of an "A" car and a "B" car, semi-permanently coupled and sharing certain essential apparatus, and the smallest unit capable of independent operation.

MAXIMUM LOAD POINT – The segment of a line that carries the highest number of passengers using that line.

MEAN DISTANCE BETWEEN DELAYS – A measure that reports the number of miles between railcar failures resulting in delays of service of four or more minutes. The higher the mileage for the mean distance between delays, the more reliable the railcars.

MEAN DISTANCE BETWEEN FAILURES – A measure that reports the number of miles between railcar failures. The higher the mileage for the mean distance between failures, the more reliable the railcars.

OPERATING SPARES RATIO – The number of spare vehicles (as defined by subtracting the Peak Vehicle Requirement from the total available fleet) divided by the Peak Vehicle Requirement.

OPERATOR – The individual on board who is responsible for train operation in manual modes and overseeing train operation in any automatic mode.

OVERHAUL – Disassembly into component parts or subassemblies; replacement of worn and defective parts (with new or reconditioned parts as approved by Metro); and reassembly into complete functional assemblies, in accordance with the applicable instructions/procedures.

PEAK HOUR – The hour when passenger volume is greatest in the system.

PEAK VEHICLE REQUIREMENT (PVR) – The total number of revenue vehicles, inclusive of scheduled standby (gap) vehicles, required to operate schedule peak period service.

PERFORMANCE – The measure of output or results obtained by a component, system, etc.

POCKET TRACK – A third track between mainline tracks capable of storing a train, enabling mid-route turnbacks.

POWER SUBSTATIONS – Stations that convert electrical power into the necessary form needed to supply electricity to the contact third rails.

PREVENTIVE MAINTENANCE – A core Metro strategy of maximizing the reliability of vehicles in revenue service and reducing the maintenance spares requirement.

QUAD – The configuration of two married pairs of 7000-Series railcars to form a four-car unit.

RAILCAR OFFLOADS – When critical failures result in the offloading of customers from a train.

RECTIFIERS – Power converters that are part of traction power system.

RELIABILITY – The probability of performing a specified function, without failure and within design parameters, for the period of time intended under actual operating conditions.

REVENUE SERVICE – Service on routes established for train use by the public.

REVENUE VEHICLE – A heavy rail vehicle that is staffed and prepared to carry passengers.

RUNNING RAILS – Track rails that return the negative power to the substation.

SAFETRACK – A 13-month system-wide renewal initiative that required weekday service disruptions to accommodate multi-week surges of repair and renewal work.

SERVICE LIFE – The actual time during which any vehicle serves its intended purpose of safely and reliably transporting passengers. The end of service life occurs when degradation of the structural integrity of the vehicle requires that it be removed from service.

SCHEDULED MAINTENANCE PROGRAM (SMP) – an approach implemented in the Railcar Rehabilitation Program in which railcars are overhauled in stages on a recurring 6-year cycle

SHORT-LINING – When some scheduled trains terminate service and reverse directions prior to reaching the line's terminal.

SWITCHGEAR – Systems used to de-energize equipment to allow maintenance work.

TAIL TRACKS – Storage tracks beyond the terminus of a line.

TERMINAL – Where train lines originate, reverse direction, and end service.

THIRD RAIL – These rails (also referred to as Contact Rails) provide electrical power to trains.

TIE-BREAKER STATION – Stations that convert and supply power to the contact rail system.

TRACTION POWER SYSTEM – The system that provides the power source for vehicle propulsion.

TRAIN – A set of two, four, six, or eight rail vehicles coupled and operating together.

TRAIN THROUGHPUT – The number of trains traversing a given point in the Metrorail System over a period of time.

TRANSFORMERS – Devices that transfer Alternating Current (AC) to a Direct Current (DC) Substation.

TRIPPER TRAIN – An extra revenue vehicle scheduled to operate during peak hours of service to supplement the passenger capacity provided by trains operating on a regularly scheduled headway.

TURNBACK – A location where some scheduled trains terminate service and reverse directions prior to reaching the line's terminal.

YARD – A rail vehicle storage location that may also provide maintenance facilities.

