District Department of Transportation

DC Circulator Battery-Electric Bus Pilot Report

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Cover Photo: American University Radio (WAMU 88.5)

Acronyms

Acronym	Description
BEB	Battery-electric bus
DCST	DC Surface Transit, Inc.
DDOT	The District Department of Transportation
HVAC	Heating, ventilation, and air conditioning
OEM	Original equipment manufacturer
O&M	Operations and maintenance
PEPCO	Potomac Electric Power Company
RATP Dev	Régie Autonome des Transports Parisiens Développement
SOC	State-of-charge
TCO	Total cost of ownership
WMATA	Washington Metropolitan Area Transit Authority
ZE(B)	Zero-emission (bus) – a vehicle that has no tailpipe emissions, typically a battery-electric bus (BEB) or fuel cell electric bus (FCEB).

1.0 INTRODUCTION

Between April 2018 and April 2020, the District Department of Transportation (DDOT) operated a 14-battery-electric bus (BEB) demonstration pilot (BEB Pilot) on its DC Circulator transit system. The purpose of the pilot was to assess the performance of BEBs in comparison to DDOT's existing diesel bus fleet. The results of the pilot would be used to inform long-term decisions on future fleet procurements and operations.

During the two-year, two-phase pilot, several cost- and performance-related data were collected to evaluate the strengths and opportunities of the BEB fleet. At the conclusion of the BEB Pilot and pursuant to the Clean Energy DC Omnibus Amendment Act of 2018 that requires all public buses to be transitioned to 100% zero-emissions (ZE) by 2045, DDOT committed to transitioning its entire bus fleet to BEBs.

The following report synthesizes the comparative analyses, results, lessons learned, and best practices that were documented during the pilot. The findings of this report will be useful in informing subsequent stages of DDOT's fleet transition, including future studies and design. The report is divided into three major sections: Introduction, BEB Pilot Analysis, and BEB Pilot Summary. The introduction provides background on the DC Circulator, BEB technology, and the initial framework and goals for the BEB Pilot. The BEB Pilot Analysis section provides insight into the challenges experienced during each phase of the BEB Pilot, and the BEB Pilot Summary presents the results of various performance and cost analyses, and lessons learned.

1.1 DC Circulator

Starting as a product of a unique partnership between DDOT, the Washington Metropolitan Area Transit Authority (WMATA) and DC Surface Transit, Inc. (DCST), the DC Circulator is now the fourth-largest bus system in the region, providing approximately five million trips per year.

The DC Circulator system consists of six distinct routes across Washington, DC, and into Rosslyn, VA (Figure 1). The DC Circulator's goal is to service each stop every 10 minutes, providing simple, fast, and affordable transit to residents, commuters, and visitors around the nation's capital.

The DC Circulator started as a two-route diesel bus service in 2005 and is now an extensive network of six routes that are powered by clean diesel, hybrid, and electric buses. The DC Circulator has also expanded its maintenance and operational capacity to accommodate its growing fleet. Buses are dispatched and stored at three separate facilities : the 17th Street Facility, leased from Nordlinger Investment Corporation in 2018, the Hains Point Facility, leased from the National Park Service in 2017, and the South Capitol Street Facility, which DDOT acquired in 2013.

Figure 1. DC Circulator System Map

Source: DDOT

1.2 Battery-Electric Buses (BEBs)

BEBs use onboard batteries to store and distribute energy to power an electric motor and other onboard systems. Similar to many other battery-powered products, BEBs must be charged for a period of time to be operational.

Currently, BEBs can be charged at a bus storage facility, overnight or midday, or on-route (typically during layovers). A facility charging strategy typically consists of buses with high-capacity (kilowatt-hour or kWh) battery packs that are charged for four to eight hours with "slow" chargers - usually less than 100 kilowatts (kW) – while being stored overnight. An on-route charging strategy typically consists of buses with low-capacity battery packs that are charged with "fast" chargers – usually in excess of 100 kW – during bus layovers (typically 5-20 minutes).

