Zero Emission Bus Transition Plan

April 2024

MCDOT & DGS

Executive Summary

The Montgomery County Department of Transportation (MCDOT)'s commitment to transition to a zeroemission bus (ZEB) fleet is in direct alignment with MCDOT's three priority areas:

- Safety and Vision Zero
- Environment and climate resiliency
- Economic development and equitable access

The ZEB transition program is just one component of the county's Climate Action Plan (CAP) to cut greenhouse gas emissions 80 percent by 2027 and 100 percent by 2035. As a result, MCDOT is striving to have its entire fleet consist of ZEB technology by 2035. The transportation sector currently represents 42 percent of the county's greenhouse gas emissions. According to the CAP, of the total trips taken in the County in 2018, private cars accounted for approximately 75%, buses 10%, rail 5%, walking 2%, taxi/ride hailing (for example, Uber and Lyft) 1%, and biking less than 1%.

Montgomery County's ZEB Transition Plan

MCDOT's ZEB Transition Plan will serve as a road map for MCDOT's ZEB transition and will look at all of the county's existing infrastructure assets, including vehicles, bus maintenance facilities and infrastructure, bus stops, and routes. MCDOT's program mirrors a statewide initiative currently underway following the passage of Maryland's Zero-Emission Bus Transition Act, which mandates that all new buses procured for the Maryland Department of Transportation Maryland Transit Administration (MDOT MTA)'s fleet be emission-free starting in 2023, with a goal of having 50 percent of the fleet converted by 2030.

KEY DEPENDENCIES OF THE ZEB TRANSITION PLAN

- **Availability of funding** for ZEBs & associated infrastructure
- **Depot capacity** for new technology & fleet growth
- **Domestic ZEB manufacturing** capacity & lead times
- **Availability of renewable energy sources** including green hydrogen & clean power

Key Considerations for the ZEB Transition Plan

- Climate Action Plan (CAP) goals – accelerated transition and exposure to risk and uncertainty
- Changing technology – energy needs and fleet optimization
- Fiscal responsibility – transition cost and pace of spending
- Depot capacity constraints – timely capital investment and infrastructure readiness
- Market availability of equipment – increasing costs and lead times

MCDOT's ZEB Transition Plan will serve as an evolving road map and will look at all of the county's existing vehicles, bus facilities and infrastructure, bus stops & routes.

About Montgomery County

- 1.06M POPULATION IN 2023, +9.3% SINCE 2010
- 1.25M EST. POPULATION IN 2050, +18% SINCE 2023
- #1 MOST POPULOUS JURISDICTION IN MARYLAND
- 2ND LARGEST TRANSIT SYSTEM IN MARYLAND & DC METRO AREA
- 4 TRANSIT SERVICES

Purpose & Need

The transportation sector accounts for substantial greenhouse gas emissions in the United States. Greenhouse gases are comprised of a combination of emissions of carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and various fluorinated gases. Among the compilation of greenhouse gases, CO2 has the largest share, about 79%, according to the US EPA. The primary source of CO2 emissions is the use of fossil fuels in traditional internal combustion engine vehicles. Public transportation agencies like MCDOT, as providers of essential transportation services in communities and as significant users of traditional internal combustion engine vehicles, play a critical role in the transition to zero-emission vehicle technologies for a more sustainable future.

Even without a conversion to carbon-emissionsfree operations, according to the American Public Transportation Association (APTA), the "leverage ZERO EMISSION BUS TRANSITION PLAN | 5 effect" of public transportation reduces the nation's carbon emissions by 37 million metric tons annually. Public transportation saves the equivalent of 900,000 automobile petroleum fuel fill-ups every day. The typical public transit rider consumes on average ½ of the oil consumed by an automobile rider. By its nature, Montgomery County's transit network benefits the environment by providing clean, safe, affordable, and reliable transportation options in MCDOT's service area. Transit operations are a small contributor to overall transportation emissions, however the transition of MCDOT's transit bus service to zero-emission vehicles is a critical area of focus in the County's Climate Action Plan (CAP). The Montgomery County CAP is a strategic plan to cut greenhouse gas (GHG) emissions 80% by 2027 and 100% by 2035 (compared to 2005 levels), and to reduce climate related risks to Montgomery County's residents, businesses, and the environment.

In support of the CAP and the far-reaching benefits to the environment and Montgomery County residents, the County aims to

> *ZEB TRANSITION PLAN VISION STATEMENT MCDOT aims to achieve a 100% transition to zero emission buses in its fleet by 2035.*

achieve a 100% transition to zero-emission buses within the MCDOT fleet by 2035. The release of this ZEB Transition Plan represents a snapshot in time, and its development is based on both the County's completed and ongoing zero-emission fleet and facility projects, as well as the capabilities of the current zero-emission technologies available; this document will be continually updated over time as conditions evolve and new decisions are made that further define the path forward. Achieving this goal will require alignment of external technology functions, internal adaptation, and available financial resources.

The County's team began transitioning their bus fleet to zero-emission vehicles in 2019 with the acquisition of four 35' 2019 Proterra Battery Electric Buses (BEBs). In September 2021, the County began construction of its first major bus facility electrification program, the Brookville Smart Energy Depot in Silver Spring, MD. The Brookville Bus Depot includes a microgrid consisting of 2 megawatts of photovoltaic solar panels and a 4-megawatt battery energy storage system (BESS) serving as renewable energy power sources for the County's growing electric bus fleet. A microgrid is an independent local energy grid that can operate separately from a traditional grid. The Brookville microgrid has capacity for approximately 71 BEBs supported in island mode — without external support from the Potomac Electric Power Company (Pepco)'s grid. However, an additional power feeder from Pepco would provide enough capacity to support the transition of the entire Brookville fleet to 100% battery-electric.

The County is also pursuing a similar opportunity to expand on the success of the Brookville Smart Energy Depot by adding a second integrated microgrid and bus charging project at the David F. Bone Equipment Maintenance and Transit Operations Center (EMTOC). This project will support the charging capacity of up to 35 BEBs as well as provide renewable energy to power the production of green hydrogen gas, fueling up to 20 hydrogen Fuel Cell Electric Buses (FCEB).

An Evolving ZEB Transition Plan

The release of this ZEB Transition Plan represents a snapshot in time & its development is based on both the County's previously completed & ongoing zero-emission fleet & facility projects, as well as the capabilities of the current zeroemission technologies available; this document will be continually updated as time & conditions evolve, & new decisions are made that further define the path forward. Achieving this goal will require alignment of external technology functions, internal adaptation, and available financial resources.

Policies, Goals & Needs

Despite the County's trailblazing sustainability efforts, the recently completed and currently committed infrastructure projects for zeroemission operations will only accommodate 40% of the current Ride On fleet. To identify the appropriate zero-emission vehicle technology and related energy requirements to transition the balance of the fleet while ensuring seamless transit service, MCDOT collaborated with MCDGS to commission and complete a comprehensive energy modeling analysis. The energy modeling analysis includes zero-emission route simulation under the most extreme operating conditions expected in the County's service area, including complete block schedule requirements for all fleet vehicles throughout their entire day of operation, such that the vehicle technology planned for the transition can provide reliable, year-round service.

The results of the energy modeling were merged with the County's current fleet replacement schedule, including defined Ride On service expansion projects that result in growth of the fleet, and then integrated with a multifaced capacity analysis of the Ride On operation and maintenance facilities. The result is a comprehensive Fleet Transition Model depicting the successful transition of the entire fleet to zero-emissions, from present day through 2035 and in accordance with the County's Climate Action Plan (CAP).

As with any paradigm shift in deeply ingrained technology, MCDOT and MCDGS' commitment to meeting the County's CAP goals will not be achieved without facing complex challenges. Nationwide, many transit agencies are required by legislation or other mandates to transition to a zero-emission fleet by a certain date, or they are prohibited from procuring fossil fuel-powered buses. This shift has increased demand for fleet and infrastructure funding from transit agencies nationwide who are all simultaneously transitioning their bus fleets to renewable energy sources. Although the transition of Montgomery County's Ride On fleet is not currently required by legislation, the County's commitment to a clean, sustainable future and zero-emission transit fleet by 2035 is among the most aggressive transition goals in the country and places a significant focus on the various impacts, constraints, and dependencies that the County will face. While the industry is moving in this direction, a broad transition to ZEBs is dependent upon bus manufacturers that satisfy the federal Buy America requirements. These sanctioned manufacturers must also increase their production capacity to meet the growing demand of the market. This is a critical dependency that the County will be watching closely due to the recent contraction of the transit bus marketplace with the loss of domestic sales or reorganization of bus manufacturers such as Novabus, Proterra, and Eldorado National.

In addition to the limitations presented by the bus manufacturers' production capacity, costly modifications are needed at operation and maintenance facilities to support ZEB fleets. These facility modifications require comprehensive planning activities that impact facility designs, timing of vehicle purchases, the electrical grid, and standard operating procedures for these facilities. Thus, an integral component of the County's ZEB transition planning effort is identifying their facility, maintenance, and operating capacities to forecast the unmet needs of operating the future 100% ZEB fleet. Through this work, MCDOT and MCDGS are also identifying the capital improvement budgets needed to strategically pursue infrastructure upgrades and funding opportunities that support the timing of ZEB vehicle purchases. MCDOT and MCDGS remain focused on transitioning to a 100% zero emissions fleet by 2035, but the success of this effort is dependent upon the ability to obtain sufficient capital funding for facility upgrades to meet this goal. As part of this plan, a comprehensive database of current funding sources is included in Chapter 13. Additional funding sources will be incorporated into this Plan as they become available. The availability of additional funding will be a major factor in the County's ability to meet the 2035 target date for a 100% zero-emission transition. These funds are needed for improvements to the County's operation and maintenance facilities, as well as relocate the operations facility currently located at the leased Nicholson Court Small Transit Shop. The total gross cost of the transition to zero-emissions is estimated at $2.36 billion between 2024 and 2035, which includes capital vehicle and facility investments, construction of a new zero-emission bus facility, and operating (energy) and maintenance costs for the vehicle fleet. **Additional details regarding the economic analysis of this transition plan are provided in Chapter 12.**

The County's current and near-term ZEB deployments are focused on energy resiliency through implementation of microgrids, which requires active engagement and partnering with the region's electric utility provider, Pepco. This ensures that future facility upgrades are designed such that the additional load introduced to the grid may be accommodated by a hybrid approach of traditional and microgrid technologies. This relationship is critical to establishing a comprehensive energy strategy for MCDOT and MCDGS and to ensure that the timing of necessary upgrades to the electrical infrastructure reflects the zero-emission transition schedule and future needs.

The total estimated gross cost of the ZEB transition is $2.36 billion from 2024-2035.

Finally, this plan outlines MCDOT and MCDGS's commitment to retaining and training current staff members to familiarize them with ZEB service, maintenance, and operations. Transitioning away from fossil-fuel powered vehicles towards ZEBs is an iterative process that relies on continual assessment of changes in technology to help minimize risk and accommodate new developments in a rapidly evolving market. The County will routinely monitor changes in technology, service plans, peer agency and service partners' experience with ZEBs, related industry factors such as ZEB cost and availability, and various assumptions in the underlying analysis. This is a live document that represents a snapshot in time that shows the current status of the transition plan; it will be updated continuously as the County reaches future milestones and technology and industry conditions progress. Due to this, the document might show inconsistencies between implementation schedules and the County's Capital Improvements Program (CIP). These inconsistencies will be resolved as the ZEB implementation progresses and new funding sources are identified for zero-emissions projects on the overall schedule for the transition changes.

TRANSITION SCHEDULE, IMPLEMENTATION & MILESTONES

Figure E-1 outlines the progression of the zero emission fleet transition and the composition of ZEB technology employed by the fleet to accomplish a 100% zero-emission transition by 2035. Based on the fleet's age and replacement schedule, current projections, and assuming the transition plan can be fully funded, the County could achieve a 100% ZEB fleet by 2033, two years in advance of the Climate Action Plan goal; however, achieving this milestone will be very challenging and will require alignment of many internal and external factors. In addition to funding, the ability to procure the zero-emission buses, battery-electric charging infrastructure and hydrogen fuel cell electric bus fueling infrastructure projects, as well as the opening of a new ZEB facility with additional fleet capacity are vital elements in the successful transition. Ensuring that ZEB deliveries occur on schedule and that

The County could achieve a 100% ZEB fleet by 2033 — 2 years in advance of the Climate Action Plan goal.

facilities have the necessary ZEB infrastructure and capacities in place to support the growing fleet of ZEBs is critical to the success of the transition. A detailed transition roadmap is provided in Chapter 15.

ZEB TRANSITION PLAN KEY FINDINGS

- **Transition Timeline is Achievable** - The County's early actions demonstrate a clear commitment to meeting the Climate Action Plan goal of 100% zero-emissions by 2035; this momentum has the County on pace to complete the transition ahead of schedule; however, critical dependencies may cause delays
- **P3 Agreements Provide a Wide Range of Benefits** - The use of Public-Private Partnership (P3) agreements for acquiring sustainable ZEB infrastructure offers a wide range of benefits, including a predictable cost structure & the transfer of risk away from the County
- **Domestic Bus Capacity is Down** - A contraction in domestic bus production capacity has resulted in fewer ZEBs to choose from; less manufacturer competition has led to higher costs & longer lead-times — the County plans to initiate vehicle procurement multiple years in advance of target bus delivery timeframes
- **Highly Utilized MCDOT Bus Fleet** - High utilization of the County's transit fleet (in the top 8% nationwide based on annual miles per bus) will require high energy-capacity ZEB technology such as FCEBs or alternative solutions like increasing fleet size or using onroute chargers
- **Challenges of County Transit Service Plan Redesign** - Ongoing redesign of the County transit service plan (via the Ride On Reimagined study) will lead to a reassessment of future ZEB technology requirements; the County will assess impacts of service plan changes on daily energy needs & optimal ZEB fleet mix
- **Nicholson Court Depot does not Support ZEBs** - The Nicholson Court depot is leased & cannot be upgraded with ZEB infrastructure due to terms of the lease agreement; a new ZEB facility will be required with capacity for all of Nicholson's buses & able to accommodate future transit service expansions, such as planned Flash BRT service
- **ZEB Transition Cost is Higher than for Conventional Buses** - The total cost of the ZEB transition from 2024-2035 is expected to be ~$700 million higher than a baseline fleet of conventionally fueled buses; the County will continue to aggressively pursue grants & funding opportunities for ZEBs, infrastructure projects & related facility upgrades
- **Zero-Emission Technology is Rapidly Developing** - Rapidly evolving technology may not yet be "service proven"; an Emergency Contingency Vehicles provision should be considered so conventionally-fueled vehicles can be used as a contingency fleet during the County's ZEB transition, as they offer the range & flexibility needed during emergencies while advancements in technology are ongoing
- **Continue to leverage smart data and assistance technologies** such as Charge Management Systems and on-board vehicle telematics to support effective deployment of ZEBs and performance monitoring
- **Expand the County's ZEB training programs** and ensure the workforce is ready to continue providing safe, reliable operation and maintenance of zeroemission fleet equipment
- **Continue to monitor for available grants and funding opportunities** to help offset the increased costs associated with zeroemission technology
- **Continue to update the transition** plan as needed based on changes in zero emission technology, direct experience with operating ZEBs and zero-emission infrastructure, available grants and funding opportunities, changes in market factors impacting zero-emission vehicles such as the cost of renewable energy sources and the availability of green hydrogen, etc

Strategic Goals & Next Steps

Key strategic goals of the ZEB Transition Plan include the following:

- **Advance the acquisition and delivery of BEBs** under the County's current contract with bus manufacturer, GILLIG LLC
- **Expand the deployment of BEBs** at the County's Brookville Smart Energy Depot with newly acquired BEBs
- **Continually monitor BEB and microgrid infrastructure performance**; apply lessons learned to the development of future transit service plan and the expansion of future ZEB infrastructure, including continuing evaluation of on-route charging
- **Use Renewable Natural Gas (RNG) from WSSC Water** via the Piscataway Bioenergy Project to realize additional intermediate emissions reductions through operation of the current CNG fleet, resiliency and power generation equipment, and used by facilities for heating

- Explore additional RNG opportunities from conversion of County waste systems, including landfill-generated gas and future food waste composting operations
- **Expand ZEB infrastructure capacity** at the Brookville Smart Energy depot in order to achieve 100% ZEB operation at this facility
- **Complete the EMTOC depot microgrid** and the County's (and the East Coast's) first green hydrogen production project, supporting the introduction of both BEBs and FCEBs operating out of the Gaithersburg facility
- **Monitor the performance of the County's first FCEB fleet;** apply lessons learned to the development of future transit service plan design and the expansion of hydrogen infrastructure at County facilities
- **Re-evaluate the fleet's energy needs and compatibility with ZEB technology** upon completion of the Ride On Reimagined study, involving the redesign of the County's transit service plan
- **Build a new, 100% Zero-Emission Operation and Maintenance facility** for County buses, to complete the transition and provide additional capacity for transit service expansions
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KEY MILESTONES

Key milestones of the ZEB Transition Plan are shown below; a more detailed ZEB transition schedule is provided on pages 14-15:

2024 - Initiate new ZEB facility site development, community outreach, design & construction program; Initiate 5-year procurement contract for BEBs & FCEBs (deliveries occurring 2027-2031)

2026 - Complete Phase 1 BEB charging capacity expansion & hydrogen fueling capacity expansion at EMTOC facility

2028 - Complete Phase 2 ZEB capacity expansions at the EMTOC & Brookville facilities

2029 - Initiate a 4-year procurement contract for BEBs & FCEBs (deliveries occurring 2032-2035)

2030 - Open new ZEB depot & charging facility with capacity for 180 ZEBs; Close Nicholson Court facility & perform full-scale fleet reassignment & realignment with capacity constraints

2033 - Achieve a 100% ZEB fleet with retirement of the last CNG & diesel buses

2035 - Future bus depot at full operating capacity, accommodating MCDOT's various transit services, including expansions projected for 2035*

Figure E-2: Zero-Emission Transition Roadmap

This ZEB Transition Roadmap demonstrates the connection between the timing of ZEB procurement & ZEB infrastructure implementation, as well as the introduction of the necessary new bus maintenance & storage facility to support the ZEB capacity needs of the future fleet & service growth

Vehicles:

- 2023: BEB contract award (Gillig) --> 2025 – 2027: Delivery of 92 Gillig BEBs
- 2023: initiate FCEB procurement --> 2025: First FCEBs delivered & enter service
- 2024: 2024 RFP & 2025 contract award for 5-year ZEB contract (BEB & FCEB, all sizes) --> 2027 – 2031: Five-year contract delivery of 87 BEBs & 258 FCEBs
- 2029 – 2030: 2029 RFP and 2030 contract award for four-year ZEB contract(BEB & FCEB, all sizes) --> 2032-2035: Four-year contract delivery of 12 BEBs & 116 FCEBs

Facilities & Infrastructure:

- 2023: P3 awarded - EMTOC microgrid --> 2025: EMTOC microgrid complete & operational
- 2024: RFP - EMTOC H2 fueling capacity → 2026: Ph 1 EMTOC H2 fueling complete → 2028: Ph 2 EMTOC H2 fueling complete

- 2024: RFP - Brookville BEB charging & H2 fueling → 2026: Ph 1 Brookville BEB charging & H2 fueling complete → 2028: Ph 2 Brookville BEB charging & H2 fueling complete
- 2023: New facility site plan, feasibility & outreach → 2024-2025: New facility 30% design, NEPA documentation & approval → 2024-2025: New facility 100% design & permitting → 2025-2026: New facility 100% design & permitting → 2026-2027: Pre-construction: site preparation & demolition → 2027-2033: Phased construction & commissioning → 2030: New facility opens: Phase 1 complete (180 ZEBs) → 2033: New facility Phase 2 complete (257 ZEBs)
- 2024-2025: RFP – Joint development contract & award
- 2027: Nicholson Court: 3-year lease renewal → 2030: Nicholson Closes: Fleet-wide redistribution

ZEB Transition Plan Requirements

This ZEB Transition Plan satisfies the Federal Transit Administration (FTA)'s minimum requirements for the Low or No Emission (LowNo) and Buses and Bus Facilities discretionary grant applications. To fund ZEB transitions as outlined in the Bipartisan Infrastructure Law, the FTA now requires agencies applying for grants to incorporate a Zero-Emissions Transition Plan. Per FTA guidelines, these plans must include the following, which are addressed in the identified chapters of this document and marked with the corresponding icon for easy identification:

- **Fleet management** – demonstrates a long-term fleet management plan (Chapter 9: Fleet Transition Model)
- **Resource availability** – addresses the availability of current and future resources (Chapter 13: Funding & Finance Scan)
- **Policy & legislation** – considers policy and legislation impacting relevant technologies (Chapter 2: Clean Transit Regulations)
- **Facility evaluations** – includes an evaluation of existing and future facilities (Chapter 6: Facilities & Infrastructure Plan and Chapter 8: Capacity Analysis)
- **Utilities & fuel** – describes the County's partnerships with utilities and fuel providers (Chapter 6: Facilities & Infrastructure Plan)
- **Workforce impacts** – Examines the impact of the transition on the County's current workforce (Chapter 11: Workforce Training)

The ZEB Transition Plan is organized as follows:

- **Chapter 1: Transit Agency Overview** provides an overview & history of MCDOT & describes the unique goal areas set forth by the agency & other stakeholders
- **Chapter 2: Clean Transit Regulations** provides an overview of the different federal, state & municipal regulations for clean transit vehicles
- **Chapter 3: Transition Risks & Mitigation Strategies** provides a detailed summary of the risks & mitigation strategies involved with the ZEB Transition Plan
- **Chapter 4: Zero Emission Technology** provides an overview of the current state of zero emission technology for transit vehicle use
- **Chapter 5: Current Fleet & Planned Near Term Acquisitions** provides an overview of Montgomery County's bus fleet & future vehicle acquisitions
- **Chapter 6: Facilities & Infrastructure Plan** provides an overview of the three operations & maintenance plans currently used by MCDOT's bus fleet
- **Chapter 7: Service Plan & Energy Needs** provides a summary of the analysis used to identify the target mix of technologies necessary to achieve the ZEB transition goals
- **Chapter 8: Capacity Analysis** provides an overview of space, maintenance & 'fueling' capacity to determine facility based constraints throughout the ZEB transition
- **Chapter 9: Fleet Transition Model** identifies which buses will be replaced with zero-emission equivalents, when these buses will be replaced & when the fleet expansions will be added to the fleet roster
- **Chapter 10: Operations** provides an overview of the current operations of MCDOT's bus fleet as well as the impact of operations by the ZEB technology

- **Chapter 11: Workforce Training** provides an overview of the ZEB technology training that will be needed for current & future staff as the transition plan is implemented
- **Chapter12: Economic Assessment** summarizes the findings of the economic analysis, which includes a life cycle cost assessment (LCCA) as well as a cash flow analysis
- **Chapter 13: Funding & Finance Scan** provides an overview of the funding sources needed to implement this ZEB transition plan
- **Chapter 14: Emissions Analysis & Quantification Methodology** summarizes the County's economic analysis & quantifies the impacts on GHG emissions by bus depot
- **Chapter 15: Implementation & Next Steps** provides a roadmap for delivering the vehicles, infrastructure, facilities & capacity needed to accommodate the new ZEBs & future service growth
- **Appendix: Appendices** include the technical studies & reports containing information regarding detailed service & energy needs

CHAPTER 1 TRANSIT AGENCY OVERVIEW

The Montgomery County Department of Transportation (MCDOT)'s Division of Transit Services provides public transit for the most heavily populated county in Maryland, which neighbors Washington, D.C. and is home to over 1 million residents across 510 square miles. The County owns and operates almost 400 buses providing Montgomery County residents with reliable transit options and resources. The County's transportation system operates under MCDOT and complements other transit systems operated by the Maryland Department of Transportation (MDOT) and Washington Metropolitan Area Transit Authority (WMATA). MCDOT works closely with these agencies to ensure transportation efficiency for all users. A high-level MCDOT Transit service territory map is shown in Figure 1-1.

Vision & Mission

MCDOT aims to improve transportation and connect the people within the County without having an adverse effect on the environment.

- **Vision**: A seamless transportation system for people of all ages, incomes, and abilities that **supports a vibrant and sustainable community.**
- **Mission**: To move people and connect places with the best transportation choices and services.

PUBLIC TRANSIT & COVID-19

Despite the recent struggles of the Covid-19 pandemic, MCDOT's service has shown an upward trajectory of ridership since March 2020.

- FY 2020: Pre-COVID-19, average daily ridership on MCDOT's system was 80,000
- FY 2021: At the onset of COVID-19, this number dropped significantly to 53,000
- FY2022-2024: Daily ridership has since increased to 75,000 & most pre-COVID service has been restored

94% OF MCDOT'S BUS SERVICE HAS BEEN RESTORED COMPARED TO PRE-COVID LEVELS AS OF MARCH 2024 - Source: MCDOT, 2024

It is expected that ridership will continue to increase; for compatibility with the longrange planning undertaken by development of this ZEB transition plan, elements of the plan involving vehicle technology, transit service schedule & ridership use pre-Covid figures to ensure that the recent changes resulting from the pandemic do not impact the long-term success of the transition.

Figure 1-1: MCDOT Transit Service Plan

Figure 1-1 shows a map of Montgomery County Transit area with key landmarks, bus service plan areas

Regular Hours of Operation: 5:00 AM - midnight with some routes starting at 4:25 AM & ending at 2:00 AM. All routes operate during weekday rush hour with varying service levels & frequency. Weekend service is limited to 47 routes in operation on Saturdays & 37 routes in operation on Sundays.

- 5 BUS SERVICE PLAN AREAS
- 79 BUS ROUTES OPERATED OUT OF 3 BUS DEPOTS
- 13 WMATA METRO RAIL STATIONS
- 8 MARC COMMUTER RAIL STATIONS

MONTGOMERY COUNTY TRANSIT

Ride On

- Fixed-route service
- Started: 1975

Ride On extRa

- Limited-stop service on MD355
- Started: 2017

Flex

- On-demand microtransit service
- Started: 2019

FLASH

- Bus rapid transit service
- Started: 2020

PRIORITY AREAS

MCDOT and MCDGS recognize the importance of embracing sustainability in operations, with an emphasis on slowing or reversing climate change. Simultaneously with changes in the regulatory environment, MCDOT and MCDGS recognize that now is the right time to move forward with a transition to a zero-emission bus service to continue supporting County ridership. This commitment is in direct alignment with three critical priority areas:

- **Priority Area #1**: Safety & Vision Zero
- **Priority Area #2**: Environment & Climate Resiliency
- **Priority Area #3**: Economic Development & Equitable Access

Priority Area #1: Safety & Vision Zero

Safety is an integral part of Montgomery County's mission and is at the forefront of its everyday activities. MCDOT aims to create a safe environment for transportation of all modes for the residents of Montgomery County. MCDOT has an abundance of safety programs in place to support safe conditions. Vision Zero is an action plan that aims to eliminate all serious and fatal collisions for drivers, passengers, pedestrians, and bicyclists on county roadways by the year 2030 (Montgomery County, 2020). The action plan highlights safety initiatives with deadlines for implementation which drive the actions and decision making of Montgomery County to meet this goal of ending transportation-based fatalities.

SAFETY & VISION ZERO ZEB LINKAGE: Providing safe & sustainable non-auto travel options will support Vision Zero goals by helping to increase pedestrian safety & reduce collisions.

Priority Area #2: Environment & Climate Resiliency

In June 2021, Montgomery County finalized their Climate Action Plan (Montgomery County, 2021). This is an aggressive plan that outlines strategies and actions to reduce greenhouse gas emissions and adjust to the changing environment. MCDOT and MCDGS are supporting the efforts of the Climate Action Plan by pledging to a zero-emission bus service by the year 2035. MCDOT is committed to meeting this goal and linking efficient transportation systems with low environmental impacts. The County, through MCDGS' mission, is also committed to replacing its transit infrastructure with zero emission systems and designing and building net zero facilities, which will contribute to the environment and climate resiliency goals.