A.2 Metrorail Service Planning Model

The Metrorail service planning model is a multi-step process used to develop fleet size requirements. Fleet size requirements are updated on a periodic basis prompted by events such as opening of new rail segments or the procurement of new railcars. The elements are as follows:

- Step One: Determine future peak hour passenger demand for Metrorail service.
  Develop peak hour passenger demand projections at the maximum load points of each Metrorail line.
- Step Two: Determine the service level requirements for each line.
  Apply Metro Board-adopted peak period service standards for maximum headways (i.e. minimum frequencies) and passenger loading to the maximum load points in the system. The frequency and train length requirements to meet target service levels determine the service level requirements of each line.
- Step Three: Determine number of cars needed for strategic gap trains.
  Determine the number of gap trains, and the resulting number of railcars, needed to maintain scheduled service levels and deliver reliable service.
- Step Four: Determine total operating Peak Vehicle Requirement (PVR).
  Apply vehicle running times (inclusive of recovery time) and operating constraints to the service level requirements to calculate the total scheduled vehicle requirements by route. The peak vehicle requirement is the sum of the scheduled peak car requirements of all lines in the system plus those of gap trains.
- Step Five: Determine Operating Spares Ratio (OSR).
  The operating spares ratio (OSR) is meant to accommodate vehicles being out of service during peak periods due to both scheduled and unscheduled maintenance.
- Step Six: Determine total fleet requirement.
  The total fleet requirement is the sum of the railcars required for peak service (including gap trains) and the railcars included in the operating spares ratio. The total fleet requirement is the basis for managing the supply of revenue vehicles through planning railcar procurements and retirements as well as developing needs for supporting systems and facilities.

A.3 Additional Tables and Figures

TABLE A-1: CURRENT S&I AND RUNNING REPAIR CAPACITY

S&I and Running Repair Capacity				
Shop	Present Capacity	Yard	Revenue Vehicle Storage	Shop to Storage Ratio
Shady Grove	*36*	Shady Grove	*166*	
		Glenmont	*132*	
Brentwood		Brentwood	*90*	
Total	36		388	9%
Alexandria	*20*	Alexandria	*176*	
Total	20		176	11%
New Carrollton	*16*	New Carrollton	*120*	
		Largo	*38*	
Total	16		158	10%
Greenbelt	*16*	Greenbelt	*270*	
Branch	*8*	Branch	*174*	
Total	24		444	5%
West Falls Church	*20*	West Falls Church	*188*	
WFC-Annex	*8*	West Falls Church		
Total	28		188	15%
Dulles	*20*	Dulles	*168*	
Total	20		168	
Total S&I	144		1552	11%
HR&O Shop Capacity				
Brentwood	*42*	Brentwood	-	
Greenbelt	*4*	Greenbelt	-	
Total HR&O	46		1552	3%
Total Shop Capacity	190		1552	12%

TABLE A-2: FUTURE S&I AND RUNNING REPAIR CAPACITY

S&I and Running Repair Capacity						
Shop		Present Capacity	Yard		Revenue Vehicle Storage	Shop to Storage Ratio
Shady Grove	*36*		Shady Grove	*166*		
			Glenmont	*132*		
Brentwood	*30*		Brentwood	*90*		
Total		66			388	17%
Alexandria	*20*		Alexandria	*176*		
Total		20			176	11%
New Carrollton	*16*		New Carrollton [64]	*176*		
			Largo	*38*		
Total		16			214	7%
Greenbelt	*16*		Greenbelt	*270*		
Branch Avenue	*8*		Branch	*174*		
Total		24			444	5%
West Falls Church	*20*		West Falls Church	*188*		
WFC-Annex	*8*		West Falls Church			
Total		28			188	15%
Dulles	*20*		Dulles	168		
Total		20			168	
Total S&I		174			1578	11%
HR&O Shop Capacity						
Brentwood	-		Brentwood		-	
Greenbelt	*4*		Greenbelt		-	
HR&O Facility	*40*		HR&O Facility	*24*		
Total		44			1602	3%
Total Shop Capacity		218			1602	14%