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

Figure 2. Charging Strategies

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

Under existing conditions, BEBs cannot meet the ranges that traditional internal combustion engine buses can. BEBs typically have a range of 125-150 miles, and this range is affected by a myriad of factors, including temperature and HVAC usage, driving behavior, and topography. For this reason, if an agency's service blocks cannot be completed with BEBs, other capital-intensive strategies must be considered to meet range requirements, including, but not limited to, additional BEBs, on-route charging infrastructure, service changes, and/or a mixed-fleet strategy with the incorporation of fuel cell electric buses.

1.3 DC Circulator BEB Pilot

In 2017, DDOT procured 14 Proterra Catalyst BEBs that were then placed into service in Spring 2018 for a BEB Pilot. The 40-foot BEBs had a nominal range of up to 250 miles and would be stored, maintained, and charged by 14 50-kilowatt (kW) Tritium ground-mounted, plug-in chargers at DDOT's bus facility on South Capitol Street, SE, Washington, DC.

The BEB Pilot was launched with five goals:

- Establish a cost benefit of operating BEBs compared to diesel buses;
- Determine if BEB technology is viable for the DC Circulator's service needs;
- Quantify the positive and negative environmental impacts of the technology;
- Guide DDOT staff in whether to include BEBs as an option for future bus procurements; and
- Determine whether operating costs are lower for BEBs than diesel buses and if the difference offsets the higher capital costs of BEBs.

Figure 3. DC Circulator Zero-Emission Bus

Source: DDOT

The pilot was planned to be conducted in two distinct phases over an estimated 17-month period (April 2018 through August 2019). Phase I, designated as the evaluation and troubleshooting period, would be conducted between April 2018 and September 2018. The primary focus was to establish performance metrics, collect data, and familiarize operations and maintenance (O&M) staff with the technology. A one-month interim phase was planned during October 2018 to allow for a new O&M contractor, Régie Autonome des Transports Parisiens Développement (RATP Dev), to properly transition by familiarizing staff with DC Circulator operations and the BEB Pilot.

Phase II would immediately follow the interim phase in November 2018. During Phase II (November 2018 – August 2019), DDOT would analyze reliability, maintenance data, and fuel economy. DDOT planned to progressively increase service hours for the BEBs over the duration of the pilot to test the technology's limits and more closely align the BEBs' service profile with the existing requirements. Table 1 summarizes the planned phases, durations, and goals for the BEB Pilot.

Table 1. BEB Pilot Overview

Phase	Duration	Timeframe	Goal
I	6 months	April 2018 – September 2018	-Establish performance metrics -Collect data -Familiarize O&M staff with BEB technology
Interim Phase	1 month	October 2018	-Transition O&M contractors (First Transit to RATP Dev)
II	10 months	November 2018 - August 2019	-Analyze reliability, maintenance data, and fuel economy

Source: DDOT

To successfully operate the BEB Pilot, DDOT partnered and coordinated with several public and private entities, including Proterra and Tritium for the buses and chargers, respectively, the Potomac Electric Power Company (PEPCO) for utility interconnections, and several consultants and software providers to collect, analyze, and report data related to the BEB Pilot.

In April 2018, DDOT placed the BEBs into service, launching the first full-scale BEB technology pilot in the region.

2.0 BEB PILOT ANALYSIS

While the BEB Pilot was successful in achieving its goals, there were several challenges that led to adjustments to the original approach and schedule (outlined in Section 1.2). The following sections provide an overview of the BEB Pilot's phases and the comparative analyses between BEBs and diesel buses as informed by the BEB Pilot.

