ZERO EMISSIONS
Let's clear the air

Maryland Zero Emission Bus Transition Act Legislative Report

DECEMBER 2022

Submitted by:

MDOT MARYLAND DEPARTMENT OF TRANSPORTATION
MARYLAND TRANSIT ADMINISTRATION

The Maryland Department of Transportation Maryland Transit Administration (MDOT MTA) offers this report in response to language contained in Senate Bill 61, Chapter 463, Acts of 2022.[1] The language states:

> *On or before January 1, 2022, and each January 1 thereafter, the Administration shall, in accordance with § 2–1257 of the state government article, submit a report to the Senate Budget and Taxation Committee, the Senate Education, Health, and Environmental Affairs Committee, the House Appropriations Committee, and the House Environment and Transportation Committee on the implementation of this section. The annual report shall include:*
>
> *(i) a schedule for converting the administration's state transit bus fleet to zero–emission buses exclusively;*
>
> *(ii) an evaluation of the charging infrastructure needed for the administration to create and maintain a state transit bus fleet of zero–emission buses;*
>
> *(iii) a plan for transitioning*
>
> 1. *any state employees adversely affected by the conversion from a diesel–powered state transit bus fleet to a zero–emission state transit bus fleet to similar or other employment within the administration or department that has commensurate seniority, pay, and benefits;*
> 2. *ensuring that no duties or functions of state employees are transferred to a contracting entity as a result of the conversion from a diesel–powered state transit bus fleet to a zero–emission state transit bus fleet; and*
> 3. *ensuring that any entity other than the administration that operates or maintains zero–emission buses on behalf of the administration provides employee protections equivalent to the protections required by the plan;*
>
> *(iv) a certification that the administration is adhering to the plan required under item (iii) of this paragraph;*
>
> *(v) in coordination with other appropriate state agencies, an estimate of the reduction in the amount of carbon dioxide emissions, measured in pounds, that will be obtained through the use of zero–emission buses each year until the state transit bus fleet is converted to zero–emission buses; and*
>
> *(vi) a financial analysis:*
>
> 1. *of the projected cost of purchasing, maintaining, and providing charging infrastructure for the zero–emission state transit bus fleet each year until the fleet is converted to zero–emission buses; and*
> 2. *comparing the projected cost under item 1 of this item to the projected cost of continuing to operate a diesel–powered state transit bus fleet.*

[1] Maryland State Law (Md. Code, Transportation Sec. 7-406).

In 2016, the Maryland Greenhouse Gas Reduction Act Reauthorization[2] set a 40 percent reduction target for statewide emissions by 2030 from 2006 levels. The MDOT MTA subsequently established a goal to convert 50 percent of its Core Bus fleet in Greater Baltimore to zero emission buses (ZEBs) by 2030. This goal was also included in the 2020 Greater Baltimore Regional Transportation Plan (CMRTP), along with a longer-term goal to convert 95 percent of the Core Bus fleet to zero-emission buses by 2045. The passage of Senate Bill 137 in 2021 and of Senate Bill 67 in 2022 prohibited the MDOT MTA from entering into new procurements for non-ZEBs beginning in fiscal year 2023.

In 2020, the MDOT MTA commenced a two-phase Zero-Emission Bus Transition Study that evaluated facility upgrades, utility infrastructure, rolling stock, and charging infrastructure needed to achieve the 2030 transition goal. Since then, the MDOT MTA has undertaken extensive work toward preparing charging infrastructure, developing workforce training and procedures, and procuring zero-emission buses.

In 2022, the MDOT MTA contracted for its first zero-emission buses; seven buses are in production and expected to arrive by June 2023. Utility upgrades have been completed to power vehicle chargers at the Kirk Bus Division and implementation of a training plan has begun across the Administration. Additionally, in the fall of 2022, the MDOT MTA advanced engineering and operational planning for the ZEB transition by issuing a Request for Proposal (RFPs) for a new multiyear zero-emission bus contract, a bus depot, support chargers, and an electrification partner to install and support chargers.

Approximately 5-10 percent of the U.S. transit fleet currently consists of ZEBs. Transit agencies will be implementing larger ZEB fleets in the immediate future, and agencies are facing fast learning curves as ZEBs are integrated into fleets. Technology advancements are beginning to improve vehicle efficiency, such as battery capacity, but testing and evaluation will take time.

