DASH ZEB Transition Plan
Phase 2: Fleet Planning
Final Report

June 2023

Table of Contents

List of Tables

List of Figures

List of Acronyms

Acronym	Description
AC	Alternating Current
BEB	Battery-electric bus
BEV	Battery-electric vehicle
CMS	Charge management software
CNG	Compressed natural gas
DASH	Driving Alexandria Safely Home
DC	Direct Current
ESS	Energy storage systems
EV	Electric vehicle
FTA	Federal Transit Administration
HT	High tension
HVAC	Heating, ventilation, and air conditioning
ICE	Internal combustion engine
ICEB	Internal combustion engine bus
ICEV	Internal combustion engine vehicle
kW	Kilowatt
kWh	Kilowatt-hour
LT	Low tension
MV	Medium voltage
OEM	Original equipment manufacturer
PHEV	Plug-in hybrid electric vehicle
ROM	Rough order of magnitude
SoC	State of charge
TBA	To be announced
V	Voltage
ZE	Zero emissions
ZEB	Zero emissions bus
ZEV	Zero emissions vehicle

1 Introduction

1.1 Overview

The Alexandria Transit Company (DASH) Board of Directors and the City of Alexandria have adopted a policy goal of converting the entire fixed-route bus fleet to 100% zero emissions (ZE) technology by the year 2037 and have adopted the goal that all new bus purchases starting in 2027 will have zero tailpipe emissions. Based on this policy directive, DASH has been at the forefront of the fleet electrification movement over the last three years. In 2020, DASH completed the DASH Zero Emission Fleet Feasibility Study to determine the best feasible technologies for DASH to achieve its goals of transitioning its fleet to zero emission buses while meeting service requirements. DASH then completed the first phase of its Zero Emission Bus (ZEB) Implementation Plan in 2021, which focused on facility expansion and improvements needed to support a ZEB fleet.

WSP is developing the second phase of the ZEB Implementation Plan for DASH to guide its full fleet conversion. The cost estimates will be developed based on analyses of market conditions, vehicles, service, infrastructure, and utility costs. These costs and analyses will inform the fleet conversion roadmap for DASH and are presented in a series of technical reports which are synthesized in this report:

- Task 1: Current ZEB Fleet Analysis
- Task 2: Full Fleet Assessment
- Task 3: Energy Assessment
- Task 4: Maintenance Assessment
- Task 5: Utility Grid Assessment
- Task 6: Total Cost of Ownership

2 Current ZEB Fleet Analysis

This section provides an overview of the current ZEB deployment, data sources and limitations, and in-service results.

2.1 Introduction

DASH is the city bus system in Alexandria, Virginia, owned by the City of Alexandria and operated by the Alexandria Transit Company. DASH provides service to approximately four million passengers a year within the city of Alexandria. DASH has developed and implemented several initiatives to incorporate zero emission bus technologies into their current fleet and long-term fleet planning. The DASH revenue bus fleet is comprised of 101 buses, including 14 battery-electric buses (BEBs), 52 diesel electric hybrid buses, and 35 clean diesel buses. DASH typically has an additional eleven conventional buses that are used as operational spares.

DASH first introduced BEBs into regular service in September 2020. To assess the energy use and reliability of DASH's current 14 BEBs, WSP analyzed available data on in-use performance of these buses, including the number of road calls, resulting mean distance between in-use failures (MDBF), and average in-service electricity use in kilowatt-hours per mile (kWh/mi). Data sources for this analysis included Connect 360 (New Flyer) and Valence (Proterra) telematics systems installed on each bus which report daily summary data for various metrics, as well as daily mileage records, and road call records obtained from DASH's Fleet Watch system. The collected and analyzed data for these BEB fleets is captured in section 2.3 Data Collection. Within that section, Table 1 includes summary information for road calls, mileage, and MDBF for DASH's other diesel and hybrid-electric buses over the same time period. Average energy use for these buses, which all have diesel engines, is not shown as it is not directly comparable to electricity use by BEBs.

Figure 1. A 60-foot bus in service

DASH received its initial deployment of BEB buses in 2020 with three 40-foot New Flyer BEBs received in 2020 and three 40-foot Proterra BEBs which arrived in 2021. Throughout 2021, DASH received an additional eight BEBs, for a total of 14 BEBs in the fleet, evenly split between New Flyer and Proterra models. Of the 14-vehicle BEB fleet, three of the New Flyer buses are 60 feet in length, while the rest of the vehicles are 40 or 42 feet.

2.2 Methodology

Data sources used for this analysis include Connect 360 (New Flyer) and Valence (Proterra) telematics systems installed on each bus, which report daily summary data for various metrics when a bus is used in service. This data was used to calculate usage (days in service, miles accumulated) for each BEB, as well as average energy use (kWh/mi) in service. As noted below, the New Flyer and Proterra systems report different metrics, which affected the analysis that could be completed for each group of buses. In particular, the Proterra system reports daily energy use and accumulated miles but does not report daily in-service hours, so daily average in-service speed could not be calculated for these buses. In addition, the New Flyer system separately reports daily energy used by the traction motor, the low voltage accessories (lights, signals, etc.), high voltage accessories (air compressor, air conditioning) and the heating system. This allowed WSP to separately evaluate energy used for propulsion and cabin heating in New Flyer buses. The Proterra system only reports total energy used, so WSP could not separately evaluate energy use for propulsion and cabin heating in Proterra buses.

WSP also gathered daily mileage records, road call records, and road call cost data for each BEB from DASH's Fleetio system. This data was used to calculate mean distance between failures (MBDF) in miles for each group of BEBS as a measure of reliability, as well as average road call maintenance costs ($/mile) to date. The energy use during the November 2021 to June 2022 period was analyzed for the New Flyer 40-foot, New Flyer 60, and Proterra 42-foot fleets. This timespan represents the period in which data was available for all the BEB types.

2.3 Data Collection

The timeframes of data analyzed between subfleets differ due to data availability limitations from BEB systems. Data sources included:

- Fleetio: Overall fleet information such as vehicle model, make, propulsion type; and road calls
- FLEETWATCH: ICEB mileage and ICEB fuel consumed
- Valence: Proterra energy usage and mileage
- Connect 360: New Flyer energy usage and mileage

During this analysis, WSP found that some of the daily data reported by New Flyer Connect 360 for the 40-foot BEBs was corrupted, and daily accumulated miles was either not reported or was reported incorrectly for some buses on certain days. For these bus-days, WSP used mileage data reported by the FLEETWATCH system and energy data reported by New Flyer Connect 360 to complete the analysis. A portion of energy usage data received from New Flyer Connect 360 was corrupted and had to be discarded. Mileage data provided by the Proterra Valance system for BEBs 804, 805, and 806 was inaccurate, as records show it was not automatically generated. WSP relied on FLEETWATCH mileage data to complete the assessment for the Proterra subfleet. It is highly recommended that DASH consider investing in comprehensive charge monitoring, charge management, and vehicle telematics systems (such as ChargePoint's ViriCiti) that captures consistent vehicle and infrastructure data so there is a Single Source of Truth (SST) for DASH to assess the performance of their fleet and infrastructure. Ideally, data from all OEM systems should be consolidated and available in a single third-party system.

WSP used the following datasets to complete the analysis of DASH's current BEB fleet:

Table 1. Current ZEB Fleet Analysis Datasets

Dataset	Bus Type	Bus Size	OEM	Timeframe	Data Source
Fleet Inventory	Diesel, Hybrid, Electric	29-, 35-, 40-, 42-, and 60-foot	Gillig, New Flyer, Orion, Proterra	August 30, 2022	Fleetio
Road Calls	Diesel, Hybrid	29-, 35-, and 40-foot	Gillig, New Flyer, Orion	July 2021 – October 2022	Fleetio
Road Calls	Electric	40-, 42-, and 60- foot	New Flyer, Proterra	July 2021 – October 2022	Fleetio
Energy Usage	Electric	42-foot	Proterra	November 2021 – June 2022	Valence
		40-foot	New Flyer	November 2021 – June 2022	Connect 360
		60-foot			
Fuel consumed	Diesel, Hybrid	29-, 35-, and 40-foot	Gillig, New Flyer, Orion	July 2021 – October 2022	FLEETWATCH
Mileage	Diesel, Hybrid	29-, 35-, and 40-foot	Gillig, New Flyer, Orion	July 2021 – October 2022	FLEETWATCH
	Electric	42-foot	Proterra	November 2021 – June 2022	Valence
		40-foot	New Flyer		Connect 360

Source: WSP

Although energy consumption data was not available for DASH's current fleet of internal combustion engine buses (ICEBs), WSP estimated energy usage for current ICEBs by evaluating the average miles per gallon (MPG) used to populate Table 2. Hybrid buses are included in the 40-foot buses ICEB group, as energy data was also not available for hybrid buses in the datasets provided.

2.4 In-Service Results

The seven Proterra 42-foot BEBs were in service for a total of 1,041 bus-days (defined as one bus in service for one day) during the analysis period, and accumulated 119,371 miles, for an average of 114 miles/day. During that time the buses averaged 1.5 kilowatt-hours per mile (kWh/mi) in energy use. This fleet experienced four recorded road calls during the analysis period, for an MDBF of 29,843 miles. The cost of responding to these road calls averaged $0.01 per mile.

The three New Flyer 40-foot BEBs were used in service for a total of 709 bus days during the analysis period and accumulated 31,989 miles, for an average of 45 miles per day per bus. During that time, the buses averaged 2.3 kilowatt-hours per mile (kWh/mi) in energy use. This sub-fleet experienced two recorded road calls while in service, for a MDBF of 15,994 miles. The cost of responding to these road calls averaged $0.02 per mile.

The three active New Flyer 60-foot BEBs were in service for a total of 315 bus-days during the analysis period and accumulated 18,623 miles, for an average of 59 miles per day. During that time the buses averaged 3.5 kilowatt-hours per mile (kWh/mi) in energy use. This fleet experienced four recorded road calls while in service, for an MDBF of 4,656 miles. The cost of responding to these road calls averaged $0.02 per mile.

Table 2. Summary of Data Collection

Fleet Type[1]	Road Calls	Miles[2]	MDBF	Road Call Cost Per Mile	Average Energy Use
BEBs	10	169,982	16,998	$0.01	NA

1 29-ft, 35-ft and 40-ft ICEBs include hybrid vehicles.

2 BEB mileage provided by OEM datasets and ICEB mileage provided by FLEETWATCH.

Fleet Type[1]	Road Calls	Miles[2]	MDBF	Road Call Cost Per Mile	Average Energy Use
42-ft Proterra BEB	4	119,371	29,843	$0.01	1.5 kWh/mi
40-ft New Flyer BEB	2	31,988	15,994	$0.02	2.3 kWh/mi
60-ft New Flyer BEB	4	18,623	4,656	$0.02	3.4 kWh/mi
ICEBs	202	4,146,648	20,528	$0.018	NA
29-ft ICEBs[3]	3	21,593	7,198	$0.161	1.80 kWh/mi
35-ft ICEBs	160	3,301,743	20,636	$0.016	2.44 kWh/mi
40-ft ICEBs	39		21,111	$0.019	2.51 kWh/mi

Source: Fleetio and FLEETWATCH

The average energy use (kWh/mi) for the three BEB sub-fleets varied by bus type. The relative difference in average energy use between the 40-foot and 60-foot New Flyer BEBs is in line with general expectations due to the difference in size and weight of these buses. However, the New Flyer 40-foot BEBs were used on a lower-speed duty cycle, averaging 7.5 miles per hour (MPH) in-use speed compared to 11.1 MPH for the 60-foot BEBs. This slower duty cycle represents more stops per mile on average, which is expected to result in higher average energy use. For all New Flyer BEBs, approximately 80% of net energy was used for propulsion and vehicle accessories (lights, air compressor, air conditioning, etc.) and 20% was used for passenger cabin heating during cold weather. There were relatively few cold days during the period analyzed with an average temperature below 64°F.

The 42-foot Proterra BEBs used, on average, significantly less energy per mile than the 40-foot New Flyer BEBs. However, the Valence telematics system on the Proterra buses reports less detailed daily information than the New Flyer Connect 360 system. In particular, the Proterra buses do not report daily in-service hours, so average in-service speed could not be calculated for these buses. Also, the Proterra buses do not report how much daily energy was used for heat compared to other uses. As such, the contributions of different factors to lower energy use (kWh/mi) by the Proterra buses cannot be determined. These factors could include a more efficient drive system including the effect of lower bus weight), a more efficient heating system, and differences in average duty cycle (i.e., a higher speed duty cycle would be expected to use less energy per mile). Data on energy consumption was not available for Gillig and New Flyer hybrids. Data inputs in on ICEBs were estimated by evaluating average miles per gallon (MPG) and these subfleets include hybrid vehicles. WSP understands that since energy usage data was not available for hybrid buses, the average energy usage for 29-ft, 35-ft and 40-ft is only an estimate.

Compared to DASH's diesel and hybrid buses ,both sub-fleets of New Flyer BEBs had a lower MDBF, while the Proterra BEBs had a higher MDBF. These findings are based on a relatively small data set, so DASH should not extrapolate this data to assess future BEB performance. Of the ten recorded road calls experienced by the BEBs, only three (30%) were related to the electric drive system. The other road calls were related to other bus systems such as doors, mirrors, brakes, and suspension. By comparison, of the 54 road calls recorded for the diesel and hybrid buses, 90% were related to the powertrain. The most frequent issues were engine shut down, engine coolant leaks, and check engine light on.

2.4.1 Proterra 42-foot Buses

Energy Usage

The in-use performance of the 42-foot Proterra BEBs between November 2021 and June 2022 is summarized in Table 3. As shown, over this period this group of buses was used in service for a total of 1,041 bus-days and accumulated 119,371 miles, an average of 115 miles/bus/day while in use. Individual buses averaged between 56 and 204 miles/day. For individual buses utilization ranged from 22% to 80%, with an overall average fleet utilization of 58%. Utilization is calculated as the number of days in service divided by the total number of days in the period. Insufficient data was available to calculate an availability metric, which would take into consideration periods in which the bus was unavailable due to maintenance or other issues. Over this period, net total energy use by the Proterra BEBs ranged from 1.4 to 1.6 kWh/mi for individual buses, with a fleet average of 1.5 kWh/mile.