ENVIRONMENT & CLIMATE RESILIENCY ZEB LINKAGE: ZEBs do not emit greenhouse gases or particulate matter that combustion engine buses do. Transitioning to ZEBs will reduce carbon emissions and improve local air quality. Moreover, quieter operating ZEBs may contribute to reductions in transit associated noise levels.

Priority Area #3: Economic Development & Equitable Access

Montgomery County is the most populous county in Maryland and is located adjacent to Washington, D.C. As of the 2020 census, the county's population was 1,062,061, increasing by 9.3% from 2010. Jobs within the region will grow alongside the population creating opportunities for economic growth. The Montgomery County Planning Department forecast estimates the county will have an additional 143,000 jobs in 2050, up from 493,600 in 2020 to 636,500 in 2050, a 29% increase. Population forecasts jump 18% with 189,000 additional residents (up from 1.06 million to 1.25 million) in 2050. Additionally, an estimated increase of 88,000 households (up from 386,600 to 474,300) — a 23% increase — is forecasted during the same period. (Lee & Kraft, n.d.)

The MCDOT Fare Equity Study found that the average income of County transit riders in 2018 was $35,000, as compared to a median County income of $108,000. MCDOT understands the link between reliable and affordable transportation and the success of the region's economy, and strives to incorporate the needs of the community into decision-making to improve transit service and transportation access in the County with equity in mind. For the zero-emission transition, an important objective is to deploy the new, cleaner technologies across different parts of the County's transit service area focusing on equity emphasis areas (EEA) with lower income and historically disadvantaged communities. This will ensure that the needs of the growing population are considered to create the best services for the present community and that of the future.

ECONOMIC DEVELOPMENT & EQUITABLE ACCESS ZEB LINKAGE: Implementing ZEB service in disadvantaged communities reduces exposure for transitdependant populations to harmful emissions while also connecting these communities to jobs, services & businesses.

Service to Disadvantaged Communities

The Montgomery County community is made up of a blend of various income levels, races, education levels, religions, and ages. The disparities within the community make it vitally important for the County to emphasize equity in all decision-making to evoke a change. Montgomery County's Office of Racial Equity and Social Justice (ORESJ) was created in December 2019 with a mission to reduce and eliminate racial disparities and inequities across the county. As a County priority, the ORESJ brings issues related to race and equity to the forefront to promote transformational change. The County's ORESJ initiatives incorporate various programs, initiatives and guidelines as described below.

According to the Union of Concerned Scientists, low-income communities & communities of color often bear disproportionate burden of air pollution from transportation sources

GUIDING PRINCIPLES

- Provide an effective & efficient transportation system
- Provide & maintain a transit system that is reliable, safe & secure
- Engage, listen to & support our diverse communities
- Enhance the quality of life for everyone in our community
- Demonstrate leadership by being innovative & forward-thinking

The transition to ZEBs supports these principles because ZEBs are part of an innovative approach to public transit that offers safe, effective, and quiet rides that serve the diverse community of Montgomery County. ZEBs provide the same level of service to the community as diesel buses while also supporting a healthy environment. The transition to ZEBs is forward-thinking and moves Montgomery County toward sustainable technologies for the future.

Justice40

The Biden-Harris Administration named racial equity and addressing the climate crisis as immediate priorities and called on a whole-ofgovernment approach to address two of the most important and urgent challenges of our time. These issues are related and often intersecting. So, the Administration created the Justice40 Initiative which aims to deliver 40 percent of the overall benefits of federal investments in climate and clean energy, including sustainable transportation, to disadvantaged communities. MCDOT is committed to incorporating Justice40's guidelines into its ZEB transition plan by developing a framework centered on racial justice and equity in its investments.

Metropolitan Washington Council of Governments

The Metropolitan Washington Council of Governments (MWCOG) and Transportation Planning Board (TPB) have identified Equity Emphasis Areas (EEAs) to inform equitable future growth and investment decisions. These EEAs are made of areas with high concentrations of low-income individuals and/ or racial and ethnic minorities. MWCOG and the TPB use EEAs as selection criteria in their grant programs including alternative modes of travel.

As seen in Figure 1-2 the current Ride On routes serve multiple EEAs across Montgomery County. The three current bus maintenance facilities fall in or are adjacent to EEAs; the conversion of existing combustion engine operations to ZEB operations will directly benefit the communities in the vicinity of these facilities not only by providing increased access to public transit, but also by way of a reduction in noise and emissions.

Figure 1-2 shows a map of Ride On routes with areas of equity emphasis along areas adjacent to I-270 near Germanown, Gaithersburg, Aspen Hill, Wheaton and Silver Spring, as well as parts of Rockville.

USDOT Guidance

The USDOT defines an area as a "Area of Persistent Poverty" (APP) if:

- The County in which the project is located consistently had greater than or equal to 20 percent of the population living in poverty in all three of the following datasets: the 1990 and 2000 census and the 2020 Small Area Income Poverty Estimates
- The Census Tract in which the project is located has a poverty rate of at least 20 percent
- The project is in any territory or possession of the United States

The USDOT defines an area as a "Historically Disadvantaged Community" (HDC) if:

- The project is in certain qualifying census tracts
- The project is located on Tribal land
- The project is in any territory or possession of the United States

Based on the DOT Persistent Poverty Project (APP) and Historically Disadvantaged Community (HDC) Status Tool there are 45 census tracts within Montgomery County that qualify as historically disadvantaged communities and 6 tracts that qualify as both areas of persistent poverty and as historically disadvantaged communities

Residents of EEAs, APPs, and HDCs are generally among the most vulnerable populations. The residents of these communities often rely on public transit as their primary means of transportation. They are also more frequently exposed to harmful emissions and pollutants that result in negative health outcomes.

Implementing and prioritizing a ZEB service in disadvantaged communities is an exciting opportunity for MCDOT to contribute to local and regional equity.

CHAPTER 2 CLEAN TRANSIT REGULATIONS

Montgomery County has been a national leader in responding to the challenge of climate change and implementing clean transit regulations. In December 2017, the County adopted the Montgomery County Council Emergency Climate Mobilization Resolution 18-974 (Emergency Climate Mobilization, n.d.). This resolution set the objective to reduce greenhouse gas (GHG) emissions by 80 percent by 2027 and 100 percent by 2035. Resolution 18-974 aligns with MCDOT's goal to transition to a full ZEB fleet by 2035. Additionally, there are multiple Federal and State incentives and regulations that encourage MCDOT to make the transition to ZEB.

FTA Regulation

On December 1, 2021, the FTA announced the Zero-Emission Plan requirement as now part of the implementation of the Grants for Buses and Bus Facilities Competitive Program and the Low or No Emission Program (Administrator, n.d.). Under this mandate, any applications for projects related to zero-emission vehicles must include a ZeroEmission Transition Plan.

FTA ZEB TRANSITION PLAN REQUIREMENTS
This chapter is written in compliance with the following FTA requirement(s) for ZEB transition plans:
***Policy & legislation** — considers policy & legislation impacting relevant technologies*

State Legislation & Administrative Actions

Maryland

In 2020, the Governor of Maryland signed Maryland into the Multi-State Zero Emission Medium- and Heavy-Duty Vehicle Memorandum of Understanding (MOU, n.d.). This is a 15-state commitment to work together to phase out fossil fuel usage for electric medium- and heavy-duty vehicles, including large pickup trucks and vans, delivery trucks, box trucks, school and transit buses, and long-haul delivery trucks (big-rigs). The goal is to ensure that 100 percent of all new medium and heavy-duty vehicle sales be zero emission vehicles by 2050 with an interim target of 30 percent zero-emission vehicle sales by 2030.

Montgomery County's neighboring jurisdictions, Virginia and Washington D.C., are also signed into this Memorandum of Understanding.

Maryland is also a member of the United States Climate Alliance (Alliance, n.d.). This multistate partnership of governors pledges to reduce carbon emissions in line with the Paris Agreement. Specifically, each member state commits to "reducing collective net GHG emissions at least 26-28 percent by 2025 and 50-52 percent by 2030, both below 2005 levels, and collectively achieving overall net-zero GHG emissions as soon as practicable, and no later than 2050."

Other States

Eight states have currently enacted legislation or funding requirements mandating the conversion of public transit fleets to ZEB by 2040, as well as systemically banning the procurement of internal combustion engine (ICE) vehicles as early as 2023.

It has become important for transit agencies to understand ZEB technology, its specifics, the way it will affect existing transit bus operations, staff and key personnel requirements, and work on the solutions that could be implemented to keep the same efficiencies as using diesel buses in their current operating environment. Advancements in bus propulsion technologies continue to provide transit providers with a diverse range of green technology options that can provide future benefits.

Federal Policy & Regulations

At the forefront of Federal policy and legislative action is a focus on clean electric vehicles, reduced reliance on fossil fuels and external energy sources, and reduced carbon emissions. Desired objectives are being implemented through comprehensive federal legislation that has far-reaching impacts on all departments and levels of government. While many federal agencies play a role in supporting the legislative agenda enacted through law, the primary focus of sections below is on the FTA.

The State of Maryland has received $15 million from the Bipartisan Infrastructure Law to invest in zero emissions vehicle infrastructure. Source: Congressman Steny Hoyer (MD-5), January 2024

Bipartisan Infrastructure Law

The Bipartisan Infrastructure Law (BIL) was enacted as the Infrastructure Investment and Jobs Act (IIJA) on November 15, 2021. BIL makes the most transformative investment in electric vehicles and charging infrastructure in U.S. history, setting the country on a path to net-zero emissions by 2050. As part of a comprehensive investment package of $89.9 billion in guaranteed funding for public transit over the next five years, IIJA includes increased investment in zero-emission vehicles through grant programs, studies, fleet funding, and other measures. IIJA also continues FTA's preexisting Grants for Low or No (Low-No) Emission and Buses and Bus Facilities programs, with increased funding levels when compared to previous authorizations. The programs make funding available to states, designated recipients, and local governmental entities that operate fixed route bus service to replace, rehabilitate, and purchase buses and related equipment and to construct busrelated facilities including technological changes or innovations to modify low- or no-emission vehicles or facilities. Funding is provided through formula allocations and competitive grants. Two subprograms provide competitive grants for buses and bus facility projects, including one that supports low and zero-emission vehicles.

Inflation Reduction Act

On August 16, 2022, President Biden signed the Inflation Reduction Act (IRA) into law, marking one of the largest investments in the American economy, energy security, and climate that Congress has made in the nation's history. The Inflation Reduction Act provides billions of dollars in consumer incentives to put more clean vehicles on the road and commits to making more of those vehicles and their components in the United States. Funding highlights include tax credits for new and used electric vehicles (EVs), incentives for commercial EVs, and loans and grants to ramp up EV manufacturing.

CHAPTER 3 TRANSITION RISKS & MITIGATION STRATEGIES

The transition from conventional bus technology (diesel, CNG, and diesel-electric hybrid) to zero-emissions (battery-electric and hydrogen fuel cell) will introduce numerous layers of change and uncertainty that will impact several County departments at various levels. Change and uncertainty introduce risks. To assess risk in a structured environment and build mutual understanding from various perspectives, a risk assessment was facilitated in May 2023. This assessment included eight County stakeholder group interview sessions and a three-hour Risk Workshop.

The purpose of the County stakeholder interviews was to hear individual group perspectives on the major risks associated with the ZEB transition to guide the workshop discussions. These interviews were held with County key stakeholders involved in the purchase, operation, and maintenance of transit buses, support vehicles, infrastructure and facilities. The small group interviews allowed stakeholders to share more detailed feedback and discuss impacts in depth prior to the larger workshop. The workshop also allowed the team leading the development of the ZEB Transition Plan to generate awareness, engagement, and support in all areas impacted by the transition. From the stakeholder interviews, 11 total topic areas were identified, nine of which were the focus for the risk workshop. Many of the identified key risks are intricately linked; Figure 3-1 depicts the key risks and demonstrates their interrelatedness.

Twenty-one individuals from various County departments and offices participated in the Risk Workshop which focused on the above key topic areas. The purpose of the workshop was as follows:

- Present and examine the risks identified by stakeholders during the pre-workshop interviews
- Collectively identify risk severity, likelihood, and begin outlining potential mitigation strategies

Each workshop participant was asked to provide feedback on the severity, probability, and potential mitigations for each of the key risks. Figure 3-2 presents an overview of the key challenges and top potential mitigation strategies identified during the stakeholder interviews and risk workshop.

As the County continues to advance the ZEB transition plan and approach, the risk mitigation strategies will guide the project team and decision makers to timely, adequately, and accurately evaluate options and strategically make decisions in support of a successful transition to zero- emissions vehicles. The County is actively following ZEB implementations throughout the country and in the global market to learn from the varied successes and challenges brought on by the adoption of this new technology. County stakeholders are also regularly collaborating with other agencies and participating in industryrelated forums and working groups, such as those made available by the American Public Transit Association (APTA), in order to share their initial experiences with the implementation of ZEBs and benefit from those provided by their peers.

Figure 3-1: Key ZEB Transition Plan Risks

Cost/Time:

- Accelerated Transition Schedule
- Power Constraints & Utility Coordination
- Budget Constraints

Capacity:

- Depot Space/ Capacity
- Internal Staffing Constraints
- Internal Procedural Constraints

Technology:

- Changing Technology
- ZEB Safety
- Supply Chain Factors

Figure 3-2: Key Risks, Challenges & Potential Mitigations

COST/TIME:

Accelerated Transition Schedule

- ANTICIPATED CHALLENGES
    - Potential delay
    - Haste makes waste
    - Limited future flexibility
    - Thorough analysis
    - Emergency service
- MITIGATION STRATEGIES
    - Define & follow a planning process
    - Reassess the project schedule

Power Constraints & Utility Coordination

- ANTICIPATED CHALLENGES
    - Uncertainty of power needs
    - Lack of incentives
    - Infrastructure constraints
    - Evolving transition
    - Risk of P3 agreements
- MITIGATION STRATEGIES
    - Coordinate with Public Service Commission to develop working agreements
    - Provide utility companies with tax incentives

Budget Constraints

- ANTICIPATED CHALLENGES
  - Inflation
  - Budget uncertainty
  - Risk of P3 financingCapacity
  - Grant funding
  - Tax pressures
- MITIGATION STRATEGIES
  - Attain budget certainty for total program costs & yearly expenditure level
  - Identify & pursue early-investment opportunities

CAPACITY:

Depot Space/ Capacity

- ANTICIPATED CHALLENGES
  - Limited existing capacity
  - Expanded space requirements
  - Capacity uncertainty
  - Construction phase operations
  - Hydrogen generation
- MITIGATION STRATEGIES
  - Selecting a site & moving forward
  - Securing stakeholder agreement & political buy-in

Internal Staffing Constraints

- ANTICIPATED CHALLENGES
  - Attracting/retaining bus operators & mechanics
  - Increased management & administrative needs
  - Organizational capacity constraints
  - Safety protocols/training
  - Effective consultant support
- MITIGATION STRATEGIES
  - Create a dedicated ZEB transition team
  - Invest in ongoing training for internal & external staff

Internal Procedural Constraints

- ANTICIPATED CHALLENGES
  - Lengthy procurement process
  - Addressing resilience
  - Land acquisition
  - Developing better contracts
- MITIGATION STRATEGIES
  - Incorporate clear incentives & disincentives in ZEB-related contracts
  - Streamline internal processes by eliminating unnecessary steps

TECHNOLOGY:

Changing Technology

- ANTICIPATED CHALLENGES
    - Reliability & consistency
    - Reassessing transition period
    - Potential service changes
    - Technology maturity & obsolescence
    - Maintain cost
- MITIGATION STRATEGIES
    - Use standards & specifications
    - Partner with other agencies

Supply Chain Factors

- ANTICIPATED CHALLENGES
    - Delayed transition
    - Early transition
    - Purchasing power
    - High equipment demand
- MITIGATION STRATEGIES
    - No top strategies selected

ZEB Safety

- ANTICIPATED CHALLENGES
    - Fire safety
    - Insurance cost
    - Changing technology
    - Storage & disposal
    - Employee exposure
- MITIGATION STRATEGIES
    - Provide training
    - Prioritize fire protection

CHAPTER 4 ZERO EMISSION TECHNOLOGY

There are two main zero-emission vehicle technologies that are currently being widely adopted by fleet operators of conventionally-fueled buses, such as the County's transit system: Battery-Electric Buses (BEBs) and Fuel-Cell Electric Buses (FCEBs). While this plan focuses on BEBs and FCEBs as viable options for the transition, the County continues to closely monitor the ZEB industry for advancements that may provide advantages over the primary ZEB technology options currently available. Alternative technologies are also addressed at the end of this chapter.

BATTERY ELECTRIC BUSES TYPICAL CHARACTERISTICS

- On-board lithium-ion energy storage
- ~ 4 – 6 hour overnight charge required
- Requires ~ 1 charger for every 3 buses
- Operating range ~ 50% of conventional buses – Based on a single, full charge – can be extended with mid-day & onroute charging
- Range decreases in extreme weather

- Range decreases over life of bus/ batteries

FUEL CELL ELECTRIC BUSES TYPICAL CHARACTERISTICS

- On-board energy storage in the form of hydrogen gas & lithium-ion battery
- 10 – 15 minute refueling
- Infrastructure scales similar to conventional fueling
- Operating range ~85% of conventional buses – Based on single H2 fuel load – can be extended with mid-day refueling
- Range stability in extreme weather
- Operational flexibility – longer range & faster refueling

BATTERY ELECTRIC BUSES

Batteries & BEB Manufacturers

The technology and market products available in the BEB industry are rapidly changing. For the purposes of this transition plan and based on anticipated market products, this analysis assumes that the energy storage capacity, measured in kilowatt-hours (kWh), of new batteries for a 40' bus will be 660 kWh and have a usable service energy of 528 kWh (New Flyer, 2023). The level of usable service energy relative to the rated battery capacity is based on the top 10%, and bottom 10% of the battery's total energy considered unusable for service. This is controlled by the battery manufacturer and protects the batteries from extreme over- or under-charged conditions which accelerate degradation

Service energy for a degraded or "seasoned" battery is further reduced by 20% to 422 kWh, as shown in Figure 4-1, this is consistent with industry standards (V2G-Sim, n.d.). The actual degradation experienced in the field, and how long it takes to happen, is contingent upon multiple factors such as the average state-of-charge (SOC) maintained, number of recharging cycles, the typical depth of discharge of the battery, the speed of charging and discharging, and other factors. A typical seasoned battery faces a 20% performance reduction over 5 to 7 years.

Figure 4-1: Current & Future Battery Power
This figure shows a graph of battery capcities and energy output for new and degraded batteries for current and future technology batteries.

- *Current New Battery: 528 kWh*
- *Current Degraded Battery: 422 kWh*
- *Future New Battery: 640 kWh*
- *Future Degraded Battery: 512 kWh*

Additionally, battery capacities are expected to improve by at least 5% every year. With this assumption, 800 kWh batteries would be available within 10 years. The service energy of a new and degraded 800 kWh is 640 kWh and 512 kWh, respectively.

Average ranges of BEBs are an approximate number and are impacted by real world conditions including temperature, passenger load, route elevation, etc. Conventional diesel buses generally allow for about 300 miles on trips before needing to re-fill. Based on available BEB market products, BEBs are expected to travel approximately 150- 225 miles before requiring re-charging, depending on route conditions.

Bus manufacturers who may support the County's transition plan include Gillig and New Flyer. BEB market products are currently expected to require approximately 20 months from order to delivery, as evidenced by the 22-month lead time the County experienced for their most recent BEB order, though these durations would be affected by ongoing supply chain impacts, and changes in BEB demand. Figure 4-2 below lists BEB manufacturers.

Figure 4-2: Market Scan – Available BEB Manufacturers that meet FTA Buy America Requirements

This figure shows buses made by Gillig and New Flyer, as well as by ENC. But ENC is closing at the end of CY 2024. Gillig offer 40ft buses with rated battery capacities of 490, 588, up to 686 kWh. New Flyer offers 35 (350, 440 kWh), 40 (350, 440, 525 kWh) and 60 (525 kWh) ft buses.

Not listed here: Proterra's future participation in bus manufacturing may be impacted by sale/reorganization under bankruptcy. BYD is barred from any federally-funded procurement by the National Defense Authorization Act of 2021. Novabus is closing the Plattsburgh, NY assembly facility and is exiting U.S. bus production in 2025; buses will not meet Buy America requirements and will therefore be ineligible for FTA funding.

BEB Infrastructure

BEB Charging Manufacturers

There are a variety of manufacturers offering charging devices for BEBs and EVs. Charger and bus manufactures follow the SAE J-1772 and SAE J-3105 standardizations (Electric Power Research Institue, 2020), which allows for universality amongst chargers and ZEBs in the marketplace. Typically, chargers are grouped into two types: plug-in cable chargers (as shown in the image to the top right) and overhead pantograph chargers (as shown in the image to the bottom right). Chargers come with varying maximum power outputs, with lower power chargers typically being used during night-time charging and higher-powered chargers being used during daytime or on-route charging to allow for faster charges. Chargers may also be able to support multiple dispensers, meaning several buses can be connected to a single charger, although the charging power must be split amongst the connected buses or dedicated to one bus at a time, sequentially; this approach is currently being utilized with the BEB infrastructure installed by the County. Figure 4-3 to the right gives an overview of some current charging manufacturers and their products. Typical overnight charging rates range from 75kW to 150kW. Typical mid-day quick chargers can support charging rates up to 450kW, but450kW but require overhead pantographs.

Implementation of BEB Charging Technology

The County is implementing both types of chargers (plug-in and pantograph) with their current BEB charging infrastructure.It should also be noted that "wireless" inductive charging technology is also available for transit buses and heavy-duty vehicles, however the development of industry standards and adoption of such technology is significantly behind that of plug-in and pantograph charging systems. The County continues to monitor advancement and availability of inductive charging solutions for consideration in future updates to this plan.

Figure 4-3: Market Scan – Examples of EV & BEB Chargers

A table with the following columns: Manufacturer – Model – Maximum Power – Mounting Style – Notes

On-Route Charging or Layover Charging

The County is not precluding the possibility of implementing on-route charging to supplement electric charging equipment at its maintenance facilities. On-route charging can help maintain appropriate state-of-charge on BEBs while carrying out revenue operations, as well as assist in spreading the power demand of the bus fleet away from maintenance facilities, thereby reducing the total power demand per facility.

On-route charging infrastructure generally includes pantographs, charging cabinets, gantries to support pantographs, and similar improvements. Best practices related to installation of on-route charging include choosing locations with space owned or managed by the County (or partner agencies, such as WMATA or local jurisdictions) and generally away from the street (such as transit centers or terminals), where operators currently have layovers. This provides time for charging that is already built into the current operating plan, minimizing impacts to route operations. While the County is not currently planning to deploy on-route chargers to support the transit fleet, a best practice would be to choose locations along routes that are unlikely to change from network redesigns, such as established bus rapid transit (BRT) services, to avoid the high cost of relocating on-route charging infrastructure once installed.

A few critical considerations as to why the County is not pursuing on-route chargers:

- Locations of on-route chargers would be dispersed throughout the County's service area and away from operating and maintenance facilities; they may be more difficult to access when problems occur, and availability of renewable power sources may be limited.
- Optimal location of on-route chargers may not be on County-owned property; development challenges include permitting and land/rightof-way acquisition.
- On-route chargers are typically aboveground structures that utilize the overhead pantograph-type connection to the vehicle; residents may consider the industrial aesthetic to be an eyesore.
- On-route chargers are typically used to support a larger number of buses than depot chargers (e.g., 1 charger for 10 buses vs. 1 charger for 3 buses), therefore there is a greater risk of a significant service disruption.
- On-route chargers operate at higher power levels because buses typically have a shorter amount of time to charge while in service; higher charging power levels can lead to faster degradation of bus batteries over time.

Service Planning Software

While there is a wide variety of companies that offer fleet management and scheduling software, the need for electric buses requires different considerations compared to conventional vehicles. The conditions of the route and weather can influence the range and capabilities of electric buses greatly, and such factors must be considered in the scheduling process. Additionally, the longer refueling time of electric buses can also be a factor that disrupts the scheduling of ZEBs and this needs to be accounted for. Thus, current service blocking must be revisited and reviewed during the transition to ZEBs to account for the operational challenges brought by ZEBs.

Considering these variables, a few companies are already offering scheduling software specifically built to handle the charging demands of BEBs.

Clever Devices, HASTUS, and Optibus were identified as examples of providers with mature scheduling software products available, specifically for the deployment of ZEBs. This scheduling software can be used to assist in the process of reviewing and adjusting the current service blocking to accommodate ZEBs, and their unique functionalities can be seen in Figure 4-4.

Figure 4-4: Market Scan — ZEB Schedule Software Examples

CLEVER DEVICES

- Offers a purpose-built electric vehicle fleet management program that uses real variables such as temperature & topography to predict consumption rates
- Software claims to be able to use these constraints as well as fleet information to create a schedule

- Information gathered by buses on route can be used to tailor energy predictions based on variables like traffic patterns & passenger loading, further improving accuracy of predicted energy consumption

HASTUS

- A software developed by GIRO, offers electric bus specific scheduling capabilities
- GIRO claims that HASTUS allows the user to explore different scenarios, like different electric bus types, charging stations, weather, route topology & operating conditions
- Can also optimize schedule based on charging times, charging locations & vehicle range
- Can handle mixed-fleet scheduling, including those using multiple recharging technologies; charging station capacity management; visual tracking of state-of-charge; & depot parking & charging processes

OPTIBUS

- Offers scheduling & planning software for electric buses as well
- Allows user to set rules & preferences related to battery use & charging requirements; based on these preferences, Optibus then generates an operational schedule including optimal charging times & locations
- Can integrate received BEB performance & iterate the schedules for further optimization

BEB Warranties

The cost of purchasing and maintaining BEBs will also be affected if battery warranties are purchased. Typical, base warranty coverage for BEB batteries are 6 years/300,000 miles, with extended warranty coverage options out to 12 years/600,000 miles; following the manufacturer's prescribed maintenance schedule is required regardless of whether or not extended warranties are purchased. Factors such as the average SOC can affect the longevity of a battery's life. Therefore, the operations and standards used by transit agencies can affect battery life, and the life span of two batteries of the same type may not be the same, depending on how the buses are operated.

Batteries are one of the most expensive components of a BEB. Although battery cost per kWh has been substantially reduced in the automotive industry from around $591 per kWh in 2015 to an average between $100 and $160 per kWh today, prices for transit bus batteries remain high due to market factors and a decrease in the average cost of a BEB has not yet been realized. BEB prices remain in the $1.2 million range per bus. Likewise, the battery warranty offered by the manufacturer remains high, averaging between $29,540 and $39,880 per bus. As a result, the County will need to determine whether battery warranties are appropriate for its transition plan and revise its capital and operating costs accordingly. Including extended battery warranty options in the procurement of ZEBs may offer a financial benefit to the County, particularly if a portion of the increased cost can be covered by available grant funding.

Battery Leasing

Battery leasing is a financing solution that can provide the following benefits:

- Closer price parity with diesel vehicle upfront costs
- A faster full conversion to an electric vehicle fleet
- Savings from lower fuel and maintenance costs

Realizing these benefits can offset the battery lease payments altogether. However, the market for battery leasing is limited to vendors that own their batteries. This presents a significant barrier given that battery ownership is not common for most BEB Original Equipment Manufacturers (OEMs).

End-of-Life Options

With the coming transition to electric bus fleet operations, transit agencies can expect to encounter new challenges and opportunities involving the management of EV batteries beyond their useful life. This is not a situation that agencies will face alone as, following the exponential growth of worldwide EV sales, the global automotive, battery manufacturing, and recycling industries are bracing for an inundation of used EV batteries. For perspective, in 2018 there were approximately 55,000 used EV battery packs entering the “waste stream.” Seven years later, in 2025 the stockpile of used EV batteries is expected to have grown to more than 3.5 million packs – increasing by a factor of around 70 (Stringer & Ma, 2018). Given that lithium-based EV batteries are considered hazardous material, this projection highlights the need for rapid advancements in the development of responsible, sustainable, and economical strategies for managing retired EV batteries entering the waste stream.