Further, global supply chain issues will constrain delivery timeframes from vehicle and infrastructure manufacturers for the next few years. Vehicle production lead times, as well as charging infrastructure and utility support equipment, are strained by material sourcing delays and can be over 12 months. Transit agencies nationwide are concurrently placing large ZEB orders as ZEB fleets continue to grow nationwide. As ZEB technology is constantly changing, warranty terms for buses and chargers are critical to ensure transit service to the Greater Baltimore region is not disrupted. Where possible, the MDOT MTA is preparing contingency plans to mitigate external risk factors, including vehicle and charger delivery delays.

<u>Background</u>

MDOT MTA's Phase II Transition Study (2020-2021) evaluated the feasibility of implementing battery-electric buses (BEBs) and fuel-cell electric buses (FCEBs) in the Core Bus fleet. Results from the study recommended that the MDOT MTA pursue BEBs for an initial pilot program to

2 2030 GGRA Plan Executive Summary

assess their performance. The study also recommended that BEBs be chosen as the propulsion type for the first few years of ZEB-only procurement from 2025-2030. The recommendation to operate BEBs over FCEBs from 2025-2030 was based on several findings. First, BEBs are more widely available and have been deployed in greater quantities in the U.S. transit market. Second, BEBs have lower initial capital costs for both rolling stock and charging infrastructure (depending on scale) compared to FCEBs. Finally, many of MDOT MTA's operating divisions are incompatible with existing fire safety codes that regulate the distance between hydrogen storage tanks, vehicles, and buildings.

Furthermore, service modeling during Phase II of the Transition Study found that BEBs can complete a majority of MDOT MTA's existing service blocks (the group of daily assignments for an individual bus), given current range capabilities and conservative operating assumptions. These assumptions incorporate weather, gross vehicle weight, and battery availability. Inputs to this service modeling included assumptions that factored in:

- Greater Baltimore's topography
- MDOT MTA service and schedule data from General Transit Feed Specification (GTFS) data, representing pre-pandemic operations
- Gross Vehicle Weight of BEBs, based on vehicles available on the market in 2020
- Assumed temperature of winter months, to utilize as conservative an assumption as possible.

The facility transition schedule (**Table 1)** was developed based on a service block completion analysis. Due to its short service blocks, the MDOT MTA identified Kirk Division as the most suitable location for the pilot program and the initial full-facility BEB retrofit. The rebuilt Kirk Division opened in 2021, which minimizes construction risk during the retrofit period compared to older facilities.

This study, which provided the framework for the MDOT MTA's fleet conversion through 2030, recommended that the integration of FCEBs remain under evaluation for future facility transitions. Specifically, FCEBs should be considered for facility transitions at Northwest Division due to the division's longer service blocks that may exceed currently available BEB range capabilities, as well as its ample space to accommodate the required setback requirements for hydrogen infrastructure in relation to buildings. A planned Hydrogen Fuel Study will evaluate the feasibility of hydrogen production, delivery, storage, and fueling at the MDOT MTA, focusing on portions of Northwest Division. This analysis commenced in 2022. The MDOT MTA is initiating a Phase III ZEB transition planning assessment in 2023, which will focus on determining specific plans for vehicle propulsion type(s), charging/fueling and maintenance locations, and service integration beyond 2030.

<u>Fleet Transition Schedule</u>

The MDOT MTA developed a transition schedule for which facilities will be partially or entirely retrofitted to support ZEB deliveries from 2025-2030. More detailed transition planning analysis is ongoing, which will yield a quarterly phasing of charging infrastructure installation and vehicle delivery.

Several initiatives are underway to advance the upcoming phases of MDOT MTA's ZEB transition. A Charge Management Study, completed in March 2022, provided detailed recommendations for how much energy will be consumed, how much on-site power is needed, and how many BEBs may be required to complete existing service requirements. The MDOT MTA's first full procurement of exclusively zero-emission buses was released for bids in the fall of 2022, with award to a bus manufacturer anticipated in 2023 to support vehicle deliveries from 2025 through 2028 (the contract will have extension options through 2030). The MDOT MTA is also preparing to onboard a developer in 2023 to support the design, construction, operations, and maintenance of BEB charging infrastructure at Kirk and Northwest Divisions, in an innovative arrangement that will provide turnkey bus charging, allowing MDOT MTA's workforce to maintain focus on operating service and maintaining the bus fleet. For the Eastern Division, which will be reconstructed into one of the first bus divisions purpose-built for BEBs in the U.S., a construction manager for pre-construction services is anticipated to be brought on board in Spring 2023 to support construction activities.