The Valence telematics system installed on the Proterra BEBs does not report daily in-service hours, daily energy use (kWh) by different bus systems (propulsion, heat), or ambient temperature (°F) as the New Flyer Connect 360 system installed on New Flyer BEBs does. Therefore, for the Proterra buses WSP could not calculate and plot daily energy use (kWh/mi) versus in-service speed (MPH) or daily average heating load versus ambient temperature, as was done for the New Flyer BEBs. Consideration of ambient temperature data from other sources such as the National Weather Service was not possible during this analysis.

However, the Proterra system does provide data on total energy consumed by the bus systems, energy collected via regenerative braking, and net energy used. This data indicates that on average the Proterra buses collected 0.47 kWh/mile in regenerative braking energy, which reduced net energy draw from the battery while in service by 31%.

Table 3. Proterra 42-Foot Buses Energy Consumption Summary

Vehicle ID Number	Service Days	Service Miles	Utilization %	Average Daily Net Energy Consumed (kWh)
804	111	11,612	44%	154
805	189	22,349	74%	165
806	204	23,190	80%	179
807	164	20,135	64%	195
808	156	17,151	61%	163
809	161	18,309	63%	171
810	56	6,625	22%	161
Fleet Total	**1,041**	**119,371**	**58%**	**172**

Source: Valence

The 42-foot Proterra BEBs used, on average, significantly less energy per mile than the 40-foot New Flyer BEBs. WSP does not have enough information to definitively identify which factors are most important with respect to the demonstrated lower energy use by the Proterra buses. It is not possible to assess what percentage of the net energy reduction derived from factors inherent in the bus design (such as a more efficient drive train, a more efficient heating system, better regenerative braking energy collection) or from duty cycle related factors (stops per mile, topography, passenger loading, driver behavior). The reason why these buses used less energy per mile could be due to a combination of the following factors:

- Proterra buses may have been used on routes with a higher average speed and fewer stops per mile than New Flyer buses.
- Proterra buses may have been used on flatter routes than New Flyer buses, using less energy needed for hill climbing.
- Proterra buses may have been driven by bus operators with less aggressive driving habits (acceleration and braking) than New Flyer buses.
- Proterra buses may have been driven on routes with lower passenger loading than New Flyer buses.
- Proterra buses may have a more efficient drive system than New Flyer buses.
- Proterra buses may have a more efficient heating system than New Flyer buses.
- Proterra buses may do a better job at collecting regenerative braking energy than New Flyer buses.

The Proterra drive system and battery weight are the key contributors to the lower energy use. New Flyer buses use a BAE power unit, while Proterra buses use a ProDrive drivetrain system. Proterra units have an advantage in reduced energy needs for takeoff and torque, whereas the New Flyer system uses more energy to accomplish the same task with its motor.

Availability and Reliability

Between Nov 2021 and June 2022, the seven Proterra BEBs experienced four recorded road calls for in-service failures while accumulating 119,371 in-service miles, for an average MDBF of 29,843 miles. The cost of addressing these road calls (including total labor and parts) was $646.98, for an average of $0.01/mi. Buses 804 and 805 experienced two road calls each. Two were for low air pressure, one was for a broken mirror, and the cause of the fourth is listed as “recall.” The average MDBF for the Proterra subfleet was higher than that of the New Flyer subfleet, indicating better reliability in the Proterra subfleet. However, the sample size of the number of vehicles evaluated in this analysis was small, so caution should be exercised in drawing conclusions.

2.4.2 New Flyer 40-foot Buses

The in-use performance of the 40-foot New Flyer BEBs (buses 801, 802, and 803) between November 1, 2021, and June 31, 2022, is summarized in Table 3. As shown, over this period this group of buses was used in service for a total of 709 bus-days and accumulated 31,989 miles, an average of 45 miles/day while in-use. Individual buses had an average in-service speed of 6.8 to 8.7 MPH, with an overall average of 7.5 MPH for the fleet. For individual buses utilization ranged from 65% to 81%, with an overall fleet average utilization of 73%. For this table, utilization is calculated as the number of days in service divided by total days in the period.

Table 4. New Flyer 40-Foot Buses Service and Utilization Summary

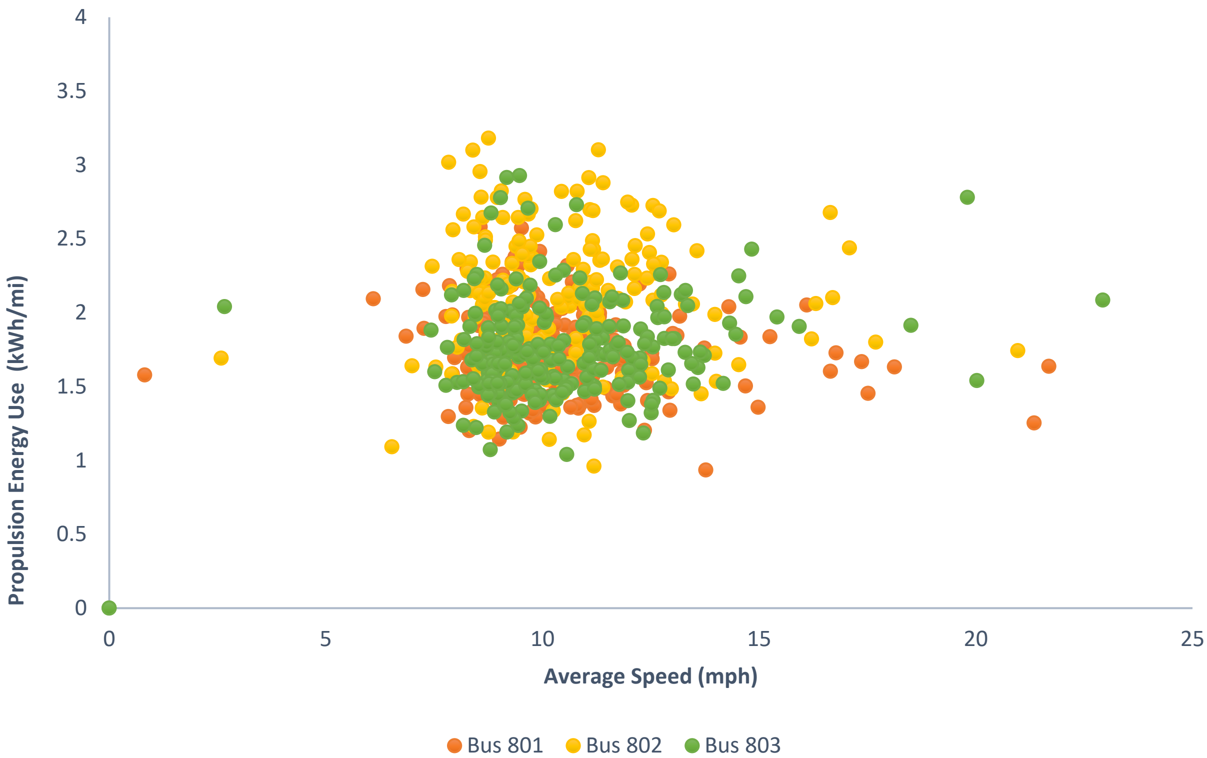
Bus Number	Total Service			Average Per Day			Utilization	Average Speed
	Days	Miles	Hours	Miles	Hours	Trips	%	MPH
801	261	12,345.5	1,270.7	47.3	4.9	1.8	81%	8.7
802	209	9,610.2	975.9	46.0	4.7	0.4	65%	6.8
803	239	10,033.1	1,020.0	42.0	4.3	0.5	74%	7.1
Fleet Total	**709**	**31,988.8**	**3,266.5**	**45.1**	**4.6**	**0.9**	**73%**	**7.5**

Source: Connect 360

Energy Use

Unlike the data available for the Proterra BEBs, data was available for the New Flyer BEBs that distinguished between energy used for heat and energy used for propulsion, allowing more detailed analysis of propulsion energy and in-service vehicle speed. Figure 2 plots daily average energy use for propulsion (kWh/mi) against daily average in-service speed (MPH) for all three 40-foot New Flyer BEBs. In Figure 2Figure , each dot represents one bus-day (the performance of one bus over one full day in service). For this chart, days in which a bus accumulated fewer than ten miles were not included, as very low mileage accumulation can create unrepresentative outliers.

Figure 2. New Flyer 40-foot BEB Average Propulsion Energy Use versus Average Speed



Source: WSP

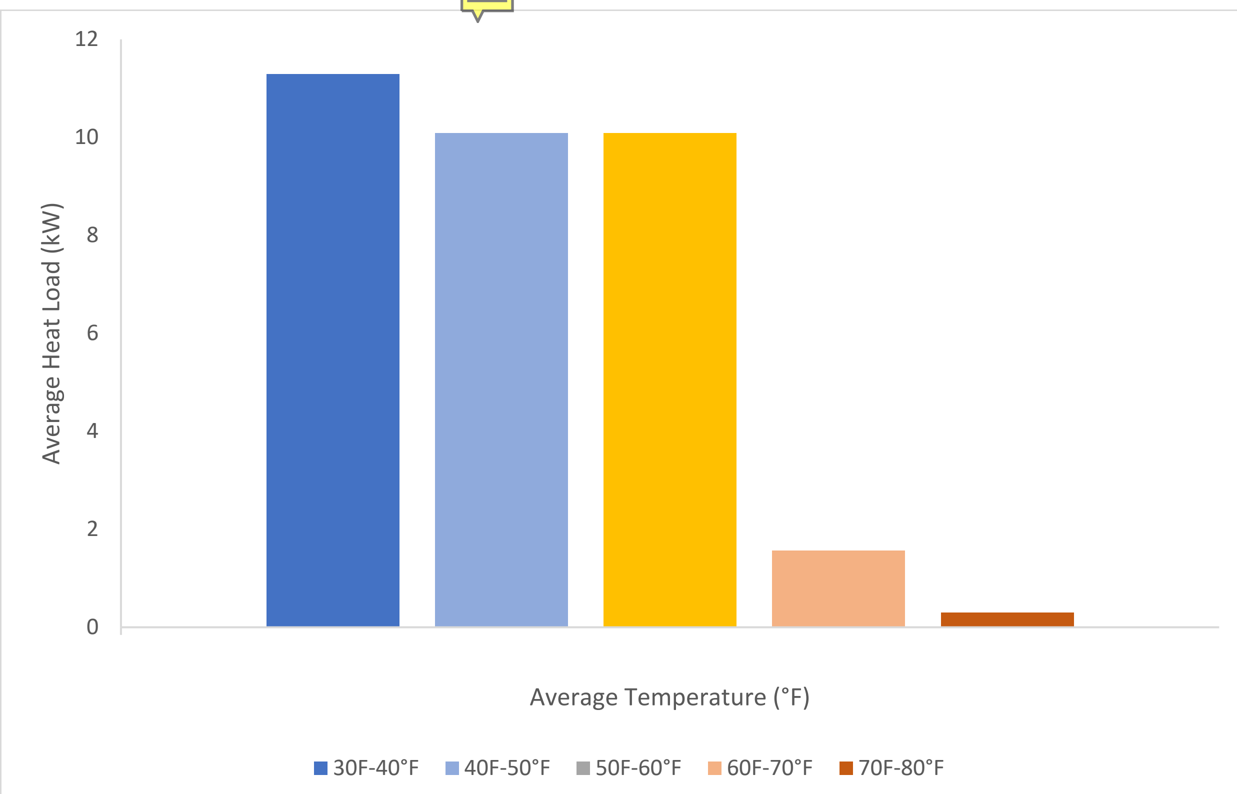
Figure 2 includes energy used by the traction motor plus energy used by the low voltage and high voltage accessories but does not include energy used by the interior heater. The data was analyzed to evaluate energy use relative to duty cycle (average speed), removing to the extent possible the effect of ambient temperature on total energy use. Energy used by the bus's air conditioning system is included in the energy used by high voltage accessories. The plotted "propulsion" energy includes energy used for air conditioning on hot days but does not include the energy used for cabin heating on cold days. Given the data available from New Flyer Connect, it was not possible to exclude the energy used for air conditioning from the calculation of propulsion energy.

As shown, daily average in-service speed for these buses generally ranged from about seven to fifteen miles per hour with a few bus-days with higher or lower average speed. Average propulsion energy use by these buses ranged from 1.7 to 2.7 kWh/mile. As expected, these buses show a general trend of higher energy use at lower average speed (line of best fit), primarily because lower average in-service speeds reflect a greater number of stops per mile. However, at any given speed actual average propulsion energy use varied by +/- 1 kWh/mile or more. This variability can be explained by energy use for air conditioning at different ambient temperatures, by driver behavior (aggressive acceleration and braking uses greater net energy per mile), by differences in topography on different routes (requiring energy for hill climbing), or by differences in passenger loading (greater bus weight uses greater energy per mile).

Figure 3 plots average energy load (kilowatts, kW) for cabin and battery heating for each ten degrees Fahrenheit change in ambient temperature. As shown, when ambient temperature was greater than 80°F essentially no energy was used for cabin or battery heating. Between 30°F and 40°F the average heating load was 11.8 kW, and between 50°F and 60°F the average cabin heating load was 10 kW. Of the bus-days used for this analysis, 82% had average ambient temperature less than 80°F, which is the break point above which heating load is essentially zero.

To calculate total energy per mile used for heating (kWh/mi), heating load (kW) is divided by average speed (MPH). The above data implies that at 7.5 MPH (the average for the 40-foot New Flyer BEB fleet), the required energy for cabin heating would be 1.1 kWh/mi at 40°F and 1.6 kWh/mi at 30°F. This energy is in addition to the energy used for propulsion, as discussed above.