2.1 Phase I (April 2018 – September 2018)

During Phase I, data on fuel economy (range, state of charge, and time traveled) were collected and analyzed using First Transit's field reports and Proterra's APEX system. BEBs were operated for approximately 8-10 hours (per day) on four of the DC Circulator's least demanding routes (shorter with fewer hills): National Mall, Georgetown – Union Station, Dupont Circle – Georgetown – Rosslyn, and Eastern Market – L'Enfant Plaza. BEBs were operated for 6-7 hours on the DC Circulator's longer routes: Woodley Park – Adams Morgan – McPherson Square Metro and Congress Heights – Union Station. In contrast, the existing New Flyer diesel buses were operating as much as 15 hours.

Due to the uncertainty and nascency of BEB technology, a conservative 30% battery reserve was established to ensure that the vehicles would maintain enough state-of-charge (SOC) to return to the facility. Establishing a battery reserve is a common practice with BEB operations, it helps reduce range anxiety for operators and maximizes charging outcomes. However, DDOT's 30% buffer was more conservative than what is typically applied by agencies (20%), resulting in a reduction of an additional 44 kWh of energy (or 25 miles of range) that could not be used[1]. The 30% battery reserve coupled with the hours of operation restriction significantly reduced each vehicle's range potential.

At the conclusion of Phase I, it was determined that the BEBs averaged approximately 108 miles of range. It was the opinion of operations staff the BEBs could travel for a minimum of eight hours on each route – the minimum amount required for viability in service.

Phase I was not without challenges. Software interoperability issues between the charger and bus coupled with overheating of the chargers resulted in nearly 40% of chargers being inoperable in July. However, the BEB and charger original equipment manufacturers (OEMs) were able to coordinate and resolve the issue by August 2018.

[1] The advertised battery capacity and range, 440 kWh and 250 miles, respectively, would result in an average efficiency of 1.76 kWh/mile.

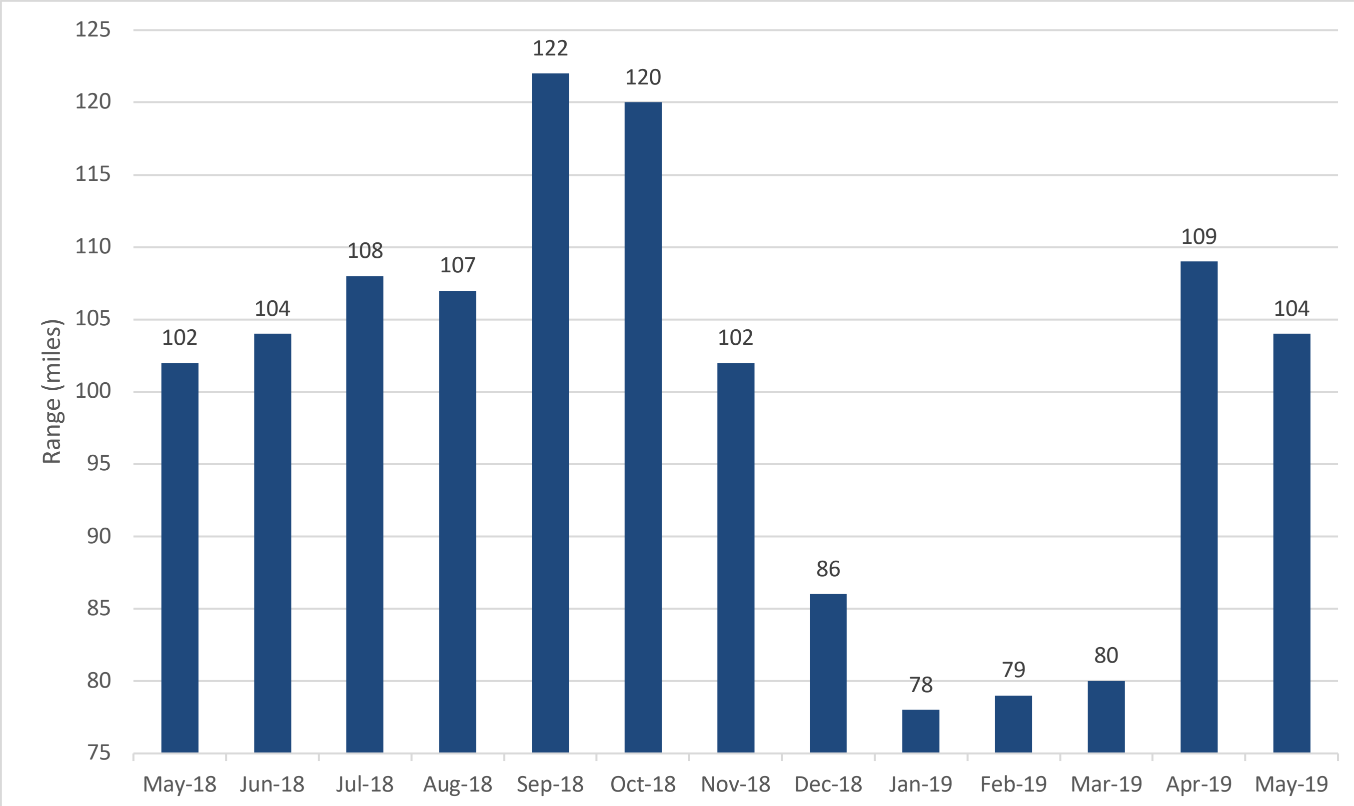
2.2 Phase II (October 2018 – April 2020)