Table 1 depicts the transition schedule for facility design, construction, and ZEBs delivery at the MDOT MTA's divisions.

Table 1: Preliminary Facility Phasing for BEBs (2025-2030)

Facility	Phase	2022	2023	2024	2025	2026	2027	2028	2029	2030
Kirk Pilot	Facility Design	Blue								
	Retrofit Construction	Red								
	ZEB Deliveries		Green							
Kirk	Facility Design	Blue	Blue							
	Retrofit Construction		Red	Red						
	ZEB Deliveries				Green	Green				
Northwest	Facility Design		Blue							
	Retrofit Construction				Red	Red				
	ZEB Deliveries					Green	Green			
Eastern	Facility Design		Blue	Blue	Blue					
	Redevel. Construction					Red	Red	Red	Red	
	ZEB Deliveries								Green	Green

Blue – Design Red – Construction Green – Bus Deliveries

Table 2 depicts the current draft fleet procurement and ZEB fleet growth schedule, based on an annual 70-bus procurement both prior to and during the transition to an all-ZEB procurement in 2025. This plan anticipates that the MDOT MTA will procure clean diesel vehicles until 2024, in addition to seven pilot BEBs in 2023, and assumes the MDOT MTA will procure only ZEBs beyond 2024. Replacement of BEBs for clean diesel and hybrid buses on a 1:1 ratio was assumed in this procurement schedule, though a higher replacement ratio may be needed to maintain existing service levels, pending the assessment of BEB performance in Greater Baltimore during the pilot program in 2023-2024. Retirement of buses is assumed to occur 12 years after purchase, per the MDOT MTA's current retirement cycles. This procurement schedule is subject to refinement based on the MDOT MTA's Bus Fleet Management Plan.

Table 2: Preliminary Annual Deliveries and ZEB Fleet Percentage Schedule[3]

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030[4]
Bus Deliveries[5]	70	70	77	70	70	70	70	70	70	70
Fleet Share of ZEBs (End of Year)	0.0%	0.0%	0.9%	0.9%	9.9%	18.2%	24.7%	33.8%	42.1%	50.4%

Several key transition considerations may impact the schedule in **Table 2**, including contracting lead times, material shortages and delivery delays, and permitting. The MDOT MTA is incorporating risk management strategies where possible to maintain schedule and avoid service impacts throughout the transition to zero-emission buses.

ZEBs require infrastructure to be constructed, installed, and tested at the divisions before the vehicles can begin operating. While work needs to begin on bus procurements one to two years in advance, the MDOT MTA is working to ensure all procurement efforts account for global supply chain issues that are impacting production and delivery of bus components, including chemicals needed for vehicle batteries. These delays may cause a production delay of several months.

Additionally, transit agencies across the U.S. are simultaneously delivering public commitments to scale their ZEB fleets and responding to State and municipality mandates to adopt ZEBs. As a result, the MDOT MTA is proactively initiating bus procurements and executing orders in advance to ensure bus deliveries are not delayed due to production of larger orders for other transit agencies.

The MDOT MTA is currently evaluating the number of spare vehicles needed for maintenance purposes, rail replacement ("bus bridges"), training, and other special uses. As the ZEB fleet grows, the MDOT MTA is working to ensure that consistent levels of reliable service can be delivered by ZEBs throughout the transition. The MDOT MTA will assess fleet transition needs beyond 2030 in a third phase of the Transition Study.

Evaluation of Charging Infrastructure

The Phase II Transition Study evaluated various types of BEB charging infrastructure, including overhead pantograph charging, ground-mounted and overhead plug-in charging, and inductive charging.

3 Subject to revisions during updates to MDOT MTA's Bus Fleet Management Plan
4 ZEB deliveries are expected to continue beyond 2030. Transition Planning analysis for vehicle deliveries beyond 2030 is underway.
5 Deliveries will be diesel vehicles through 2024, excluding 7 BEBs for a pilot program in 2023, and BEBs from 2025-2030.