Figure 3. New Flyer 40-foot Average Heat Load versus Average Temperature



Source: WSP

Availability and Reliability

Between November 1, 2021, and June 31, 2022, the three 40-foot New Flyer BEBs experienced three road calls for in-service failures, while accumulating 31,988 in-service miles, for an average MDBF of 15,994 miles. The cost of addressing these road calls totaled $635.80, including cost of labor and parts, for an average of $0.02/mile.

2.4.3 New Flyer 60-foot Buses

The in-use performance of the three 60-foot New Flyer BEBs (buses 901, 902, and 904[4]) from November 2021 to June 2022 is summarized in Table 5. As shown, over this period this group of buses was used in service for a total of 315 bus-days and accumulated 18,623 miles, an average of 59 miles/day while in-use. Individual buses had an average in-service speed of 10.5 to 11.6 MPH, with an overall average of 11.2 MPH for the subfleet. Individual bus utilization ranged from 37% to 76%, with an overall fleet average utilization of 61%. Utilization is calculated as number of days in service divided by total days in the period.

The three buses were operated similarly and present similar results across all energy systems. The traction averages are about 1 kWh/mi higher on average than compared to the 40-foot bus traction average. This may be due to the three motors used by the 60-foot buses, versus the one motor used by the 40-foot buses. The high voltage and low voltage accessories display about the same amount of energy on average. The HVAC system averages also display higher averages since the 60-foot buses encompass a larger interior and therefore need to supply more heat to reach desired temperature in cold weather. Additionally, the 60-foot buses have three doors, leading to a greater density of service doors per interior length.

Table 5. New Flyer 60-Foot Buses Service and Utilization Summary

Bus Number	Total Service			Average per Day			Utilization	Average Speed
	Days	Miles	Hours	Miles	Hours	Trips	%	MPH
901	122	7,179	663	15.8	1	4.6	71%	11.6
902	130	7,988	832	33.4	3	2.4	76%	10.5
904	63	3,456	326	13.3	1	4.5	37%	11.3
Fleet Total	**315**	**18,623**	**1822**	**59.1**	**5**	**3.7**	**61%**	**11.2**

Source: Connect 360

Table 6. New Flyer 60-foot buses Energy Usage

Bus Number	Total Energy (kWh/mi)	Propulsion (kWh/mi)	HVAC (kWh/mi)
901	3.5	2.7	0.8
902	3.4	2.7	0.7
904	3.1	2.7	0.4

4 Data for bus 903 was not available during the period analyzed.

Fleet Total	3.4	**2.7**	**0.7**

Source: Connect 360

Energy Use

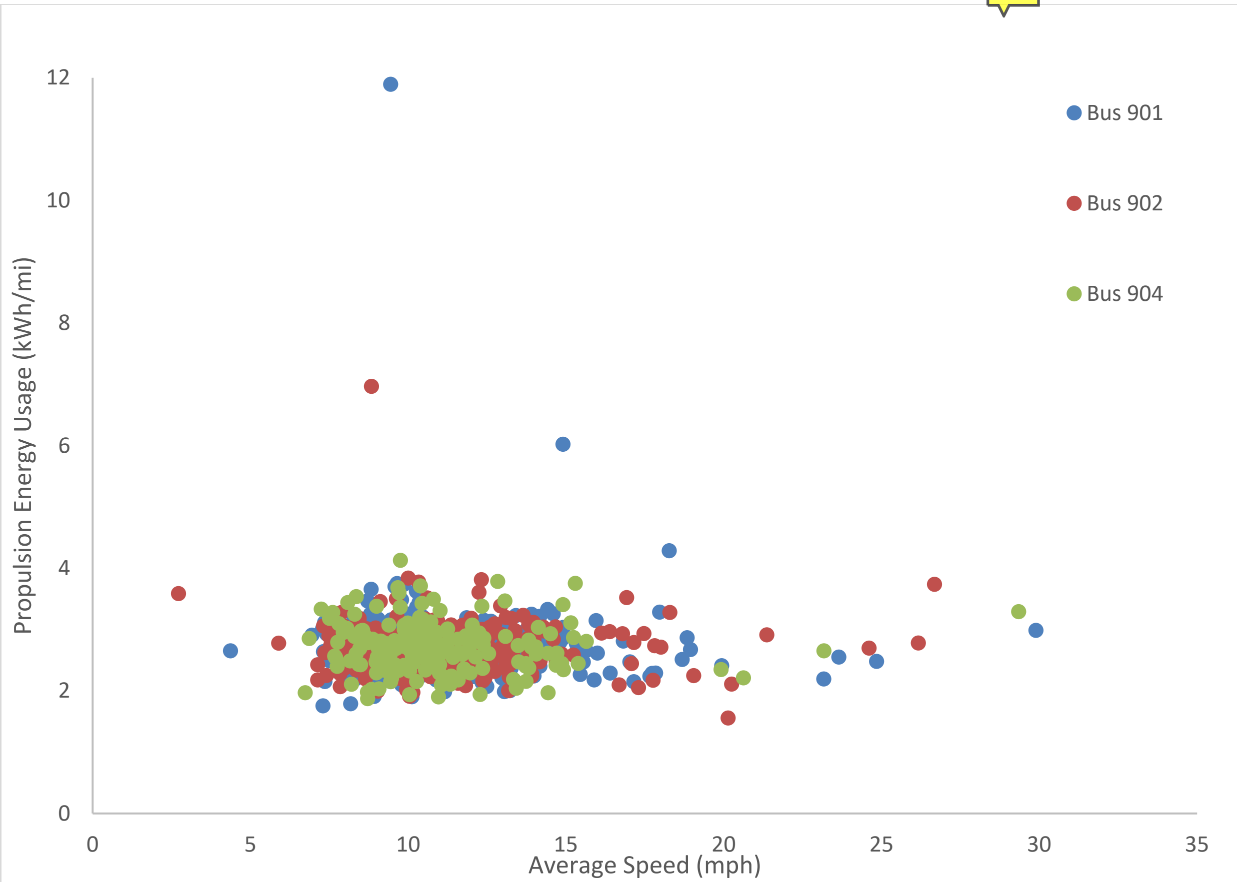
Figure 4 plots daily average energy use for propulsion (kWh/mi) against daily average in-service speed (MPH) for the three 60-foot New Flyer BEBs. In the chart, each dot represents one bus-day (one bus over one full day in service). For this figure, days in which a bus accumulated fewer than ten miles were not included, as very low mileage accumulation can create unrepresentative outliers (either high or low).

Figure 4 includes energy used by the traction motor plus energy used by the low voltage and high voltage accessories but does not include energy used by the on-bus heater. The data was analyzed to evaluate energy use relative to duty cycle (average speed), removing to the extent possible the effect of ambient temperature on total energy use. Energy used by the bus's air conditioning systems is included in the energy used by high voltage accessories. The plotted "propulsion" energy includes energy used for air conditioning on hot days but does not include the energy used for cabin heating on cold days. Given the data available from New Flyer Connect 360, it was not possible to exclude the energy used for air conditioning from the calculation of propulsion energy.

As shown, daily average in-service speed for these buses generally ranged from about seven to seventeen miles per hour with a few bus-days with higher or lower average speed. Average propulsion energy use by these buses generally ranged from 1.8 to 4.0 kWh/mile. As expected, these buses show a general trend of higher energy use at lower average speed (line of best fit), primarily because lower average in-service speeds reflect a greater number of stops per mile. However, at any given speed actual average propulsion energy use varied by +/- 2 kWh/mile or more. This variability can be explained by energy use for air conditioning at different ambient temperatures, by driver behavior (aggressive acceleration and braking uses greater net energy per mile), by differences in topography on different routes (requiring energy for hill climbing), or by differences in passenger loading (greater bus weight uses greater energy per mile).

Also as expected, propulsion energy use for these 60-ft BEBs is on average about 50% higher (+1 kWh/mi) than energy use by the 40-ft BEBs at the same average speed. This is due to the greater weight of the longer buses.

Figure 4. New Flyer 60-foot Average Propulsion Energy Usage versus Average Speed



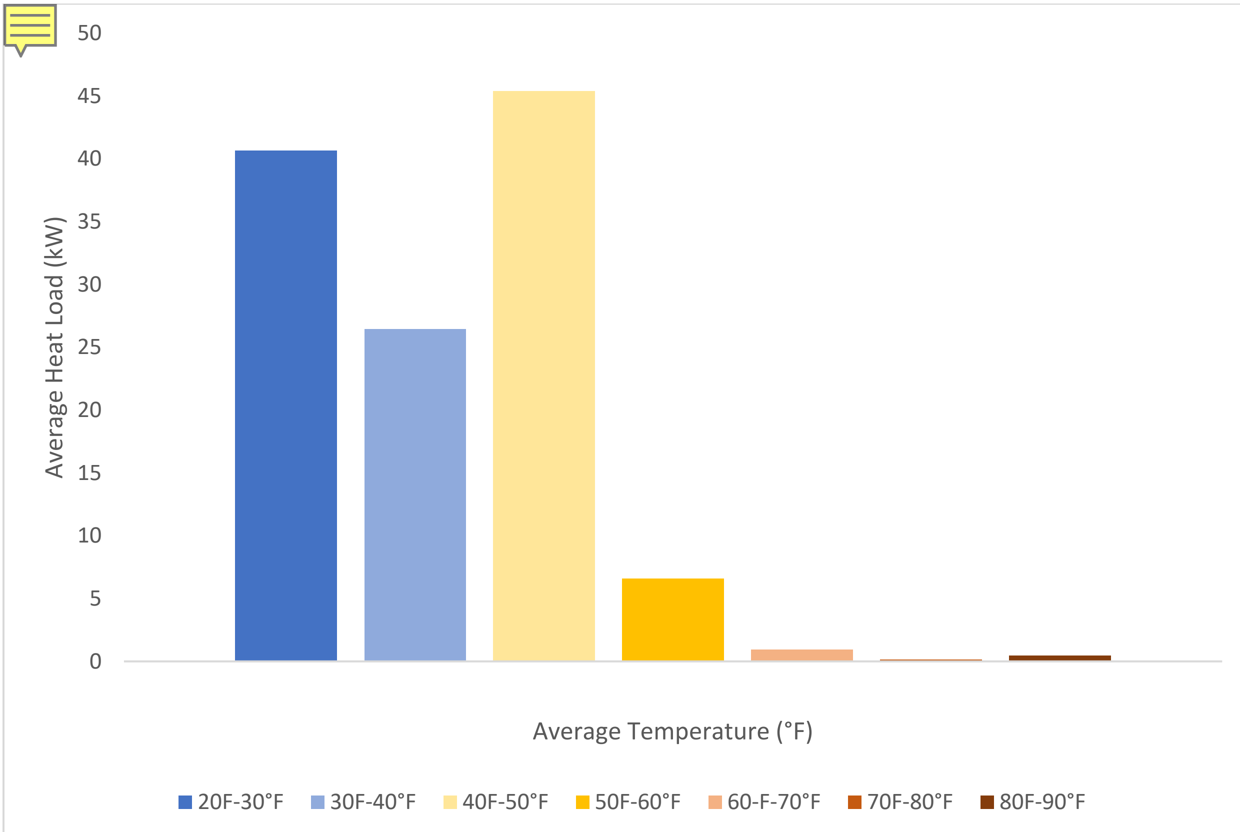
Source: WSP

Figure 4 compares the expected trend seen in the 40-foot buses to that of the 60-foot buses. The 60-foot buses require more energy to start moving from a stopped position due to the size of the vehicle, which necessitates the use of two power units for propulsion. The effects of propulsion usage when driving more slowly are greater for the 60-foot buses, therefore, the data demonstrates nonlinear trends even though the buses operated at similar speeds to the 40-foot buses.

Figure 5 plots average energy load (kW) for cabin heating for each ten-degree Fahrenheit change in ambient temperature. As shown, when ambient temperature was greater than 70°F essentially no energy was used for cabin or battery heating. Between 30°F and 40°F the average heating load was 26.2 kW, and between 50°F and 60 °F the average cabin heating load was 6.7 kW. Of the bus-days used for this analysis 71% had average ambient temperature less than 80°F.

To calculate total energy per mile used for heating (kWh/mi), heating load (kW) is divided by average speed (MPH). The above data therefore implies that at 11.1 MPH (the average for the 60-foot New Flyer BEB subfleet) required energy for cabin heating would be 2.0 kWh/mi at 40°F and 1.2 kWh/mi at 30°F. This energy would be in addition to energy used for propulsion, as discussed above.

Figure 5. New Flyer 60-foot Average Heat Load Usage Versus Average Temperature



Source: WSP

Availability and Reliability

Between November 2021 and June 2022, the three 60-foot New Flyer BEBs experienced four road calls for in-service failures while accumulating 18,623 in-service miles for an MDBF of 4,656 miles. The cost of addressing these road calls, including labor and parts costs, totaled $289 for an average of $0.02/mi.

Bus 904 had the most road calls (two) and buses 902 and 903 had one each. Most road calls (56%) were either to" Check engine light on" and "Engine shutdown" notifications. The Engine shutdown issues required the most labor as well as cost the most for labor and parts. Two of these road calls were for door problems, and one occurred because the battery had run out of energy and the bus had to be towed back to the depot to be re-charged.

2.5 Conclusion

Due to the constraints of available data between New Flyer and Proterra, WSP was limited in possible analyses. The 42-foot Proterra BEBs used, on average, significantly less energy per mile than the 40-foot New Flyer BEBs. At least some of the relative energy savings in Proterra's 40-foot buses derive from the Proterra bus design. The lower bus weight would be expected to result in lower energy use when operated in the same duty cycle and with the same passenger loading and driver behavior.