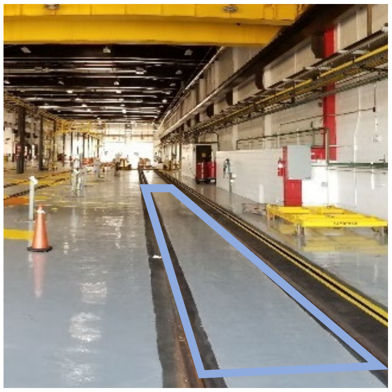
[64] Assumes planned expansion of New Carrollton revenue storage by 56 spaces.

TABLE A-3: SHOP CAPACITY – DETAIL

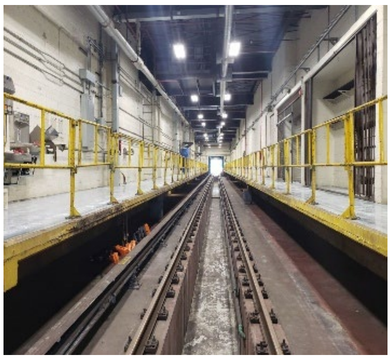
Yard	Location	Maintenance Bay												
		Lifts												
		w/o Body Jacks	w/ Body Jacks	Total Lifts	Posted Rail	Flat Track	Total Maint. Bay	Blow Pit	Lathe/ Wheel Truing	Clean-ing Tank	Paint	Body	Comm. Fac. [65]	Train Wash [66]
A99	Shady Grove	6	8	14	20	2	36	4	1	0	0	0	0	Yes
B98	Glenmont	0	0	0	0	0	0	0	0	0	0	0	0	Yes
B99	Brentwood	28	6	34	6	2	42	0	1	0	0	0	0	Yes
C99	Alexandria	2	4	6	10	4	20	2	1	0	0	0	0	Yes
D99	New Carrollton	4	4	8	6	2	16	4	1	0	0	0	0	Yes
E99	Greenbelt	12	4	16	2	2	20	4	1	4	2	2	8	Yes
F99	Branch Avenue	4	4	8	0	0	8	0	0	0	0	0	0	Yes
G05	Largo	0	0	0	0	0	0	0	0	0	0	0	0	No
K99	West Falls Church	2	8	10	10	8	28	2	1	0	0	0	0	Yes
N99	*Dulles* [67]	*8*	*8*	*16*	*2*	*2*	*20*	*2*	*1*	*2*	-	-	-	*Yes*
Z99	*HR&O* [68]	-	-	-	-	-	*40*	-	-	-	-	-	-	-
Total		**58**	**38**	**96**	**54**	**20**	**170**	**16**	**6**	**4**	**2**	**2**	**8**	

[65] Commissioning Facility: Reserved for the commissioning of railcars and engineering campaigns.
[66] The train wash facilities at Branch Avenue, Brentwood and New Carrollton are inoperative, while others need improvements. The train wash facilities at Brentwood and New Carrollton are inoperable for environmental reasons. The Brentwood train wash facility has been inoperative for many years and consists of some track-level equipment. A train wash improvement program is in development to assess and address train wash needs throughout the system.
[67] Dulles and HR&O not included in total counts.
[68] HR&O facility is under construction.