Currently, the MDOT MTA intends to provide all BEB charging at the operating divisions where buses are stored and maintained while not in revenue service. However, the Administration continues to evaluate in-route fast charging stations and the viability and value of installing these at certain locations within the region.

Overhead pantograph charging was determined to be the optimal charging infrastructure method for the BEB pilot and initial facility conversions at the MDOT MTA. In this type of charging, the pantograph on the bus is automatically deployed to begin charging when the bus parks and the emergency brake is engaged. Overhead pantograph charging provides the fewest disruptions to the existing site, is the least restrictive to future modifications, and minimizes additions to operations and maintenance staff workloads. As transit agencies nationwide begin to scale up their BEB fleets, overhead pantograph dispensers are becoming increasingly selected among the larger transit agencies due to the aforementioned benefits.

Ground-mounted, plug-in charging stations would reduce the number of BEBs that the MDOT MTA can store at facilities in which they are used, due to the additional ground space that they occupy. Due to their in-ground power distribution, these units are less flexible for redeployment upon shifts in fleet composition.

Overhead plug-in charging stations, where charging cords connect from ceiling-mounted dispensers, require staff to physically connect and disconnect the plugs to the buses and may present a safety hazard to staff.

Inductive charging, which wirelessly connects the bus to a charging unit embedded in the pavement, is considerably more expensive and complicated to install than plug-in or overhead charging. Inductive charging is disruptive to deploy and presents additional maintenance challenges and expenses associated with pavement upkeep.

Figure 1 below provides an overview of hardware that will need to be installed at MDOT MTA operating divisions to power BEBs and depicts the flow of electricity from transformers to overhead pantograph chargers, where it is dispensed to the bus.

Figure 1: Battery-Electric Charging Infrastructure Overview[6]

6 Overhead pantograph charger is depicted.

Utility Upgrades

Table 3 depicts the unit cost estimates of charging infrastructure as accounted in MDOT MTA's Lifecycle Cost Analysis. For initial deployments, the MDOT MTA is planning to utilize a ratio of two pantograph dispensers per every one charging cabinet.

Table 3: Approximate Unit Costs of Charging Equipment (2022)

	ABB HVC 150
Cost per cabinet	$120,000
Cost per dispenser	$30,000
Cost per one cabinet and one dispenser	$150,000

New, large-scale electrical service will be required to install the new charging stations. The new loads are greater than 10 times the existing electrical loads at the sites and will require significant investments by the MDOT MTA to support electrical service upgrades to each facility. The voltage and capacity of that service will be determined by Baltimore Gas and Electric (BGE), according to the power demand required by the new equipment. The MDOT MTA will apply for this new service with BGE and during this process, BGE will review the available capacity on the overhead or underground circuits near the location and will present the available alternatives and options for installing the new service. Installation plans will be site dependent – while the enhancements required for the seven-bus Kirk BEB Pilot included a new utility pole, transformer, and conduit, as well as some earthwork to level land, larger load enhancements later in the transition may require significantly more construction work to accommodate the additional equipment and redundancy required to support larger BEB fleets. The MDOT MTA and BGE are coordinating on long-term energy load planning for all three divisions that includes the scaling of utility infrastructure based on anticipated demand. Optimizing utility infrastructure sizing to align with daily service requirements, as opposed to total connected load, that will never be fully used, may save millions of dollars in capital investment at each depot.

The MDOT MTA is continuing to evaluate alternate energy systems, such as solar energy and microgrids, to ensure the resilient power supply needed to maintain 24/7 transit operations. The MDOT MTA will collaborate with BGE and the Maryland Public Service Commission (PSC) to determine innovative solutions that are appropriate for this purpose. Alternative energy systems will allow the MDOT MTA to benefit from cost savings and will enable the MDOT MTA to have reliable power during times of the year when the local utility is straining to supply power to its customers, such as during heat waves or serious storms.

While hydrogen fueling infrastructure will not be used for initial ZEB facility conversions between 2025 and 2030, the MDOT MTA is conducting a study of optimal hydrogen fuel storage, delivery, and generation methods for its operating facilities to continue evaluating future opportunities for this technology. The MDOT MTA will be evaluating the results of this study in 2023 and may elect to conduct a pilot deployment of FCEBs to test vehicle performance and fueling.