The analysis also found that Proterra BEBs were the most reliable buses, as the subfleet recorded the highest MDBF. The reason why these buses were more reliable could be due to a combination of factors. Proterra BEBs were newer by the time all four subfleets performance were assessed. This is consistent with the mechanical failure types associated to buses 804 and 805 (low air pressure and broken mirror), as opposed to the three mechanical failures experienced by New Flyer's 60-foot buses, which were mainly related to the vehicles' engine. The motor used by Proterra vehicles may be more efficient and reduce strain on the engine.

Since the subfleet sizes were small, caution should be exercised in drawing comparisons between performance levels of subfleets. DASH may wish to further examine the historical reliability of the New Flyer ICEBs and use to evaluate the reliability of the New Flyer BEBs. The New Flyer BEB models were built upon the original diesel bus platform, with the engine and transmission removed and replaced with batteries and a new propulsion system. Proterra BEBs, on the other hand, were originally developed as BEBs, but have been known to structural issues with several years of use (including unreliable air system compressors, component pieces debonding from the vehicles, and structural cracking).

To ensure that the buses are being optimally maintained and managed, DASH should also undertake a full analysis of maintenance work performed on its current BEB fleet and determine whether warranty claims are used to the extent possible. DASH should regularly review BEB performance and maintenance data on a quarterly basis with the intent to increase BEB utilization. As new BEBs are added to the fleet, data should be closely analyzed after one year of service. Additionally, as the fleet transitions to fully ZEVs, implementing a unified vehicle telematics system will be critical.

3 Full Fleet Assessment

The Full Fleet Assessment provides a projected timeline for replacement of DASH's current buses with ZEBs consistent with the agency's fleet replacement plan. In 2019, the Center for Transportation and the Environment (CTE) conducted a Zero-Emission Bus Feasibility Study for the DASH fleet. DASH adopted a mandate to transition its entire fleet to zero emissions by 2037, making no further purchases of conventional buses starting in 2027. The Full Fleet Assessment uses the CTE Feasibility Study as a baseline for the future fleet, noting updates for overall fleet size, the current and future state of technology, and the system's service profile. WSP developed the parameters of the schedule through an interactive Fleet Workshop with relevant DASH staff in February 2023, which confirmed the selection of a future 134-vehicle ZE fleet size. The fleet transition schedule demonstrates how necessary infrastructure aligns with fleet deliveries.

3.1 Introduction

The transition to a ZE fleet requires the alignment of several related elements: BEBs should not be delivered until the necessary facilities have charging infrastructure to support them, and existing vehicles should not be replaced until they reach their useful life retirement age. Furthermore, BEB procurement lead times as of June 2023 can span two years from order to delivery (not including procurement solicitation). Therefore, careful planning is needed to achieve a successful transition. The following fleet replacement plan considers the following factors:

- DASH's goals for sunsetting the purchases of conventional buses by 2027, and its goals for fully transitioning the fleet (by 2037)
- BEB procurement lead times
- Facility construction completion date
- BEB delivery dates
- Current fleet retirement dates

3.2 Methodology

3.2.1 Facilities

The DASH facility expansion has a target goal of completion by 2025. The expansion will ultimately include 36 additional charging cabinets to support the incoming BEB fleet.

3.2.2 Existing Fleet

The current fleet is made up of 101 vehicles including 35 Clean Diesel vehicles, 52 hybrid vehicles, and 14 BEBs that were put into service between 2020 and 2022. Existing fleet vehicles are eligible for retirement after 12 years of use. As of FY (fiscal year) 2023, all active vehicles in the fleet are below or at 12 years of age except for six contingency vehicles.

3.2.3 Transition Assumptions

The WSP team initially analyzed three transition scenarios and presented preliminary findings at a workshop held on February 10, 2023. The scenarios were developed based on different assumptions considering future fleet size, allowable useful life (UFL) of vehicles and full transition target as follows:

- Preliminary Scenario 1: increase fleet to 119 vehicles, maximum UFL at 12 years, transition by FY 2027
- Preliminary Scenario 2: increase fleet to 134 vehicles, maximum UFL at 12 years, transition by FY 2027
- Preliminary Scenario 3: increase fleet to 119 vehicles, maximum UFL at 15 years, transition by FY 2027

The WSP team found that if DASH employs each vehicle for exactly 12 years of UFL, as in Scenarios 1 and 2, the agency will face considerable procurement pressure, as the industry is experiencing lengthened bus delivery times. This will also produce a procurement plan with vehicle procurement quantity fluctuating significantly from year to year. Between FY 2023 and FY 2037, limiting UFL to 12 years produces many vehicle retirements in two years with over 20 buses being replaced, four years with 12 to 16 buses being replaced, and seven years with fewer than eight buses or zero bus replacements.

To produce a smooth transition, both from an operations and cost perspective, Scenario 3 was developed to demonstrate an alternate procurement timeline with a relaxed UFL. As a result, the overall procurements from year to year are more evenly distributed and the initial pressure to procure buses immediately is alleviated. During the workshop, participants expressed a preference for updating the procurement timeline to highlight the point in time of purchase, rather than delivery time, and agreed to consider the FY 2037 target as an aspirational goal allowing more flexibility to DASH when finalizing the procurement plan.

The project team developed the final fleet procurement plan, provided in Table 7 and Figure 7, based on feedback collected from the workshop and the assumption that the future fleet size will increase to 134 BEBs with a maximum 14 years of UFL (except for those contingency vehicles that are already over 20 years old). This future fleet will replace, and expand upon, the existing fleet. The existing fleet vehicles will be retired as the new BEBs arrive.

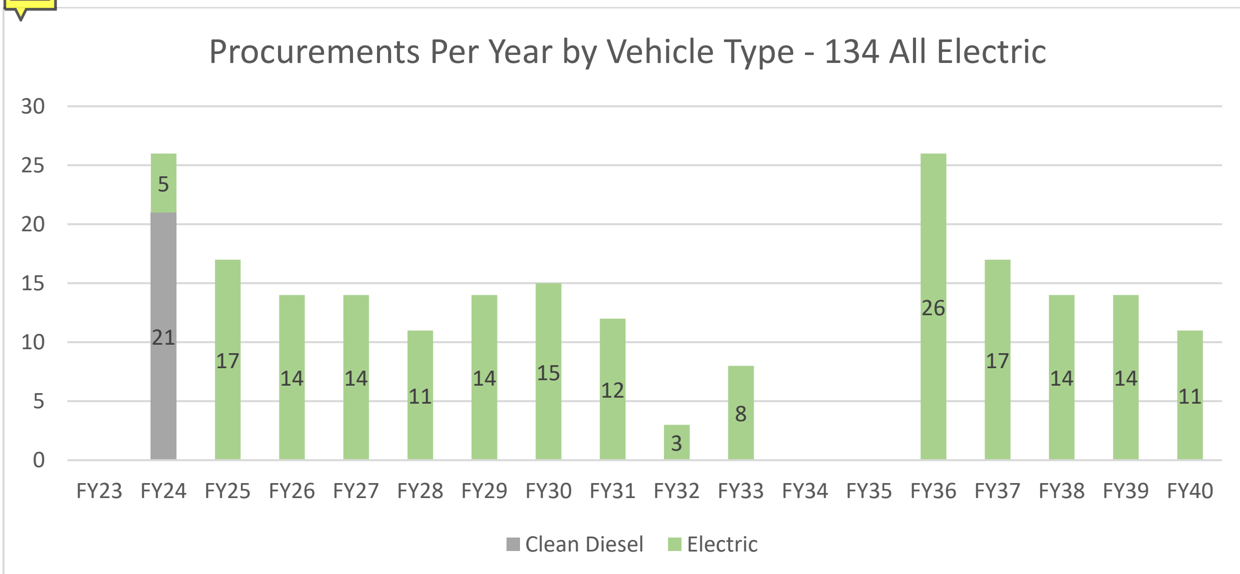
3.3 Implementation Strategy

The following tables and figures provide a recommended fleet procurement schedule for DASH to follow in transitioning to a 134-vehicle ZE fleet. Table 7 provides estimated timeframes for charging infrastructure availability required in advance of BEB deliveries.

3.3.1 Fleet Procurement Schedule

The following procurement chart (Figure 6) adheres to the methodology described above. The chart is focused on the year of procurement and assumes that the actual delivery will occur approximately two years later. According to this schedule, the last clean diesel buses will be procured in FY 2024. If any conventional buses are procured after this, because of the standard 12-year useful life, they will not be eligible for retirement until after the agency's full transition goal of 2037.

Figure 6. Procurements Per Year by Vehicle Type



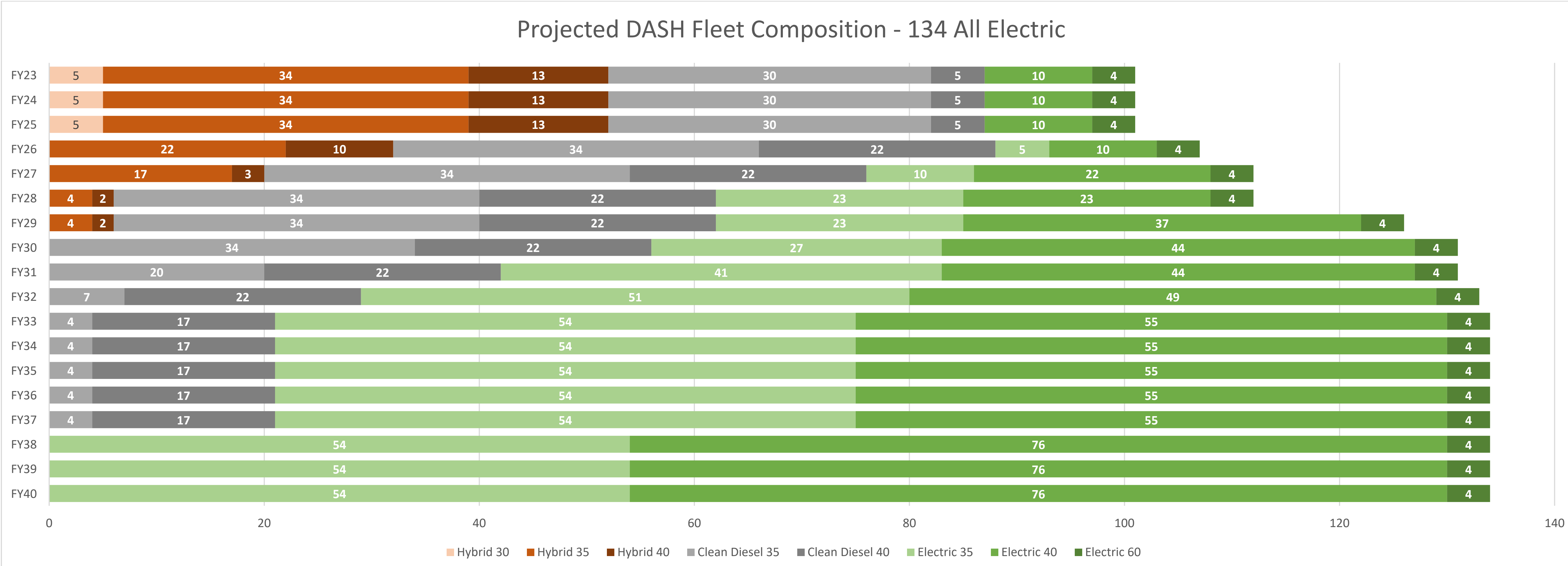
Fleet Procurement Schedule forecasts the procurement for the new 134 ZEB is forecasted to end by FY40. The schedule accounts for the standard 12-year useful life of each bus included in DASH's current fleet.

Source: WSP

Figure 7 shows the fleet composition by vehicle type from FY 2023 until FY 2040. The initial BEB procurements from FY 2024 shown in the previous chart are expected to arrive in FY 2026. From then on, each year sees a further shift away from conventional buses to BEBs. In this scenario, FY 2037 is the last year in which the fleet includes conventional buses. By the next fiscal year, the entire fleet is expected to be zero-emission.

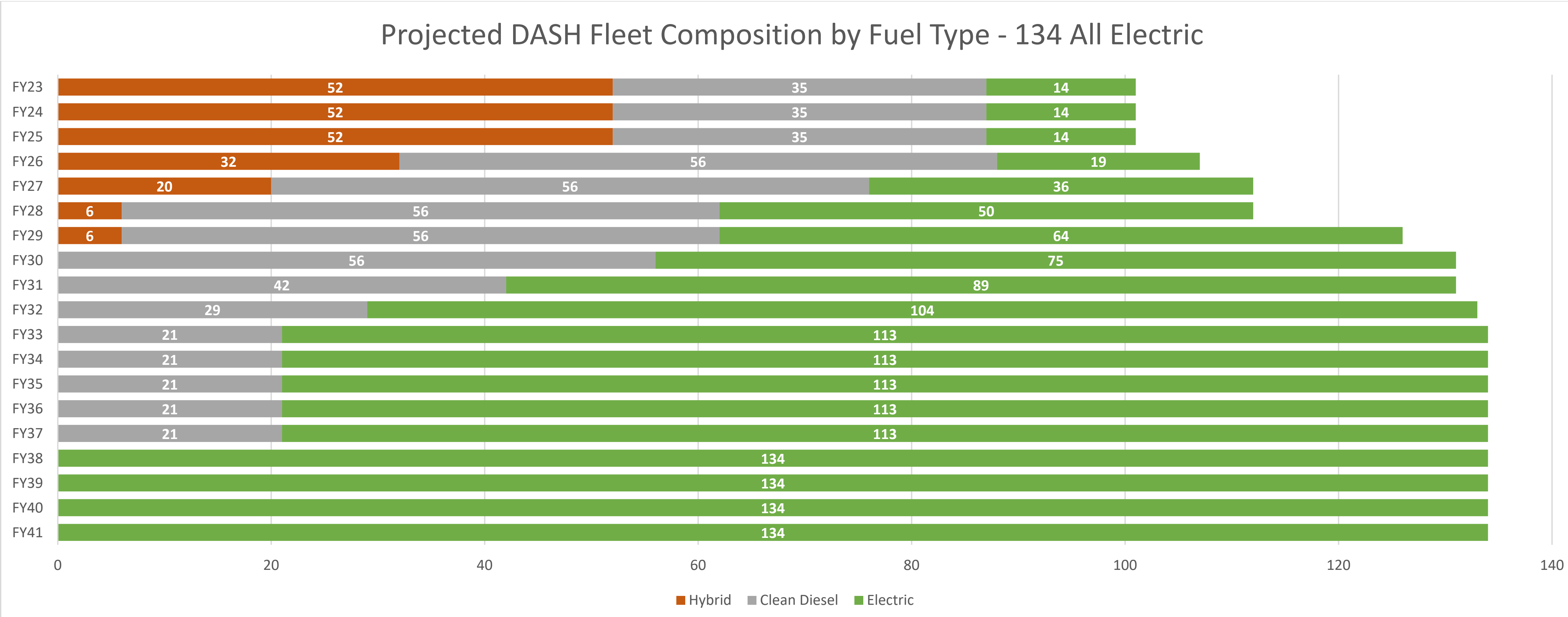
To incorporate infrastructure planning with fleet purchases, Table 7 provides a roadmap that includes vehicle procurements for the last round of clean diesel and BEB purchases. The table includes the charging capacity needed to support the newly arriving BEBs.