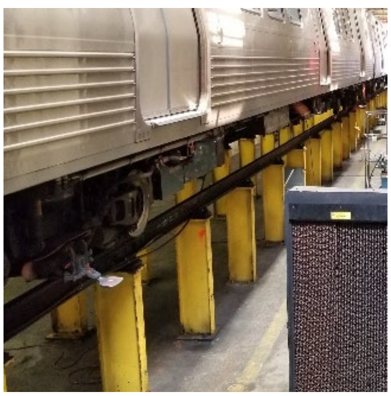
FIGURE A-1: SHOP EQUIPMENT EXAMPLES



Flat Track

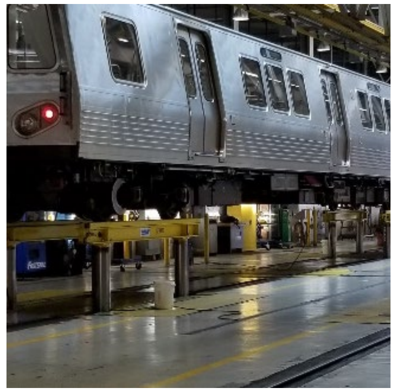


Blow Pit

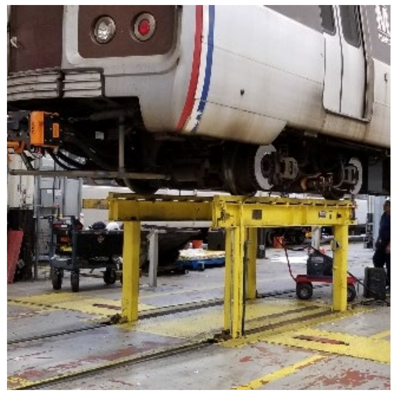


Posted Rail

Wheel Lathe



Lifts



Lifts with Body Jacks

Collapsed

Lifts with Body Jacks

Fully Extended

TABLE A-4: FORECAST AM PEAK HOUR MAXIMUM PASSENGER FLOW BY LINE, FISCAL YEAR 2020-2040[69]

Line	Segment From-To	2018 (July 2017)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Red	Judiciary Square - Gallery Place/Chinatown	10,922	11,860	12,128	12,396	12,664	12,932	13,200	13,304	13,408	13,512	13,616	13,720	13,814	13,908	14,002	14,096	14,190	14,284	14,378	14,472	14,566	14,660
	Dupont Circle - Farragut North	10,482	10,540	10,676	10,812	10,948	11,084	11,220	11,284	11,348	11,412	11,476	11,540	11,592	11,644	11,696	11,748	11,800	11,852	11,904	11,956	12,008	12,060
	Gallery Place/Chinatown - Metro Center		11,390	11,532	11,674	11,816	11,958	12,100	12,184	12,268	12,352	12,436	12,520	12,596	12,672	12,748	12,824	12,900	12,976	13,052	13,128	13,204	13,280
Blue	Rosslyn - Foggy Bottom-GWU		5,150	5,268	5,386	5,504	5,622	5,740	5,800	5,860	5,920	5,980	6,040	6,076	6,112	6,148	6,184	6,220	6,256	6,292	6,328	6,364	6,400
	L'Enfant - Smithsonian		3,510	3,530	3,550	3,570	3,590	3,610	3,668	3,726	3,784	3,842	3,900	3,948	3,996	4,044	4,092	4,140	4,188	4,236	4,284	4,332	4,380
	Pentagon - Arlington Cemetery	5,171	4,470	4,588	4,706	4,824	4,942	5,060	5,104	5,148	5,192	5,236	5,280	5,328	5,376	5,424	5,472	5,520	5,568	5,616	5,664	5,712	5,760
Orange	Courthouse - Rosslyn	6,603	7,580	7,724	7,868	8,012	8,156	8,300	8,348	8,396	8,444	8,492	8,540	8,587	8,634	8,681	8,728	8,775	8,822	8,869	8,916	8,963	9,010
	L'Enfant - Smithsonian		4,150	4,256	4,362	4,468	4,574	4,680	4,714	4,748	4,782	4,816	4,850	4,889	4,928	4,967	5,006	5,045	5,084	5,123	5,162	5,201	5,240
Silver	Courthouse - Rosslyn	4,837	6,490	6,566	6,642	6,718	6,794	6,870	6,886	6,902	6,918	6,934	6,950	6,976	7,002	7,028	7,054	7,080	7,106	7,132	7,158	7,184	7,210
	L'Enfant - Smithsonian		2,430	2,472	2,514	2,556	2,598	2,640	2,646	2,652	2,658	2,664	2,670	2,699	2,728	2,757	2,786	2,815	2,844	2,873	2,902	2,931	2,960
Green	Waterfront - L'Enfant Plaza	5,252	5,560	5,704	5,848	5,992	6,136	6,280	6,356	6,432	6,508	6,584	6,660	6,745	6,830	6,915	7,000	7,085	7,170	7,255	7,340	7,425	7,510
	Shaw-Howard - Mt. Vernon Square	6,087	6,130	6,196	6,262	6,328	6,394	6,460	6,514	6,568	6,622	6,676	6,730	6,764	6,798	6,832	6,866	6,900	6,934	6,968	7,002	7,036	7,070
Yellow	Pentagon - L'Enfant Plaza	4,765	5,450	5,548	5,646	5,744	5,842	5,940	5,970	6,000	6,030	6,060	6,090	6,135	6,180	6,225	6,270	6,315	6,360	6,405	6,450	6,495	6,540
All	System-Wide Total		84,710	86,188	87,666	89,144	90,622	92,100	92,778	93,456	94,134	94,812	95,490	96,149	96,808	97,467	98,126	98,785	99,444	100,103	100,762	101,421	102,080