State Employee Transition Plan

The MDOT MTA plans to maintain its current workforce throughout the transition to a ZEB fleet through a training and retraining program. This program is currently under development and draws upon best practices from large transit agencies that have been operating BEBs, industry groups, and vehicle manufacturers. The MDOT MTA has coordinated with the local chapter of the Amalgamated Transit Union (ATU), the International Leadership and Training Center (ILTC), and other U.S. transit agencies that have begun training their workforce to support ZEB maintenance to ensure that the MDOT MTA's training program incorporates best practices from peer deployments and is developed with the needs of the MDOT MTA's workforce in mind. Training and Standard Operating Procedure (SOP) development is a significant investment within the overall fleet transition plan, as the new fleet will impact thousands of employees and multiple departments within the MDOT MTA.

The MDOT MTA has a draft ZEB Workforce Development Plan to provide a roadmap for implementing training. For example, maintenance activities will need to adjust, as some components of conventional buses and ZEBs differ. Additionally, these vehicles will require new maintenance functions and training, such as high-voltage safety education. **Table 4** lists the required training modules for the Transition.

Table 4: Proposed MDOT MTA ZEB Training Program Modules

Training Module	Source
BEB 101 Overview	MDOT MTA/Third Party
Operator Orientation	OEM
High Voltage Safety Basics (part of BEB 101)	MDOT MTA/Third Party
Maintenance Orientation	OEM
Entrance and Exit Doors	OEM
Wheelchair Ramp	OEM
Coolant Loop Fill Procedures	OEM
Towing/Recovery	OEM
Propulsion & ESS Familiarization/High Voltage Safety	OEM
Propulsion & ESS Systems Trouble Shooting	OEM
Siemens Propulsion Troubleshooting	OEM
XALT ESS Troubleshooting	OEM
Troubleshooting for Dispatchers/Starters/Supervisors/BOCC	MDOT MTA/Third Party
CPR & AED	MDOT MTA
Multiplex Systems	OEM
Suspension and Steering	OEM

Training Module	Source
Electric Fan Drive	OEM
Articulate Joint	OEM
HVAC Maintenance	OEM
First Responder Training for BEB	MDOT MTA/Third Party
Schedulers/Planners	MDOT MTA/Third Party
Charger Basics (as part of BEB 101)	MDOT MTA/Third Party
Depot Charger Familiarization (all brands and types)	OEM
Depot Charger Troubleshooting & Repair (all brands and types)	OEM
Charge Management	OEM
Charge Management Advanced	OEM
Mobile Charger Familiarization	MDOT MTA/Third Party
First Responder Training for Charging Infrastructure	MDOT MTA/Third Party

The workforce development training provided by the MDOT MTA will include registered apprenticeships. Since August 2022, the Maryland Apprenticeships in Transportation Workgroup, a group between the MDOT and the Maryland Department of Labor, has convened monthly. In collaboration with the MDOT's Transportation Business Units, the group is producing a report on the qualifications, structure, limitations, and advantages of apprenticeship programs in skilled trades areas within the MDOT. The TBUs are contributing data on skilled trade areas, needs/barriers to training and recruitment, vacancy/attrition rates, and other HRIS data for the report. The report will be completed in December 2022.

Several TBUs are in the process of developing Joint Apprenticeship Committees to further develop apprenticeship programs by technical area. The MDOT MTA has established a Joint Apprenticeship Council to develop an apprenticeship program with a specialized focus on Zero-Emissions for Bus Maintenance Technicians as its inaugural program.

Estimate of Carbon Dioxide Reduction

Transitioning the MDOT MTA's bus fleet to ZEBs with a 50 percent fleet conversion to BEBs by 2030 will reduce carbon dioxide emissions by an estimated 483 million pounds over the lifecycle of BEB operations. This calculation was developed based on current grid power supply assumptions and projected a partial transition to renewable sources by the existing utility provider.

Upstream emissions include considerations of diesel production through conventional petroleum refining and supply to the region for diesel buses, and of the production of electricity, based on current grid power for BEBs.[7]

Tailpipe emissions include estimates of CO_2, NO_X, SO_X, PM_{10}, $PM_{2.5}$, and VOC for clean diesel vehicles, as well as PM_{10} and $PM_{2.5}$ emissions attributed to brake and tire wear. For BEB emissions, the MDOT MTA has considered PM_{10} and $PM_{2.5}$ attributed to brake and tire wear.