While technology matures and the market is responding to the worldwide increase in EV batteries, the County will continue to evaluate the most economical and environmentally-friendly alternatives for addressing the fleet’s end-of-life batteries. The main bus chassis itself would be sold per the County’s existing end-of-life residual value recuperating policies. Current options include:

Repurposing: Although used battery packs having approximately 60-70% of their original capacity no longer meet transit operating requirements, batteries in this condition can be repurposed for second-life applications. Rapid growth in the second-life battery marketplace is expected, both in direct sales and applied solutions. One such company who appears to be ahead of the curve is B2U Storage Solutions based in Santa Monica, CA. B2U has been operating a renewable grid storage system in Lancaster, CA since May 2020 that has reached a current storage capacity of 25 MWh made from 1,300 EV battery packs (About B2U, 2023).

Recycling: There are a few processes being developed for recovering many of the expensive or rarer components in degraded batteries which can then be used to manufacture new batteries such as pyrometallurgy (metal extraction with heat) and hydrometallurgy (metal extraction with liquids). Processes like these can create a closed loop system where batteries can be recycled and reused repeatedly at a fraction of the cost to produce new batteries. One battery recycling company, Li-Cycle, was able to successfully recycle 95% of materials from lithium-ion batteries provided by New Flyer with their Spoke & Hub technology (New FLyer: Press Releases, 2021). Thus, recycling processes and technologies can be thought of as a cost saving measure for battery replacements or newly manufactured batteries.

Disposal: From a sustainability perspective, disposal is the least desirable option for retired EV batteries. Although raw materials used in current EV battery chemistries are not typically toxic to the environment (there are exceptions), many are considered critical materials; disposal by landfill or incineration would make these materials unrecoverable. According to the EPA, critical materials are raw materials that are economically and strategically important to the U.S., have a high risk of their supply being disrupted, and for which there are no easy substitutes. In EV batteries these critical materials include cobalt, graphite, and lithium. With advances in recycling processes and second-life battery applications, even batteries that are removed through a “disposal” service are expected to be either recycled or repurposed due to the high residual value and remaining energy capacity of EV batteries.

FUEL CELL ELECTRIC BUSES

Fuel Cells & FCEB Manufacturers

Hydrogen fuel cell electric buses (FCEBs) are also ZEBs that use electric motors to move the vehicle, however, FCEBs store their energy in the form of hydrogen gas. Electricity is generated when hydrogen gas and oxygen combine in the fuel cell, with water and heat as the byproducts of this reaction. This process happens in the fuel cell which converts chemical energy into electrical energy. Fuel cell buses store gaseous hydrogen in onboard tanks up to a pressure of 350 bar (5,076 psig). The system can operate at a pressure as low as 6-9 bar, allowing the total stored hydrogen to be depleted down to about 4%

The ranges of FCEBs are much more stable and less influenced by factors like temperature when compared to BEBs, as fuel cell performance does not degrade at low temperatures. Additionally, hydrogen storage of a standard bus can store more usable energy compared to a battery electric bus of the same class and size. Finally, FCEBs contain lithium-ion batteries as well. The battery is smaller than the one on a battery electric bus. This battery is typically charged through braking of the vehicle, running downhill, and by the fuel cell as controlled by an energy control system on the bus. The battery is mostly used for acceleration of the vehicle and in cases of insufficient energy from the fuel cells, such as when running uphill with a full passenger load. The power rating, sizing, and pairing of FCEB batteries and fuel cells is critical to ensure that performance of the vehicle is appropriate for the service conditions. FCEBs can have a range of up to 300 miles before needing to refuel, comparable to conventional diesel buses (New Flyer, n.d.). FCEBs currently available in the domestic marketplace are listed in Figure 4-5.

Figure 4-5: Available FCEB Manufacturers

A chart showing MANUFACTURER & MODEL - LENGTH (FT) - FUEL CAPACITIES (kg) - EQUIVALENT BATTERY ENERGY(kWh):

- ENC* Axess EVO-FC –
  - 40ft - 57.5kg – 920 kWh
- New Flyer Xcelsior Charge FC -
  - 40 ft - 37.5kg- 734 kWh
  - 60 ft - 56kg - 1030 kWh

** The REV Group, Inc. (parent company of ENC) recently announced the closure of the ENC business by the end of CY2024 due to supply chain challenges and related impacts to the transit bus business.*

FCEB Infrastructure

Hydrogen Suppliers

As the County incorporates FCEBs into their ZEB fleet, hydrogen will be needed to support these vehicles. The most efficient bulk delivery method for hydrogen is in form of cryogenic liquid, although it may be delivered at high pressure gaseous form as well. Currently, hydrogen suppliers are limited in North America. Nearly all the hydrogen currently produced in the U.S. comes from steam-methane reformation (SMR). Commercial hydrogen producers and petroleum refineries use steam-methane reforming to separate hydrogen atoms from the carbon atoms in methane (CH4). The primary feed stock is natural gas as a source for hydrogen production. Landfill gas, biofuels, and petroleum fuels are also potential feed stocks for hydrogen production. Electrolysis is a process that splits hydrogen from water using an electric current producing only hydrogen and oxygen. Electricity is supplied from the grid through a mix of renewable sources such as solar PV arrays and wind power, nuclear energy, fossil fuels, local electricity generation, or other sources.

Recently, through the "Jobs Act", Congress allocated $8 billion for the creation of hydrogen hubs (Resources for the Future, 2023). Following a Request for Information in Spring 2022 to solicit public input, the Department of Energy solicited applications for H2Hubs via a Funding Opportunity Announcement (FOA) in September 2022, and conducted merit reviews of eligible project submissions in 2023. Of the 22 different hydrogen hub applications submitted only seven were selected for award negotiations (Figure 4-6) and, unfortunately, the proposed Mid-Atlantic Hydrogen Hub (MAHH) that the County participated in was not among those selected. Two nearby projects that were selected include the Appalachian Regional Clean Hydrogen Hub (ARCH2), spanning West Virginia, Pennsylvania, and Ohio, and the MidAtlantic Clean Hydrogen Hub (MACH2), spanning Pennsylvania, Delaware, and New Jersey. It should be noted that both of these nearby hubs were proposed as low-carbon intensity hydrogen projects and not "green" hydrogen. A green hydrogen facility recently opened by Plug Power in Woodbine, Georgia and is currently the largest of such plants operating in the United States. The County will continue looking for opportunities to advance its hydrogen initiatives.

Figure 4-6: Selected Regional Clean Hydrogen Hubs (Energy D. o., n.d.)

A map of the US showing Hydrogen Hubs and proposed H2 Facilities. Including Pacfic Northwest Hydrogen Hub, Caliornia Hydrogen Hub, Heartland Hydrogen Hub, Gulf Cost Hydrogen Hub, Midwest Hydrogen Hub, Appalachian Hydrogen Hub and the Mid-Atlantic Hydrogen Hub.

Options of Hydrogen Fueling Infrastructure

Multiple options are available to implement a hydrogen facility to fuel FCEBs. The hydrogen commodity may be trucked-in and delivered to the site in either gas or liquid forms. This requires tanks to store the hydrogen. Alternatively, hydrogen may be generated directly on-site, in a similar way to how the County is implementing their first hydrogen project. Currently, commercially available technologies for on-site generation include Electrolysis and Steam Methane Reform (SMR) systems. Both options have varying environmental impact potential depending on the type of power source and feed stock required for hydrogen production.

The electrolysis process uses electricity to separate water into hydrogen and oxygen gas; when the electricity required for this process is sourced from renewable sources, the most environmentally-friendly hydrogen is produced. This is known as "green" hydrogen. Conversely, the SMR process requires the use of methane gas as a feed stock (often sourced from fossil fuels) and is less environmentally friendly.

For transit FCEB facilities that are unable to produce their own hydrogen on-site, a different type of process equipment would be needed depending on the hydrogen delivery method used to support the fleet. Liquid delivery is more efficient and less expensive than gas delivery. Delivered gaseous hydrogen costs about three times more than delivered liquid hydrogen. The capital cost of implementation as well as required space for an equipment yard for a truck-in facility is significantly less than those of on-site generation. Maintenance of this type of facility is simpler than on-site generation methods. Its power demand is significantly less than that of electrolysis and slightly less than SMR systems. However, the commodity price is significantly higher in comparison with the operating cost of on-site generation. In the future, hydrogen gas delivered via pipeline directly to end-users is expected to be available although timeframes are speculative, at best. Based on future availability, pipeline hydrogen will require dedicated analysis of cost and environmental impact if considered by the County as an option to support zero-emissions buses.

In the future, expansion and advancement of hydrogen generation nationwide is expected to decrease the commodity price gradually, however operating fuel cost is expected to always be higher than the cost of charging BEBs, although the Total Cost of Ownership (TCO) of FCEBs may not always be higher. Governments and agencies that anticipate needing a substantial amount of hydrogen to operate a zero-emission fleet, such as Montgomery County and MCDOT, might need to evaluate the feasibility of buying hydrogen from a third party producer and having it delivered to their depots as an interim option as soon as hydrogen supply is more readily available. The County is mindful of the fact that, currently, vehicles used to deliver hydrogen may not be zero emissions and therefore this adds a component of indirect emissions to the hydrogen supply chain. Due to limited product availability, however, this could be a viable interim solution while the technology evolves and is available for all, and until the transition to zero emissions is complete.

Repair Depot Modifications for FCEBs

An operating and maintenance depot for hydrogenfueled buses needs to be modified per Fire Code and NFPA requirements to stay safe. This is to detect any leakage and immediately perform a specified sequence of operation to ensure the safety of the depot and its personnel.

A repair depot of vehicles fueled with lighter-thanair gas like hydrogen, needs to be equipped with a detection system including hydrogen sensors, audible and visible annunciators, and a control system to run the sequence of operation. The detection system will include a set of relays to control HVAC, annunciators, staff messaging, roll-up doors, and some circuit brakers as needed. The depot ventilators' air intake should be near the highest point of the ceiling. The HVAC fans should be explosion proof and spark resistant. The County is implementing its first hydrogen project at the EMTOC Bus Depot. This facility, and any future hydrogen facilities, will comply with these requirements.

FCEB Warranties

Warranties will vary by manufacturer, but 6-year warranty on the fuel cells can be expected, with 10- 12 year warranties on the batteries.

Technology Comparison

There are a significant number of factors that must be taken into consideration during the selection of a zero-emission bus technology for a transit agency. A summary of the most important factors is provide in Figure 4-7. Ultimately, more than one type of technology may be appropriate to serve an agency's needs and the deciding factor(s) will likely be focused on cost (capital and operating) or addressing the specific constraints and challenges associated with each agency's unique operation.

This is the case for MCDOT. Many of the factors associated with each zero-emission technology are interrelated, which requires that an agency takes a holistic approach to technology selection. For example, although the cost of a BEB is currently less than a FCEB, the operating range and quick refueling time of FCEBs provides greater service flexibility and operating characteristics more like that of conventionally fueled buses. As a result, an agency transitioning to BEBs can expect the need to increase their fleet size in order to provide the same level of service as their current conventional bus fleet. Alternatively, energy recovery strategies such as the implementation of on-route chargers can be utilized to offset the limited operating range of BEBs, however, this adds cost to the total operation and introduces new constraints such as a potential loss in service flexibility (buses must periodically return to the on-route charging sites) and the requirement of maintaining charging infrastructure that is deployed throughout the service area. This is just one example of the various pros and cons of the different zero-emission technologies, and the County has remained acutely aware of these factors since the introduction of ZEBs and throughout the development of this transition plan.

Figure 4-7: BEB vs. FCEB Summary (Data based on 2024 information)

This figure is a chart with columns for Category/40-ft BEB/40-ft BCEB

Range:

- BEB: 150-225 miles
- BCEB: 200-300 miles

Vehicle Cost

- BEB: $1.2 million
- BCEB: $1.5 million

Fleet Size

- BEB: Typically requires more buses to accomplish same level of service as FCEB fleet
- BCEB: Can accomplish a similar level of service as same size diesel fleet

Energy/Fuel Cost

- BEB: Will fluctuate depending on utility rates
- BCEB: High cost now, expected to decrease over time

Infrastructure Cost

- BEB: More linear capital cost as fleet size increases from small fleet; larger fleets will require large capital cost for infrastructure
- BCEB: High upfront cost, more cost effective for larger fleets resulting in less capital cost per bus

Safety

- BEB: Highest risk during charging; Li-ion battery fires are self-oxidizing & typical fire suppression tactics are ineffective
- BCEB: Highest risk during refueling; explosions are possible (also has Li-ion batteries but much smaller than BEBs)

Energy/Fuel Availability

- BEB: Grids may struggle to supply demand
- BCEB: Hydrogen may not be readily available

Charging/ Refueling

- BEB: 3-6+ hours (depends on charging rate/battery capacity & SOC)
- BCEB: ~10-15 minutes

High-Mileage Capability

- BEB: On-route charging allows increased range but is costly & provides limited operating flexibility
- BCEB: Fast refueling time & high energy capacity results in significant highmileage capability

Maintenance Facilities

- BEB: High-voltage systems require maintenance facility upgrades
- BCEB: CNG facilities are similar to hydrogen & won't require as many upgrades

Resiliency

- BEB: Off-grid power to charge a fleet is difficult
- BCEB: Backup power to run a fueling station is much easier

Technology Benefits

Transitioning to zero-emission technology has numerous potential benefits to the region as described in Figure 4-8. MCDOT and MCDGS are committed to actualizing these potential regional benefits to the greatest extent possible.

Figure 4-8: Zero-Emission Vehicle Benefits

- Economic Competitiveness » Reduce operational costs through savings from lower fuel & maintenance costs » Advance potential workforce development
- Environmental » Avoid carbon & nitrogen oxide emissions
- Health » Reduce noise levels » Decrease potential respiratory issues like asthma & allergies, & other air quality-related health risks
- Equity » Offers flexibility to support County goals by deploying ZEBs in disadvantaged areas » Support sustainable transit system's growth to improve connectivity
- Security » Create more resilient operations due to less outside energy dependency
- Other » Optimize energy consumption through regenerative braking buses » Improve vehicle acceleration » Enhance customer experience

Alternative Technologies

Alternative types of zero-emission buses include trackless trolley buses, which require a fixed, electrified overhead wire infrastructure for operation, and ultra or super-capacitor powered electric buses which have a very short operating range and require wide deployment of on-route charging infrastructure. This type of technology has a significant impact on the aesthetics of the communities they are installed in due to the necessary network of overhead cables to power them. Deployment of trackless trolley buses or super-capacitor powered zero-emissions solutions

is feasible; however, domestic bus builders have very limited options available with either technology and the main drawback for both alternatives is the lack of operating flexibility with regard to service routes.

Renewable Natural Gas

Although not a 100% zero-emissions technology, the County is incorporating the use of Renewable Natural Gas (RNG) in its transition plan as it provides incremental, environmental benefits for the County while new zero-emission vehicles and equipment are being implemented. RNG will be produced by WSSC Water at the Piscataway Water Resource Recovery Facility in Accokeek, MD (pictured above), and provided to the County under a five-year agreement beginning in late 2024. Also known as the Piscataway Bioenergy Project, the new $271 million facility will utilize innovative technology to break down the nutrient-rich, organic biosolids "waste" generated by the water treatment process into methane gas, which will replace the fossil fuel-based natural gas the County currently receives from the local utility company, Washington Gas.

The environmental benefit of using RNG results from the lower carbon intensity of the natural gas production process, of which the County currently estimates will be ~50% lower than the CNG they currently use to operate a portion of the fleet. Applied to its current fleet of 94 CNG buses, the use of RNG will reduce the County's annual emissions by approximately 4,600 megatons of CO2e (carbon dioxide equivalent). Although this decrease in annual emissions represents a substantial environmental benefit, it is important to note that the reduction is the result of RNG having lower indirect emissions than its fossil fuel-based counterpart; the direct emissions from the County's CNG fleet's tailpipes will be unchanged. Regardless, the benefit of using RNG is significant for the region and can only be realized through the active demand for and utilization of more sustainable fuel products.

CHAPTER 5 - CURRENT FLEET & PLANNED ACQUISITIONS

Current Bus Fleet

Currently, the County owns and operates nearly 400 buses. Figure 5-1 provides a detailed breakdown of MCDOT's existing bus fleet. The current bus fleet is made up of a combination of diesel, hybrid, CNG, and electric buses. The county owns 100 40-foot diesel buses, 53 40-foot hybrid buses, 94 40-foot CNG buses, 105 29-foot diesel buses, four 35-foot electric buses, ten 40-foot electric buses, 16 62-foot BRT diesel buses, and seven 25-foot on demand vehicles. MCDOT's fleet has an assorted mix of model years, dating as far back as 2008, with Gillig as the majority fleet manufacturer.

Figure 5-1: MCDOT Bus Fleet Composition

Figure 5-1 shows the current MCDOT bus fleet of almost 400 vehicles

Planned Acquisitions

2025-2027 BEB RFP

The County is actively engaged with Gillig for the procurement of up to 100 40' BEBs with deliveries scheduled for 2025-2027. The first Purchase Order released under the current contract was for 31 buses. Delivery quantities for 2026 and 2027 are assumed to be 31 and 30, respectively. This large acquisition of BEBs via the multi-year contract with Gillig, when combined with the current BEB fleet operated by the County, will maximize the utilization of the County's microgrid projects at the Brookville Smart Energy depot (completed October 2022) and EMTOC depot (scheduled completion in 2025). Additional details regarding the County's BEB infrastructure and charging capacity are provided in Chapter 7 and Chapter 9, respectively.

2025 Hydrogen FCEB Program (FY22 FTA Grant)

MCDOT and MCDGS are advancing the addition of hydrogen fuel cell buses to the County's fleet as another technology option along with BEBs. MCDOT is planning on procuring their initial 13 40' FCEBs via a state buy board, joint procurement consortium. These first FCEBs will be operated at the EMTOC bus facility and in coordination with the EMTOC microgrid and hydrogen generation, storage, and fueling projects described in Chapter 7. This FCEB fleet and associated infrastructure project at EMTOC demonstrates the County's commitment to achieving a clean, sustainable future and represents one of the most significant investments to-date in green hydrogen made by a transit agency nationwide. The longer operating range and faster refueling time of FCEBs will allow the County to operate ZEB service on some of the most demanding service blocks. The experience gained with this initial group of FCEBs will provide critical insight for future updates to this transition plan.

CHAPTER 6 - FACILITIES & INFRASTRUCTURE PLANS

MCDOT currently has three facilities to operate and maintain the fleet: Brookville Smart Energy Depot, the David F. Bone Equipment Maintenance and Transit Operating Center (EMTOC), and Nicholson Court Depot. Brookville Smart Energy Depot supports diesel, hybrid, and electric buses with a capacity of 140 buses. EMTOC currently supports diesel and CNG buses and holds a capacity of 200 buses. EMTOC will require upgrades to support the transition of the bus fleet. Nicholson Court Depot has a capacity of 67 buses and can support diesel fueled buses. A summary of the current conditions of the facilities are presented in Figure 6-1.

FTA ZEB TRANSITION PLAN REQUIREMENTS
This chapter is written in compliance with the following FTA requirement(s) for ZEB transition plans:

- *Facilities evaluations — includes an evaluation of existing & future facilities*
- *Utilities & fuel — describes the County's partnerships with utilities & fuel providers*

Figure 6-1: Existing Bus Facilities Summary

Fig 6-1 shows three existing facilities for buses, described in detail below.

CURRENT FACILITIES

Facility modifications are essential to the transition to ZEB. This includes the eventual decommissioning of conventional fleet fueling equipment, enhancements to and expansions of electrical equipment, additional electrical supply, and the installation of BEB chargers, dispensers, fire suppression enhancements and other components, as well as any other infrastructure and equipment that might be necessary to support hydrogen fuel cell buses. The County has been performing extensive analysis on transition requirements of their bus facilities and has made significant initial investments in ZEB infrastructure that provide both reliable and sustainable power sources.

Brookville Smart Energy Depot

MCDOT's Brookville Smart Energy Depot is located in Silver Spring, Maryland. The depot is used as

a service, storage, and maintenance facility for vehicles in the County's bus fleet. Through a Public-Private Partnership (P3) contract, MCDOT and MCDGS partnered with AlphaStruxure to design, build, own, operate and maintain the depot energy systems. This business model, also known as Energy as a Service (EaaS), delivers long-term cost certainty, sustainability, reliability, and resilience backed by a performance-based energy service agreement. In September 2021, Montgomery County broke ground on their bus electrification program. The Brookville Smart Energy Depot includes a clean, solar energy microgrid as the power source for its growing electric bus fleet. A microgrid is an independent energy system that can operate separately from the utility-owned power grid. The Brookville microgrid has the capacity to support 71 battery-electric buses while operating in island mode, meaning without any reliance on power supplied by the utility provider. There is a grid connection to the depot that will enable electrification of additional BEBs, however, in the event of a utility grid disruption, resiliency will be limited to operating on an 'S' service schedule. 'S' service is an emergency schedule used when severe snow, storms, or other special circumstances occur that affect the transit fleet's ability to follow normal weekday schedules. The Brookville microgrid was designed to support this emergency operation. As the number of battery electric buses at the Brookville Depot increases, additional chargers will be installed as space allows and the remaining required electrical service will be provided by Pepco. The microgrid will always serve the load requirement during an emergency. The upgrade of the Brookville Smart Energy Bus Depot was completed in the fall of 2022. Key elements of the microgrid include:

- 2 megawatts (MW) of solar photovoltaic canopies that will provide electrical power to the buses and to the battery storage systems
- 4.3-megawatt hours (MWH) battery storage
- 2 MW of natural gas generation

- Microgrid controllers

The facility upgrades currently service the four electric buses that were added to the fleet in September 2020 (previously reliant on portable 50 kW chargers), and 10 new Gillig BEBs that entered service in 2023. The completion of the Brookville Smart Energy Bus Depot is a landmark achievement in support of the County's goal of operating a 100% zero-emission fleet by 2035. The upgrades provide the following benefits:

- Bus electrification
- Environmental sustainability (cut carbon emissions by 62%)
- Climate resilience and operational reliability
- Flexible fleet operations
- Economic development (the creation of more than 50 construction jobs)

Figure 6-2: Microgrid Controllers Site Plan – Equipment Layout

Fig 6-2 shows a map of the Brookeville facility with the placement of solar panels, electric bus chargers, battery storage and natural gas generators.

David F. Bone Equipment Maintenance & Transit Operations Center (EMTOC)

Through a federal RAISE grant, Montgomery County is currently implementing a project that will expand on the success of the Brookville Smart Energy Depot by adding a similar, integrated microgrid and bus charging project at the David F. Bone Equipment Maintenance and Transit Operations Center (EMTOC) in Gaithersburg. This project will support the charging capacity of up to 35 battery-electric buses as well as provide clean, renewable energy to support the production of green hydrogen that will power up to 20 FCEBs. The project will include the installation of: (1) approximately 5 megawatts (MW) of solar photovoltaics (PV); (2) approximately 1.5 MW of battery backup storage; (2) up to ten (10) 180 kW vehicle chargers and one (1) 450 kW vehicle charger to support up to 35 battery-electric buses; and (4) tie in two (2) existing backup natural gas generators that support existing CNG operations. The microgrid is designed to be expandable to support additional charging of BEBs or expansion of green hydrogen generation in the future.

EMTOC MICROGRID

Montgomery County is in the process of implementing the first green hydrogen transit application on the East Coast at the EMTOC facility. The new hydrogen fuel production and fueling station, powered by the EMTOC microgrid, will support the county's first 13 hydrogen FCEBs. Hydrogen buses will allow for coverage of longer bus routes as compared to current BEB technology, making this a critical step in the County's transition to zero-emissions.

The hydrogen generated at this site will be greener than traditional fossil fuel-based hydrogen production since it will be produced from water using electrolysis. Currently in the infrastructure planning and design phase, the County expects to begin operation of the fueling station and FCEBs in Q3 2025.

Nicholson Court Depot

The Nicholson Court Depot is in the White Flint area, and it is not a County owned facility. The current lease for this facility expires in 2027, however due to the expected timeframe required to open a new zero-emission bus facility, the lease for Nicholson Court might need to be renewed through 2030 in order to maintain the operating fleet. Since this is a leased facility and due to the significant investment associated with any zero emission infrastructure upgrades, the County is not planning to transition the Nicholson Court Depot to a zero- emissions facility. This represents a transitional constraint. However, in coordination with the introduction of the future new bus facility and based on the age of the vehicles at this location, it is anticipated that this constraint, by itself, will not prevent MCDOT from meeting the *Climate Action Plan* transition goal by 2035. For the foreseeable future, this depot will continue to operate diesel buses.

UTILITY PROVIDERS

The Potomac Electric Power Company (Pepco) is the power utility provider for Washington, DC and neighboring Maryland communities, including Montgomery County.

While the County's partner, AlphaStruxure, delivered the Brookville Smart Energy Bus Depot integrated microgrid and is currently advancing the EMTOC microgrid, Pepco has provided critical support. The Brookville microgrids' lithium-ion battery system is participating in Pepco's Demand Response Program that will support regional grid performance and optimization for greater energy resilience overall. The County proactively reviews all zero-emission infrastructure and technology options available in the market for the supply and demand of power, to ensure a best-value approach is provided for its riders and residents.

The County recognizes that the transitioning of vehicle fleets to zero emissions across the nation is creating rapid changes in market demand and significant challenges for utility companies. To mitigate these challenges, the County is committed to continuing their successful partnership with Pepco, Washington Gas, WSSC Water, and other local utilities through active communication and planning.

CHAPTER 7 - SERVICE PLAN & ENERGY NEEDS

PEER Analysis Overview

MCDOT and MCDGS partnered with STV Incorporated to perform a detailed route energy modeling assessment using STV's proprietary PEER Analysis tool as a critical preliminary step in successful transition planning. PEER (Performance and Evaluation of Electric bus Routes) is a simulation model designed to predict a ZEB's energy consumption as it travels along a specified route under specified loading and weather conditions. The PEER analysis includes an evaluation of a ZEB's expected performance on every trip on each of the transit system's routes to develop a real-world operating range that accounts for:

- Bus stop dwell time
- Ambient temperature
- Passenger counts
- Route grades and elevation
- Bus type and properties

The purpose of this analysis is to quantify the extent of MCDOT's current service needs that can be met by ZEBs. Assuming a full ZEB fleet, this simulation was performed on all weekday transit service blocks. PEER analysis will aid in operational and financial decisions during fleet electrification, including planning, staging, and phasing. The primary output from the PEER analysis is an understanding of the amount of energy required for each bus to complete its operating service based on average and extreme operating conditions. Understanding the total energy requirement, and as informed by the various constraints and challenges the County will face throughout the transition, the selection of a ZEB technology compatible with the service demand for each bus is identified.

Results from the PEER analysis have informed development of the County's transition plan and identified areas of the existing schedule that may need adjustments. Figure 7-1 shows several operating statistics for MCDOT's fleet used in the PEER analysis based on the combined "blocks" of transit service assigned to each bus for each weekday.

Figure 7-1: Ride On Service – Reference Operating Statistics

Shows daily distances and times for buses from each depot.