Per the original BEB Pilot project schedule, an Interim Phase during October 2018 was planned as a “soft launch” before the initiation of Phase II in November 2018. The Interim Phase would allow DDOT staff to troubleshoot, resolve issues, and possibly augment standard operating procedures (SOPs) based on lessons learned from Phase I. The Interim Phase would also serve as a transition period for the new incoming O&M contractor (RATP Dev) to familiarize with DDOT, the DC Circulator service, and the BEBs.

Due to unforeseen challenges with data reliability and complications with the transition of O&M contractors, DDOT made the decision to extend the Interim Phase through March 2019 with Phase II being conducted between April 2019 and April 2020. Phase II would expand the scope of performance measures to include environmental impacts, reliability, and maintenance. Ultimately, the Interim Phase became the de facto Phase II, extending through April 2020.

Due to Phase II’s extension, DDOT was able to assess BEB performance over several seasons and under varying operating conditions. DDOT was then able to make adjustments based on lessons learned earlier in the phase to improve performance in the latter half of Phase II. The most significant finding during this time period was battery performance (range) was significantly reduced during winter months. Figure 4 presents the average operating range (between Oct. 2018 and May 2019) and clearly indicates that operating range was significantly reduced during the winter months. In the BEB Pilot’s first winter, several buses were forced to return to the facility earlier than anticipated due to a significant loss in SOC. It was found that this reduction was largely a result of the heat, ventilation, and air conditioning (HVAC) systems onboard requiring more power and usage during colder temperatures. Based on DDOT’s analysis, for every one-degree decrease in ambient temperature, BEBs experiences a 2.1% increase in power usage. This resulted in a 14% reduction in range between fall and winter months. It was noted that some of the reduction in range could be attributed to the conservative 30% battery reserve buffer.

Figure 4. Average Operating Range (by Month)



Source: DDOT

To mitigate these impacts, DDOT established several new procedures and recommendations for winter and summer operations. For the winter, DDOT developed a winterization protocol that required RAPT Dev to pre-condition buses before service, preset temperatures on the vehicles, and the replacement of buses in-service with low SOCs with buses with higher SOCs to maintain service continuity. For summer months, staff recommended that an enclosure or tarp be constructed to protect buses and chargers from the elements – this is in direct response to the overheating that was experienced during Phase I.

There were additional challenges experienced during Phase II. Data quality proved to be an issue and resulted in inconsistent fuel economy and maintenance data. DDOT halted data collection until January 2020 when new and more reliable data logger hardware was installed on buses, however, due to the impacts of the COVID-19 pandemic, transit service staff determined pilot data collected during that period would not accurately reflect real world operating conditions given the significant decrease in ridership. The pilot was discontinued and limited analysis of the winter months of Phase II was examined due to data being unreliable or inconsistent with typical ridership and service patterns.