7 Maryland State Law (Md. Code, Public Utilities Sec. 7-703) and MDOT MTA 2020 Sustainability Report

Emissions data was derived from the U.S. Department of Energy's Alternative Fuel Life-Cycle Environmental and Economic Transportation model, the Argonne National Laboratory's Greenhouse Gases, Regulated Emissions and Energy Use in Transportation model, and the EPA MOVES 2014b model. Emissions were compared and refined to incorporate actual operational experience from comparable transit agencies. Resulting per-unit emissions values were applied to MDOT MTA's fleet and operating environment with considerations of average vehicle efficiency and annual miles.

Financial Analysis

The MDOT MTA conducted a lifecycle cost analysis to compare the MDOT MTA's capital and operating expenses for fleet acquisition, operation, and maintenance associated with vehicles purchased between 2025 and 2030. The lifecycle cost analysis compares two "Build" scenarios[8] in which the MDOT MTA operates a ZEB fleet consisting of 70 or 77 BEB deliveries per year, and a "No-Build" scenario[9] that assumes the existing diesel bus fleet will be replaced by 70 similar models each year.

Lifecycle cost analysis inputs include current data from the existing MDOT MTA clean diesel fleet, such as annual mileage levels, fuel costs, and fuel economy, and replacement dates for the active fleet. For replacement ZEB options, such as active data for ZEBs that the MDOT MTA has not yet operated, data from peer transit agencies, and industry-wide research were applied to the MDOT MTA's assumed fleet and operating conditions.

Overall, the cost analysis shows that the full lifecycle cash cost of a transition to BEB is higher than the cost of continuing operations of clean diesel buses. While fueling costs are lower for BEBs than for clean diesel buses, overall operating costs for BEBs are higher than for clean diesel buses. Notably, the high capital costs of BEBs, their batteries, and charging infrastructure offset the fuel savings. However, the operating cost benefits are highly dependent on factors that are continually evolving as BEBs deploy in transit services. Current market conditions in 2022 have resulted in a shortage of parts and increasing lead times, which have caused price increases due to spiking BEB demand. Operating costs are anticipated to decrease in future years when market conditions and supply chains stabilize.

The analysis provided should be considered a conservative assessment of BEB costs, as the industry in North America is still in the preliminary stages of development. Production costs may decrease as production increases to meet future demand and economies of scale are achieved. However, cost reductions may be offset by reductions in tax breaks, grant programs, discounts, and incentives that are currently available for BEB acquisition and associated charging infrastructure. Additionally, MDOT MTA will continue to monitor supply chain challenges that

8 Both "Build" scenarios include the delivery of 7 BEB pilot buses in 2023.
9 Does not include the delivery of 7 BEB pilot buses in 2023.

have significantly delayed vehicle and component production. For example, delays for parts such as microchips may impact vehicle delivery timeframes and pricing.

The range of BEB models available for varying operating and climate conditions continues to evolve. The costs for batteries may decline with continued development of more efficient technology and lower production costs resulting from economies of scale. Some potential future cost reductions, however, may be slightly or drastically offset through increases in the cost of acquiring the primary battery components, specifically lithium or other alternative materials.

The costs of diesel fuel and electricity also strongly impact the lifecycle benefits of BEBs. While utility prices are historically less volatile than diesel prices, there is still the potential for utility price fluctuations, specifically increases to cover the cost of capital investments and rehabilitation.

Projected costs per year for all scenarios evaluated are presented in **Table 5** in 2020 dollars and in **Table 6** in Year of Expenditure (YOE) dollars.