Figure 7. Projected DASH Fleet Composition by Year



Future Fleet Procurement schedule forecasts that the DASH fleet will fully transition to 100% zero-emission by FY38.

Figure 8. Projected DASH Fleet Composition by Year, Vehicles Grouped by Fuel Type



Future Fleet Procurement schedule is provided with vehicle lengths combined into fuel type categories.

Source: WSP

Table 7. Infrastructure Roadmap

Fiscal Year/Quarter		FY2024				FY2025				FY2026				FY2027				FY2028				FY2029				FY2030				FY2031				FY2032				FY2033				FY2034				FY2035				FY2036				FY2037				FY2038			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Vehicles	Clean Diesel RFP/Bid																																																												
	Production for First Clean Diesel Delivery																																																												
	Clean Diesel Vehicle Delivery											21 CDs																																																
	BEB RFP/Bid																																																												
	Production for First BEB Delivery																																																												
	BEB Vehicle Delivery											5 BEBs				17 BEBs				14 BEBs				14 BEBs				11 BEBs				14 BEBs				15 BEBs				12 BEBs				3 BEBs				8 BEBs												26 BEBs	
Charging Need	New Charging Capacity Needed (Dispensers)										6				18				12																																										
	Total Dispensers *6 existing chargers (12 dispensers)	12	12	12	12	12	12	12	12	12	18	18	18	18	36	36	36	36	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48

The Infrastructure Roadmap shows new charging capacity procured through FY 2028, but BEB procurements continuing afterward. By FY 2029, the DASH fleet will include 64 BEBs, but only 48 dispensers, presenting an operational challenge. Prior to FY 2029, DASH should explore options to move buses non-manually to address charging needs or consider increasing the number of dispensers available.

Source: WSP

3.4 Recommendations

3.4.1 Phasing Strategy

WSP recommends that DASH consider the fleet transition plan's implications for facility and infrastructure procurement and construction. Under an ideal scenario, BEBs should not arrive at DASH's facility until there is adequate infrastructure to charge them and space to store and maintain them. A utilization analysis of current chargers was not possible in this study. As DASH is currently planning a facility expansion, the agency should ensure that the facility construction completion and commissioning timeline aligns with any planned BEB purchases.

3.4.2 Charging Infrastructure Needs

Under the recommended scenario, the total number of BEBs in the full fleet (134) will exceed the total number of dispensers (48). As new BEBs arrive and are put into operation, it is recommended that DASH regularly evaluate whether the vehicles can maintain a consistently state of charge from day to day while in service. A high state of charge can be achieved by maximizing dispenser utilization, such as by charging during the day as buses return to the facility, and rotating buses in and out of charging positions throughout the night. As discussed in the 2021 DASH ZEB Implementation Final Report, two buses can be charged by the same dispenser if moved manually, or by implementing an automated bus yard, which would involve nascent technology that, as of 2023, has not been implemented by any transit agency. Assuming that DASH is limited to 48 charging positions for its full fleet, WSP recommends that DASH plan for manual repositioning of buses for charging and conduct a cost-benefit analysis to determine whether continued manual repositioning or the purchase of additional chargers would be more effective for charge maintenance. DASH may also wish to evaluate the state of automated bus yard technology in FY 2028.

3.4.3 Charge Management

WSP recommends that DASH invest in charge management scheduling software to proactively manage the daily SOC for the BEB fleet. Charge management software (CMS) can help DASH cost-effectively charge the fleet while maintaining service requirements. As electricity rates can change throughout the day, the CMS software can manage the charging loads to ensure pull-out each morning with the most advantageous operating costs. In addition, a CMS may earn revenues for DASH by performing grid services for Dominion, such as demand response, similar to a battery. DASH may want to consider third-party ownership of the charge management system to transfer risk and responsibilities.

The DASH route structure, both current and future, generally supports the transition to an all-electric fleet, and utilizing battery electric buses will most likely require a larger fleet assuming today's level of technology, as additional buses may be needed to run blocks or portions of blocks that cannot be served on single battery charges. The 2019 Zero-Emission Bus Feasibility Study recommended that DASH eventually convert to fully ZE buses as soon as possible. As the DASH BEB fleet expands, it is recommended DASH continue to track vehicle performance and emissions reductions through a validation reporting/KPI program.

4 Energy Assessment

This energy assessment focuses on the estimated daily energy needs of a fully electrified DASH fleets. The assessment uses service data to understand the distances that current vehicles drive on a daily basis, then models that service using BEBs of the same vehicle type. The analysis uses an ambient temperature scenario which is locally calibrated to Alexandria, Virginia, and assesses potential BEB performance under typical winter and extreme winter weather conditions. Although DASH charges its current BEBs throughout the day, this analysis assumes a depot-based charging scheme (i.e., no opportunity charging during the day, only plug-in overnight) to conservatively demonstrate what is feasible with the simplest charging method.

This section is organized into the following sections:

1. Report Purpose and Approach – Overview of the Energy Assessment's purpose, approach, and structure.
2. Modeling Overview – Overview of the modeling process, including inputs, assumptions, and approach.
3. Data and Assumptions – Data inputs used to complete the analysis.
4. Modeling Results – Details service modeling results and strategies to address failed blocks.
5. Conclusion and Recommendations – Concludes the report and presents recommendations.

4.1 Report Purpose and Approach

The purpose of the Energy Assessment is to determine the viability of operating the entire DASH service with BEBs.

Currently, DASH operates diesel, diesel hybrid, and electric vehicles, in 29, 35, 40, and 60-foot configurations. BEBs currently do not match the mileage ranges of conventional buses. The variation in performance makes it essential that BEB implementation include performance modeling of BEBs within existing (or planned) service to develop strategies that will reduce or eliminate negative impacts to service. When service cannot be completed with a BEB, agencies can consider making service adjustments, purchasing additional vehicles, incorporating opportunity charging (charging at stops while the bus is in service), bringing a vehicle back to the depot for midday charging, or delaying BEB integration until the technological advances meet range requirements.

The following results should be used for planning and informative purposes only. It is likely that results will be different as DASH proceeds with detailed design and implementation. In addition, this is a high-level modeling approach that leaves room for different results depending on the variable conditions encountered throughout the service area, including individual driving style, network topography, and weather conditions. Finally, technology is advancing rapidly and is anticipated to quickly increase the vehicles' estimated range.

4.2 Modeling Overview

This analysis incorporates a 15-month time span of data, including distance, duration, average speed, and average miles per gallon. This supplies an expected range of service. From there, different BEBs were modeled on the existing service structure to determine if they have enough battery capacity to complete the assignment.

Different operating conditions, such as weather, can significantly impact vehicle energy consumption rates. The following analysis factors in two distinct weather conditions to assess typical winter operations, and extreme cold weather conditions. Experience grounded in other transit agencies indicates that energy use is higher in the winter than the summer due to cabin heating demand, and, as such, represents worst case conditions with respect to BEB operating range.

The results of the analysis identify the percentage of DASH service that can be supported by a single BEB. In the analysis, if the modeled BEB fails to complete the block (meaning the energy needs of the vehicle's block assignment exceeds its energy storage capacity, or "battery range"), the output captures the degree of failure (additional energy needed, measured in kilowatt hour [kWh]). From there, preliminary solutions are suggested, which may include adjusting the model using fewer conservative variables or modifying the typical manner of use of BEBs such as including midday charging, an auxiliary diesel heater, or maintaining some percentage of the fleet as Internal Combustion Engine (ICE) vehicles for use on the longer daily assignments. The completion rates can help DASH make informed decisions for both short- and long-term operation and procurement strategies. These strategies will, in turn, serve to inform the energy needs of the future fleet and the eventual costs of the transition.

The following sections describe the data and assumptions applied and the approach and outputs of the service modeling analysis.

4.3 Data and Assumptions

The inputs used for the model fall into two categories: service data and operating parameters. The following section details the service data and operating parameters established in the model.

1. Service Data – All weekday service blocks provided by DASH from the October 2022 Optibus schedule, including total mileage (both revenue and non-revenue) and platform time, as well as historical data on local winter ambient temperature (from December 2021 through February 2022)
2. Operating Parameters – Specific BEV-related assumptions and adjustments, including vehicle weight, length, and battery capacity. The following section details the service data and operating parameters established in the model.

4.3.1 Service Data

Schedules

A fixed route vehicle's "block"—generally defined as a day's work starting from when the bus it leaves the maintenance base and ending when it returns—is inconsistent in both duration and distance. For this analysis, July 2021 through October 2022 service data was provided as daily mileage and daily diesel fuel consumed per bus. This data was used to derive average miles per gallon of diesel fuel per each bus type in the DASH fleet.

Vehicle Inventory

This analysis categorized the diesel vehicles currently used for service into categories by length, as 29, 35, and 40-foot buses, and then models the performance of equivalent BEBs. However, for reasons explained below, only 35-foot and 40-foot BEB equivalents were modeled on DASH's current service blocks. The BEB equivalents of these vehicles will have different battery capacities and consumption rates depending on the example model used.

Service Blocks

DASH provided a list of service blocks developed in Optibus in October 2022. The list of blocks included revenue and non-revenue distance and scheduled time. The analysis added the revenue and non-revenue distance together to produce total block distances, which were then divided by platform time to produce average vehicle speed per block. The list designated types of buses to use on each block, but DASH personnel advised that these designations are not used for dispatching specific vehicles, unless the vehicle is a 29-foot trolley. Additionally, DASH personnel advised that in future procurements, the 29-foot trolleys will be replaced by 35-foot buses. Thus, the analysis modeled completion for each block for both 35 and 40-foot BEBs. Additionally, although DASH operates 60-foot BEBs, they are not dedicated to any particular service block. Thus, 60-foot BEBs were not modeled in this analysis, which provides a conservative understanding of estimated block completion.

4.3.1 Operating Parameters

Vehicles

Battery capacity and vehicle weight—and thus, range—vary by original equipment manufacturer (OEM) and vehicle size (length, passenger capacity). The battery assumptions in this analysis use capacities from comparable vehicle models for each vehicle length. It is important to note that BEB technology is rapidly advancing, thus larger battery capacities and improvements in BEB range may be available by the release of this report and as DASH begins the next round of BEB procurements. This analysis does not model potential future improvements in battery capacity, so DASH should work with OEMs to understand usable battery capacity in new vehicle models.

Battery Capacity

The *advertised* capacity of a battery differs from the *operating* (or usable) capacity that a battery offers. It is important to clarify and establish the operating capacity of a battery to accurately assess range and performance. Generally, 10% or more of a battery's advertised capacity is deemed unusable by the OEM in order to support the health of the battery. Additional capacity of the battery may be deemed unusable to provide a *safety buffer* to reduce "range anxiety" for operators and mitigate impacts to service. Providing a safety buffer can also ensure that, while charging, the battery maximizes charger use and reduces charging times (batteries typically receive peak power between 20% and 80% State of Charge) while minimizing battery degradation.

Table 8 shows the vehicles and sizes used to model service for DASH's service and the associated average and operating battery capacity.

Table 8. Replacement BEV Inventory Used in Analysis

Vehicle Name	Length (ft)	Range* (miles)	Battery Size (kWh)	Agency Vehicle Equivalent
New Flyer Xcelsior CHARGE NG	35	182-224	345-435	35-foot diesel or diesel hybrid
New Flyer Xcelsior CHARGE NG	40	178-258	345-520	40-foot diesel or diesel hybrid

Source: WSP (as of June 2023)

Energy Consumption and Range

A BEB's performance is typically measured through its range (miles). This is a direct factor of its energy consumption, as expressed in kWh/mi, and battery capacity, as expressed in kWh. A vehicle with a higher numerical energy consumption has a shorter range, whereas a vehicle with a lower numerical energy consumption has a longer range, if equipped with the same capacity battery. Energy consumption varies based on several factors, including:

- Battery health and state of charge (SoC)
- Operator driving behavior
- Temperature (HVAC usage)
- Travel speed
- Vehicle weight/passenger load
- Route topography

The performance of the modeled vehicles is derived from the vehicle type's assumed baseline consumption rate (the kWh/mile of the propulsion system), with additional consumption stemming from HVAC use. This analysis models vehicle range using two scenarios (Typical Winter and Intensive Winter).

The baseline energy consumption is provided by OEM specifications (which do not account for all the factors that impact BEB performance in actual operations). The adjustments to the consumption rates are made using data derived from existing performance evaluations, research, and physics-based calculations. In this analysis, the usable battery capacity was adjusted to 90% of the advertised nameplate capacity, reflecting DASH's current BEB operational practice. Although this analysis aims to capture significant influences on BEB performance, the applied metrics are not exhaustive and are limited to current published data and the methodologies used herein. The metrics and methodologies used in this analysis are outlined below.