KEY PEER ANALYSIS FINDINGS

» The County's service plan is extremely demanding in terms of the average annual distance traveled by each bus, each day

» Based on the FTA National Transit Database data for Service (by Mode and Time Period) for 2022, the Ride On bus service ranks in the top 8% of the nation for average annual miles per bus

» Predominantly impacted by the quantity of service miles for each bus, the amount of energy required to provide uninterrupted bus service (without adding additional vehicles to the fleet to make up for a deficit in energy capacity operating range) is pushing the limits of today's ZEB technology

Compatible Technology

Through the analysis of the service schedule at each depot, including the specific block combinations that the County utilizes over a complete day of service, the total amount of energy required for each individual bus is able to be determined. Based on the service energy available for each of the ZEB technologies, a breakdown of the total energy required and the number of buses that fall within that energy requirement range is able to be provided. An appropriate ZEB technology can then be assigned to the vehicles within each depot's fleet based on the energy capacity of each technology. With the intent of establishing a successful future fleet technology mix at each depot, this approach utilizes conservative modeling assumptions including degraded batteries, high passenger loading and cold weather operating conditions to ensure that the selected technology mix will be able to provide uninterrupted service, year round. The analysis also takes into consideration the amount of time each vehicle spends at its operating depot, including between morning and evening service blocks, for example, and assumes that energy recovery options such as mid-day charging (BEBs) and mid-day refueling (FCEBs) are utilized during these dwell periods. The following figures present the results of this technology compatibility assessment at each depot. It should be noted that the total number of vehicles analyzed are derived from the service schedule; spare vehicles are not included.

Figure 7-2 through 7-4: Compatible ZEB Technology – for each Depot

Fig 7-2, 7-3 and 7-4 show the number of buses by type and the amount of energy required to run them at the EMTOC depot, the Brookville Depot and the Nicholson Depot, respectively

Target Future Fleet Components

As described in the previous section, the compatibility of ZEB technology with the County's transit service plan is a critical component of zero-emission transition plan development, and is performed after energy modeling in order to identify a recommended mix of ZEB technology for each operating depot. The following figures present a summary of the target future fleet mix at the three locations that are expected to be in operation in 2035, and the overall fleet mix. Additional detail and considerations for the fleet allocations and projected fleet mix at the New Facility are described in Chapter 9 and Chapter 10.

Future Flash BRT Service Analysis

In addition to the PEER analysis of the County's current transit service, a preliminary analysis on future FLASH Bus Rapid Transit (BRT) services was conducted. Additional details regarding the Future FLASH service analysis are provided in the Appendix. In general, the results of the analysis found that FCEBs are the preferred technology for this type of service and this transition plan reflects the acquisition of FCEBs when fleet expansions occur in order to support future FLASH services. It is to be noted, that as technology advances, these assumptions might be revised in future ZEB Transition Plan updates.

Figure 7-5: Overview of Future ZEB Fleet Mixes (2035)

Shows the percentage of bus required (BEB vs BCEB) at each depot

Figure 7-7: MCDOT ZEB Procurement Schedule

Shows the number of each type of bus to be procured every year until 2035

Ride On Reimagined Study

Development of the County's ZEB Transition Plan is taking place concurrently with MCDOT's *Ride on Reimagined* study. The *Ride On Reimagined* study is a comprehensive, forward-looking assessment of the bus network that may result in significant recommended changes to transit operations in Montgomery County based on current and future needs. This study takes an in-depth look at the County's existing and planned transit systems, including WMATA Metrobus services that operate within the County limits and the future MDOT Purple Line light rail system. The study will also provide an opportunity to guide the future direction of Ride On through data analysis and community engagement. The study will have the primary goal of recommending system-wide changes that address the current and future needs of the community it serves for both Ride On and WMATA Metrobus services. The culmination of the study will be the development of a new service plan that will extend for several years and be updated as service enhancements occur.

An overview of the proposed expansions, replacements, and enhancements of existing services from the *Ride On Reimagined* study is presented in Figure 7-8. Examples include:

- Create new routes
- Expand Flex zones
- Increase frequency

- Extend weekend services
- New route classifications

Figure 7-8: Ride On Reimagined Study Preliminary Network Recommendations

A map showing recommended changes and additions to routes for Ride On

Chapter 8 Capacity Analysis

Assessment of vehicle performance and compatibility with the service plan is undoubtedly a critical element of transition planning, however, of similar importance is the understanding of all bus facilities' operating capacities. Three principal capacity metrics, including space capacity, maintenance capacity, and 'fueling' capacity, are evaluated to determine current and projected facility-based constraints throughout the planned transition. The timing and quantification of capacity constraints are utilized to inform implementation of the transition.

Space capacity considers the number of designated parking spaces available at each facility compared to the current and projected fleet components. Sufficient parking capacity is required to ensure a satisfactory level of yard operation and bus circulation, which is closely tied to efficiency of operation and safety. Projected reductions in operating parking capacity are considered based on the total number of ZEBs in the fleet and the understanding that requisite ZEB infrastructure may displace parking space.

FTA ZEB TRANSITION PLAN REQUIREMENTS
This chapter is written in compliance with the following FTA requirement(s) for ZEB transition plans:
***Facilities evaluations** — includes an evaluation of existing & future facilities*

Maintenance capacity considers that the ratio of Mechanic Technicians to the number of vehicles is of particular importance to the success of the Fleet Maintenance operation. The DGS Fleet Section's target is 4.0 buses per Mechanic Technician and is currently operating at 4.4 buses per Mechanic Technician. Collective industry experience with zero-emission buses indicates that reliability and availability are currently lower than conventional buses. The preventive maintenance labor requirements for ZEBs are however slightly lower than conventional, but a potential increase in allowable buses per mechanic is quickly offset by a higher frequency of defects and service failures. A maximum allowable ratio of 4.5 buses per mechanic is utilized for the assessment, and the total number of mechanics at each facility considers the increase in manpower which results when going from two to three-shift operation, affecting the maintenance capacities at EMTOC and Nicholson.

'Fueling' capacity considers the unique requirements of fueling and charging conventional buses and ZEBs within the County's fleet at each facility. Conventional fueling manpower and service is currently provided by a 3rd party contractor. Estimated diesel and CNG fueling capacities are provided based on number of dispensers, service time per bus, and daily service window; future projections for hydrogen fueling capacity utilizes this same approach. Battery electric charging capacities are provided based on number of charging dispensers, charger-type (60 kW depot chargers & 450 kW fast chargers) estimated charging time per bus, and daily charging window.

The following figures summarize the results of the capacity analysis for each facility at milestone transitional years: 2023 (current), 2029, 2030, and 2035. Additional information regarding the Space, Maintenance and Capacity analysis is located in the Appendix.

Figure 8-1: Capacity Analysis Summary — 2023-2035

Current and projected Fleet Size by Depot with parking spaces and labor, service and fueling capacities.

CHAPTER 9 FLEET TRANSITION MODEL

As previously shown in Figure 5-1, the majority of MCDOT's current bus fleet is comprised of either diesel, CNG, or hybrid buses, apart from the 14 BEBs. Thus, to accomplish Montgomery County's CAP and their goal of reducing GHG emissions by 100% in 2035, these conventionally fueled buses must be replaced with zero-emission equivalents. These replacements must take into consideration multiple factors, such as the varying ages of the current fleet, current planned acquisitions between 2025 and 2027, FTA standard useful service life for transit buses, depot operating and maintenance constraints as determined by the capacity analysis (Chapter 8), the target future fleet mix at each depot as identified by the energy modeling and compatible technology assessments (Chapter 7), and any planned fleet expansions. As such, a fleet transition model is developed based on these inputs, constraints, and assumptions, identifying which buses will be replaced with zero-emission equivalents, when the replacements occur, the inclusion of new vehicles in the fleet to support service expansions, and the resulting introduction of zero-emission buses over time. A detailed list of the inputs and assumptions for the transition model are provided in the Appendix.

FTA ZEB TRANSITION PLAN REQUIREMENTS
This chapter is written in compliance with the following FTA requirement(s) for ZEB transition plans:
***Fleet management** — demonstrates a long-term fleet management plan*

FLEET TRANSITION BY MAINTENANCE & STORAGE FACILITY

The information presented in this document is a baseline scenario analysis. The actual implementation of the transition will almost certainly result in a different solution. This analysis is based on current operational assignments that may be adjusted to optimize service and operations at each depot and to reflect technology updates in the next few years. MCDOT continues to work on identifying funding sources for its transit projects to resolve any inconsistencies between the required number and type of buses and the current funding allocated to the zero emissions bus transition plan.

Brookville Smart Energy Depot

Figure 9-1 shows the transition from conventional buses to ZEBs for vehicles assigned to the Brookville Smart Energy Depot. The purple bars represent the number of conventional buses, green bars represent the number of BEBs, and the light blue bars represent the number of FCEBs. The percentage values above the stacked bars represent the percentage of the fleet at Brookville that are ZEBs.

Figures 9-1, 9-2 and 9-3: Fleet Transition Forecast by Depot

Graph showing the % of bus type that makes up the fleet at each depot between 2023 and 2035.

As shown in Figure 9-1, 54% of the buses assigned to the Brookville Smart Energy Depot in 2027 will be ZEBs, falling short of the 80% reduction in GHG by 2027, as outlined in Montgomery County's CAP. However, the fleet at Brookville will be completely comprised of ZEBs by 2029, much earlier than the goal of 100% GHG reduction by 2035.

One important note is that the percentage of ZEBs at the Brookville Smart Energy Depot reduces from 100% to 99% in 2030 and 2031. This is due to the closure of the Nicholson Court Depot in 2030, requiring all buses from Nicholson Court to be relocated to a different facility, including a single 2021 29-foot diesel bus. As the New Facility will not support conventional buses, this 29-foot diesel will have to be relocated to Brookville before being replaced with a ZEB equivalent in 2032.

Additionally, the current fleet transition model shows the Brookville fleet is exceeding the available spatial capacity. Brookville's current spatial capacity is 140 buses. However, due to additional ZEB charging and fueling infrastructure, the spatial capacity is anticipated to reduce to 135 buses. To account for this capacity reduction and alleviate potential operational concerns, four 35-foot BEBs and ten 40-foot BEBs are relocated to the New Facility in 2030. However, as previously mentioned, the Brookville Smart Energy Depot also gains a single 29-foot diesel bus in 2030 after the closure of the Nicholson Court Depot. This results in an overall fleet count of 135 buses in 2030, which matches the total expected spatial capacity at Brookville in 2030.

EMTOC Maintenance & Storage Depot

Figure 9-2 shows the transition from conventional buses to ZEBs for vehicles assigned to the EMTOC depot. The purple bars represent the number of conventional buses, green bars represent the number of BEBs, and the light blue bars represent the number of FCEBs. The percentage values above the stacked bars represent the percentage of the fleet at the EMTOC Depot that are ZEBs.

As shown in Figure 9-2, only 9% of the fleet at EMTOC in 2027 will be ZEBs, falling short of the 80% reduction in GHG by 2027, as outlined in Montgomery County's *Climate Action Plan*. The fleet at EMTOC will not reach 80% ZEBs until 2032. However, the fleet at EMTOC could reach 100% zero-emissions by 2033, two years earlier than the goal to achieve 100% reduction in GHG by 2035. This is based on the age of the buses and their schedule of replacement.

Additionally, the current fleet transition model for EMTOC shows the EMTOC fleet will exceed the available spatial capacity in 2028 and 2029, before reducing again in 2030. This is due to the planned Great Seneca service expansion, resulting in the acquisition of 39 40-foot BEBs in 2027 and 2028. Alongside the Great Seneca expansion, MCDOT has also planned for bus procurements for future Veirs Mill Road BRT and MD355 Central BRT services, resulting in an additional 24 60-foot FCEBs in 2027 and 2028. This results in a total fleet size of 239 vehicles assigned to EMTOC.

As mentioned in Chapter 6, the overage in depot parking capacity is currently assumed to be mitigated by repurposing "bus storage space" as operating bus parking. This exchange is a difficult compromise as the current bus storage space is used for critical commissioning of new fleet equipment (including the installation of County fare collection and proprietary communication systems equipment), and processing (removal of same) and temporary storage of decommissioned vehicles. It is understood that the reallocation of storage and parking space at EMTOC is an outstanding item that requires additional, careful consideration as the total operating bus parking capacity approaches full saturation in the coming years of the transition. Storage space will also be affected by the implementation of the planned EMTOC microgrid and hydrogen generation, storage, and dispensing projects described in Section 9. Once the New Facility opens in 2030, these 39 40-foot BEBs operating the Great Seneca expansion are relocated to the New Facility to ease operational conditions at EMTOC, reducing the total fleet size at EMTOC to 200 vehicles.

Nicholson Court Maintenance & Storage Depot

Figure 9-3 shows the transition from conventional buses to ZEBs for vehicles assigned to the Nicholson Court facility. The purple bars represent the number of conventional buses, green bars represent the number of BEBs, and the light blue bars represents the number of FCEBs. The percentage values above the stacked bars represent the percentage of the fleet at Nicholson Court that are ZEBs.

As shown in Figure 9-3, no ZEBs are assigned to the Nicholson Court Depot as the County does not own this facility and cannot upgrade its infrastructure to support ZEBs. For this reason, the County plans to relocate its Nicholson Court operation to a new facility and close this depot in 2030.

The current fleet transition for the Nicholson Court Depot shows the fleet exceeding the available spatial capacity in 2028 and 2029. This is due to the projected microtransit expansion in 2028, resulting in an additional 11 22.5-foot diesel buses. As previously mentioned, the Brookville and EMTOC depots are already at, or exceeding, their maximum capacities by 2028, thus these 22.5-foot buses are assigned to Nicholson Court.

New Bus Maintenance & Storage Facility

Figure 9-4 shows the transition from conventional buses to ZEBs for vehicles assigned to the New Facility. The purple bars represent the number of conventional buses, green bars represent the number of BEBs, and the light blue bars represent the number of FCEBs. The percentage values above the stacked bars represent the percentage of the fleet at the New Facility that are ZEBs.

As shown in Figure 9-4, almost all vehicles assigned to the New Facility will be ZEBs. The exception is due to the previously mentioned 11 29-foot diesel buses procured in 2028 for the microtransit expansion. These 29-foot buses will need to be relocated after the closure of Nicholson Court in 2030. However, buses from Brookville and EMTOC will be relocated to the New Facility in 2030 due to spatial constraints. Thus, these 29-foot diesel buses must be temporarily assigned to the New Facility unless alternative arrangement opportunities are identified. While this may present some operational concerns on servicing and maintaining these buses, the expected location of the new bus facility will provide for relatively convenient access to conventional fueling at EMTOC, allowing the County to plan for a new, fully zero-emissions bus depot.

Additionally, the New Facility fleet grows from 156 buses in 2030 to 257 buses in 2035. This is due to the various BRT expansions, such as the New Hampshire, Randolph Road, Georgia Avenue North and South, and University Boulevard BRT services, and additional 60-foot ZEBs needed to support these BRT services. The total number of buses required to expand Flash BRT services, and to accommodate other future enhancements to the transit services provided by the County, will require continued assessment throughout the implementation of the zero-emission transition plan. Because capacity planning is a critical factor in the success of ZEB implementation, the current Fleet Transition Model is conservative in that it assumes all new services require the addition of vehicles to the fleet in order to provide said services. The County recognizes that the level of fleet growth presented does not take into consideration the number of vehicles that may be offset by the duplication of new service with existing, and therefore the future fleet requirement will be less than that depicted in this current version of the plan. This aspect of the transition will continually be reviewed in the development of future iterations of the plan, with particular focus on the results and recommendations of the Ride On Reimagined study being performed concurrently.

New Bus Maintenance and Storage Facility Fleet Composition

To better understand the vehicle reassignments in 2030, Figure 9-5 identifies vehicles assigned to the New Facility in 2030 and their origins. Seventy-five of the 156 vehicles assigned to the New Facility are related to relocations from Nicholson Court, though most of these vehicles are also replaced with ZEB equivalents. Fifty-three of the 156 vehicles were relocated from Brookville and EMTOC, due to these facilities exceeding their spatial capacity. The remaining 28 vehicles are new acquisitions to support the MD355 North and South BRT and North Bethesda Transitway BRT.

Figure 9-5: New Facility Fleet Composition in 2030

Shows fleet composition by age in years by bus type and length and bus year

OVERALL TRANSITION FORECAST

As mentioned before, as the County's Ride On Reimagined Study is finalized, new funding sources are identified, technology advances and the local service is coordinated with WMATA, the number of buses needed to support the County's service area might need to be adjusted further.

Figure 9-6 outlines the transition from conventional buses to ZEBs for MCDOT's entire fleet, including the planned acquisitions described in Chapter 5. The purple bars represent the number of conventional buses, green bars represent the number of BEBs, and the light blue bars represent the number of FCEBs. The percentage values above the stacked bars represent the percentage of the entire fleet that are ZEBs.

As shown in Figure 9-6, 32% of MCDOT's entire fleet will be zero-emission vehicles, falling below the 80% GHG reduction defined in Montgomery County's CAP. The County envisions a bus fleet comprised only of ZEBs by 2033, two years earlier than the 2035 goal outlined in the CAP, assuming adequate funding for this transition is identified in the coming years and favorable external factors.

As previously mentioned, the Brookville, EMTOC, and Nicholson Court depots will all be operating with exceeded parking capacity for their buses in 2027, due to the various planned fleet expansions, until 2030, when the New Facility is available.

Figure 9-6: MCDOT Overall Fleet Transition Forecast

Graph showing number of vehicles by type over each year until 2035

KEY CHALLENGES

Parking Capacity

MCDOT's active fleet includes 389 vehicles across its three facilities. Further, a maximum of an additional 203 vehicles may be needed by 2035 to support additional routes and BRT service. This results in a maximum planning scenario of 592 vehicles by 2035. However, as previously mentioned, these fleet expansions will be done in multiple stages. As some of these expansions are scheduled before the New Facility is available in 2030, the overall fleet size will be larger than the parking capacity available across the three facilities. In 2027, 2028, and 2029, the expected fleet size is 414, 463, and 463, respectively. However, before the New Facility opens in 2030, there is a total parking capacity of 405 buses across the Brookville, EMTOC, and Nicholson Court depots. While the EMTOC Depot can utilize "dead bus parking" space and has excess maintenance labor and equipment capacity, as discussed in Section 7, the Brookville and Nicholson Court depots do not. Any reductions to parking capacity, potentially due to the installation of additional ZEB infrastructure, will further exacerbate the issue.

As demonstrated by this analysis, the County is closely monitoring parking capacity as a critical factor in the deployment of ZEBs and infrastructure. Where short term capacity deficits are anticipated, the County has identified multiple off-site parking provisions near each depot that will be used as a temporary solution.

ZEB Infrastructure

ZEB infrastructure is needed to charge or refuel and support a ZEB fleet. However, as mentioned in Chapter 6, only part of the ZEB fleet can be supported by the current ZEB infrastructure plans.

The EMTOC Depot will need hydrogen fueling infrastructure by 2025 to support the replacement fleet of 13 40-foot FCEBs, with additional infrastructure needed to support the added 12 60- foot FCEBs for the Veirs Mill Road and MD355 Central BRT expansions. Additional battery-electric charging infrastructure will be needed by 2026, due to the replacement of three 40-foot vehicles.

Similarly, the Brookville Depot will also need additional hydrogen fueling and battery-electric charging infrastructure to support a ZEB fleet. While Brookville already has infrastructure to support up to 71 BEBs, this charging capacity will need to be expanded by 2026 when the projected number of BEBs is expected to begin increasing up to a peak of 107 BEBs in 2029. Brookville will additionally need hydrogen fueling infrastructure by 2029 to support FCEBs, due to the replacement of 40 40-foot buses, otherwise, some of the routes currently serviced out of the Brookville Depot might need to be relocated to EMTOC or the New Facility and their service would need to be adjusted to address the additional headway.

While the Nicholson Court Depot is anticipated to support only conventional buses until its closure in 2030, the New Facility will need both BEB and FCEB infrastructure to support the incoming bus reassignments and relocations in 2030.

CHAPTER 10 – OPERATIONS

The County has identified a wide range of impacts that ZEBs will have on daily operations. As the transition progresses, the County's current policies and procedures (originally tailored for the storage, operation and maintenance of conventionally-fueled vehicles) will continue to be updated and optimized for the needs of zero-emission bus technology.

Effects of ZEB Technology on Depot Operations

The County must employ strategies to incorporate systemic changes during the transition from conventional buses to ZEBs. Transition planning requires comprehensive review and update of all standard operating procedures, including bus circulation, maintenance procedures, and how these vehicles deliver service. The following sections provide insight on the County's progress in these areas, however, as the transition progresses and technologies advance, all aspects of depot operations will be continually reviewed and evaluated for potential improvements.

Servicing

The County's transition to a ZEB fleet requires additional facilities space to accommodate ZEBs, chargers, and hydrogen fueling stations to match the final chosen fleet composition.

As shown in the PEER analysis described in Chapter 7, if a BEB fleet is selected, bus-to-block assignments will need to be more rigid, due to limited battery capacities of part of the fleet during the transition. This is especially important when supporting a BEB fleet of mixed battery capacities. The fleet will have mixed battery capacities if buses are procured at different years, since batteries will improve as the transition progresses. These issues result in lower flexibility in bus deployment. While this inflexibility can be mitigated with smart charging software and automatic vehicle location systems, the flexibility will still be reduced compared to current operating conditions and should be taken into consideration.

While the County transitions its fleet and infrastructure to support ZEBs, MCDOT will remain focused on its priority of delivering service to its riders. To mitigate any risks associated with a transition, County staff will need to evaluate external factors that could potentially impact service and operations. Understanding these threats and vulnerabilities will enable MCDOT and MCDGS to develop strategies and mitigation measures to ensure the continuity of operations, service, and emergency response. Some examples of threats and vulnerabilities are natural disasters, such as extreme heat, fires, flooding, sea level rise, physical and cyberattacks, geomagnetic disturbance, threats to the power grid, pandemics, fuel (hydrogen) delivery interruptions and human error.

Back-up power can meet service requirements during short-term outages and long-term emergency events. Stationary batteries can store electrical energy but require considerable space and are expensive. Depending on their type and size, batteries typically provide emergency power during short outages. They can also flatten a facility's peak load throughout the day, reducing operating costs. Through the implementation of industry-leading microgrids, the County is well-provisioned with resilient, sustainable power to help manage the various risks associated with ZEB technologies.

Maintenance

ZEB vehicles use much simpler propulsion systems with fewer moving parts that require less labor to perform preventive maintenance tasks. The baseline conventional bus preventive maintenance interval employed by the County is 6,000 miles which is predominantly driven by engine oil service requirements. Although ZEB inspection intervals are typically still in the 6,000 mile range, the labor time required to complete the inspection and preventive maintenance is lower due to removal of various fluid changes and the replacement of consumable maintenance items. Although ZEBs have some fluid and filter replacements that are comparable to conventional bus requirements, they do not require fuel filters, engine air filters, or crankcase filter replacements. The majority of ZEBs available in the marketplace also use a direct-drive traction motor arrangement, which removes the need for a transmission, as well as the fluid, filters, and costly rebuilds associated with maintaining transmissions. ZEBs also utilize regenerative braking to increase efficiency of operation, resulting in a significant reduction of brake wear as compared to conventional buses. Factoring in these key differences in vehicle equipment and associated maintenance requirements, there is potential to realize reductions in maintenance costs over the life of ZEBs as compared to conventional buses. Although preventive maintenance costs are expected to be lower, the reliability of ZEB technology has been inconsistent across the industry which can quickly negate the benefit of reduced scheduled maintenance. The County is closely monitoring reliability and maintenance costs of ZEB deployments as critical insight for long term budgeting.

The transition from a conventional bus fleet to BEBs or FCEBs also requires planning and utilization of the maintenance planners and material control group. As with all fleet changeovers, some common parts may remain in inventory. Operating mixed fleets, here consisting of diesel and BEBs or FCEBs, typically require more inventory storage space as each type of bus will require different unique parts to be stored separately from each other. The County will be required to maximize every opportunity to expel outdated stock. A sequenced replacement of the bus fleet provides an option to plan out the stockroom conversion to ZEBs over time in a controlled manner.

Potential Changes for Depot Operations

The addition of BEB charging infrastructure to the existing depots adds additional hazards to the facilities that must be properly mitigated. Personnel will also need to be aware of these hazards and be trained to work with the new technology.

Charging Locations & Capacity

The infrastructure required to support BEBs will decrease the amount of space available at the facility for bus parking and storage. This infrastructure includes electrical substations, charging equipment, generators, and battery electric storage systems. The addition of FCEBs in conjunction with BEBs will require additional space to support hydrogen fuel tanks. During the early years of the transition to ZEB technologies, the County will operate a mixed fleet of ZEB and conventional buses. This transitional composition will require semi- temporary supplementary space to support the different types of buses. This additional space would be transitioned from conventional-to ZEB- supporting, once the conventional buses have reached their end of useful life.

Dispatching and Circulation of Vehicles

The dispatch of buses will change when utilizing ZEBs for revenue service. As a result of the service schedule, BEBs would have varied overnight charging times, depending on the energy required to complete a block and the amount of opportunity charging received between blocks or possible terminal charging. Additionally, since BEBs will be procured over the span of a few years, the BEBs will have varied battery capacities. Based on the analysis conducted in Section 4, these varied battery capacities will have an impact on service completion, as some blocks require considerably more energy than currently available on the market. This will result in a fleet mix that will require stricter bus-to-block assignments, as not all buses will be able to complete all blocks. Both bus-to- block assignments and recharging times need to be considered for overnight charges at the County's facilities. With the service needs driving an expected future fleet mix of BEBs and FCEBs, MCDOT will also need to ensure that bus-to-block assignments are made using buses that are compatible with the specific energy need. With the County's current deployment of BEBs at the Brookville Smart Energy Depot, the operation currently utilizes The Mobility House's smart charging and energy management system, ChargePilot, which coordinates charging with the microgrid by optimizing the buses' charging schedules based on route blocks and energy demands to ensure vehicle readiness.

The reduction in available facility space described in Chapter 7 has the potential to hinder the circulation of ZEBs at each facility. Infrastructure and charging/ fueling equipment layout of the facility should be designed to minimize the amount of encroachment on bus servicing, storage, and drive lanes.

Mixed Fleet Operations

Based on Montgomery County Transit's Fleet Management Plan and maintaining the fleet's state of good repair, it is anticipated that the acquisition of ZEBs will occur in various phases. As groups of conventional vehicles reach the end of their useful life, MCDGS ensures that ZEB procurement contracts are already in place in order to have new vehicles ready to enter service and maintain the fleet size. Based on this phasing, ZEBs and various types of conventionally fueled buses will be in use at the same time. Based on the PEER analysis performed, it would be recommended that BEBs are assigned to blocks that are less energy intensive and that conventional buses and FCEBs are assigned to service the longer, more energy intensive blocks. As battery technology improves and the conventional buses are phased out, the newer BEBs should be assigned to the longer blocks that were once serviced by the older conventional buses. Any FCEBs purchased could be utilized in place of BEBs as their operation, range, and fueling times are similar enough to diesels; they could be utilized directly in place of conventional buses too for route planning purposes, however the longest and most severe bus assignments are expected to require mid-day refueling and the County will need to have a work plan in place to accommodate this need.

Compared to many of their peer agencies, MCDOT is well-positioned to take on the challenges of mixed fleet operation due to their experience with a wide range of conventional bus technology (diesel, CNG, and diesel-electric hybrids). Notably, these conventional vehicle technologies have already prepared the County to operate and maintain ZEBs whose propulsion systems also employ high voltage batteries and lighter-than-air gaseous fuel systems.

Electrical Hazards

The pantograph connections used for charging the BEBs will have live, exposed parts during charging. During normal operation, safety is ensured through physical distance and use of un-grounded systems with insulation monitors. In an ungrounded system contact with both positive and negative rails on the roof of the bus for current to flow through a person. The insulation monitors should shut down the equipment if either positive or negative rails are grounded. Furthermore, the placement of live rails on the roof of the BEB prevents inadvertent contact. However, it is essential that there are procedures in place to ensure any work above a certain height observes the necessary clearance from a potentially energized pantograph, and that the required lock out/tag out procedures are used when appropriate.

Arc flashes are violent releases of energy that occur when electric current leaves the intended path and travel through air from one conductor to another to ground. Fire, pressure blast, flying objects (often molten metal), sound blast as loud as a gun, and heat upwards of 35,000 degrees Fahrenheit can be produced from arc flashes associated with the voltage and current used in BEB charging.