Table 5: Preliminary Projected Costs in 2020 $ for Buses Purchased 2023-2030

2021-2041 Fleet Replacement Cost Comparison[10] (2020 $ million)		Build (BEB)[11]	No-Build (Clean Diesel)[12]
Capital	Vehicle Purchase Price	$328.9-361.4	$179.0
	Modifications & Contingency	$7.6-8.3	$8.9
	Charging/Fueling Infrastructure	$84.6-90.0	$0.0
	Major Component Replacement	$0	$27.8
	Incremental Initial Training Cost	$6.7-7.4	$0
	Total Capital Costs	*$427.8-467.2*	*$215.8*
Operating	Vehicle Maintenance	$65.9-68.9	$55.3
	Tire Replacement Cost	$6.0-6.3	$5.4
	Vehicle Fuel Costs[13]	$36.8-40.2	$55.6
	Charging/Fueling Infrastructure	$7.0-7.7	$0.6
	Incremental Ongoing Training Cost	$20.3-21.9	$0
	Total Operating Costs	*$136.1-144.9*	*$116.9*
Disposal	Bus Disposal	$0.8-$0.9	$0.8
	Total Disposal Costs	*$0.8-0.9*	*$0.8*
Total Cash Costs		**$564.7-613.0**	**$333.5**
Total Cash Cost per Mile		**$3.16-3.28**	**$1.87**
Emissions	Emissions - Tailpipe	$1.4	$13.6
	Emissions - Refining/Utility	$0.8	$2.4
	Noise	$3.8-$4.0	$5.2
	Total Environmental Costs	*$6.0-$6.3*	*$21.2*
Total Cash and Non-Cash Costs		**$570.7-619.3**	**$354.6**
Total Cash and Non-Cash Costs per Mile		**$3.19-3.32**	**$1.98**
Total Mileage (average million miles per year)		***179-187***	***179***

10 This analysis captures the lifecycle of capital, operating, emissions and disposal costs of all vehicles in the fleet procured from 2023 through 2030.

11 This table depicts the range of costs indicative of the "Build" scenarios evaluated – one scenario evaluates 70 and the other 77 BEB deliveries per year. All "Build" scenarios assume that seven pilot BEBs are delivered to MDOT MTA in 2023.

12 Annual mileage for no-build scenario is lower because in the Build scenario, there are 7 more buses to account for the pilot BEBs and potential increased deadhead mileage due to limited battery range.

13 Vehicle fuel cost includes costs of delivery, consumption and demand charges (for electric buses only).

Table 6: Preliminary Projected Costs in Year of Expenditures $ for Buses Purchased 2023-2030

2021-2041 Fleet Replacement Cost Comparison[14] (YOE $ million)		Build (BEB)	No Build
Capital	Vehicle Purchase Price	$590.5-649.0	$321.1
	Modifications & Contingency	$13.6-14.9	$16.1
	Charging/Fueling Infrastructure	$138.8-148.6	$0
	Major Component Replacement	$0.0	$93.7
	Incremental Initial Training Cost	$12.9-14.1	$0
	Total Capital Costs	*$755.7-826.7*	*$430.8*
Operating	Vehicle Maintenance	$230.3-240.6	$187.7
	Tire Replacement Cost	$19.3-20.1	$17.4
	Vehicle Fuel Costs	$116.3-126.7	$179.0
	Charging/ Fueling Infrastructure	$22.2-24.4	$1.7
	Incremental Ongoing Training Cost	$58.8-64.7	$0
	Total Operating Costs	*$446.8-476.4*	*$385.8*
Disposal	Bus Disposal	$4.3-4.7	$4.3
	Total Disposal Costs	*$4.3-4.7*	*$4.3*
Total Cash Costs		**$1,206.8-1,307.8**	**$820.8**
Total Cash Cost per Mile		**$6.75-7.00**	**$4.59**
Environmental	Emissions - Tailpipe	$4.4-4.6	$44.1
	Emissions - Refining/Utility	$2.6-2.7	$7.9
	Noise	$12.3-12.9	$16.5
	Total Environmental Costs	*$19.3-20.2*	$68.6
Total Cash and Non-Cash Costs		**$1,226.1-1,328.0**	**$889.4**
Total Cash and Non-Cash Costs per Mile		**$6.86-7.11**	**$4.98**
Total Mileage (average million miles per year)		***179-187***	***179***

14 This analysis captures the lifecycle of capital, operating, emissions and disposal costs of all vehicles in the fleet procured from 2022 through 2030.

Conclusion

Zero-emissions vehicles represent a new technology that is still changing rapidly. The MDOT MTA is closely following industry developments, including the experiences of peer transit agencies that have begun operating ZEBs. The MDOT MTA continues research and analysis to refine its preliminary plans to scale up the ZEB fleet and understands the need to remain flexible and adapt as needed to new technology and market conditions. Furthermore, the MDOT MTA is building a strong coalition of project stakeholders to ensure all aspects of the fleet transition and associated impacts are carefully considered to avoid risks during integration. The MDOT MTA's primary goal is to maintain reliable service for passengers throughout the duration of the zero-emissions transition.