Ambient air temperature: Drawing upon existing research, the model estimates the on-board energy needs of two sets of HVAC under two Winter temperature scenarios. The first set of temperatures, which are outlined below, can be used to objectively compare potential performance for bus service in Alexandria, Virginia.

1 Average winter daytime temperature for the Typical scenario as 41.3°F

2 Extreme winter temperature conditions for the Intensive scenario as 17°F.

If electric cabin heating is used within DASH's service area, heating during extreme low temperatures uses more HVAC energy than cooling during extreme high temperatures.

4.4 Modeling Results

While the ICE vehicles currently used for service may have no problem completing a day's work on a single tank of fuel, BEBs are limited in range. The primary outputs of this analysis estimate rates of completed service by modeled BEBs. The results show how much of the service is achievable and the extent of the incomplete service. The performance data also supplies vehicle range estimates, as well as possible mitigation strategies for incomplete service, so that future service can be managed to fit within these constraints.

4.4.1 Default Temperatures (41.3°F or 17°F)

The modeling analysis found the following consumption rates for each BEB type, for the Typical and Intensive Winter weather scenarios at 41.3°F and 17°F, respectively (Table 9). The modeled 35-foot bus had a Typical Winter consumption rate of 2.81 kWh/mile, resulting in an estimated range of 140 miles. In the more Intensive Winter scenario, the 35-foot bus consumption rate was 3.28 kWh/mile, generating an estimated range of 119 miles. The modeled 40-foot bus had a Typical Winter consumption rate of 2.95 kWh/mi, resulting in a range of 159 miles; and an Intensive Winter consumption rate of 3.52 kWh/mi, resulting in a range of 133 miles. Insufficient data was available from DASH's current BEB fleet to validate the modeled Typical and Intensive Winter scenarios, as only New Flyer provided heating energy data, and DASH does not operate 35-foot BEBs. The energy usage difference between Typical and Intensive Winter scenarios was derived from data provided by peer transit agencies.

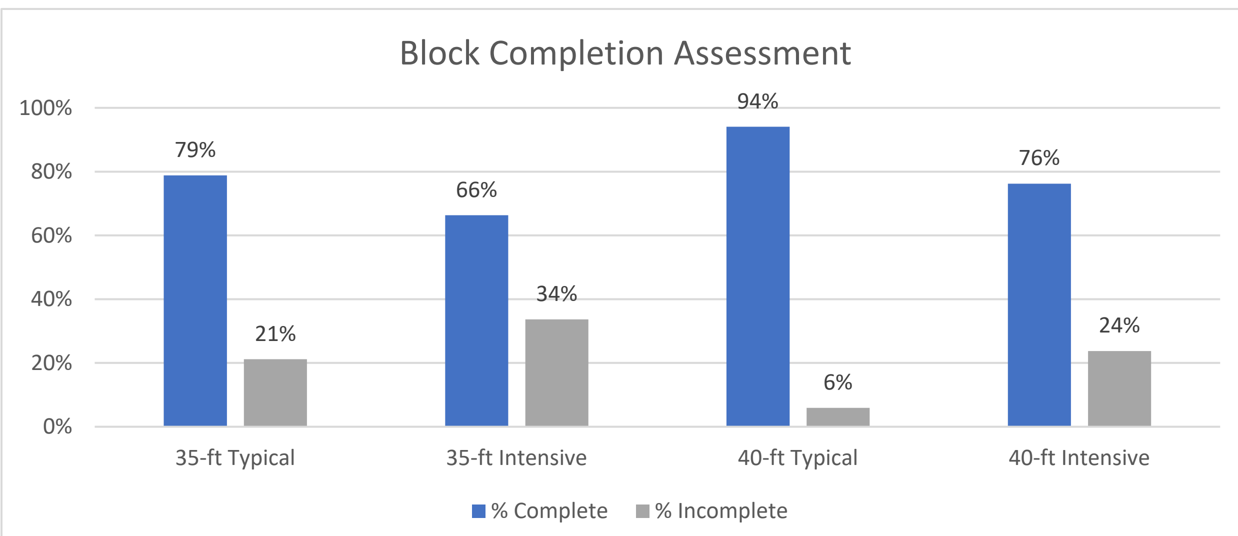
Table 9. Modeling Results – Energy Consumption Rates and Vehicle Ranges by Vehicle Type (Default Temperatures)

Vehicle Type	Usable Battery Capacity (kWh)	Typical Winter Weather		Intensive Winter Weather	
		Modeled Consumption Rate (kWh/mi)	Projected Range (mi)	Modeled Consumption Rate (kWh/mi)	Projected Range (mi)
New Flyer Xcelsior CHARGE NG (35 ft)	391.5	2.81	140	3.28	119
New Flyer Xcelsior CHARGE NG (40 ft)	468	2.95	159	3.52	133

Source: WSP

Figure 9 shows the proportion of service that is estimated to be achievable by a BEB direct replacement for each vehicle type. The modeled 35-foot bus completed 79% of service blocks under the Typical scenario, and 66% of blocks under the Intensive scenario. The modeled 40-foot bus completed 94% of blocks under the Typical scenario, and 76% of blocks under the Intensive scenario.

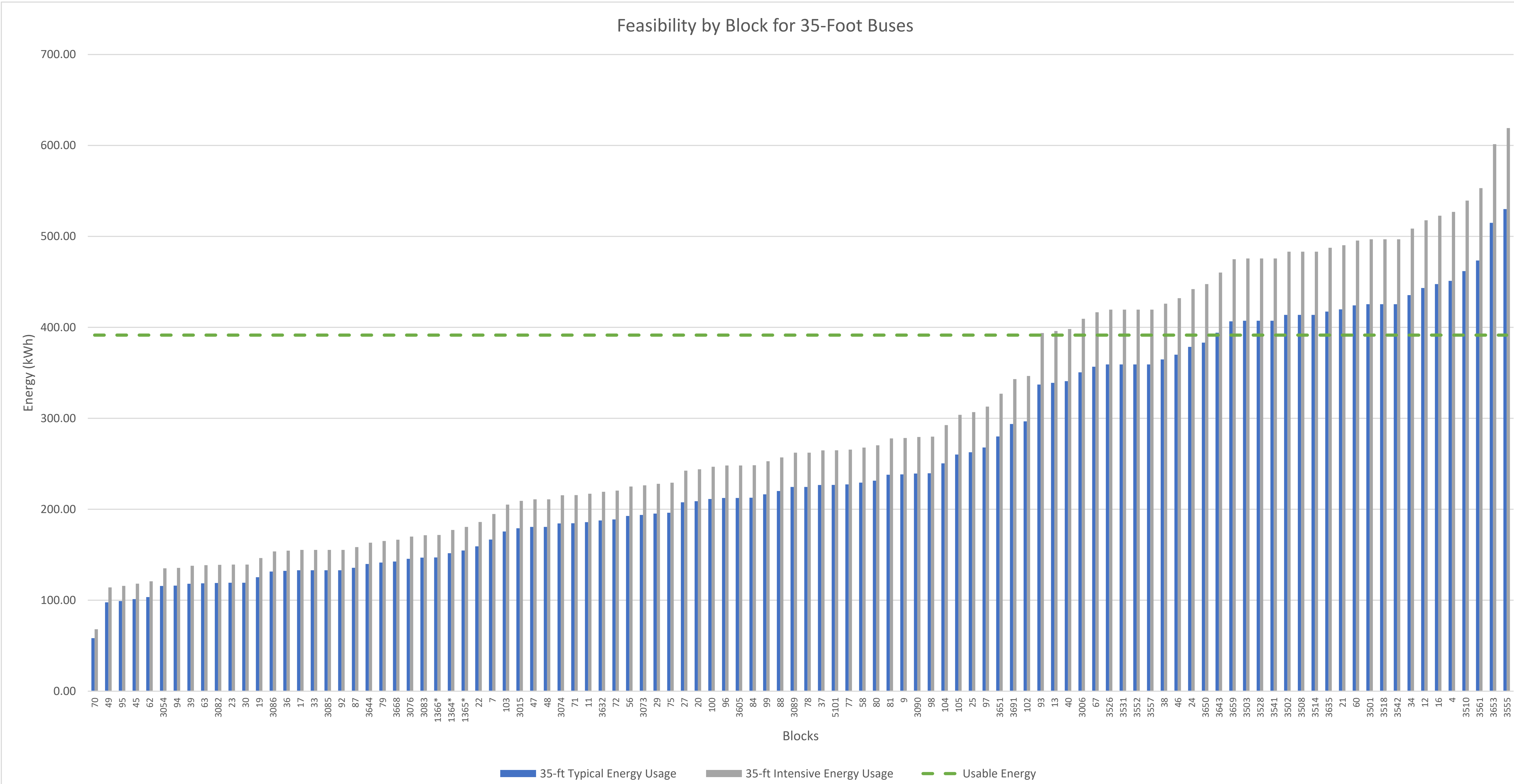
Figure 9. DASH Service Block Completion by Vehicle Type



Source: WSP

Figure 10 and Figure 11 provide service assessment results for all blocks modeled against the Typical and Intensive Winter scenarios for both 35- and 40-foot BEBs. The three trolley blocks (1364, 1365, and 1366) were modeled only for 35-foot buses.

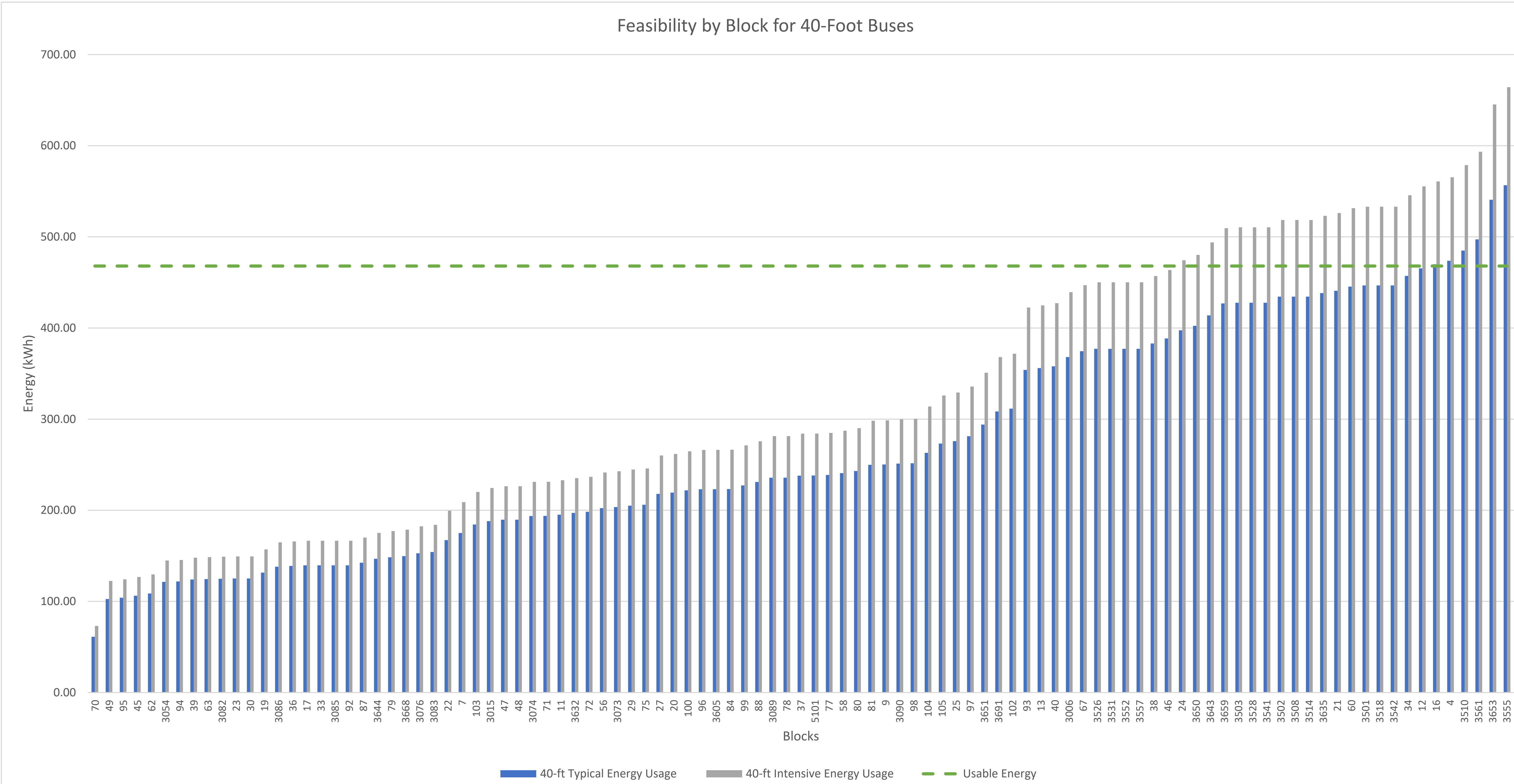
Figure 10. Feasibility by Block for 35-Foot Buses



Source: WSP

*Denotes trolley blocks

Figure 11.Feasibility by Block for 40-Foot Buses



Source: WSP

4.5 Conclusion and Recommendations

4.5.1 Conclusion

Overall, in the Typical Winter scenario, 79% of DASH's service is estimated to be achievable by BEBs if the system is operated by only 35-foot buses. If DASH were to operate the system with only 40-foot buses, 94% of the service would be achievable by BEBs under the Typical Winter scenario.

BEB technology will improve over time and has the potential to be able to complete the entirety of DASH's service as currently structured. However, it is feasible for DASH to complete most service blocks using existing BEB technology.

4.5.2 Recommendations

As DASH continues its ZE transition, the agency should examine the longer blocks that make up its current service structure and failed the block completion analysis. DASH may wish to collect data on the dwell times and dwell locations of vehicles service these blocks to explore opportunities for opportunity charging during service, or consider shortening existing blocks to allow for midday charging of buses at the garage. The addition of midday charging will help vehicles complete more miles each day.