[69] Ridership forecasts were modeled for the milestone years (2020, 2025, 2030, 2035, 2040) and interpolated for intermediate years for planning purposes The Green Line's peak hour is half an hour earlier (07:30-08:30) than that of the other lines (08:00-09:00).

TABLE A-5: RAIL YARD STORAGE CAPACITY TRACK DETAIL

A99—Shady Grove

Track #	Storage Capacity
21	8
20	10
19	12
18	14
17	14
16	14
15	16
14	14
13	12
12	12
11	10
10	10
10A	10
10B	10
Total	**166**

B98—Glenmont

Track #	Storage Capacity
Y1	10
Y2	10
Y3	10
Y4	12
Y5	14
Y6	14
Y7	14
Y8	12
Y9	12
Y10	12
Y11	12
Total	**132**

B99—Brentwood

Track #	Storage Capacity
17	10
18	10
19	8
20	6
21	6
1	8
2	8
3	8
4	8
5	8
6	10
Total	**90**

C99—Alexandria

Track #	Storage Capacity
26	8
25	8
24	10
23	12
22	14
21	14
20	14
19	14
18	12
17	12
16	10
15	8
14	8
13	8
12	8
11	8
10	8
Total	**176**

D99—New Carrollton

Track #	Storage Capacity
7	10
8	12
9	12
10	14
11	16
12	14
13	12
14	10
15	10
16	10
Total	**120**

E99—Greenbelt

Track #	Storage Capacity
20	8
17	6
16	16
15	16
14	16
13	16
12	16
11	16
10	16
9	16
8	16
7	16
6	16
5	16
4	16
3	16
2	16
1	16
Total	**270**

F99—Branch Avenue

Track #	Storage Capacity
15	12
14	12
13	12
12	12
11	12
10	14
9	14
8	12
7	12
6	12
5	10
4	10
3	10
2	10
1	10
Total	**174**

G98—Largo Tail Track

Track #	Storage Capacity
42	16
43	10
41	12
Total	**38**

K99—West Falls Church

Track #	Storage Capacity
1c	10
1b	10
1a	12
1	12
2	12
3	12
4	12
6e	8
6d	8
6c	8
6b	8
6a	8
6	8
7	10
8	12
9	12
10	12
11	14
Total	**188**

N99—Dulles

Track #	Storage Capacity
16	12
15	12
14	12
13	12
12	12
11	12
10	12
9	12
8	12
7	12
6	8
5	8
4	8
3	8
2	8
1	8
Total	**168**

TABLE A-6: YARD STORAGE UTILIZATION AS PERCENT OF TOTAL, BASELINE CAPACITY SCENARIO

		6- and 8-car trains	100% 8-car trains		
Code	**Location**	**Current Headway**	**8-minute Headway**	**7-minute Headway**	**6-minute Headway**
A99	Shady Grove	100%	102%	119%	153%
B98	Glenmont	100%	100%	115%	124%
B99	Brentwood	78%	100%	100%	100%
C99	Alexandria	105%	100%	100%	100%
D99	New Carrollton	105%	127%	168%	193%
E99	Greenbelt	93%	73%	83%	100%
F99	Branch Avenue	70%	48%	53%	62%
G05	Largo	100%	100%	100%	100%
K99	West Falls Church	105%	84%	100%	100%
N99	Dulles	-	100%	100%	114%

The Baseline Capacity scenario shows projected yard storage utilization in several service scenarios, given existing Metro railcar storage capacity as shown in Table A-5. It includes the completion of the Dulles Yard (168 spaces added). The yard storage utilization column reflects the service plan prior to the opening of the Dulles Yard and Silver Line Phase 2.