3.0 BEB PILOT SUMMARY

While DDOT's BEB Pilot project experienced several challenges, DDOT's staff and partners were able to make adjustments, develop solutions that will be useful in future stages of operation and implementation of a 100% BEB fleet, and achieve the original five goals.

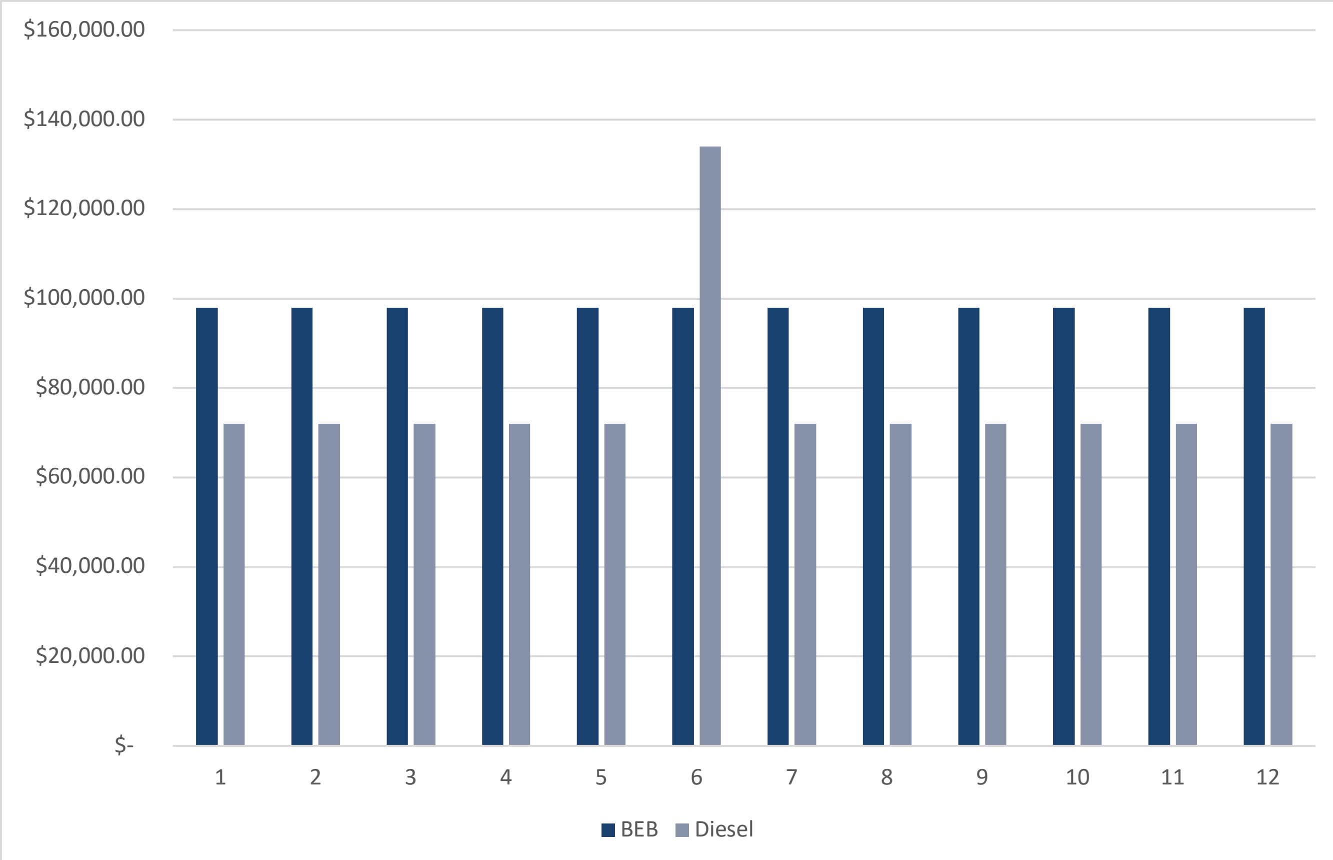
After the BEB Pilot, DDOT came to the following conclusions between their BEBs and diesel buses:

- **It is currently cheaper (per mile) to operate BEBs.** Diesel buses cost about 24% more per mile to operate ($0.45 for BEBs and $0.56 for diesel buses) and are expected to become more expensive based on Producer's Price Index assumptions. Whereas, the BEB's price per mile can be reduced further if charge management strategies are implemented to take advantage of PEPCO's off-peak TOU rates.

- **Capital expenditures are higher for BEBs than diesel buses.** The transition to BEB will be more costly due to the costs for new infrastructure (chargers and utility enhancements) and the price of BEBs can be almost 75% more expensive than diesel buses (DDOT's per bus price for its BEBs were $939K as compared to $540K for its diesel buses).

- **Over a 12-year lifecycle, it will be more expensive to operate BEBs than diesel buses.** This is primarily due to the higher initial purchase price of the BEB. It should be noted that the total cost of ownership (TCO) of a BEB is expected to rapidly decrease over time and it is anticipated to reach parity with diesel buses within the next 10 years.

Figure 5. BEB vs. Diesel 12-Year Annual Cost of Ownership



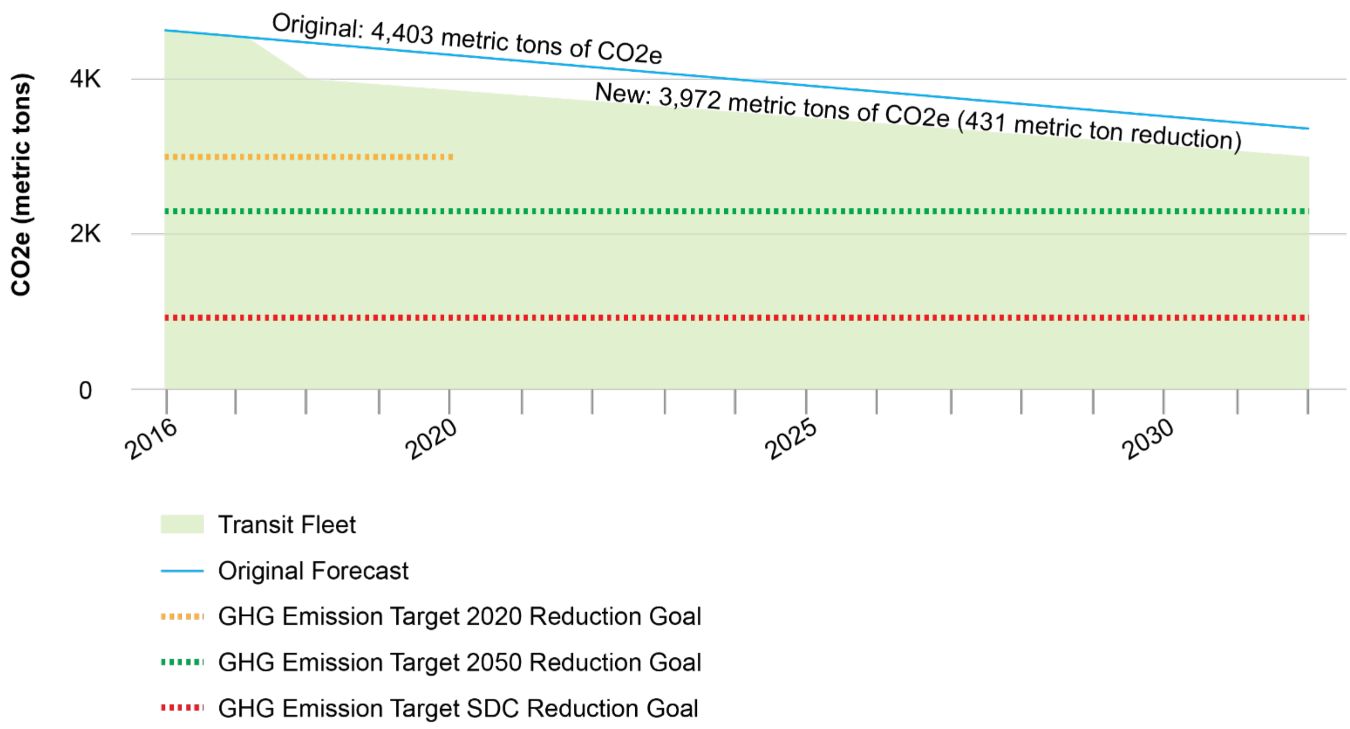
Source: DDOT

Note: Year 6 is the assumed mid-life overhaul; for BEBs, this would include the replacement of its battery packs.

- **BEBs have a lower range than existing diesel buses.** BEB technology still does not match the range of diesel buses. In the case of DDOT, BEBs were capped at the amount of hours they could operate per day and there was also a large portion of the battery that was reserved and unusable – making it difficult to fully assess the actual range of the BEB Pilot. However, a study on the Congress Heights route found that a range of 106 miles – easily achieved by diesel buses - could be scheduled for BEBs. It was recommended that a similar analysis be conducted on other routes to determine similar maximum ranges.

- **BEBs will greatly reduce CO2e emissions.** The Department of Energy and Environment (DOEE) found an effective reduction of 431 metric tons from tailpipe emission reduction (from baseline) of CO2e per year as a result of purchasing BEBs over diesel buses (based on 14 buses). Figure 6 presents the original emissions forecasts (purchasing 14 diesel buses) and the new forecast based on replacing those same buses with 14 BEBs.