BEB chargers, inverters, and electric motors can create electromagnetic fields that can interfere with other devices, such as pacemakers. Equipment with low EMI radiation, isolation from public/non- essential workers, testing, shielding, and signage can control the hazard that EMI poses.

The County will address these hazards through training of employees, personal protective equipment, insulated tools, working de-energized, and warning labels. While these hazards are inherent in the use of this equipment, they can be managed and mitigated. The County is quickly growing these competencies and skills.

Hydrogen Hazards

Hydrogen is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200). It is an extremely flammable gas that burns with an invisible flame. Hydrogen may form explosive mixtures with air if ignited with aflame, but it is not self-igniting. It is not specifically toxic but can displace oxygen and cause rapid suffocation. There is no known extinguishing agent for hydrogen. The material safety data sheet recommends shutting off the flow of hydrogen in the event of a fire if it can be done safely. If impossible, to withdraw and allow the fire to burn.

Like any other fuel or energy carrier, hydrogen poses risks if not properly handled or controlled. The risk of hydrogen, therefore, must be considered relative to the common fuels such as gasoline, propane or natural gas. The specific physical characteristics of hydrogen are quite different from those common fuels. Some of those properties make hydrogen potentially less hazardous, while other hydrogen characteristics could theoretically make it more dangerous in certain situations. Since hydrogen is the smallest molecule, it has a greater tendency to escape through small openings, as compared with other liquid or gaseous fuels. Based on properties of hydrogen such as density, viscosity and diffusion coefficient in air, the propensity of hydrogen to leak through holes or joints of low pressure fuel lines may be only 1.26 to 2.8 times faster than a natural gas leak through the same hole. If a leak should occur for whatever reason, hydrogen will disperse much faster than any other fuel, thus reducing the hazard levels.

Hydrogen is both more buoyant and more diffusive than either gasoline, propane or natural gas. Liquid hydrogen presents another set of safety issues, such as risk of cold burns, and the increased duration of leaked cryogenic fuel. A large spill of liquid hydrogen has some of the same characteristics as a gasoline spill, however it will tend to dissipate much faster. Another potential danger is a violent explosion of a boiling liquid expanding vapor, which can occur from a pressure relief valve failure.

Mitigations for the above hazards will be addressed through personnel safety training, and by including the appropriate safety systems and components in the design and modification of the County's facilities, such as detection, ventilation, and automated shutoff systems. Vehicle based hazards will also be addressed.

Maintenance Needs

ZEBs utilize much simpler propulsion systems with fewer moving parts that require less frequent service intervals. Full courses along with repair procedures on any ZEB being evaluated are provided by the bus manufacturers; a similar style course would be required for the County maintenance department, prior to any ZEB implementation. The baseline bus preventive maintenance intervals on diesel buses are predominantly driven by engine oil service requirements. Although ZEBs have some fluid and filter replacements that are comparable to conventional diesel bus requirements, they do not require fuel filters, engine air filters, or crankcase filter replacements. The majority of ZEBs available in the marketplace also use a direct-drive traction motor arrangement, which removes the need for transmission and thus fluid and filter maintenance. ZEBs also utilize regenerative braking to increase efficiency of operation, resulting in a reduction of brake wear as compared to conventional buses.

Effects on Spare Ratio

Based on cumulative industry feedback from operators of electric buses (BEB and/or FCEB) , many agencies have not been experiencing the need to increase their spare ratio. On the contrary, the consensus indicates that ZEBs will provide increased reliability, availability, and lower maintenance costs when compared with traditionally fueled vehicles, especially as the market matures. Factoring in these positive trends in vehicle performance and reliability, agencies are recommended to focus on maximizing the performance of their charging infrastructure, and, to the extent practicable, minimizing their exposure to significant infrastructure failures, rather than planning to address operational worst-case scenarios by increasing the size of their spare vehicle fleets.

It is important to note that there are caveats to consider with the state of the industry at the time of writing. Agencies are generally not reporting a need for increased spare ratios of vehicles. The County's need for additional space, however, is based mostly on the need to replace the Nicholson Court Depot and to accommodate new services. The vehicles themselves seem to be getting more and more reliable as subsequent generational improvements are released. ZEB vehicle is still mostly a traditional vehicle with a different powertrain; therefore, most systems will have the same reliability as their diesel counterparts. There are areas of a ZEB fleet that can cause operational issues as the technologies mature. The first is parts availability and cost as replacement powertrain components have long lead times and significant cost. The reason is simply due to availability as the market is focusing on production for new vehicles, which leaves the after-sales service parts availability very low and expensive. Charging equipment is currently the main issue any zero- emission fleet operator has to contend with. Chargers and dispensers are being improved to deal with the harsh environment of transit operations by increasing reliability, decreasing maintenance requirements, and improving replacement parts availability. The publishing of the SAE charging standards J3105(series) for on route charging and J1772 for plugin charging will improve bus and charger integration, and communications (SAE International, 2024) (SAE International, 2024).

As with any technology or piece of equipment, failures are guaranteed to occur. When they do, planning for redundancy will minimize the impact to the agency's ability to make service. Regarding BEBs specifically it is recommended to maximize backup generation capacity at the depot and utilize as many grid connection redundancies from power utilities as possible. Agencies are recommended to purchase additional depot and on-route chargers; the County is certainly considering this. A minimum recommendation of 5% beyond what would be required to support weekday peak service requirements are suggested. Agencies should also assess and prioritize their ability to quickly respond to charger failures with a float stock of spare chargers, replacement parts, trained in- house technicians, and/or service contracts with 24-hour support and immediate response times will be essential to minimizing potential service interruptions. Leveraging the high level of resiliency provided by microgrid solutions, and Energy-as-a-Service contracts with their microgrid partners, the County is well-positioned and can rely on these provisions to mitigate the impact of failures.

Planning for equipment failures is a critical part of any successful fleet operation, but consideration must also be given to the impacts of fleet electrification on other agency requirements such as providing emergency service, temporary shelters, evacuation plans, etc. While careful planning can make an agency's transition successful, the fact remains that, in many cases, ZEB range limitations may not allow for a 1:1 replacement of conventional buses under worst-case scenarios. When transitioning to ZEB vehicles agencies are recommended to be proactive in engaging with stakeholders and federal, regional, state, and local officials at the onset of fleet electrification efforts. Discussions should take place regarding the impacts of fleet electrification and whether there exists a need to reassess the County's capabilities involving emergency service operations or similar obligations.

In addition to the resiliency measures described, the County might also consider implementing an Emergency Contingency Vehicles fleet in accordance with FTA guidelines. This could allow MCDOT to retain a group of vehicles as a contingency fleet, once beyond their useful service life. The contingency fleet would be stored in an inactive state in preparation for emergencies. Conventionally fueled vehicles may be the ideal contingency fleet candidates during the transition to zero-emissions, as they may provide the range and flexibility needed during emergencies while advancements in technology are still catching up.

The County should also consider employing charging operations that take advantage of as many opportunities to replenish a vehicle's SOC as possible. Maximizing the BEB fleet's SOC at all times will provide increased readiness, flexibility and the best ability to respond to any unforeseen service and operational issues that arise. If relying on utility power when using this approach, however, the County will need to be mindful of utility rate and tariff structures that might preferably be avoided. A well-tuned Charge Management System will be essential in finding the right balance between maximum fleet readiness and avoidable energy costs.

Principal Wear Factors

Overall, ZEB maintenance requires a different skillset when compared to diesel bus maintenance. Due to the electrical systems used to drive the electric motor in ZEBs, OEMs or personnel familiarized with the electric propulsion and charging systems used are needed to support and troubleshoot these systems. For example, a ground on the high voltage electrical distribution system requires detailed understanding of the vehicle system, and knowledge of how to conduct ground isolation procedure. Additionally, brake pad replacements are required for ZEBs. While ZEBs utilize regenerative braking to slow the vehicle down, friction brakes are still utilized in emergency situations and at lower speeds when bringing the vehicle to a full stop. However, since regenerative braking is primarily used, friction brakes are used less and may not need to be replaced at the same frequency as typical diesel buses.

A final wear item, and one of the largest expenses for both BEBs and FCEBs are the lithium-ion batteries as their performance will degrade over time. The severity of this degradation, however, will depend greatly on the use case of the battery. Depth of charge, charge rate, and operational temperature of the battery are some of the factors that will affect the degradation. Battery State of Health (SOH) is a performance metric that is tracked by the vehicles battery management system, and is representative of the amount of energy capacity degradation that has occurred as compared to new condition. Battery health monitoring should be performed routinely and tracked to observe trends in the degradation of battery capacity over time. Keeping a close eye on the health and performance of the battery will be critical to a successful operation over the life of the vehicle, and can provide an early warning of battery capacity loss that may impact service operation. Depending on the severity of the degradation, battery replacements are recommended as part of a mid-life refresh to ensure that vehicles have sufficient capacity to meet the operating range and performance demands of service.

Assistance Technologies

Charge Management Software

The procurement and implementation of a Charge Management System (CMS) is strongly recommended for agencies electrifying their bus fleets with BEBs. There are several operational and financial benefits that can be gained from using a CMS, all of which become especially important as agencies' BEB fleet sizes continue to grow. Most CMS products take into consideration charging infrastructure, energy management (sometimes referred to as “smart charging”), vehicle and charging telematics data, and offer a user interface for the customer to easily visualize large sets of real time data for quick and informed decision making. The CMS optimizes charging based on operational requirements and electricity rates, which will ensure the lowest total cost of operating can be achieved. CMS technology can allow an agency to customize and implement different charging strategies, such as phased charging, where separate groups of vehicles or sections of a depot can be charged in phases rather than all at once, even if all vehicles are connected to chargers at the same time.

As with BEBs and chargers, the CMS marketplace is also seeing rapid growth. Understanding the importance of using integrated technology to improve the success of ZEB fleet operations, the County is currently using The Mobility House’s smart charging and energy management system, ChargePilot, which coordinates charging with the microgrid by optimizing bus charging schedules based on route blocks and energy demands to ensure vehicle readiness at the Brookville Smart Energy Depot. MCDOT should continue to monitor and explore new product options as technology improves, but the CMS products available today already offer significant benefits to agencies transitioning to full electrification. Ideally, selected CMS products will be compatible with all current industry charging standards, enabling them to be upgraded to meet future standards and/or compatibility requirements, and not be restricted to any specific charger or bus manufacturers. CMS products currently available provide many of the features and capabilities in the following sections.

Planning and Historical Data

MCDOT should integrate data from their unique operational requirements to buses and chargers and allow integration into its planning system. This will permit MCDOT’s electric bus operation to be intelligent, efficient and can reduce operational inefficiencies. This step is necessary for smart charging which will lower peak demand charges and automate the entire charging routine.

Telematics

Real time data monitoring and range prediction are key factors to operate electric buses without range anxiety, which is often influenced by driver behavior, weather, traffic, passenger load, and elevation. Real time data enables a transit agency to monitor, plan, and adapt the bus routes according to the information received from the buses. This permits transit agencies to make real time operational decisions depending on the daily unknown circumstances. The County is currently utilizing the ViriCiti telematics system with the deployment of its currrent BEB fleet, and will continue to leverage the real-time and historical data available from telematics to inform the transition to zero-emissions.

Advancements and Standardization

The emergence of smart charging and smart grids – a large and evolving ecosystem of new players, devices, protocols and charging technology companies – has pushed the industry to design and accommodate any type of charging technology toward one communication standard: Open Charge Point Protocol (OCPP). OCPP is the industry supported standard communication between charging stations and charging Management Systems. When connecting charge stations to an appropriate backend, OCPP protocol allows for remote resets, saving time, and making bus operations run smooth and efficiently.

It is important to note that there is no adopted industry standard for CMS. CMS vendors can offer some features without offering the others. For example, some vendors can offer smart charging without offering Fleet Management Software.

The landscape for hydrogen is similar as there is little standardization, although regulatory restrictions (i.e., max onboard pressure) have impeded some FCEB development. FCEB vehicles, hydrogen delivery, storage would benefit greatly in performance if for example liquid hydrogen were to become widely available.

CHAPTER 11 – WORKFORCE TRAINING

The transition to ZEBs will impact MCDOT and MCDGS’ service and operations at all levels of the organization. As such, providing workforce training on the new technologies being adopted is a critical element of the County’s transition plan and is key in its implementation. The initial fleet addition of BEB vehicles from two different OEMs, combined with the development of the Brookville Smart Energy Bus Depot project, represent initial electrification projects that illustrate how managers and staff will adapt during the systematic transition to zero-emission operation.

MCDOT and MCDGS recognize that the transition will require extensive changes in route optimization, vehicle operation characteristics, energy management, servicing operations, and training. As these changes affect the availability and need of existing positions, the County will make every effort to offer any affected employee comparable positions to the ones they held at the time these new equipment and technologies are implemented with the intention to avoid the elimination of positions or demotions. If the changes in technology significantly alter the essential tasks and skills of a job, the County will provide a reasonable amount of training so the incumbent can obtain the requisite skill to continue to hold their position. If employees affected by new technology are not qualified for and cannot be trained to perform the duties of the revised position, the County will make reasonable efforts to place the employee in a vacant position for which they are qualified. While the vehicle maintenance needs of ZEBs are generally less than those of buses equipped with an internal combustion engine, it is anticipated that the size of the workforce will not need to be reduced. This projection is maintained even if the County's planned transit fleet growth between now and 2035 is disregarded. Rather, employees and contractors who have skills in maintaining engine-related systems would transition to developing skills in maintaining electric motors, HV systems, vehicle chargers, and fuel cell system components including high-pressure gaseous storage, fuel cell stacks, and auxiliary systems.

A safety course will be mandatory for all staff to highlight the basic safety rules for high voltage (HV) ZEB batteries, HV subsystems, and FCEB systems and components where applicable. General training can be provided by MCDGS's training staff, with the assistance of the bus manufacturer, on the features of zero-emission buses. Bus manufacturers are typically contractually required by agencies to provide significant assistance to develop training curriculum, specific training aids and modules, diagnostic equipment, manuals, and lesson plans, as well as train-the-trainer scenarios.

Extra caution and proper usage of PPE are of paramount importance. Fall protection systems will need to be installed (and employees trained to their proper use) due to the roof mounted HV components. Scissor lift safety training should also be provided for maintenance staff. Administration of systems, troubleshooting, and repair training should be assigned based upon the employee's skill level. Incremental levels of training are necessary to properly match the type of work performance assigned to each group.

Additional training is available from the subcomponent manufacturers who can provide detailed instruction on such systems as the HVAC, fire suppression system, and energy storage systems (ESS). This training will be provided for the County's instruction staff who would in turn incorporate the subject matter into a defined training course.

The transition to ZEBs will significantly alter MCDOT's service and operations. Training will need to be conducted in parallel with the delivery of new buses to ensure that all personnel will be adequately trained before being required to maintain and operate the new equipment. Training conditions and schedules will be included in procurement documents, as they are with all existing procurements. If other OEM- provided buses are procured in the future and/ or if new components, software, or protocols are implemented, it is expected that County staff will be trained well in advance of the commissioning of these additions. Since zero-emission vehicle technology is rapidly evolving, it is likely that buses and supporting battery chemistries, fuel cell design and implementation, and software will change between now and 2035; therefore, MCDOT's future procurements/deliveries will require consistent, updated trainings for relevant staff.

WORKFORCE DEVELOPMENT PLAN

Training is required with all new and updated equipment that uses new technology. MCDOT and MCDGS are implementing a workforce development program that equips staff members with the skills necessary to properly use new technology. To achieve this goal, MCDOT and MCDGS have identified skills and credential gaps to generate long-term support and is committed to investing in a workforce development plan to deploy this long-term project successfully. A detailed overview of these plans is listed in the following sections. These sections were developed in part through the FTA's workforce evaluation tool.

Bus Operator Training

As the County transitions to a ZEB fleet, bus operators are getting familiarized with the BEBs' safety, bus operations, and charging operations. Training programs for the County's bus operators are included with the procurement of new ZEBs, often receiving this information via train-the- trainer sessions and disseminating the curriculum through the County's in-house operations instructors. ZEB operators are trained on how to understand and use readings such as battery SOC, remaining operating time, estimated range, and other system notifications that may occur during operation. One key area of focus for operator training is the use of the accelerator pedal to accelerate and decelerate. The accelerator pedal response on ZEBs is different than conventional combustion-engine equipped buses and the operators have a significant effect on energy consumption and regenerative braking efficiencies. Emphasis is given to operators regarding the regenerative braking capability and its significant impact to ZEB range and performance.

The County is following the FTA recommendations for training on concepts, working principles, and details of regenerative braking (specifically the differences between regenerative braking and conventional braking), mechanical braking, hill holding, and roll back. Additionally, the County's bus operator training also includes emergency response policies and guidelines to assist First Responders.

Bus Maintenance Training

The County's bus maintenance staff is also provided with a training plan for a maintenance transition based on existing BEB technology. Key elements of the training plan include:

- Coordination with internal stakeholders
- Identifying and prioritizing target participants
- Plan training with OEM and sub-component suppliers
- Ensuring prerequisites are scheduled before successor courses

Additional training is under development and evaluation for the bulk of new battery electric and fuel cell bus-related activities, as it pertains to the mechanical and electrical staff.

Facilities Maintenance Training

Detailed maintenance of complex systems require additional specific training for systems such as high voltage charging systems. The new technologies required for charging batteries and fueling with hydrogen require detailed and specific training for the facilities maintenance staff. New standard operating procedures, tools, equipment, PPE, and uniforms are provided for some routine inspections, preventative inspection/repair work, and major repairs. The appropriate MCDOT and MCDGS staff will receive basic safety and familiarization training on new, ZEB-supporting facility equipment, however, the majority of the facilities-related maintenance requirements is the responsibility of AlphaStruxure under the County's P3 service agreement.

First Responder Training

High voltage batteries in large numbers have been used in vehicles for well over a decade, and as more are being introduced, efforts by first responders to become aware of how to respond to incidents have been constantly evolving. First responder training is required to allow fire fighters, police, and other safety personnel to become familiar with the specific aspects of ZEBs. The County's first responders receive training with the arrival of all new buses in the transit fleet; most bus OEMs include the cost of this training in the base purchase price of buses due to its critical importance.

Safety concerns regarding the high voltage of batteries and charging systems are addressed through Maintenance and Operator training, warning labels, color coded cables that clearly indicate high voltage, standards of manufacturers, and technology to control the systems and safety enclosures. Fire detection and suppression systems are built into the buses to add an additional layer of safety. Batteries are located outside of the passenger compartment in enclosures designed for passenger protection and safety. A cooling system is part of the battery management system to remove excess heat from the batteries.

Figure 11-1: List of Personnel Required for ZEB Retraining

Table shows the training required for various types of personnel.

Other Required Training

Figure 11-1 provides a list of additional personnel and positions not mentioned in previous sections that also need to be retrained upon further adoption of BEBs and FCEBs (this list is not exhaustive).

Apprenticeship Program

The County is also in the process of developing a formal apprenticeship program for various transit positions to build a future workforce while also lifting up the community. The goal of the program is to offer on-the-job training and work experience to attract, develop and retain a successful workforce through structured training and mentoring from veteran employees. The program will:

- Recruit and develop a diverse and highly skilled workforce
- Improve productivity
- Reduce turnover
- Create flexible training options that ensure workers develop the right skills
- Retain workers
- Foster a diverse and inclusive culture

CHAPTER 12 – ECONOMIC ASSESSMENT

This section summarizes the findings of the economic analysis, which includes a life cycle cost assessment (LCCA) as well as a cash flow analysis. A detailed economic assessment that describes the methods, assumptions, and findings can be found in the Appendix.

Life Cycle Cost Assessment

The LCCA examines the financial implications of converting the County's fleet from its current mix of diesel, CNG, and hybrid buses to one that is 100-percent reliant on ZEBs, including BEBs and FCEBs on a per-bus basis.

LCCAs include one-time and initial capital investments, reoccurring operations and maintenance (O&M) costs, and renewal costs. A LCCA is a tool to determine the most cost-effective option among different competing alternatives to purchase, maintain and operate an object (in this case a bus), when each is equally appropriate to be implemented on technical grounds.

The LCCA for this ZEB transition plan assessed the capital costs of procuring one BEB or one FCEB, the necessary fueling and charging infrastructure, and O&M costs to support continued transit service. The LCCA includes cost estimates for scenarios where BEBs and FCEBs are fully powered by the on-site microgrids at the EMTOC and Brookville Depots. Because the Performance Evaluation of Electric Routes (PEER) Analysis completed as part of the transition plan determined that the microgrids will not generate enough electricity to fully power the County's ZEBs, the LCCA also includes the scenarios where BEBs draw electricity from the Pepco-supplied electric grid and FCEBs are fueled with hydrogen that is generated using electricity from the Pepco-supplied electric grid. The total life cycle costs per bus over 12 years are presented based on the 12-year service life of transit buses as defined by the FTA. The LCCA per bus associated with the transition to ZEBs is benchmarked against the costs associated with procuring, operating, and maintaining each bus propulsion technology included in the current fossil fuel-based fleet, which includes CNG, diesel, and hybrid buses. To allow for a direct comparison across bus propulsion technologies, the LCCA assesses the costs associated with each standard length, 40-foot bus. Benchmarking the impacts of transitioning to a ZEB fleet against the make-up of the current fossil fuel-based fleet on a per-bus basis allows for a meaningful comparison of costs associated with the transition plan.

The LCCA compares life cycle costs associated with the following bus propulsion types: BEB (including scenarios where the BEB is charged with electricity from the microgrid and where the BEB is charged using electricity from the Pepco-supplied grid), FCEB (including scenarios where hydrogen fuel is produced on-site using energy from the microgrid and where hydrogen fuel is produced on site using energy from the Pepco-supplied grid), diesel, CNG, and hybrid.

For BEBs powered using electricity from the microgrid, rather than buying the microgrid and charging infrastructure outright, the County partnered with AlphaStruxure, who builds, owns, operates, and maintains these systems. The County then purchases the electricity and resilience supplied by the microgrid and charging infrastructure on an ongoing basis; these costs are captured under energy consumption costs.

The LCCA includes one-time capital costs as well as reoccurring energy and O&M costs. Figure 12-1 displays cost items captured in the LCCA by propulsion type. To allow for a direct comparison, all costs in the LCCA were escalated to 2023 dollars using the White House GDP deflator (The White House, n.d.). The preliminary findings of the LCCA are summarized in Figures 12-2 and 12-3. The life cycle cost of BEBs, FCEBs, diesel, CNG, and hybrid buses are estimated over 12 years. Using the inputs and assumptions described in this memorandum, diesel buses have the lowest life cycle cost, followed by BEBs powered by the Pepco-grid. FCEBs fueled with hydrogen produced on-site have the highest life cycle costs, followed by FCEBs fueled with hydrogen generated using electricity from the Pepco-grid.

Figure 12-1: Cost Items included in LCCA per Propulsion Technology

A table showing cost items by bus type.

Cash Flow Analysis

A cash flow analysis was conducted; this comprises a year-by-year estimate of expenditures, including capital and operations and maintenance (O&M) expenditures by bus depot over the next 12 years. The cash flow analysis used the costs identified in the LCCA to project costs over the analysis period (2024-2035).

The cash flow analysis assessed initial capital costs for bus procurement as well as the costs associated with the mid-life bus overhaul and battery replacement on a year-by-year basis, broken down by bus propulsion type. Also included in the cash flow analysis is the costs of associated equipment, annual energy and fuel costs, and O&M costs. Figures 12-4 and 12-5 display year-over-year expenditures for MCDOT at all facilities.

The County is mindful of the capital cost spike in 2030 resulting from a substantial replacement of conventional buses with FCEBs projected in that year. A potential mitigation involves deferring some of these scheduled replacements and shifting the associated capital outlay across 2031-2033. This approach will decrease the spike without delaying achievement of a 100% zero-emission fleet in 2033, however, an increase in O&M costs would be expected in years that replacements are deferred due to the operation of vehicles beyond their useful life.

Figure 12-6 displays aggregate expenditures at MCDOT facilities between 2024 and 2035, which are summarized year-over-year in Figure 12-4 and displayed year-over-year in Figure 12-5. The total cost of transition over the 2024 to 2035 assessment period is $2.359 billion ($YoE$) and this includes rough order of magnitude costs associated with the construction of the new facility, capital costs associated with bus procurement (582 total) and bus overhaul (240 total), infrastructure upgrades, energy and fuel costs, as well as operations and maintenance costs. MCDOT conducted a high- level baseline analysis to compare the cost of transitioning to a ZEB fleet to a scenario where its current (2023) fleet inventory made up of 61-percent diesel, 25-percent CNG, and 14-percent hybrid is maintained in order to understand the marginal costs of the transition plan. The high-level analysis estimated the baseline costs to be 70-percent of the ZEB transition costs.

Figure 12-2: Comparison of Life Cycle Costs by Propulsion Type (thousands of 2023$

Shows capital and operating costs by vehicle type.

Figure 12-3: Comparison of Life Cycle Costs by Propulsion Type (thousands of 2023 $)

Compares life cycle costs of buses by type, also by capital and operating cost.

Figure 12-4: Year-Over-Year Expenditures at all Facilities (thousands of YoE$)

Shows costs by year and type of cost (new facilty, capital, energy/fuel, O&M,

Figure 12-5: Year-Over-Year Expenditures at all Facilities (YoE$)

Chart showing costs by year by cost type

Figure 12-6: Aggregate Expenditures, 2024-2035

Chart with single bar showing total costs from 2024 to 2035, broken down by type of cost

CHAPTER 13 – FUNDING & FINANCE SCAN

The Funding and Finance Scan covers the following sources:

- County Capital Improvements Program
- Federal Funding
- State Funding
- Alternative Sources

COUNTY CAPITAL IMPROVEMENTS PROGRAM

The Montgomery County FY25-FY30 Capital Improvements Program (CIP) includes $245 million to support the transition to a zero-emission Ride On fleet, and provides for the replacement of 182 heavy- duty zero-emission buses. The CIP also includes an additional $11 million for the EMTOC Hydrogen Fuel Cell Buses and Fueling Site project, with expenditures in FY25 and FY26.

The County conducted a funding and finance scan using the Grant Research and Analysis Navigation Tool System (G.R.A.N.T.S.) and the County consultant's Dashboard tool (Dashboard). The Dashboard is an integrated, user-friendly tool that streamlines the grant discovery process. Through automated data extraction and a facilitated quality control process, users can leverage easily accessible grant information to better align with project planning as well as provide insight on eligibility requirements.

> *The County continuously evaluates & identifies all available funding sources; this will be even more critical as it transitions its fleet to zero emissions in the next few years.*

The Dashboard is an internal tool that identifies potential available funding sources based on project type and location. The tool was supplemented by in-depth review of funding opportunities offered by the major federal departments and their respective divisions and agencies, such as the U.S. Department of Transportation, the U.S. Environmental Protection Agency, and the U.S. Department of Energy. The scan was further supplemented with a review of state and local funding opportunities.

The funding and financing scan is considered a living document to be updated as additional funding opportunities are announced or notice of funding opportunities (NOFOs) are revised. Through MCDOT, the County is eligible to apply for some of the opportunities identified; for others, MCDOT must partner with an eligible applicant. An expanded funding and finance scan can be found in the Appendix.

FEDERAL FUNDING

Multiple funding sources are offered by federal agencies to aid in the transition to ZEB. The County already takes advantage of some of these funding programs and successfully receives grants from them. The funding agencies include FTA, USDOT, EPA, and FHWA as outlined in Figure 13-1.

Figure 13-1: Potential Federal Funding Sources

Federal funding sources with name of funding or grant program, the agency from which it comes, and a description of each source.