It will be important for vehicle operators to be mindful of their vehicle's battery state of charge. Each OEM has a recommended threshold to maintain the battery state of charge, otherwise increased battery life degradation may occur. For example, batteries should not be discharged beyond their remaining 10% capacity. Different weather conditions will impact battery consumption rates as well. The colder the temperature, the more impact on battery capacity will occur. Similarly, headwinds and precipitation affect battery capacity because the vehicle expend more energy against opposing forces.

5 Utility Grid Assessment

This section provides a utility grid assessment of the DASH ZEB program, from establishing existing conditions to determining design, resiliency options, incentives and tariffs associated with the project.

1. Existing Conditions Assessment
2. Potential Design
3. Resiliency Options
4. Tariffs

5.1 Introduction

The work in this task is intended to provide a high-level overview of the onsite electrical infrastructure and utility requirements that must be considered when designing for new EV supply equipment (EVSE) to accommodate BEBs.

5.1.1 Structure

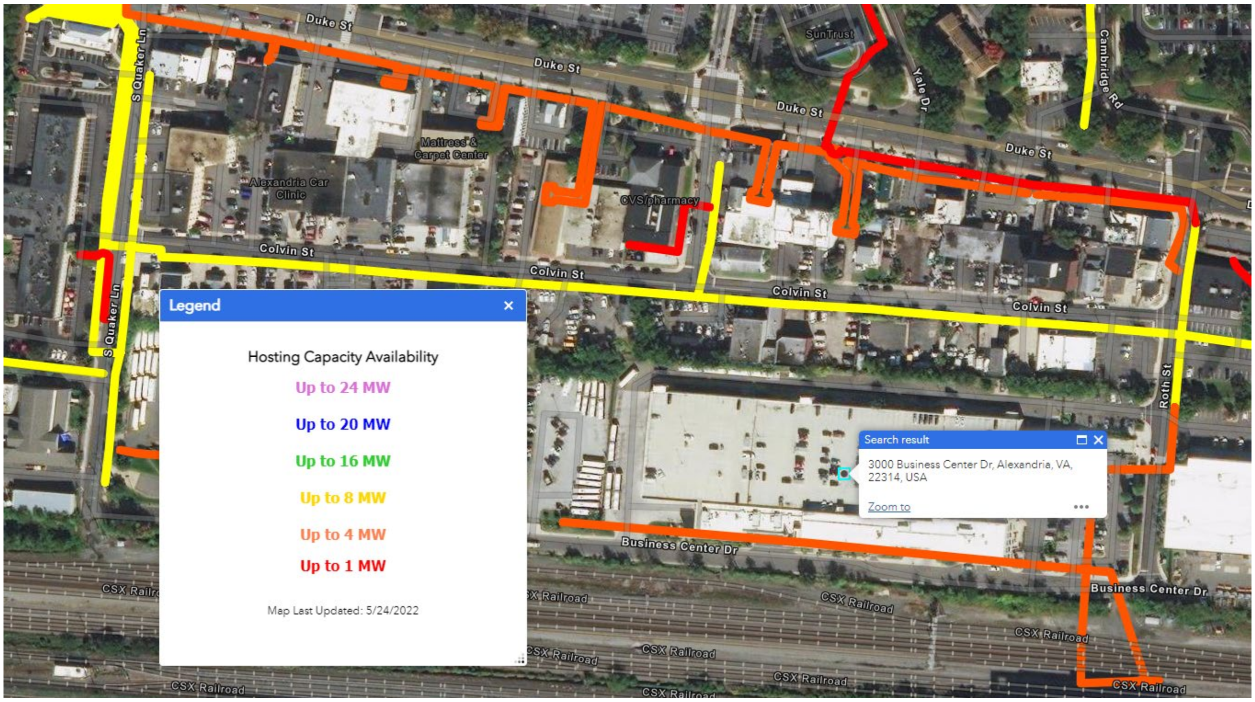
The sections contained in this report are a series of analyses that focus on different aspects of the utility assessment. These analyses are:

1. Existing Conditions Assessment
2. Potential Design
3. Resiliency Options
4. Incentives
5. Tariffs

5.2 Assessment

5.2.1 Existing Conditions

Figure 12: Dominion Energy's Distribution Lines to DASH Facility



Source: Dominion

The William B. Hurd Transit Facility is located at 3000 Business Center Drive in Alexandria, Virginia. The facility has one main distribution line feeding the DASH facility as shown in Figure 12. Coordination with Dominion Energy was conducted through meetings and phone calls to assess the existing utility service, timeframes to provide new service, and reliability of new circuits and substations. The facility's main distribution line has up to seven megawatts (MW) of hosting capacity remaining that is available for new loads. The distribution line enters the facility through the on-site transformer on the southwest side of the yard. The main substation that serves the DASH facility is the Jefferson Street Substation, located at 1250 Jefferson Street in Alexandria. The substation is 2.3 miles away from the DASH facility. There are other available substations in the system's architecture including, but not limited to, North Alexandria (Monroe Avenue) and Arlington (Glebe Road) that can potentially serve the projected new load as well.

WSP is unable to identify and assess potential pinch points related to the local electrical grid that could cause electrification delays due to lack of publicly available data. City of Alexandria staff advised that, over the five years prior to March 2022, the DASH facility experienced nine power outages with the average outage lasting 1.24 hours, excluding major weather events.

5.2.2 Design

There are 36 charging positions planned for the initial interim facility expansion where each position will charge sequentially at 150 kW. The site will include charging systems rated at 150 kilowatts (kW), with two vehicles assigned per charger. There would be 18 EV supply equipment systems, and the estimated input power is 162 kW per EVSE to account for the power loss in the equipment and required output power of 150 kW[5]. The total connected load is around 3,000 kW for the required chargers. The current electric service to the DASH facility has insufficient capacity to support the new load, so DASH should request new service from the utility. In the submission process, DASH should provide updated load letters, site plans, and single line diagrams for the utility to approve the application for new service. After the specific vendor of chargers is chosen, DASH's engineer of record should review the datasheet and determine the input power necessary for the chargers. If the input power for the charger is higher than 162 kW, then the Dominion Energy application needs to be updated accordingly.

DASH would require two 3000 A, 480/277 V, 4 Wire, three-phase switchboards to power all 18 EVSEs, with ten EVSEs per switchboard. Each switchboard would be connected to a Dominion Energy provided transformer. The transformers would connect to the main switchboard provided by Dominion Energy. Dominion Energy would provide power to the point of interconnection at the main switchboard and the subsequent 480/277 V transformers. Dominion Energy has stated that the circuit that serves the DASH facility will be Circuit 41309. DASH will install, maintain, and own all the equipment downstream of the secondary power transformers which includes the EV charger switchboards and charging equipment. Before detailed engineering and construction, the project team recommends that DASH coordinate with Dominion Energy to establish the final costs, responsibilities, equipment to be provided, and service terms in detail. The final design is subject to change and larger transformer and switchboard sizes may be used depending on the design engineer's preference.

A total of 30 new chargers would be capable of fully charging the connected BEBs at one time with 6 MW service. As shown in Table 7, DASH expects to have a total of 48 BEB dispensers (including the existing 12 dispensers) available by FY 2029. This would require equipment to provide 2.92 MW of capacity by FY 2028. However, the 6 MW electrical infrastructure can accommodate additional chargers. DASH has advised that, if needed a further ten chargers could be installed in the existing facility, providing an additional 20 dispenser positions. If possible, WSP recommends that DASH consider installing these additional ten chargers, as well as a further two

5 The required input power of each EV charger is dependent on the manufacturer model. This analysis estimates that the input power is 1.1 times greater than the output power. DASH should check the selected equipment datasheet for more accurate information.

chargers, which could all be accommodated within the 6 MW without charge management software.

Table 10 provides an overall charger installation plan and timeline. As these recommendations were developed in 2022, DASH will need to factor updated funding options and planned equipment purchases into this plan. In FY 2030, WSP recommends that DASH to install an additional pair of a 3000 A,480/277 V, 4 Wire switchboard and 2.0 MVA transformer to accommodate a further ten chargers and utilize the full 6 MW of utility service available. Five new chargers could be installed in FY 2030 and would be connected on the new switchboard while one new charger would connect to the switchboard from the 2.92 MW upgrade. This additional electrical infrastructure upgrade could accommodate five additional chargers in FY 2031. Any additional chargers beyond this will require a utility service upgrade. As the DASH facility receives additional buses, DASH will need to either shift BEBs (either manually or through automated means) to adequately charge them prior to service, or increase the site's utility service capacity. Additionally, even if DASH implements WSP's recommendations to increase the number of chargers through FY 2031, in FY 2032 the number of dispensers will be 72 and the number of BEBs will be 104, meaning that DASH will need to use yard shifters to properly charge the full fleet, or procure more chargers and pursue greater power supply from Dominion.

Table 10. Planned and Recommended Charger Installations

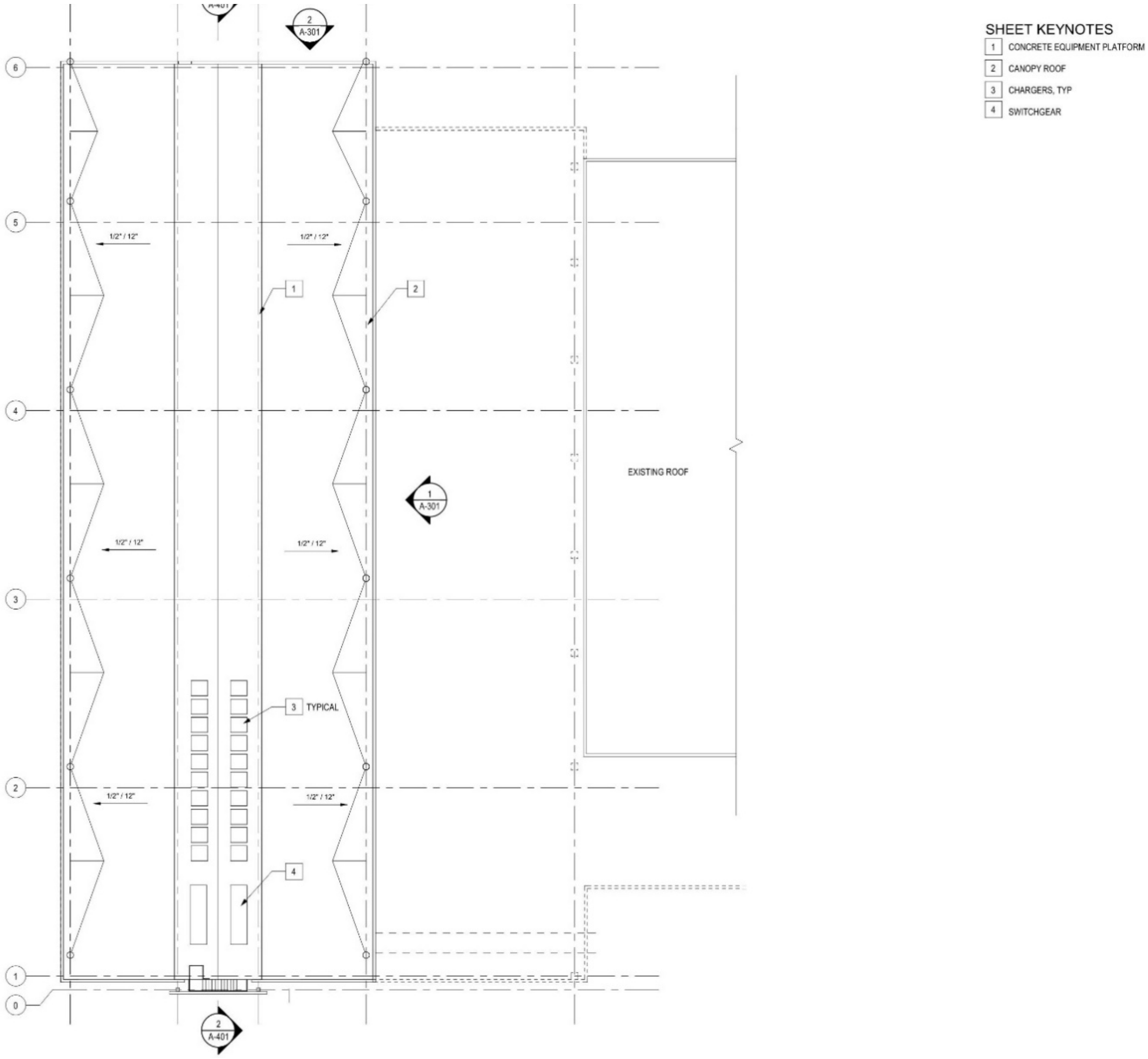
Fiscal Year	Additional Buses	Chargers Planned	Chargers Recommended	Total Dispensers Planned	Total Dispensers Recommended	Electrical Equipment	Notes
FY 2025	0	6 existing chargers onsite		12		No upgrades needed	
FY 2026	2	Additional 3 chargers		18		• Add main medium voltage switchgear • Add (1) 3000 A, 480/277 V, 4 Wire switchboard • Add (1) 2.0 MVA transformer	
FY 2027	17	Additional 9 chargers		36		• Add (1) 3000 A, 480/277 V, 4 Wire switchboard • Add (1) 2.0 MVA transformer	
FY 2028	14	Additional 6 chargers		48		No upgrades necessary	
FY 2029	14		Additional 1 charger		50	No upgrades necessary	DASH to determine if additional chargers are required or increase yard shifters64 BEBs and only 50 planned dispensers.
FY 2030	12		Additional 6 chargers		62	• Add (1) 3000 A, 480/277 V, 4 Wire switchboard • Add (1) 2.0 MVA transformer (Installed 6MW worth of equipment onsite)	
FY 2031	14		Additional 5 chargers		72	No upgrades necessary, but max chargers installed on 6 MW utility service	
FY 2032	15						If DASH implements WSP's recommendation to increase the number of chargers through FY 2031, in FY 2032 the number of dispensers will be 72 and the number of BEBs will be 104. DASH to determine if additional chargers are required or increase yard shifters
FY 2033	12						
FY 2034	3						
FY 2035	8						
FY 2036	0						
FY 2037	0						
FY 2038	26						

Figure 13. DASH Site Plan from WRA (September 2022)

Source: DASH

As shown in the latest site plan received from WRA (Figure 13, dated September 2022), the new transformers and MV switchgear will be installed near the existing DASH facility's bus storage, next to the existing underground storage tanks facing Business Center Drive. As shown in Figure 14, the new 480/277V switchboards and 150 kW chargers will be installed on the charging depot canopies located above the proposed bus storage. The associated pantographs would be installed underneath the canopy.