Figure 6. Reduction in CO2e



Source: DDOT

Table 2 provides a summary of the BEBs as compared to the existing diesel buses in terms of costs, performance, and environment, and Table 3 summarizes the major goals, findings, and solutions for each phase of the pilot.

Table 2. BEB Pilot Summary of Performance Measures

Category	Measure	Proterra (440 kWh BEB)	New Flyer (Diesel)
Costs	Average cost per mile	\$0.45	\$0.56
	Bus purchase price	\$939,938	\$539,641
	Total cost of ownership (12-years)	\$1,458,553	\$925,601
Performance	Average operating distance in revenue service	44 miles	96 miles
Environmental	Total Fleet CO2e annual emissions baseline value = 4,403 metric tons	-431 metric tons (from baseline)	-

Source: DDOT

Note : Average cost per mile is expected to diverge further as BEB technology improves, BEBs are operated longer distances, and diesel prices increase. The average operating distance in revenue service is also a factor of conservative battery reserves and an artificially maintained maximum eight hours of operating service for the BEBs.

Table 3. Summary of BEB Pilot Phases

Phase	Timeframe	Goals	Findings/Challenges	Solutions
I	Apr. 2018 – Sep. 2018	-Collect and analyze fuel economy-related data, including range, state-of-charge, and time traveled by buses.	-Range was relatively low due to conservative battery reserve (30%) and maximum operating time (eight hours). -Interoperability challenges between buses and chargers due to overheating and software issues.	-Enhanced training for operators and more coordination between hardware and software OEMs.
II	Oct. 2018 - Apr. 2020	-Continue to collect and analyze fuel economy-related data, as well as maintenance, and environmental data.	-BEB range is drastically reduced in winter due to the power that heating systems require.	-Developed winterization protocol that requires more training, and pre-conditioning and preset temperatures on BEBs.

Source: DDOT

3.1 Next Steps

DDOT has committed to transitioning the fleet to BEBs based on the results of the BEB Pilot and the Clean Energy DC Omnibus Amendment Act of 2018. Currently, DDOT is in the process of developing a BEB transition plan that focuses on both the fleet and facilities. This report is anticipated to be completed in 2022 and will serve as the framework for design and implementation for the full fleet transition.