STATE FUNDING

The Maryland Energy Administration offers multiple funding sources in support of ZEBs, such as:

Clean Fuels Incentive Program

- The Clean Fuels Incentive Program provides financial assistance for the purchase of new converted alternative fueled fleet vehicles in the state of Maryland
  - Both electric and hydrogen buses are covered under the program
- This is a competitive state-wide grant program
  - Eligible applicants for the program include municipal authorities and local governments

Electric Vehicle Supply Equipment (EVSE) Rebate Program

- The Electric Vehicle Supply Equipment (EVSE) Rebate Program provides funding assistance for costs incurred acquiring and/or installing qualified EV supply equipment
- Eligible applicants for the rebate program include units of state or local government
- Costs for the rebate include site design, charger equipment, installation, labor, site preparation, upgrade for utility connections, signage, and equipment necessary to implement and operate the charging station

ALTERNATIVE SOURCES

The County is also using public-private partnership (P3) business models to finance/design/build/own/ operate/maintain some of its ZEB investments. For example, MCDGS entered into an agreement under a P3 contract with a private concessionaire to deploy the Brookville Smart Energy Bus Depot microgrid project selecting the Energy-as-a-Service (EaaS) business model. EaaS consists of turn-key project management services for the construction and installation of infrastructure and the deployment of smart charging. This contract allows the microgrid and charging infrastructure to be delivered at no upfront cost to the County. and provides a long-term agreement between the Concessionaire and the County ensuring predictable operating expenses and guaranteed performance for sustainability, resilience, and reliability. As implemented for the Brookville Smart Energy Bus Depot, EaaS offers a financing mechanism for additional facility modifications in the future. The County is pursuing similar business models to support additional ZEB projects at its EMTOC facility, including a new microgrid to support BEBs and FCEBs.

CHAPTER 14 - EMISSIONS ANALYSIS & QUANTIFICATION METHODOLOGY

As part of this initial ZEB transition study, the County conducted an economic analysis including an emissions analysis that quantifies the impacts on greenhouse gas emissions (GHGs) by bus depot. The emissions analysis assesses the emissions impacts of diesel, CNG, and hybrid buses, as well as the emissions impacts of BEBs and FCEBs powered by a microgrid. This analysis only considers the GHG emissions emitted directly by the vehicles which is consistent with the requirements of 49 U.S. Code § 5339 – Grants for buses and bus facilities. While not currently included in the transition plan, this emissions analysis also estimated the emissions associated with Renewable Natural Gas (RNG) powered buses anticipating the possibility of this type of fuel being available to the County to charge zero emission vehicles in the future.

The emissions analysis assesses the following GHGs: carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). The findings of the emissions analysis are presented in annual metric tons of CO2 equivalent (CO2e). Using CO2e allows for a direct comparison of the GHG emissions because it estimates the comparable mass of emissions that would create an equal amount of global warming impact. For example, the CO2e of CH4 is 25, meaning releasing 1 kilogram (kg) of CH4 into the atmosphere is the approximate equivalent to releasing 25 kg of CO2.

Figure 14-1 and Figure 14-2 represent the annual CO2e by bus propulsion type. Average annual emissions are sensitive to the average distance traveled. Because buses of different propulsions have varying average annual miles traveled, as influenced by depot assignment and fueling constraints (i.e., all CNG buses operate out of EMTOC and the service operated out of EMTOC accumulates more annual miles than the other depots), the average emissions per mile by propulsion type was also quantified and provides a direct comparison between the emissions produced by each technology. These results are as displayed in Figure 14-2 and Figure 14-3. Both figures include a 10 percent buffer due to potential variances in assumptions.

The County's transit fleet direct emissions impact will decrease as MCDOT transitions from its current fleet portfolio to a zero emissions-based fleet inventory. Figure 14-4 summarizes the direct emissions over time (in thousands of metric tons), as well as the percent of MCDOT's fleet that is ZEB. As displayed in Figure 14-4, the County will complete their transit fleet transition by 2033, at which point the transit operations will have zero direct emissions impacts.

When the transit fleet transition is complete in 2033, Montgomery County's transit operations will have zero direct emissions impact.

Figure 14-1: Annual Emissions Impacts per Bus Propulsion Type

Shows emissions by vehicle type with CO2/bus, annual miles and CO2/mile

Figure 14-2: Annual CO2e by Bus Propulsion Type – 2023

CO2 produced by bus type

Figure 14-3: CO2e per Mile by Bus Propulsion Type

Emissions per mile by bus type

Figure 14-4: County Transit Buses Direct Emissions Over Time

Bus direct emissions over time, starting at 33 MT of CO2 in 2024 and getting lower and lower until the number reaches 0 in 2033

CHAPTER 15 - IMPLEMENTATION & NEXT STEPS

ZEB Transition Roadmap

MCDOT is slated to convert their entire fleet to ZEB by 2035, has already made significant, indus- try-leading investments in sustainable zero-emission supporting infrastructure, and is confidently progressing along the path to a successful, sustainable, and better future for the County, its residents and the millions of riders that utilize the County's transit services each year. The major elements of the transition are detailed in Figure 15-1.

This ZEB Transition Roadmap demonstrates the connection between the timing of ZEBs and ZEB infrastructure implementation, as well as the in- troduction of the necessary new Bus Maintenance and Storage facility to support the ZEB capacity needs of the future fleet and service growth.

Key Findings & Recommendations

- The County's early actions have demonstrated a clear commitment to meeting the Climate Action Plan goal of 100% zero-emission in 2035; this momentum has the County on pace to complete the transition ahead of schedule, however, critical dependencies have the poten- tial to cause delays
- The use of Public-Private Partnerships (P3) agreements for acquiring sustainable ZEB infrastructure offers a wide range of benefits, including a predictable cost structure, and the transfer of risk away from the County

- Domestic bus production capacity has recently seen a rapid contraction with products from several major manufacturers no longer available in the marketplace due to economic factors; lower total manufacturing capacity and fewer options means less competition, higher costs and longer lead-times to acquire ZEBs – the County should initial vehicle procurement programs multiple years in advance of target bus delivery timeframes

- The high utilization level of the County's transit fleet places them in the top 8% of the nation based on annual miles per bus; this results in an expected reliance on high energy-capacity ZEB technology, such as FCEBs, especially for service operated by the EMTOC depot, other- wise alternative solutions may be required (i.e., increasing the fleet size, significant use of on- route chargers, reduction in transit service, etc.)

- The parking, servicing, and ZEB "refueling" capacity of each of the County's bus operation and maintenance facilities is critical to the suc- cess of the transition; capacity and infrastruc- ture must be available and ready on-time to support the future ZEB fleet – completed and committed infrastructure projects will only be able to transition ~40% of the current fleet

- The ongoing redesign of the County transit service plan (via the Ride On Reimagined study) creates challenges for an accurate assessment of future ZEB technology requirements; the County should assess the impact of the service plan changes on daily energy needs and optimal ZEB fleet mix.

  - The Nicholson Court depot is not owned by the County and cannot be upgraded with ZEB infrastructure due to the terms of the lease agreement; a new, zero-emission bus facility must be made available to complete the tran- sition, with enough capacity for all of Nich- olson Court's buses and able to accommodate planned transit service expansions, such as the County's future Flash BRT services

  - The total cost of the transition from 2024 through 2035 is expected to be ~$700 million higher than a baseline fleet of conventionally fueled buses; the County should continue to aggressively pursue grants and funding oppor- tunities for ZEBs, zero-emissions infrastruc- ture projects, and related facility upgrades

  - Zero-emission technology is continually seeing rapid development; product offer- ings and solutions may not yet be considered "service proven." The County should consider the utilization of an Emergency Contingen- cy Vehicles provision in accordance with FTA guidelines. Conventionally fueled vehicles may be the ideal contingency fleet candidates during the County's transition to full electrification, as they offer the range and flexibility needed during emergencies while advancements in zero-emission technology are still ongoing

Key Implementations

- Advance the acquisition and delivery of BEBs under the County's current contract with bus manufacturer, GILLIG LLC

- Expand the deployment of BEBs at the Coun- ty's Brookville Smart Energy Depot with newly acquired BEBs

- Continually monitor BEB and microgrid infra- structure performance; apply lessons learned to the development of future transit service plan and the expansion of future ZEB infrastructure

- Use Renewable Natural Gas (RNG) available from WSSC Water via the Piscataway Bioenergy Project to realize additional intermediate emissions re- ductions via operation of the current CNG fleet, resiliency and power generation equipment, and as used by facilities for heating purposes

- Expand ZEB infrastructure capacity at the Brookville Smart Energy depot in order to achieve 100% ZEB operation at this facility
- Complete the EMTOC depot microgrid and the County's (and the East Coast's) first green hydrogen production project, supporting the introduction of both BEBs and FCEBs operating out of the Gaithersburg facility
- Monitor the performance of the County's first FCEB fleet; apply lessons learned to the devel- opment of future transit service plan design and the expansion of hydrogen infrastructure at County facilities
- Re-evaluate the fleet's energy needs and com- patibility with ZEB technology upon completion of the Ride On Reimagined study, involving the redesign of the County's transit service plan
- Build a new, 100% Zero-Emission Operation and Maintenance facility for County buses, to complete the transition and provide additional capacity for transit service expansions
- Continue to leverage smart data and assis- tance technologies such as Charge Management Systems and on-board vehicle telematics to support effective deployment of ZEBs and per- formance monitoring
- Expand the County's ZEB training programs and ensure the workforce is ready to continue providing safe, reliable operation and mainte- nance of zero-emission fleet equipment
- Continue to monitor for available grants and funding opportunities to help offset the in- creased costs associated with zero-emission technology
- Update the transition plan as appropriate based on changes in zero-emission technolo- gy, direct experience with operating ZEBs and zero-emission infrastructure, available grants and funding opportunities, changes in market factors impacting zero-emission vehicles such as the cost of renewable energy sources and the availability of green hydrogen, etc.

Key Milestones

- In 2024:
  - Initiate new zero-emission bus facility site development, community outreach, design, and construction program
  - Initiate 5-year procurement contract for BEBs and FCEBs (deliveries occurring in '27-'31)
- In 2026
  - Complete Phase 1 BEB charging capacity expan- sion and H2 fueling capacity expansion at the EMTOC Facility
- In 2028
  - Complete Phase 2 hydrogen fueling capacity expansions at the EMTOC and Brookville facil- ities
- In 2029
  - Initiate a 4-year procurement contract for BEBs and FCEBs (deliveries occurring in '32-'35)
- In 2030
  - Open the new zero-emission bus facility with capacity for 180 ZEBs
  - Close Nicholson Court facility and perform full- scale fleet reassignment and realignment with capacity constraints

- In 2033
  - Achieve a 100% Zero-Emission bus fleet with retirement of last CNG and Diesel buses
- In 2035
  - The future bus depot will be at full operating capacity, accommodating Montgomery Coun- ty's various transit services, including expan- sions projected for 2035; estimated bus counts are included in Chapter 8

Figure 15-1: Zero-Emission Transition Roadmap

Chart showing key events over time for several aspects of the project from 2023 to 2035

Final Remarks

As indicated in the Executive Summary, this analysis is a living document. The County, through MCDOT and MCDGS, will routinely monitor any changes in technology, service plan, peer agency and service partners' experience with ZEBs, related industry factors such as ZEB cost and availability, and various assumptions in the underlying analysis; updates to this transition plan will be made as appropriate.

APPENDIX

The Appendix contains the following detailed technical studies that were summarized and referenced in this ZEB Transition Study:

- Appendix A: Detailed Energy Modeling Approach and Findings
- Appendix B: Future "FLASH" (BRT) Service Analysis
- Appendix C: Zero-Emission Fleet Transition Model Assumptions and Methodology
- Appendix D: Space, Maintenance, and Fueling Capacity Analysis
- Appendix E: Economic Analysis – Technical Memorandum
- Appendix F: Emissions Analysis – Technical Memorandum; Consideration of Renewable Natural Gas

Appendix A - *Detailed Energy Modeling Approach and Findings*

Detailed Energy Modeling Approach and Findings

PEER Inputs

To model the potential variety of operating conditions in the County's service area, a variety of ambient temperatures and bus types were simulated in PEER. The PEER analysis simulation was conducted using 2019 and 2022 General Transit Feed Specification (GTFS) data. Results from the PEER simulation may differ when analyzing more recent GTFS data. Related Ride On operating conditions were reviewed for incorporation in the analysis and the following list of inputs were utilized.

- September 2019 and September 2022 GTFS data pertaining to Ride On's fixed-route service
  - September 2022 GTFS data was utilized to capture current FLASH services, the County's Bus Rapid Transit system

    - 1,111 unique blocks identified from GTFS datasets, including 649 unique weekday blocks
    - 82 unique routes identified from GTFS datasets
- Passenger loading for 82 unique routes
- Montgomery County historical seasonal temperature data (NREL, n.d.)
    - Average temperature of coldest day within past six years used for simulations: 10°F
    - Average temperature during Winter operations with a Diesel Fired Heater (DFH): 32 - 40°F
    - DFH Specifications:
        - 35 kW of heater power (Valeo, n.d.)
        - 3.6 kg/h diesel consumed (Valeo, n.d.)
        - 11.49 (kg-CO2/hr.) emitted
    - Average temperature during Spring and Fall Operations: 68°F
    - Average temperature of hottest day within past 6 years used for simulations: 88°F
- Vehicle types modeled with both new and seasoned batteries
    - Technical data on 35-ft BEB (560 kWh capacity)
    - Technical data on 40-ft BEB (660 kWh capacity)
    - Technical data on 60-ft BEB (660 kWh capacity)
- Current, degraded, and estimated future battery capacities
    - Future battery capacities are based on the assumption that battery density will increase by ~5% every year; the specific future battery capacity to analyze in-depth was chosen to be 800kWh
    - These values are deduced by reviewing data provided by energy.gov, which shows an average year-over-year energy density increase from 2008-2020 of 24.5% in conjunction with a review of historical BEB energy values (Energy Efficiency & Renewable energy, 2022).

Methodology

The PEER ZEB Energy Consumption model considers three major energy-drawing components of a ZEB. These components include the dynamic/propulsion system, the HVAC system, and the auxiliary loads. By combining the energy demands for all three systems, the model delivers an estimated kWh/mile value for a specific bus traveling along a specific route under certain weather conditions.

1. The dynamic/propulsion system takes into consideration inputs including a bus's velocity, accelerations, displacement, and weights. The model also considers several forces such as the drag, rolling resistive forces, and gradient forces that act on the bus as it travels on its service block. Inputs for the dynamic/propulsion system include the type of bus used for the simulation,

the route the bus travels on, travel time, the acceleration of the bus, the size of the battery, and the efficiency of the bus.

2. The next system that the PEER model considers is the HVAC system. The model utilizes a “ground- up” approach to determine the HVAC system energy requirements. Using inputs such as passenger loading, ambient temperatures, desired internal bus temperatures, fresh air, solar loads, and heat losses through walls and windows, the energy demand for the HVAC system is calculated. Due to the significant amount of energy consumed by HVAC systems (especially in colder climates) and the resulting reduction in operating range, agencies may elect to have their BEBs equipped with Diesel Fired Heaters (DFHs). These auxiliary heating devices help reduce the impact of cold-weather operation on range but result in having a direct source of diesel combustion emissions on board each vehicle, including a “tailpipe.” Despite their advantages, DFHs are not being utilized in this ZEB Transition Plan as they are contrary to the County’s transitional goals, however, their potential impact on energy consumption and schedule compatibility are presented in portions of the analysis below for informational purposes, only.

3. In determining the energy demands of the auxiliary loads, the model assumes all non-HVAC auxiliary appliances will be drawing power at a constant rate while in operation based upon the power rating of all the auxiliary loads equipped on the modeled bus.

The PEER model can be utilized to generate different predicted energy consumption rates each under different conditions. The energy consumption rates can be calculated for conditions representing ideal conditions, minimal HVAC needs, off peak traffic patterns, and passenger loads.

Block Analysis

The PEER analysis provides essential information to determine if blocks can be completed with facility- only charging, or if on-route charging is required for a full fleet of BEBs. If on-route charging is deemed necessary, then proposed locations can be evaluated for satisfying block range needs and providing desired comfort levels in terms of block completion and remaining State of Charge (SOC). Additionally, the block analysis that determines the SOC remaining after each bus returns to the facility can be used to determine a peak kW charging demand for each half-hour period throughout the night. Blocking is used in this analysis to refer to the practice of optimizing schedules by dividing parts of scheduled routes among vehicles and drivers. Blocks are defined as paths taken by a bus from when it leaves the facility to when it returns to the facility. During this period, the bus may assist in providing service on multiple routes.

Energy requirements are calculated for each block by simulating bus operation along the prescribed route(s), to every scheduled stop, and in consideration of various operating conditions, including:

- Temperature
- Route elevation profile
- Regional solar loading
- Passenger loading by route
- Bus type and properties
- Heating mechanism (diesel versus electric)

Completion Rates Using Montgomery County's Existing Block Schedule

The following tables show the results of the PEER simulation system wide using the most current data available, including a combination of MCDOT's 2019 and 2022 block schedules; Fall 2019 provides the baseline, and US-29 FLASH bus service is incorporated from 2022 (this was the most recent schedule data available when the analysis was conducted – the County will continue to utilize the latest schedule data available for future plan revisions and updates). These tables show that the most favorable scenario in terms of block completion is the FCEB with a DFH. This is due to the long range gained from FCEBs, and the DFH being able to supplement the battery energy when heating the bus during the winter months.

Table A-1 below shows the number of MCDOT's existing block assignments that could be completed with BEBs, under winter conditions, with and without a DFH.

Table A-1: Block Completion Summary – Seasoned Battery in Winter

Table showing block possibilities by facility vehicle propulsion, size, energy and completable blocks

Additionally, **Table A-2** below shows the completion rates of blocks operating current FLASH service on US-29 using technical data for 60-ft buses.

Table A-2: Flash US-29 Block Completion Summary – Seasoned Battery in Winter without DFH

Table showing completion rates of blocks for current FLASH service

Future Battery Technology

From the route and block analysis data generated from PEER, the energy required to complete each block was calculated. Using these results, the minimum theoretical energy capacity needed to achieve 100% completion on all blocks without any rescheduling was calculated. The results are shown in **Table A-3**.

Table A-3: Energy Capacity Needed for 100% Block Completion

Table showing energy capacity needs by facility and bus type and size

As shown in the table above, all 2019 and 2022 service blocks can be completed with no schedule changes when battery capacity reaches 1,408 kWh even with a seasoned battery on a 40-foot bus. Similarly, a fuel cell bus that has a 970 kWh equivalent fuel cell can complete all blocks. These values decrease to 1,261 and 868 kWh for a BEB and FCEB, respectively, when a DFH is used. Some of these capacities may be achievable in the future but will take considerable time before they become available for commercial purposes. For some of the extremely long and energy intensive blocks, re-blocking is suggested, even if alternative technologies like on route charging or fuel cells are used. Current hydrogen capacities on fuel cell buses range from 38kg to 57.5kg.

Table A-4 below shows the energy capacities needed to complete the blocks operating the County's US- 29 FLASH services.

Table A-4: Energy Capacity Needed for 100% Block Completion – US-29 FLASH

Table showing energy capacity needed for EMTOC facility for FLASH buses

Energy Consumption

Table A-5 below shows the minimum, average, and maximum energy consumption of the bus for each heater type on all blocks when the buses are operated in winter. When operating with a DFH, significantly less energy is being pulled from the battery per mile, which allows for great block completion and operation flexibility.

Table A-5: All Facility Energy Consumption at Winter, With DFH-Equipped BEBs

Table showing energy consumption by bus size during Winter with heating and no heating

Block Combination Completion Rates

The block analysis above assumes that one bus operates one block per day. However, this does not properly reflect operations from a vehicle-level perspective because the County's transit buses operate multiple blocks each day. To better reflect this operating service and provide completion rates that are more representative of a fleet of vehicles, the individual blocks were linked together using the bus to the County's block linkages. This information includes the bus size assigned to each block, which is also considered in this combined block analysis. With this information, along with the individual block analysis described in **Table A-3**, a combined block analysis can be performed, analyzing the completion rates when linking multiple blocks to a single bus. This analysis was done using both BEB and FCEBs. However, when conducting the FCEB combined block analysis, 35-ft buses were modeled with 40-ft bus specifications, as technical data on a 35-ft FCEB is not currently available.

If there was more than 30 minutes of time between blocks, it was assumed that these buses would return to their depot to get recharged or refueled, depending on if they were BEBs or FCEBs. Following the County's substantial BEB infrastructure deployment (Brookville Microgrid), it was assumed that BEBs were charged with 60 kW chargers (3:1 dispensers-per-charger, 1:1 dispensers-per-bus, using 180 kW Heliox Flex chargers), while FCEBs were assumed to be fully refueled in 15 minutes. Based on these linkages, as well as the block analysis results described above and mid-day recharging or refueling, the number and completion rate of these combined blocks was calculated. **Table A-6** show the results of this analysis when using 35-ft, 40-ft, and 60-ft buses with a degraded battery operating in winter conditions on weekdays without DFH.

Table A-6: Weekday Combined Block Completion Summary – Seasoned Battery, Winter, No DFH

Table showing completed blocks by facility and bus type.

Model Recommendations

In summary, the transition strategy recommendation informed by the model results is:

1. Sequence the procurement of BEBs over several years to match blocks that can be completed with current technology, in anticipation of future technology that will allow for most, if not all, blocks to be completed. This approach can also be used to reduce or even eliminate the need for block splitting. Coordinating the Fleet Replacement Plan with charging infrastructure installation based on the PEER results will allow the agency to take advantage of the time required to install charging infrastructure prior to BEB deliveries. As the infrastructure and fleet installation/delivery continues, energy density increases will be experienced allowing additional blocks to be completable until 100% fleet electrification is achieved.

2. Combine separate blocks for buses that return to the facility with significant SOC remaining. As shown in the block analysis above, mid-day charging can increase the number of blocks that a BEB can operate in a day. However, this may increase operating costs due to higher "peak" or "demand" electricity costs during the mid-day hours.

3. Adjust or split longer blocks. As shown in the block analysis, there are several blocks that cannot be completed, even with a 54% increase in battery capacity from future battery technology. By splitting these longer blocks, the current schedule can become completable without compromising service levels. However, this will increase operating costs due to the operation, maintenance, and storage of the additional buses that will likely be required, particularly if no DFH is used.

4. FCEBs offer 100% completability due to the higher onboard energy and refueling times that are comparable to conventional buses. FCEBs offer a feasible way to convert the fleet to ZEB with today's technology. There are other challenges associated with hydrogen that should be considered such as infrastructure upgrades and sourcing hydrogen, as well as the higher ongoing cost for fuel that will impact lifecycle costs and total cost of ownership.

5. Utilize a charge management system to optimize the facility charging requirements and minimize (or eliminate) peak power demand.

Appendix B - Future "FLASH" (BRT) Service Analysis

Future "FLASH" (BRT) Service Analysis

In addition to the PEER analysis of the County's current transit service, a preliminary analysis on future FLASH Bus Rapid Transit (BRT) services was conducted. The PEER analysis described above utilizes current schedule information to provide information on all blocks within the County's system. This information includes total number of blocks, total number of routes, deadhead distances, departure and arrival times, stop locations, and distances between stops. From this information, the PEER analysis can simulate these service blocks and estimate the total energy required to operate these blocks with ZEBs. At the point of completing this initial release of the transition plan, such information is not available for future routes and blocks that are still in the planning phase. Thus, to conduct an analysis of future FLASH services, a few assumptions needed to be made in place of the block information that is typically provided by GTFS. Additional details regarding the Future FLASH service analysis are provided in Appendix X. In general, the results of the analysis found that FCEBs are the preferred technology for this type of service and the transition plan reflects the use of FCEBs where fleet expansions occur in order to support future FLASH services.

Approach and Methodology

Four (4) different future FLASH services were analyzed using the latest information for this analysis:

- Veirs Mill Road
- MD355
- New Hampshire Ave
- North Bethesda

These routes were simulated based on current stop location information available on these future FLASH services. The current stop locations were used to determine the time, distances, and elevations between stops. Once the route information was obtained, these routes were modeled using PEER to estimate the energy required to complete the route.

Typically, the next step would be to get the block energy rates based on the route energies from the PEER simulations and GTFS information for each block. However, since this information is not available for these future routes, the following assumptions were made in place of the block information:

- Service begins at 5:30 AM, ends at 1:00 AM
- Peak Periods:
  - Morning Peak Period: From 5:30 AM to 8:30 AM
  - Afternoon Peak Period: From 3:30 PM to 7:00 PM
- Headways:

  - 7.5-minute headways during peak periods
  - 15-minute headways during off-peak periods
  - MD355 headways were based on published information
- Vehicle Conditions:
  - Technical data for 60-ft FCEB (920 kWh Capacity)
  - 10°F Ambient Temperature
  - No DFH
  - 25% Passenger Capacity
- Minimum recovery time of 5-minutes
- HVAC energy consumed during recovery times
- All buses were presumed to operate from the EMTOC facility

With these assumptions and derived route information, a schedule for each route in both directions was made to determine the level of service needed to meet the assumed headways. These schedules were then used to determine the amount of energy required for each bus, based on the estimated energy consumption rates from the PEER simulations. **Figure B-1** below shows a sample of the built schedule, tracking the time, distance, and energy levels.

Figure B-1: Sample Schedule for Future Flash Analysis

Image of a spreadsheet showing sample schedule routes for FLASH

If the energy required exceeded the energy capacity of the bus, the schedule was adjusted to account for the additional buses needed to maintain the assumed headways. With this approach, the minimum number of buses needed to operate each route was determined.

FLASH Analysis Results

Veirs Mill Road

The Veirs Mill Road FLASH route is currently planned to be a limited-stop, BRT service with twelve stations planned along Veirs Mill Road and MD 355. This BRT route aims to improve passenger transit mobility by connecting riders to high density housing, employment centers, and both branches of the Metrorail Red Line. **Figure B-2** below shows the route map of the Veirs Mill Road FLASH route.

Figure B-2: Veirs Mill Road FLASH BRT Route Map

Map with Veirs Mill Road FLASH route map

The currently planned Veirs Mill Road BRT route has a trip distance of 8.04 miles, a trip time of 26 minutes, and consumes 3.72 kWh/mi in winter conditions without DFH, based on PEER simulations of this route. **Table B-1** below shows a summary of the analysis of the Veirs Mill Road BRT route.

Table B-1: Summary of Veirs Mill Road FLASH BRT Analysis

Table shows a variety of key datapoints about the FLASH route.

As shown above, a minimum of 10 buses are needed to service the Veirs Mill Road BRT route. However, this minimum number of buses assumes that 4 of the 10 buses return to the depot to be refueled. Adding an additional 20% spare ratio to the minimum 10 buses needed, a total of 12 buses are needed to operate this route. This is less than the 15 buses that are currently planned to be allocated to the Veirs Mill Road route.

MD 355

The MD 355 FLASH BRT route is planned to provide upgraded service along the MD 355 Corridor. However, unlike the other future FLASH BRT routes, the MD 355 route has been split into five different variations: Clarksburg, Milestone, Germantown, Lakeforest, and Montgomery College. **Figure B-3** below shows the overall route map of the MD 355 BRT route, as well as the individual variations of the MD 355 BRT route.

Figure B-3: Route Map and Variations of MD 355

Map of FLASH Route for MD 355 with route variations

Due to the varied nature of the MD 355 route, as currently planned, each individual variation was treated as its own route and analyzed similarly to the previous BRT route analyses, with exception to the assumed headways. As shown above, the headways for each variation are defined, with added complexity due to certain variations overlapping with each other. As such, the analyses for the MD 355 route variations were adjusted to match the headways for each variation. **Table B-2** below shows a summary of the analysis for all five variations of the MD 355 FLASH BRT route.