TABLE A-7: YARD STORAGE UTILIZATION AS PERCENT OF TOTAL, 8-MINUTE BUILD SCENARIO

		100% 8-car trains		
Code	**Location**	**8-minute Headway**	**7-minute Headway**	**6-minute Headway**
A99	Shady Grove	102%	119%	153%
B98	Glenmont	100%	115%	124%
B99	Brentwood	100%	100%	100%
C99	Alexandria	100%	100%	100%
D99	New Carrollton	100%	115%	132%
E99	Greenbelt	70%	83%	100%
F99	Branch Avenue	48%	53%	62%
G05	Largo	100%	100%	100%
K99	West Falls Church	81%	100%	100%
N99	Dulles	94%	100%	114%

The 8-Minute Build scenario shows projected yard storage utilization in several service scenarios, given existing Metro railcar storage capacity as shown in Table A-5. It includes the completion of the Dulles Yard (168 spaces added), the Heavy Repair and Overhaul Facility (24 spaces added) and the New Carrollton West Yard expansion (56 spaces added).

TABLE A-8: YARD STORAGE UTILIZATION AS PERCENT OF TOTAL, 7-MINUTE BUILD SCENARIO

		100% 8-car trains		
Code	**Location**	**8-minute Headway**	**7-minute Headway**	**6-minute Headway**
A99	Shady Grove	93%	100%	134%
B98	Glenmont	93%	100%	100%
B99	Brentwood	72%	100%	100%
C99	Alexandria	100%	100%	100%
D99	New Carrollton	96%	100%	100%
E99	Greenbelt	67%	77%	100%
F99	Branch Avenue	48%	53%	62%
G05	Largo	100%	100%	100%
K99	West Falls Church	74%	93%	100%
N99	Dulles	79%	100%	114%

The 7-Minute Build scenario shows projected yard storage utilization in several service scenarios, given existing Metro railcar storage capacity as shown in Table A-5. It includes the completion of the Dulles Yard (168 spaces added), the Heavy Repair and Overhaul Facility (24 spaces added), a larger New Carrollton expansion (112 spaces added), and storage expansion within Red Line yards (52 additional Red Line spaces resulting from 32 spaces added at Shady Grove, 32 spaces added at Glenmont, and 12 spaced removed at Brentwood).

TABLE A-9: YARD STORAGE UTILIZATION AS PERCENT OF TOTAL. 6-MINUTE BUILD SCENARIO

		100% 8-car trains		
Code	**Location**	**8-minute Headway**	**7-minute Headway**	**6-minute Headway**
A99	Shady Grove	69%	78%	98%
B98	Glenmont	98%	98%	100%
B99	Brentwood	51%	82%	92%
C99	Alexandria	100%	100%	100%
D99	New Carrollton	96%	100%	95%
E99	Greenbelt	67%	77%	100%
F99	Branch Avenue	48%	53%	62%
G05	Largo	100%	100%	100%
K99	West Falls Church	74%	88%	96%
N99	Dulles	58%	77%	93%

The 6-Minute Build scenario shows projected yard storage utilization in several service scenarios, given existing Metro railcar storage capacity as shown in Table A-5. It includes the completion of the Dulles Yard (168 spaces added), the Heavy Repair and Overhaul Facility (24 spaces added), a larger New Carrollton expansion (112 spaces added), storage expansion within Red Line yards (132 additional Red Line spaces resulting from 112 spaces added at Shady Grove, 32 spaces added at Glenmont, and 12 spaced removed at Brentwood), and an additional railcar storage expansion at Dulles Yard (60 spaces added).