Table B-2: Summary of MD 355 Analysis

Table of MD 355 Routes with information on energy consumption rate, trip time, recovery time, headways, buses assigned as well as spare and recovery buses

As shown above, a minimum of 56 buses are needed to complete all variations of the MD 355 FLASH BRT route. When adding a 20% spare ratio to this minimum, a total of 69 buses are needed. Additionally, some buses will need to return to the depot for refueling, depending on the variation the bus is servicing. All buses running the Clarksburg variation will need to return to the depot for mid-day refueling. Buses running the Milestone variation, however, do not need to return to the depot. Of all buses running the Germantown, Lakeforest, and Montgomery College variations, two buses for each variation will need to return to the depot. In other words, of the 34 buses operating on the Germantown, Lakeforest, and Montgomery College variations, six of them will need to return to the depot for mid-day refueling.

New Hampshire Avenue

The New Hampshire Avenue FLASH route aims to provide high quality transit service that improves the speed and reliability of bus service along the New Hampshire Avenue corridor. **Figure B-4** below shows the planned stop locations and route map of the New Hampshire Avenue FLASH BRT route.

Figure B-4: New Hampshire Ave. FLASH Route Map

Map of New Hampshre Ave FLASH route

The currently planned New Hampshire Ave. FLASH route has a trip distance of 9.51 miles, a trip time of 26 minutes, and is estimated to consume 3.18 kWh/mi in winter conditions without DFH, based on the PEER simulations of this route. **Table B-3** below shows a summary of the analysis of the New Hampshire Ave. BRT route.

Table B-3: Summary of New Hampshire Ave. Analysis

Table that summarizes New Hampshire Ave key requirements

As shown above, a minimum of 10 buses are needed to service the New Hampshire Ave. FLASH route. However, this minimum number of buses assumes that all 10 buses return to the depot to be refueled.

Adding an additional 20% to the fleet size, in accordance with the FTA's maximum allowable spare ratio a total of 12 buses are needed to operate this route. This is less than the 24 buses that are currently planned to be allocated to the New Hampshire Ave route.

North Bethesda

The North Bethesda FLASH BRT route is intended to connect the MD 355 BRT and Randolph Road BRT routes. **Figure B-5** below shows the planned stop locations and route map of the North Bethesda BRT route.

Figure B-5: North Bethesda FLASH BRT Route Map

Map of North Bethesda FLASH route

The currently planned North Bethesda FLASH BRT route has a trip distance of 3.31 miles, a trip time of 15 minutes, and consumes 3.89 kWh/mi in winter conditions without DFH, based on PEER simulations of this route. **Table B-4** below shows a summary of the analysis of the North Bethesda BRT route.

Table B-4: Summary of North Bethesda Analysis

Table showing key requirements of North Bethesda FLASH route

As shown above, a minimum of 6 buses are needed to service the North Bethesda FLASH BRT route. However, unlike the other BRT routes, these buses can complete all their assigned services without the need to return to the depot for refueling. This is most likely due to the short route distance and trip time. Adding an additional 20% ratio to the minimum 6 buses needed, a total of 8 buses are needed to operate this route. This matches the 8 buses that are currently allocated to the North Bethesda route.

Appendix C - *Zero-Emission Fleet Transition Model* - Assumptions and Methodology

Fleet Transition Model

Assumptions and Methodology

The following inputs and assumptions were utilized for the development of the fleet transition model:

- Fleet Inputs:
  - Current active fleet roster, as shown in **Chapter 5**
  - Currently planned acquisitions, as described in **Chapter 5**
  - Facilities and infrastructure plans, as described in **Chapter 6**
- Service Assumptions:
  - Continuous service provided throughout the transition, without the need for cuts or alterations
  - Service blocking from Fall 2019 schedule and ridership figures
  - Service blocking from Fall 2022 schedule for current Flash BRT services
  - Planned future services
- Vehicle Assumptions:
  - ZEBs must replace conventional buses at a 1:1 ratio (driven by capacity constraints)
    - BEB and FCEB assignments are based on the results of the energy modeling analysis, shown in **Chapter 7**
    - Introduction of BEBs to the fleet generally precedes FCEBs (driven by infrastructure capacity)
  - Conventional buses are replaced with ZEBs as soon as possible (informed by capacity and infrastructure constraints)
  - Expected service life based on FTA guidelines and County trends (generally, MCDOT service life = FTA ULB +1 year)
    - Near term replacements were adjusted to account for current BEB RFP and FCEB pilot program
      - Assumed 31 BEBs in 2025 and 2026 and 30 BEBs in 2027 are delivered with the current BEB RFP, for a total of 92 BEBs, which will replace 92 conventional buses at EMTOC and the Brookville Smart Energy Depot
      - Assumed 13 40-foot FCEBs are procured in 2025 as a part of the FCEB pilot program and will be replace 13 conventional buses at EMTOC
      - Assumed no other buses are procured until 2028

- Facility Assumptions
    - Depots are limited in which vehicle sizes that can be maintained and serviced at the depot
        - EMTOC can support 30-foot, 35-foot, 40-foot, and 60-foot vehicles
        - Brookville can support 22.5-foot, 30-foot, 35-foot, and 40-foot vehicles
        - Nicholson can support 22.5-foot, 30-foot, and 35-foot vehicles
        - New Facility can support all vehicle sizes
    - Spatial, maintenance, and fueling capacities described in **Chapter 8**
    - Depots will have the ZE charging/fueling infrastructure available in time and necessary to support the recommended fleet mix in 2035 goal (informed by energy modeling analysis)
        - New Facility will support BEBs and FCEBs; opens in 2030
        - Nicholson Court is a leased facility and will be unable to support ZEBs
        - Vehicles assigned to Nicholson Court will be relocated to either the New Facility or Brookville

Appendix D - Space, Maintenance, and Fueling Capacity Analysis

Space, Maintenance and Fueling Capacity Analysis

The intent of this analysis is to determine the maximum capacity at each facility in terms of space, maintenance, and fueling operations, separately. This allows us to identify which function is the primary limiting factor, secondary limiting factor (disregarding the other operating factors), etc., at each location, and quantify the potential unmet needs in each of these categories. The analysis utilizes 2023 as the baseline and the projections for the CAP goal target years of 2027 and 2035. The STV Fleet Transition Model is utilized for the fleet breakdown (quantity, length, fuel type, storage location, etc.) which was informed by STV PEER analysis for the Ride On operation and identified the prospective energy needs and ZEB fleet mix between BEBs and FCEBs.

Space Capacity

2023

Current space capacity at all three operating facilities is within acceptable limits. The recent construction of the microgrid at Brookville resulted in a reduction of (10) operating bus parking spaces taking the capacity from 150 down to 140 buses and an overage of 6% in rated capacity. Where short term capacity deficits are anticipated, the County has identified multiple off-site parking provisions near each depot that will be utilized as a temporary solution.

Table showing current space capacity by location

2027

Space capacity projected in 2027 reflects the displacement of (65) 22’-32’ vehicles currently operating at Nicholson Court (STS) and increases in the fleet size for GSSC (+13 40’ BEBs), and Veirs Mill and MD355 Central BRT operation (+25 60’ FCEBs). The majority of the displaced vehicles from Nicholson Court (50) are assigned to EMTOC based on surplus operating bus parking and the potential to utilize dead bus storage space; the balance (15) are assigned to Brookville. A reduction in dead bus storage capacity will also result from the implementation of the EMTOC microgrid which has not yet been quantified.

Brookville will exceed its operating bus parking capacity by (22) buses and, in order to maintain a satisfactory level of yard operation and bus circulation, these buses would need to be stored off-site. EMTOC will face significant operational challenges and inefficiencies in bus movements due to congestion, particularly due to an increase in the total 60' articulated bus fleet size from (16) to (41). Space currently used for commissioning and acceptance of new buses, and processing of buses retired at the end of their useful life, will not be available. In order to maintain a satisfactory level of yard operation and bus circulation, a minimum of (51) buses would need be stored off-site.

Table of space capacity by facility updated to 2027 estimates

2035

Space capacity projected in 2035 reflects the fleet growth of an additional (178) buses, comprised of (11) cutaway buses for the expansion of micro-transit service, (26) 40' BEBs for GSSC Phase 2, and (141) 60' FCEBs for the balance of the FY24-35 BRT projects, as listed.

Brookville will exceed its operating bus parking capacity by (73) buses and, in order to maintain a satisfactory level of yard operation and bus circulation, these buses would need to be stored off-site.

EMTOC will exceed its operating bus packing capacity by (192) buses and, in order to maintain a satisfactory level of yard operation and bus circulation, these buses would need to be stored off-site.

Table with space capacity estimates by facility for 2035

Maintenance Capacity

Maintenance Labor Capacity

Current Personnel

Current Fleet staffing levels and maintenance operations metrics are provided and are a critical factor in the accommodation of future fleet growth. The ratio of Mechanic Technicians to the number of vehicles is of particular importance to the success of the Fleet Maintenance operation. Fleet's target is 4.0 buses per Mechanic Technician and is currently operating at 4.4 buses per Mechanic Technician. Collective industry experience with zero-emission buses indicates that reliability and availability are currently lower than conventional buses. The preventive maintenance labor requirements for ZEBs are however slightly lower than conventional, but a potential increase in allowable buses per mechanic is quickly offset by a higher frequency of defects and service failures. For purposes of this capacity analysis, a maximum allowable ratio of 5.0 buses per Mechanic is provided as a point of reference but maintaining a ratio of between 4.0 – 4.5 is advisable.

Table showing maintenance personnel for current time (2023)

24/7 Operation Current

Due to the considerable fleet growth projected for the Ride On fleet, the maximum maintenance personnel capacity is considered based on a 24/7 maintenance operation at each bus facility. Brookville is currently operating 3 maintenance shifts and is at its maximum capacity of technicians. Nicholson and EMTOC are operating 2 maintenance shifts; additional technicians at Nicholson and EMTOC are calculated by multiplying the current mechanic count by 1.5. Projections on the number of buses that can be maintained are provided based on the estimated number of Mechanic Technicians. Total number of buses that can be maintained, based on the ratio of buses per Technician are provided. With all three locations operating a three-shift schedule, a maintenance personnel capacity of 522 buses is determined.

Table showing current personnel capacity by facility (2023)

*Note: Fleet has confirmed that they are currently operating at their Maintenance Techs, Max. Capacity which is limited by support elements such as locker room capacity, toolbox capacity, ancillary space capacity, etc., however, this constraint is not currently considered in the 24/7 operation calculations. An additional analysis would need to be performed to determine whether additional lockers could be provided in the existing space or the feasibility of reclaiming existing spaces to add locker room capacity.

Post-2027

Maintenance capacity is severely impacted in 2027 with the closing of Nicholson Court. The number of Maintenance Technicians is reduced from 116 to 92 which results in a reduced maintenance capacity of 108 vehicles to a total of 414 buses. Based on the projected fleet sizes in 2027 and 2035, the maintenance capacity falls short by 13 buses (3 mechanics) and 191 buses (43 mechanics), respectively.

Table showing maintenance personell capacity estimates fo 2027

Maintenance Equipment Capacity

Current

The number of buses that can be maintained is also limited by the number of service lifts/bays available at each facility, for each respective bus length. The ratio of buses to the number of applicable lifts/bays is of particular importance to the success of the Fleet Maintenance operation to ensure adequate space and availability for preventive maintenance and running repairs. Fleet's target is 11.0 buses per bay and is currently operating at up to 16.0 buses per bay in some cases. A bus to bay ratio in excess of 16.0 is not advisable and the calculations for 16.0 buses/bay is presented as the capacity limit. With the current facility space/equipment, a maximum fleet size of 480 buses is determined and is adequate for the current fleet of 389 buses.

Table showing the current bus maintenance capacity by vehicle size by facility (2023)

Post-2027

Maintenance Equipment capacity is severely impacted in 2027 with the closing of Nicholson Court. The number of buses that can be serviced with the available lifts/bays is reduced to 416. This is closely in line with the estimated maintenance labor capacity (assuming 24/7 operation) of 414 buses. Based on the projected fleet sizes in 2027 and 2035, the maintenance equipment capacity is estimated to be:

2027

- (384) 35-40' bus capacity vs. a combined, (386) 22-40' bus fleet; this is considered adequate for 22-40' buses assuming all buses 40' and smaller will utilize available 35-40' bus lifts/bays.
- (32) 60' articulated bus capacity vs. (41) 60' articulated bus fleet; this is considered inadequate and indicates a deficit of (9) buses or (1) 60' lift/bay.

2035

- (384) 35-40' bus capacity vs. a combined, (423) 22-40' bus fleet; this is considered inadequate and indicates a deficit of (39) buses or (3) lifts/bays.
- (32) 60' articulated bus capacity vs. (182) 60' articulated bus fleet; this is considered severely inadequate and indicates a deficit of (150) buses or (10) 60' lifts/bays.

Table showing 2027 levels of bus maintenance capacity by facility

Fueling Capacity Conventional Current

Conventional fueling manpower and service is provided by a 3rd party contractor. Estimated diesel and CNG fueling capacities are provided based on number of dispensers, service time per bus, and daily service window. Current diesel and CNG fueling capacities across the three maintenance facilities are determined to be 479 buses and 205 buses, respectively.

Table showing fueling capacity by facility – current (2023)

Post-2027

Estimated diesel fueling capacity is reduced due to the closing of Nicholson Court. Projected diesel and CNG fueling capacities across the two remaining maintenance facilities (Brookville, EMTOC) are determined to be 342 diesel buses and 205 buses, respectively. This is considered adequate for the projected diesel and CNG bus fleets in 2027 of (206) and (77) buses, respectively. This is considered adequate beyond 2027 as the transition continues and the conventional fleet sizes are reduced further.

Table showing fueling capacity in 2027 by bus type and facility

Battery-Electric

Current

Battery electric fueling/charging capacities are provided based on number of charging dispensers, charger-type (60kW & 450 kW chargers) estimated charging time per bus, and daily charging window. The current charging capacity of (71) buses is more than adequate for the current fleet of (14) 40’ BEBs at Brookville.

Table showing fueling/charging capacity for electric vehicles (2023)

Post-2027

Estimated charging capacity in 2027 also reflects the inclusion of the EMTOC Microgrid which adds an additional capacity of (39) battery-electric buses: (30) buses using 60 kW depot chargers and (8) buses using the 450 kW “fast” charger.

The total battery-electric bus capacity is determined to be (110) buses between the two facilities and is considered adequate for the projected fleet of (106) BEBs in 2027.

Table showing fueling/charging capacity for electric vehices 2027

As there are no other planned charging capacity improvements confirmed at this time, the total battery- electric bus capacity of (110) buses between the two facilities is considered severely inadequate for the projected fleet size of (205) BEBs in 2035; a deficit in capacity of 95 BEBs.

*Note: DGS and OES have always assumed that there would be a need to charge electric buses during layovers between peak service. Although the battery-electric bus charging capacity presented in this analysis is simplified, the STV PEER analysis previously performed takes into consideration mid-day charging, route schedule data and numerous critical operating parameters (service blocks, block linkages representing the amount of work each bus completes in a day, severe operating conditions, passenger loading, etc.) Expanding the DGS daily bus servicing arrangement would allow for additional fueling/servicing of buses throughout the day but is not expected to increase service block completability under the harshest operating conditions anticipated.

Hydrogen Fuel Cell

Current

The facilities currently do not have any hydrogen fueling dispensers or infrastructure. Accordingly, the current hydrogen fueling capacity is zero (0) buses.

Post-2027

Estimated hydrogen fueling capacity in 2027 reflects the inclusion of the EMTOC Hydrogen Program (FY22 Grant Award) consisting of the 1 MW Electrolyzer, (3) H2 Gas Compressors, and (2) 350 bar transit dispensers, expected to be operational in 2025. Estimated hydrogen fueling capacities are provided based on the number of dispensers, estimated service time per bus, and daily service window. Hydrogen service time is conservatively estimated at 15 minutes per bus. The total hydrogen fuel cell bus capacity is determined to be (64) buses based on dispensing capacity, but limited to (20) buses based on the available hydrogen produced by the electrolyzer.

The hydrogen fueling capacity of (20) buses is considered inadequate for the projected fleet of (13) 40’ FCEBs (FY22 FTA grant pilot program) and (25) 60’ FCEBs in 2027 (Veirs Mill and MD355 BRT services).

Table showing fueling capacity of hydrogen buses in 2027 by facility

As there are no other planned hydrogen fueling capacity improvements confirmed at this time, the total hydrogen fueling capacity of (20) buses is considered severely inadequate for the projected fleet size of (400) FCEBs in 2035; a deficit of (380) FCEBs.

Appendix E - Economic Analysis – Technical Memorandum

Economic Analysis Technical Memorandum

Introduction and Purpose

Montgomery County Department of Transportation (MCDOT) owns and operates almost 400 buses providing Montgomery County residents with reliable transit options and resources. At present, MCDOT’s fleet consists primarily of diesel, compressed natural gas (CNG), and diesel-electric hybrid (henceforth “hybrid”) buses. MCDOT is transitioning from its current bus fleet to a zero-emissions bus (ZEB) fleet in accordance with Montgomery County’s Climate Action Plan, which calls for the County to reduce greenhouse gas (GHG) emissions by 100-percent compared to 2005 levels by 2035. To align with the County’s ambitious GHG reduction targets, MCDOT has developed Zero Emission Bus Transition Plan (henceforth “Transition Plan”) that charts a path to convert their entire fleet to ZEB by 2035.

Included in the Transition Plan is an economic analysis that assesses the financial implications associated with the transition to a ZEB by 2035. The economic analysis includes the following components:

- Life Cycle Cost Assessment (LCCA)
- Emissions Analysis
- Review of Funding and Financing Opportunities
- Cash Flow Analysis

An LCCA is an economic assessment that considers the total cost of a project over a defined period. For the purposes of this Transition Plan, the LCCA considers the total cost of procuring and operating one 40- foot bus over its 12-year service life, the useful life benchmark of transit buses as established by the Federal Transit Administration (FTA). Whereas the LCCA considers the total cost of procuring and operating one 40-foot bus, the Cash Flow Analysis includes a year-by-year estimate of expenditures, including capital and O&M expenditures associated with the Transition Plan by facility/garage over the next 20-years. Resultantly, the LCCA forms the basis of the Cash Flow Analysis.

The purpose of this technical memorandum is to describe the methods and assumptions used to develop the LCCA and emissions analysis. Because the Cash Flow Analysis is sensitive to the assumptions used in the LCCA, the assumptions presented in this technical memorandum will be reviewed by MCDOT prior to the finalization of the cash flow analysis.

Life Cycle Cost Assessment

The LCCA examines the financial implications of converting MCDOT’s fleet from its current mix of diesel, CNG, and hybrid buses to one that is 100-percent reliant on ZEBs, which include battery electric buses (BEBs) and fuel cell electric buses (FCEBs).

LCCAs include one-time and initial capital investments, reoccurring operations and maintenance (O&M) costs, and renewal costs. A LCCA is a tool to determine the most cost-effective option among different competing alternatives to purchase, maintain and operate an object (in this case a bus), when each is equally appropriate to be implemented on technical grounds.

The LCCA for the Transition Plan assessed the capital costs of procuring one BEB and FCEB, the necessary fuel and charging infrastructure, and O&M costs to support continued transit service. The total life cycle costs per bus over 12 years are presented, based on the 12-year service life of transit buses as defined by the FTA. The LCCA per bus associated with the transition to ZEBs is benchmarked against the costs associated with procuring, operating, and maintaining each bus propulsion technology included in the current fossil fuel-based fleet. To allow for a direct comparison across bus propulsion technologies, the LCCA assesses the costs associated with each standard length, 40-foot buses. Benchmarking the impacts of transitioning to a ZEB fleet against the make-up of the current fossil fuel-based fleet on a per-bus basis allows for a meaningful comparison of costs and benefits associated with the Transition Plan.

The LCCA compares life cycle costs associated with the following bus propulsion types: BEB, FCEB (including scenarios where hydrogen fuel is produced on-site and one where hydrogen fuel is delivered from off-site), diesel, CNG, and hybrid. The LCCA includes one-time capital costs as well as reoccurring energy and O&M costs. Figure 1 displays cost items captured in the LCCA by propulsion type.

Figure 6: Cost Items Included in LCCA per Propulsion Technology

Table showing cost items included in LCCA by vehicle type

All costs were escalated to 2023 dollars using the GDP deflator.[1] A list of general assumptions that is incorporated into the LCCA for all bus propulsion technologies is provided in Table 1.

Table 3: General Assumptions to Develop the LCCA

Table listing assumptiosn used in LCCA

Battery Electric Buses

The LCCA for BEBs includes one-time capital costs and reoccurring O&M costs over the 12-year life cycle. A list of assumptions used to develop the LCCA for BEBs is shown in Table 2. Adjustments to the assumptions shown below will affect the findings of the LCCA.

Table 4: Assumptions to Develop the BEB LCCA

BEB assumptions table

[1] White House Office of Management and Budget. Historical Tables, Table 10.1 – Gross Domestic Product and Deflators Used in the Historical Tables 1940-2024.

Table showing economic inputs used in calculations with number and source

BEB Capital Costs

One-time capital costs per each BEB are shown in Table 3. The capital cost assessment for BEBs include the one-time capital costs associated with BEB and battery procurement as well as the costs associated for mid-life overhaul and battery replacement.

Table 5: One-Time Capital Costs per BEB (2023$)

Table of costs for BEB buses – capital – includes initial bus cost, a mid-life overhaul, and battery replacement

BEB Energy and O&M Costs

Energy and O&M costs per each BEB are shown in Table 4. Energy and O&M costs include the O&M cost per mile of operating and maintaining a BEB as well as the average cost per bus resulting from the agreed upon cost-structure between MCDOT and AlphaStruxure over the 12-year assessment period.

Table 6: O&M Costs per BEB over 12-year Period (2023$)

Table showing energy cost and operations/maintenance cost for BEB over time

BEB Life Cycle Costs

Life cycle costs per BEB are shown in Table 5. The total cost associated with owning a BEB over the 12- year life cycle is $2.3 million.

Table 7: Total Life Cycle Costs per BEB (‘000 2023$)

Table showing breakdown of costs both capital and operating for BEB over life cycle

Fuel Cell Electric Buses - On-site Hydrogen Production

The LCCA for FCEBs includes one-time capital costs and reoccurring annual O&M costs over the 12-year life cycle, assuming all hydrogen is produced on-site. A list of assumptions used to develop the LCCA for FCEBs is shown in Table 6. Revisions to the assumptions shown below will affect the findings of the LCCA.

Table 8: Assumptions to Develop the FCEB LCCA

Table with list of general assumptions used for hydrogen fuel cell bus analysis

FCEB Capital Costs

One-time capital costs per each FCEB are shown in Table 7. The capital cost assessment for FCEBs include the one-time capital costs associated with FCEB procurement, the equipment cost associated with FCEB procuring and installing the hydrogen fueling infrastructure, as well as the costs associated for mid-life overhaul and cell stack replacement.

Table 9: One-Time Capital Costs per FCEB – On-site Hydrogen Production (2023$)

Table showing various one-time capital costs for FCEB fuel production

FCEB Energy and O&M Costs

Energy and O&M costs per each FCEB are shown in Table 8. Energy costs include the costs of electricity and water necessary to produce hydrogen and O&M costs include the O&M cost per mile of operating and maintaining a FCEB. Electricity costs were derived by calculating the average cost per bus resulting from the agreed upon cost-structure between MCDOT and AlphaStruxure over the 12-year assessment period.

Table 10: Energy and O&M Costs per FCEB over 12-year Period (2023$)

Table showing ongoing costs of operation over time for FCEB

FCEB Life Cycle Costs – On-site Hydrogen Production

Life cycle costs per FCEB are shown in Table 9. The total cost associated with owning a FCEB over the 12- year life cycle is $5.1 million when hydrogen is produced on-site.

Table 11: Total Life Cycle Costs per FCEB – On-site Hydrogen Production (2023$) (‘000 2023$)

Table showing life cycle costs – both capital and ongoing for hydrogen fuel cell buses

Fuel Cell Electric Buses – Off-site Hydrogen Production (sensitivity)

Due to the possibility that hydrogen must be delivered to MCDOT facilities from an off-site production location, a sensitivity analysis is included to estimate the life cycle costs associated with an FCEB where hydrogen is delivered from off-site production. Where they differ from the assumptions associated with on-site hydrogen production, a list of assumptions used to develop the FCEB LCCA sensitivity analysis is shown in Table 10. Revisions to the assumptions shown below will affect the findings of the LCCA.

Table 12: Assumptions to Develop the FCEB LCCA – Sensitivity Analysis

Table showing assumptions used in FCEB analysis

FCEB Capital Costs

One-time capital costs per each FCEB are shown in Table 11. The capital cost assessment for FCEBs include the one-time capital costs associated with FCEB procurement, the equipment cost associated with FCEB procuring and installing the hydrogen fueling infrastructure, as well as the costs associated for mid-life overhaul and cell stack replacement.

Table 13: One-Time Capital Costs per FCEB (2023$) – Off-site Hydrogen Production (2023$)

Table showing capital costs for FCEB by cost type

FCEB Energy and O&M Costs

Energy and O&M costs per each FCEB are shown in Table 12. Energy costs include the costs of procuring hydrogen produced off-site as well as the O&M cost per mile of operating and maintaining a FCEB.

Table 14: Energy and O&M Costs per FCEB (2023$) – Sensitivity Analysis (2023$)

Table showing ongoing costs for FCEB

FCEB Life Cycle Costs – Off-site Hydrogen Production

Life cycle costs per FCEB are shown in Table 13. The total cost associated with owning a FCEB over the 12- year life cycle is $2.8 million when hydrogen is delivered from off-site production area.

Table 15: Total Life Cycle Costs per FCEB – Off-site Hydrogen Production (‘000 2023$)

Table showing capital and ongoing costs for FCEB

Diesel Buses

The LCCA for diesel buses includes one-time capital costs and reoccurring O&M costs over the 12-year life cycle. A list of assumptions used to develop the LCCA for diesel buses is shown in Table 14. Revisions to the assumptions shown below will affect the findings of the LCCA.

Table 16: Assumptions to Develop the Diesel Bus LCCA

Table of assumptions used for LCCA of Diesel buses

Diesel Bus Capital Costs

One-time capital costs for diesel buses are shown in Table 15. The capital cost assessment for diesel buses includes one-time capital costs associated with diesel procurement as well as the costs associated for mid- life overhaul.

Table 17: One-Time Capital Costs per Diesel Bus (2023$)

Table showing one time capital costs for diesel bus

Diesel Energy and O&M Costs

Diesel bus energy and O&M costs are shown in Table 16. Energy costs include the costs of diesel fuel and O&M costs include the O&M cost per mile of operating and maintaining a diesel bus.

Table 18: Energy and O&M Costs per Diesel Bus (2023$)

Table showing ongoing costs for diesel bus

Diesel Life Cycle Costs

Life cycle costs per diesel bus are shown in Table 17. The total cost associated with owning a diesel bus over the 12-year life cycle is $2.2 million.

Table 19: Total Life Cycle Costs per Diesel Bus (‘000 2023$)

Table showing total costs both capital and ongoing for diesel bus

CNG Buses

The LCCA for CNG buses includes one-time capital costs and reoccurring O&M costs over the 12-year life cycle. A list of assumptions used to develop the LCCA for CNG buses is shown in Table 18. Revisions to the assumptions shown below will affect the findings of the LCCA.

Table 20: Assumptions to Develop the CNG Bus LCCA

Table showing general assumptions used in LCCA analysis

CNG Bus Capital Costs

One-time capital costs for CNG buses are shown in Table 19. The capital cost assessment for CNG buses includes one-time capital costs associated with CNG procurement as well as the costs associated for mid- life overhaul.

Table 21: One-Time Capital Costs per CNG Bus (2023$)

Table showing capital cost per bus

CNG Bus Energy and O&M Costs

CNG bus energy and O&M costs are shown in Table 20. Energy costs include the costs of natural gas and O&M costs include the O&M cost per mile of operating and maintaining a CNG bus.

Table 22: Energy and O&M Costs per CNG Bus (2023$)

Table showing ongoing costs per CNG bus

CNG Life Cycle Costs

Life cycle costs per CNG bus are shown in Table 21. The total cost associated with owning a CNG bus over the 12-year life cycle is $1.3 million.

Table 23: Total Life Cycle Costs per CNG Bus ('000 2023$)

Table showing both capital and ongling costs

Hybrid Buses

The LCCA for hybrid buses includes one-time capital costs and reoccurring O&M costs over the 12-year life cycle. A list of assumptions used to develop the LCCA for hybrid buses is shown in Table 22. Revisions to the assumptions shown below will affect the findings of the LCCA.

Table 24: Assumptions to Develop the Hybrid Bus LCCA

General assumptions used

Hybrid Bus Capital Costs

One-time capital costs for hybrid buses are shown in Table 23. The capital cost assessment for hybrid buses includes one-time capital costs associated with hybrid procurement as well as the costs associated for mid-life overhaul.

Table 25: One-Time Capital Costs per Hybrid Bus (2023$)

Capital costs – hybrid

Hybrid Bus Energy and O&M Costs

Hybrid bus energy and O&M costs are shown in Table 24. Energy costs include the costs of diesel fuel and O&M costs include the O&M cost per mile of operating and maintaining a hybrid bus.

Table 26: Energy and O&M Costs per Hybrid Bus (2023$)

Ongoing costs – hybrid

Hybrid Bus Life Cycle Costs

Life cycle costs per hybrid bus are shown in Table 25. The total cost associated with owning a hybrid bus over the 12-year life cycle is $2.9 million.

Table 27: Total Life Cycle Costs per Hybrid Bus ('000 2023$)

Capital and ongoing costs

Comparative Evaluation of Preliminary Findings

The preliminary findings of the LCCA are summarized in Table 26 and Figure 2. The life cycle cost of BEBs, FCEBs, diesel, CNG, and hybrid buses are estimated over 12 years. Using the inputs and assumptions described in this memorandum, CNG buses have the lowest life cycle cost, followed by diesel buses and BEBs. FCEBs fueled with hydrogen produced on-site have the highest life cycle costs, followed by hybrid buses.

Diesel buses have the lowest capital costs over the 12-year life cycle followed by CNG and hybrid buses. FCEBs fueled with hydrogen produced on-site have the highest capital costs, followed by FCEBs fueled with hydrogen produced off-site. FCEBs with hydrogen produced off-site have the highest operating costs over their life cycle while BEBs have the lowest operating costs over their life cycle.

Table 28: Comparison of Life Cycle Costs by Propulsion Type ('000 2023$)

Shows costs for each bus type, both operating/ongoing and capital

Figure 7: Comparison of Life Cycle Costs by Propulsion Type

Bar chart showing costs by vehicle type, both ongoing and capital

Emissions Analysis

The Economic Analysis includes an emissions analysis that quantifies change in greenhouse gas emissions (GHGs) by facility associated with MCDOT's Transition Plan.

The emissions analysis assesses the following GHGs: carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). The findings of the emissions analysis are presented in annual metric tons of CO2 equivalent (CO2e). Using CO2e allows for a direct comparison of the GHG emissions because it estimates the comparable mass of emissions that would create an equal amount of global warming impact. For example, the CO2e of CH4 is 25, meaning releasing 1 kilogram (kg) of CH4 into the atmosphere is the approximate equivalent to releasing 25 kg of CO2. The conversion factors are provided in Table 29. The existing fleet's fuel economy is used to estimate the gallons or gallon equivalents of diesel fuel and CNG needed annually. The fuel economy for diesel, CNG, and hybrid buses is shown in Table 27.

The emissions analysis reflects the transition plan as of July 7, 2023. The emissions analysis is highly sensitive to the quantities of buses included in the transition timeline and the microgrid capacity. Subsequent revisions to fleet makeup of the transition timeline will affect the results of the emissions analysis.

Table 29: Fuel Economy by Bus Type

MPG by bus fuel type

The emissions analysis applies the average annual mileage traveled of 41,400 per bus to quantify the change in GHG emissions, as provided in the Ride On Bus Fleet Management Plan (June 2021). Assuming 41,400 annual miles for all buses, the approximate gallons and gallon equivalents of fuel consumed were estimated. Annual emissions associated with the operation of diesel, CNG, and hybrid buses were estimated based on the emissions rates in kilogram per gallon or grams per mile. To allow for a direct comparison, all emissions findings are presented in metric tons. The emissions rates for hybrid buses are included with diesel buses. See Table 28 for the emissions rates used in calculating CO_2, CH_4, and N_2O.

Table 30: Emission Rates

Showing emissions rates of CO_2 by bus fuel type

Applying the appropriate conversion factors, the emissions were calculated in metric tons and subsequently converted to CO_2e using the factors shown in Table 29.

Table 31: CO2E Conversion Factors

Emissions Conversion Fators

Source: Emissions Factors for Greenhouse Gas Inventories, EPA 2022,
https://www.epa.gov/system/files/documents/2022- 04/ghg_emission_factors_hub.pdf

Emissions avoided per bus are applied to the transition timelines to quantify aggregate emissions avoided associated with the transition to ZEBs per bus maintenance facility.

Emissions Analysis by Conventional Bus Propulsion

The sections below describe the methods to quantify emissions by bus propulsion type.

Diesel Buses

Applying a fuel efficiency of 4.4 miles per gallon (mpg) per 40-foot diesel bus results in an estimated 9,400 gallons of annual diesel fuel consumption per diesel bus.

Diesel fuel contains 10.21 kilograms (kg) of CO_2 per gallon, resulting in 96 metric tons (mt) of CO_2 emitted annually per diesel bus. Each diesel fuel bus emits approximately 0.0051 grams of CH_4 per mile, resulting in 211 grams (0.0002 mt) of CH_4 emitted annually per 40-foot diesel bus. Further, each diesel bus emits approximately 0.0048 grams of N_2O per mile, resulting in 199 grams (0.0002 mt) of N_2O emitted annually per 40-foot diesel bus. To allow for a direct comparison of emissions, CH_4 and N_2O emissions are converted to CO_2 equivalents using conversion factors of 25 and 298, respectively. Annual GHG emissions per diesel bus are shown in Table 30.

Table 32: Annual Greenhouse Gas Emissions per Diesel Bus

Shows emissions by pollutant type

CNG Buses

CNG buses have a fuel efficiency of 4.2 miles per diesel gallon equivalent (dge). Compared to diesel buses, which have a fuel efficiency of 4.4 mpg, CNG buses are less fuel efficient. A diesel to CNG factor of 1.05 is applied to estimate the equivalent quantity of diesel fuel consumed annually per CNG bus. After applying the diesel to CNG factor of 1.05, CNG buses consume an equivalent of 9,900 gallons of diesel fuel per year.

Annual CO_2 emissions per CNG bus are estimated by applying the gasoline gallon equivalent (gge) of 6.9 kg of CO_2 equivalent by the CNG dge of 9,900. Resultantly, each CNG bus emits approximately 68 mt of CO_2 annually. CNG buses also emit approximately 10 grams of CH_4 per mile, or 0.4 mt of CH_4 annually. Further, CNG buses emit approximately 0.001 grams of N_2O per mile, or 40 grams (0.00004 mt) annually. To allow for a direct comparison of emissions, CH_4 and N_2O emissions are converted to CO_2 equivalents using conversion factors of 25 and 298, respectively. Annual GHG emissions per CNG bus are shown in Table 31.

Table 33: Annual Greenhouse Gas Emissions per CNG Bus

Pollutants by CNG

Hybrid Buses

Applying a fuel efficiency of 4.2 mpg per 40-foot hybrid bus results in an estimated 8,500 gallons of annual diesel fuel consumption per hybrid bus. Diesel fuel contains 10.21 kilograms (kg) of CO_2 per gallon, resulting in 86 metric tons (mt) of CO_2 emitted annually per hybrid bus.

At 4.2 mpg, hybrid buses have a lower fuel efficiency compared to diesel buses, which have a fuel efficiency of 4.4 mpg. A diesel to hybrid factor of 0.9 is applied to the diesel bus emissions rates of 0.0051 grams of CH_4 per mile and 0.0048 grams of N_2O per mile to estimate CH_4 and N_2O emissions per mile from hybrid buses. After applying the diesel to hybrid factor of 0.9, hybrid buses emit 0.005 grams of CH_4 and

0.004 grams of N_2O per mile. Each hybrid bus emits approximately 190 grams (0.00019 mt) of CH_4 and 180 grams (0.00018 mt) each year. To allow for a direct comparison of emissions, CH_4 and N_2O emissions are converted to CO_2 equivalents using conversion factors of 25 and 298, respectively. Annual greenhouse gas emissions per hybrid bus are shown in Table 32.

Table 34: Annual Greenhouse Gas Emissions per Hybrid Bus

Pollutants by hybrid bus

Emissions Analysis by Facility

While the operation of BEBs and FCEBs do not result in any direct emissions, the operations of BEBs relies on direct electricity consumption. Further, the generation of hydrogen on-site to fuel FCEBs requires additional electricity consumption. At present, it is assumed that BEB and FCEB operations beyond the capacity at each facility will draw electricity from the electricity grid. Indirect emissions will result in instances where the quantity of buses at each facility exceeds the facility's microgrid capacity. Table 33 compares the microgrid's capacity (in number of buses) to the quantity of BEBs and FCEBs in 2035 at each facility.

Table 35: Quantity of ZEBs Compared to Total Capacity per Facility (2035)

Shows number of ZEB by facility along with how many are charged by PEPCO

The emissions analysis quantifies emissions changes at the EMTOC, Brookville, and Nicholson Court bus maintenance facilities.

BEBs and FCEBs that are expected to draw electricity from the Pepco-supplied grid will have emissions impacts. Assumptions used to estimate emissions associated with BEBs that draw electricity from the Pepco-supplied grid are shown in Table 34.

Table 36: Emissions Assumptions from Pepco-Supplied Electricity

General assumptions used for analysing indirect emissions

Each BEB that draws electricity from the Pepco-supplied grid consumes 92,000 kilowatt-hours (kWh) annually, or 92 megawatt-hours (mWh) annually. Applying the emissions factors used in Table 34, each BEB that draws electricity from the Pepco-supplied grid will generate 27.2 metric tons of CO2 and trace amounts of CH4 and N2O. When converting to CO2e using the conversion factors shown in Table 29, each BEB that draws electricity from the Pepco-supplied grid emits 27.3 metric tons of CO2e each year.

Applying the factors listed in Table 34, each FCEB consumes 4,780 kg of hydrogen annually. Each FCEB that draws electricity from the Pepco-supplied grid consumes 244,000 kWh annually, or 244 mWh annually. Applying the emissions factors used in Table 34, each FCEB that draws electricity from the Pepco- supplied grid will generate 72.1 metric tons of CO2 and 0.1 and 0.2 metric tons of CH4 and N2O respectively. When converting to CO2e using the conversion factors shown in Table 29, each BEB that draws electricity from the Pepco-supplied grid emits 72.5 metric tons of CO2e each year. Figure 3 displays the annual CO2e by bus propulsion type when BEBs are powered by the Pepco-supplied grid and hydrogen fuel is produced using electricity from the Pepco-supplied grid.

Figure 8: Annual CO2e by Bus Propulsion Type

Shows emissions by bus type including indirect emissions

Note: Indirect emissions associated with BEB charging and hydrogen generation are dependent on many factors. The estimates shown in Figure 3 are highly sensitive to the assumptions described in this memorandum. Any changes to the assumptions will impact the findings of the emissions analysis, particularly with regards to the capacity of the microgrid and quantities of ZEBs at each facility.

EMTOC

The EMTOC maintenance facility houses 176 buses and by 2035 is expected to house 342 buses. The transition timeline for the EMTOC maintenance facility is summarized in Table 35 and Figure 4.

Table 37: EMTOC Maintenance Facility Transition Timeline

Shows transition over time from Diesel, CNG and Hybrid to ZEB types

Figure 9: EMTOC Maintenance Facility Transition Timeline

Bar chart showing transition over time at EMTOC, by bus type

Annual emissions per diesel, CNG, and hybrid bus were quantified using the values provided in Table 30, Table 31, and Table 32 respectively. Annual emissions per BEB and FCEB connected to the Pepco-grid were quantified using the annual emissions rates of 27.3 and 72.5 metric tons, respectively.

The annual emissions associated with the buses at the EMTOC maintenance facility between 2022 and 2035 are shown in Figure 5.

Figure 10: Annual Emissions from Buses at the EMTOC Maintenance Facility (MT CO2e)

Bar chart showing emissions over time

Brookville

The Brookville maintenance facility currently houses 148 buses and by 2035 is expected to house 187 buses. The transition timeline for the Brookville maintenance facility is summarized in Table 36 and Figure 6.

Table 38: Brookville Maintenance Facility Transition Timeline

Shows transition over time from Diesel, CNG and Hybrid to ZEB types

Figure 11: Brookville Maintenance Facility Transition Timeline

Bar chart showing transition over time, by bus type

Annual emissions per diesel, CNG, and hybrid bus were quantified using the values provided in Table 30, Table 31, and Table 32 respectively. Annual emissions per BEB and FCEB connected to the Pepco-grid were quantified using the annual emissions rates of 27.3 and 72.5 metric tons, respectively.

The annual emissions associated with the buses at the Brookville maintenance facility between 2022 and 2035 are shown in Figure 7.

Figure 12: Annual Emissions from Buses at the Brookville Maintenance Facility (MT CO2e)

Emission over time at Brookeville

Nicholson Court

The Nicholson Count maintenance facility currently houses 65 buses and by 2035 is expected to house 76 buses. The transition timeline for the Nicholson Court maintenance facility is summarized in Table 37 and Figure 8.

Table 39: Nicholson Court Maintenance Facility Transition Timeline

Shows bus types at Nicholson over time

Figure 13: Nicholson Court Maintenance Facility Transition Timeline

Bar chart showing bus numbers by type over time

Annual emissions per diesel, CNG, and hybrid bus were quantified using the values provided in Table 30, Table 31, and Table 32 respectively. Annual emissions per BEB and FCEB connected to the Pepco-grid were quantified using the annual emissions rates of 27.3 and 72.5 metric tons, respectively.

The annual emissions associated with the buses at the Nicholson Court maintenance facility between 2022 and 2035 are shown in Figure 9.

Figure 14: Annual Emissions from Buses at the Nicholson Maintenance Facility (MT CO2e)

Emissions over time by type (direct vs indirect)

Review of Funding and Financing Opportunities

The results of a financial and funding scan identifying Federal, State, and Local funding sources available for project components is included in Table 38. An expanded matrix will be provided in Appendix A: Funding and Financing Options.

Table 40: Funding and Financing Options

Table showing funding and grant programs by agency

Appendix F - Emissions Analysis – Technical Memorandum; Consideration of Renewable Natural Gas

Emissions Analysis Technical Memorandum; Consideration of Renewable Natural Gas (RNG)

Introduction and Purpose

Montgomery County Department of Transportation (MCDOT) owns and operates almost 400 buses providing Montgomery County residents with reliable transit options and resources. At present, MCDOT's fleet consists primarily of diesel, compressed natural gas (CNG), and diesel-electric hybrid (henceforth "hybrid") buses, with 14 battery-electric buses (BEBs). MCDOT is transitioning from its current bus fleet to a zero-emissions bus (ZEB) fleet in accordance with Montgomery County's Climate Action Plan, which calls for the County to reduce greenhouse gas (GHG) emissions by 100-percent compared to 2005 levels by 2035.

To align with the County's ambitious GHG reduction targets, MCDOT has developed a Zero Emission Bus Transition Plan (henceforth "Transition Plan") that charts a path to convert their entire fleet to ZEB by 2035. Included in the Transition Plan is an Economic Analysis that assesses the financial implications associated with the transition to a fully ZEB fleet by 2035. The Economic Analysis includes an emissions assessment that quantifies the change in greenhouse gas emissions (GHGs) associated with MCDOT's Transition Plan.

MCDOT intends to transition to BEBs and fuel-cell electric buses (FCEBs) to meet their emissions reductions goals. However, many of the technologies necessary to support the transition to a zero-emissions economy are emerging, constraining MCDOT's ability to leverage and transition BEB and FCEB technology on the timeline necessary to meet the County's ambitious emissions reduction targets. As an interim measure, MCDOT is exploring the ability to leverage Renewable Natural Gas (RNG) as an option to meet their emissions reductions targets while they transition to a fleet make-up of BEBs and FCEBs.

The purpose of this technical memorandum is to analyze the emissions impacts of RNG compared to the existing fleet make-up of MCDOT as well as benchmarking the emissions impacts of RNG against BEBs and FCEBs. This emissions assessment quantifies the anticipated annual emissions per bus propulsion type.

Emissions Assessment

The Economic Analysis includes an emissions assessment that quantifies change in GHGs associated with MCDOT's Transition Plan.

The emissions assessment analyzes the following GHGs: carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). The findings of the emissions assessment are presented in terms of CO2 equivalent (CO2e). Using CO2e allows for a direct comparison of the GHG emissions because it estimates the comparable mass of emissions that would create an equal amount of global warming impact. For example, the CO2e of CH4 is 25, meaning releasing 1 kilogram (kg) of CH4 into the atmosphere is the approximate equivalent to releasing 25 kg of CO2. The conversion factors are provided in Table 4. The existing fleet's fuel economy is used to estimate the gallons or gallon equivalents of diesel fuel and CNG needed annually. The fuel economy for diesel, CNG, and hybrid buses is shown in Table 1.

The emissions assessment is highly sensitive to the microgrid capacity. Subsequent revisions to fleet makeup of the transition timeline will affect the results of the emissions assessment.

Table 41: Fuel Economy by Bus Type

Bus mpg per bus type

The emissions assessment is sensitive to the reality that the average mileage traveled of the MCDOT vehicles varies by propulsion type which resultantly impacts the average annual emissions per bus. The average annual mileage per bus propulsion type is displayed in Table 2.

Table 42: Average Annual Mileage per Bus Propulsion Type

Annual miles by fuel type

Source: Montgomery County Department of Transportation, Ride On Fleet Management Plan, June 2021 Notes: Average annual miles are rounded to the nearest hundred. * Assumption

The emissions assessment is to quantify the existing impact of MCDOT's existing operations, rather than a general assessment of emissions impacts by propulsion type. Emissions impacts are also presented per mile in findings to allow for a direct comparison of emissions impacts.

Annual emissions associated with the operation of diesel, CNG, and hybrid buses were estimated based on the emissions rates in kilogram per gallon or grams per mile. Because hybrid buses use diesel fuel, the emissions rates for hybrid buses are included with diesel buses. See Table 3 for the emissions rates used in calculating CO2, CH4, and N2O.

Table 43: Emission Rates

Shows types of pollutants by bus fuel type

Applying the appropriate conversion factors, the emissions were calculated in metric tons and subsequently converted to CO2e using the factors shown in Table 4.

Table 44: CO2E Conversion Factors

Shows conversion factors from pollutants to CO2E

04/ghg_emission_factors_hub.pdf

Emissions Analysis by Conventional Bus Propulsion

The sections below describe the methods to quantify emissions by bus propulsion type.

Diesel Buses

Applying a fuel economy of 4.4 miles per gallon (mpg) per 40-foot diesel bus results in an estimated 8,300 gallons of annual diesel fuel consumed per diesel bus.

Diesel fuel contains 10.21 kilograms (kg) of CO2 per gallon, resulting in 84 metric tons (mt) of CO2 emitted annually per diesel bus. Each diesel fuel bus emits approximately 0.0051 grams of CH4 per mile, resulting in 186 grams (0.0002 mt) of CH4 emitted annually per 40-foot diesel bus. Further, each diesel bus emits approximately 0.0048 grams of N2O per mile, resulting in 175 grams (0.0002 mt) of N2O emitted annually per 40-foot diesel bus. To allow for a direct comparison of emissions, CH4 and N2O emissions are converted to CO2 equivalents using conversion factors of 25 and 298, respectively. Annual GHG emissions per diesel bus are shown in Table 5.

Table 45: Annual Greenhouse Gas Emissions per Diesel Bus

Emissions by diesel buses with conversion

CNG Buses

CNG buses have a fuel economy of 4.2 miles per diesel gallon equivalent (dge), resulting in an annual consumption of 12,700 gallons of dge per year.

Annual CO2 emissions per CNG bus are estimated by applying the gasoline gallon equivalent (gge) of 6.9 kg of CO2 equivalent by the annual CNG dge of 12,700. Resultantly, each CNG bus emits approximately 88 mt of CO2 annually. CNG buses also emit approximately 10 grams of CH4 per mile, or 0.5 mt of CH4 annually. Further, CNG buses emit approximately 0.001 grams of N2O per mile, or 53 grams (0.00005 mt) annually. To allow for a direct comparison of emissions, CH4 and N2O emissions are converted to CO2 equivalents using conversion factors of 25 and 298, respectively. Annual GHG emissions per CNG bus are shown in Table 6.

Table 46: Annual Greenhouse Gas Emissions per CNG Bus

Emission by CNG bus

Hybrid Buses

Applying a fuel economy of 4.9 mpg per 40-foot hybrid bus results in an estimated 8,400 gallons of annual diesel fuel consumption per hybrid bus. Diesel fuel contains 10.21 kilograms (kg) of CO_2 per gallon, resulting in 86 metric tons (mt) of CO_2 emitted annually per hybrid bus.

At 4.9 mpg, hybrid buses have a higher fuel efficiency compared to diesel buses, which have a fuel efficiency of 4.4 mpg. A diesel to hybrid factor of 0.9 was applied to the diesel bus emissions rates of 0.0051 grams of CH_4 per mile and 0.0048 grams of N_2O per mile to estimate CH_4 and N_2O emissions per mile from hybrid buses. After applying the diesel to hybrid factor of 0.9, hybrid buses emit 0.005 grams of CH_4 and 0.004 grams of N_2O per mile. Each hybrid bus emits approximately 190 grams (0.00019 mt) of CH_4 and 177 grams (0.00018 mt) each year. To allow for a direct comparison of emissions, CH_4 and N_2O emissions are converted to CO_2 equivalents using conversion factors of 25 and 298, respectively. Annual greenhouse gas emissions per hybrid bus are shown in Table 7.

Table 47: Annual Greenhouse Gas Emissions per Hybrid Bus

Annual emissions by Hybrid bus converted to CO_2E

Emissions Analysis of Zero-Emissions Buses

The emissions analysis accounts for Scope 1 – Direct and Scope 2 – Indirect (electricity) emissions; Scope 3 emissions are not accounted for.[3] While the operation of BEBs and FCEBs does not result in any direct emissions, the operation of BEBs relies on electricity consumption. Further, the generation of hydrogen on-site to fuel FCEBs requires additional electricity consumption. At present, it is assumed that BEB and FCEB operations beyond the capacity at each facility will draw electricity from the Pepco-supplied electricity grid. The analysis assumes MCDOT has the capacity to generate enough hydrogen on-site to meet their demands.

BEBs and FCEBs that are expected to draw electricity from the Pepco-supplied grid will have emissions impacts. Assumptions used to estimate emissions associated with BEBs that draw electricity from the Pepco-supplied grid are shown in Table 8.

Table 48: Emissions Assumptions from Pepco-Supplied Electricity

General assumptions for analysis

Battery-Electric Buses

Each BEB that draws electricity from the Pepco-supplied grid consumes 65,700 kilowatt-hours (kWh) annually, or 65.7 megawatt-hours (mWh) annually. Applying the emissions factors used in Table 8, each BEB that draws electricity from the Pepco-supplied grid will generate 19.4 metric tons of CO_2 and trace amounts of CH_4 and N_2O. When converting to CO_2e using the conversion factors shown in Table 4, each BEB that draws electricity from the Pepco-supplied grid emits 19.5 metric tons of CO_2e each year.

Fuel Cell-Electric Buses

Applying the factors listed in Table 8, each FCEB consumes 6,160 kg of hydrogen annually. Each FCEB that is fueled with hydrogen generated using electricity from the Pepco-supplied grid consumes 314,200 kWh annually, or 314.2 mWh annually. Applying the emissions factors used in

Table 8, each FCEB that draws electricity from the Pepco-supplied grid will generate 93.0 metric tons of CO_2 and 0.2 and 0.3 metric tons of CH_4 and N_2O respectively. When converting to CO2e using the conversion factors shown in Table 3, each FCEB that generates hydrogen using electricity from the Pepco-supplied grid emits 93.4 metric tons of CO2e each year.

Renewable Natural Gas

RNG is an emerging fuel that is derived from waste and can fuel transit vehicles. Applying a fuel economy of 4.2 mpg per 40-foot RNG bus results in an estimated 12,700 dge of annual RNG consumption per RNG bus. Each dge of RNG weighs 6.06 pounds, or 2.75 kg,[4] resulting in an annual RNG consumption of 34,960 kg per bus. The emissions analysis accounts for Scope 1 – Direct and Scope 2 – Indirect (electricity) emissions; the assumptions used to estimate emissions from RNG are displayed in Table 9.

Table 49: Emissions Assumptions for RNG

Assumptions used for RNG emissions analysis

From the figures displayed in Table 9, RNG has an energy density of 48.3 megajoules per kg and a carbon intensity of 1,480 grams of CO2e per kg. With the annual consumption of 34,960 kg per RNG bus, each RNG bus emits 52 metric tons of CO2e each year.

Findings of Emissions Assessment

The findings of the emissions assessment are summarized in Table 10. Note that BEBs and FCEBs that are powered by or with fuel generated by the microgrid have zero emissions footprint.

Table 50: Findings of Emissions Assessment – 2023

Emissions by bus type per bus with annual miles and CO2E per mile

Figure 1 displays the annual CO2e by bus propulsion type in 2023 when BEBs are powered by the Pepco- supplied grid and when hydrogen fuel is produced using electricity from the Pepco-supplied grid.

Figure 15: Annual CO2e by Bus Propulsion Type (MT) – 2023

Bar graph showing emissions by bus type

Note: Indirect emissions associated with BEB charging and hydrogen generation are dependent on many factors. The estimates shown in Figure 1 are highly sensitive to the assumptions described in this technical memorandum. A 10-percent error bar was added to account for uncertainty.

Average annual emissions are sensitive to the average distance traveled. Because buses of different propulsions have varying average annual miles traveled, the average emissions per mile were quantified, as displayed in Figure 2.

Figure 16: CO2e per Mile by Bus Propulsion Type (Grams) – 2023

Bar chart showing emissions per mile by bus type

Note: A 10-percent error bar was added to account for uncertainty.

The results of the emissions analysis found the annual emissions impact of RNG is 51-percent of the emissions impact CNG, demonstrating that RNG has a smaller emissions impact than CNG. The analysis found that emissions impact of RNG per mile compares favorably to diesel, CNG, and hybrid. RNG also compares favorably to FCEBs that are fueled with hydrogen generated using electricity from the Pepco- supplied grid.

Sensitivity Analysis

Recognizing the State of Maryland's Renewable Portfolio Standard (RPS) Program requires that electricity suppliers procure a minimum of 50-percent of their electricity from renewable sources by 2030, a sensitivity analysis was conducted to estimate the emissions impacts in 2030. At present, 6-percent of Pepco-supplied electricity comes from renewable sources.[5]

In alignment with Maryland's RPS of 50-percent by 2030, the sensitivity analysis assumes the 2030 emissions impacts of BEBs and FCEBs that are powered using Pepco-supplied electricity to be 44-percent less than at present.

Figure 3 displays the annual CO2e by bus propulsion type in 2030 when BEBs are powered by the Pepco- supplied grid and when hydrogen fuel is produced using electricity from the Pepco-supplied grid.

Figure 17: Annual CO2e by Bus Propulsion Type (MT) – 2030

Annual emissions by bus type in 2030

Figure 18: CO2e per Mile by Bus Propulsion Type (Grams) – 2030

CO2E per mission by bus type

The results of the sensitivity analysis suggest that the comparative advantage of RNG will corrode as the share of renewable energy supplied by Pepco increases to 50-percent in 2030. Assuming all other variables remain constant, BEBs emit the less emission, while FCEBs and RNG buses follow compared to the traditional technologies.