Figure 14. WRA Canopy Roof Plan



Source: DASH

5.2.3 Capital Costs

From the meeting with Dominion Energy in February 2023, $2 million is still a good estimate on the cost to upgrade the DASH facility up to 6 MW. Dominion Energy has stated that revenue credit is available, and this can potentially offset the capital costs. The 6 MW is the max capacity available on a different circuit that is in close proximity to the DASH facility. This estimate includes the installation of associated overhead equipment to accommodate 6 MW of capacity and rework existing feeds. In the February 2023 meeting, Dominion Energy mentioned they would provide the 3750 kVA transformers regardless of primary or secondary service, but not the medium voltage switchgear. The existing underground utility feed would need to extend approximately 1000 feet from the corner of Business Center Dr. and S. Quaker Ln.

5.2.1 Resiliency

The new fleet of BEBs has a larger operational reliance on the reliability of the local utility grid which can be prone to outages. However, there are potential resiliency technologies to mitigate the facility's concerns and provide electricity when utility power is unavailable. The technology ranges from dedicated feeders, battery energy storage systems (BESS), stationary backup generators, mobile backup generators, and solar photovoltaics. A summary of the advantages and disadvantages of each technology is provided in Table 11.

Dedicated Feeders and Substations

A second dedicated utility feeder supplies power to a site when the primary feeder experiences an outage. A dedicated feeder requires little maintenance, has minimal impact design, and includes other resiliency measures. However, such feeders are usually associated with additional costs from the utility.

The potential issues that could impact cost estimates include the additional easements which require negotiations with landowners, additional duct banks in congested areas, field surveying, and manhole surveys to determine existing spare conduits or the need to install additional conduits. The considerations that could impact on-site costs are the inability to set new poles due to city ordinance and the potential need to install new duct banks. DASH should continue to coordinate closely with Dominion and the City of Alexandria to better understand potential costs and timing impacts.

Battery Energy Storage Systems (BESS)

BESS allows electrical energy to be stored in the form of chemical energy and reused as electrical energy. By charging a BESS during when site load is low, and discharging it when site load is high, a BESS can be utilized to manage loads. BESS can also be used as a form of backup power and are most suitable for supplying power during short outages.

During normal operations, the BESS will charge using on-site generation sources such as solar PV arrays or draw power from the utility grid during financially viable periods. In the event of an outage, the BESS can provide power back to the local electrical system to support on-site loads. The size and cost of available energy storage modules limit the length of outage and size of load that the BESS can support.

In addition to supplying power during an outage, a BESS allows the customer to take advantage of time-of-use rates. By charging the BESS when power is cheaper, and then using the stored energy to service loads when power is more expensive, a BESS can effectively shift the site load seen by the utility grid to a period with lower rates. This can also be used to maximize the benefit of the existing photovoltaic systems by storing excess generation for later use. A battery energy storage system does not utilize fossil fuels and produces no emissions during operation.

Internal WSP industry knowledge suggests an approximate capital cost of $432/kWh for a BESS system. Assuming a bus battery size of 500 kWh, the rough capital cost to provide a BESS sized to charge a single bus once would be approximately $220,000. Although market prices will vary, a BESS system can be an expensive solution for storing large amounts of energy. BESS are currently in high demand, so there may be delays in BESS delivery.

Stationary Backup Generator

Stationary generators burn fossil fuels to produce electrical power which can then be provided to the facility's electrical system. They are a common form of backup power and can be utilized for both long-term and short-term outages. When combined with relevant electrical infrastructure such as automatic transfer switches, stationary generators can automatically provide backup power during an outage, minimizing the need for site management.

Stationary generators are an established technology and have several manufacturers who can provide customizable configurations. Unlike mobile generators, stationary generators are owned rather than leased. While most stationary generators require a fuel tank, natural gas generators can be directly connected to a natural gas utility feed.

Because these generators use fossil fuels and combustion engines, they must meet emissions standards for CO_2, NO_X, and particulate matter, which vary based on the local authority. These standards are expected to become stricter in the coming years in all regions. Local ordinances may also have sound limits which would require the stationary generator to be carefully located and provided with sound-attenuating enclosures.

Unless a natural gas feed is utilized, stationary generators will require on-site fuel storage, which may be underground, above ground, or integrated into the generator base. Although the footprint of a stationary generator is not as large as a BESS, it is not insignificant and may impact the overall site design. Stationary generators also necessitate regular maintenance and load bank testing to ensure good service and maintain warranties. Further research would be necessary to determine the amount of generation potential and required natural gas supply.

Mobile Backup Generator

Mobile generators are portable units that can be moved from location to location. They can either be rented or purchased, with some providers offering rent-to-own options. If a mobile generator is rented, there are no installation or capital costs, other than the necessary connection infrastructure.

Mobile generators are designed for portability and can serve multiple sites. However, their use across various locations presents logistical challenges, including the time and resources needed to transport and set up the generator at each site. Their availability is also a limiting factor, as they cannot provide power to multiple sites simultaneously. Additionally, regular maintenance and refueling are necessary, complicating their use when frequently moved. Therefore, while mobile generators offer flexibility, careful planning and coordination are required for their effective deployment across multiple sites.

Mobile generators require additional electrical infrastructure to support loads, such as generator connection cabinets with CAMLOCK-style connectors or inlets, manual transfer switches, and relevant feeders. Interconnecting and energizing a mobile generator takes time, limiting their suitability for brief outages. If the mobile generator is not stored on-site, the setup period will be even longer as the time to mobilize the generator will also need to be factored in. Therefore, mobile generators are best suited for longer duration and expected outages, and are not the ideal solution for brief, frequent outages.

Like stationary generators, mobile generators produce carbon and other emissions which are regulated by local authorities. Mobile generators also face similar noise concerns, and may require sound-attenuated enclosures, per local ordinances.

Fuel storage for mobile generators is limited by the size of their mobile base; in the event of a long-term outage or continuous operation, this will necessitate more frequent refueling than stationary generators.

Mobile generators also require regular maintenance and load bank testing to ensure they are in good service and available when needed.

Solar Photovoltaics

Solar photovoltaics convert the sun's radiation into electrical power. This means that the power supplied by PV systems does not produce carbon emissions or require any "fuel costs." Some utilities will exchange excess solar for an energy credit. Alternatively, this energy could be stored in a BESS to be used when the solar panels are not producing as much energy or to be supplied to the utility when energy credits are more valuable. A rough calculation provided by the National Renewable Energy Laboratory's PVWatts Calculator[6] determined that, in total, a photovoltaic energy system installed on DASH's facilities could be capable of producing up to 2,098,132 kWh/year. This assumes that 94,227 square feet are available for a solar array on DASH's existing (providing up to 1,794,169 kWh/year), and 12,636 square feet are available on DASH's planned expansion facility (providing up to 303,963 kWh/year).

While PV systems can help reduce the overall site load, they are not designed to supply a site with all its necessary power during an outage. Thus, PV systems are not a standalone resiliency solution but must be integrated with a BESS to provide support during an outage.

6 https://pvwatts.nrel.gov/index.php

Table 11. Summary of Resiliency Technologies

Resiliency Option	Advantages	Disadvantages
Dedicated Feeders and Substations	• Can be easily paired with other resiliency options • Little impact on facility design • Very low maintenance	• Cost varies highly • May require substation upgrades, which can be very lengthy • Natural disasters may render second feed unreliable
Battery Energy Storage System (BESS)	• Can be paired with onsite solar • Produces no carbon dioxide emissions • Can be utilized for site load management • May be eligible for tax incentives	• Very costly for energy storage capacity • Ideal for short term outages, not long term • High industry demand may cause delays in delivery time
Stationary Backup Generator	• Useful for short- and long-term outages • No lease/rental agreements and associated fees • Natural gas generators do not require on site fuel storage • Can automatically supply power during outages • Configuration is customizable • Mature, stable technology with several manufacturers • Efficient	• Produces carbon dioxide emissions • Must meet strict emission standards, which progress over the years • On site fuel storage • Local noise ordinances may require sound-attenuated enclosures • Requires on-going maintenance and load-bank testing • Requires significant space, and is costly • Generators must be sized correctly to prevent charger disruption

Resiliency Option	Advantages	Disadvantages
Mobile Backup Generator	• More useful for long term outages • Minimal impact on site design • Flexibility in size • If rented there is minimal upfront cost • Rent-to-own options sometimes available	• Produces carbon dioxide emissions • Local noise ordinances may require sound-attenuated enclosures • Not readily available for short term outages • If leased, risk of limited availability during natural disasters • Requires mobile generator connection infrastructure (generator connection cabinets, manual transfer switches, and associated feeders)
Solar Photovoltaics	• Produces no carbon dioxide emissions • Can be net metered to produce energy credits • Pairs well with BESS and other on-site generation systems in microgrids	• Solar installations are not designed to provide power during an outage

Source: WSP

5.2.2 Incentives

Dominion Energy has announced an upcoming Fleet Charging Program that may allow participating customers to receive a 50% upfront incentive on EV charging construction and installation, commonly referred to as “make-ready.” Customers have on-bill payment options for the remaining costs. The details of the program are yet to be published; however the facility expansion’s detailed design team should inquire further when coordinating with their utility design representative. Federal, state, and utility incentives may be available for DASH’s alternative fuel vehicles. More information is available from the US Department of Energy’s Alternative Fuels Data Center.[7]

7 https://afdc.energy.gov/laws

5.2.3 Tariffs

Based on the proposed configuration of the equipment and subsequent discussions, Dominion Energy will provide primary service. Since DASH is located in Virginia, Dominion Energy will assign DASH the tariff rates that were negotiated between the Virginia Energy Purchasing Governmental Association (VEPGA) and Dominion Energy. All relevant rate schedules are 30-day rates. Rates are periodically amended by utilities; these rates are the original rates set by VEPGA as of May 2023.

Types of Charges

In the rate schedules relevant to this project there are several types of charges. The first is the basic customer charge which is a flat fee paid every month. Distribution service charges represent the use and maintenance of distribution infrastructure. Distribution service charges are priced based on the power (kW) consumed, depending on the rate schedule. The last category of charges is the electric supply service charge which represent the cost of energy used on-site (kWh). In the relevant schedules, there is an initial electric supply charge for all power, and subsequent adjustments which lower total cost of power based on the amount used. Additionally, the electric supply charges may include a charge based on the amount of energy consumed. In some schedules the price of this charge may vary based on time of day and year.

Schedule 134

Out of the various VEPGA rates, Schedule 134 is the most applicable for DASH's new service. The tariff applies to customers that receive transmission or primary voltage and has a measured average 30-minute interval demand peak demand of at least 1,500 kW for at least three billing months. This schedule has on and off-peak hours, which are defined as follows:

- June through September: on-peak hours are 10 a.m. to 10 p.m.
- October through May: on-peak hours are 7 a.m. to 10 p.m.

Within Schedule 134, the distribution peak demand is defined by taking the highest of the following: the high average kW measuring during the current billing period, or 85% of the highest average kVA demand measured during the current billing month. The distribution contract demand is the larger of the distribution peak demand and 1500 kW. The highest of three values is chosen to determine the electric supply demand charge: the highest average kW measured in a 30-minute interval of the current billing period, 90% of the highest average kW in a 30-minute interval in the current billing period and past eleven months, or 1000 kW. These terms are summarized below in Table 12.

Table 12. Summary of Schedule 134 Terms

Demand Table
Distribution Peak Demand

Demand Table	
1.	Highest average kW for a 30-minute interval in the billing period
2.	85% of highest kVA measured in a thirty-minute period in the current period
Distribution Contract Demand	
1.	Distribution peak demand
2.	1500 kW
Electric Supply Demand Charge	
1.	Highest average kW for a 30-minute interval in the billing period
2.	90% of the highest average kW for a 30-minute interval in the billing period and past eleven months
3.	1000 kW

Source: VEPGA

The breakdown of the different charge categories is detailed in Table 13. The recommendation is to charge the bus fleet during off-peak hours between 10 p.m. to 7 a.m. to avoid on-peak energy usage charges since there is a $0.17 difference per kWh during the two different time periods.

Table 13. Summary of Schedule 134 Charges

SCHEDULE 134 – PRIMARY SERVICE	
Customer Charges	
Basic Customer Charge	$91.41 per month
Distribution Service Charges	
First 5000 kW of Distribution Contract Demand	$1.992 per kW
Additional kW of Distribution Contract Demand	$1.231 per kW
Electric Supply Service Charges	
On-Peak Electricity Supply Demand	$8.480 per kW
On-Peak Electricity Supply kWh	0.543₵ per kWh
Off-Peak Electricity Supply kWh	0.370₵ per kWh

Source: VEPGA

5.3 Recommendations

As DASH proceeds with transitioning its entire fleet and associated operating facilities to ZE technologies, the agency will need to install new medium-voltage equipment like a new MV primary switchgear, transformers, and switchboards to serve their EVSEs. For the new 36 charging positions planned for the facility expansion, DASH would require at least two 3000 A, 480/277 V, 4 Wire, three-phase switchboards to power all 18 EVSEs, with 10 EVSEs per switchboard. Each switchboard would be connected to a 2.0 MVA transformer. The transformers would connect to the main medium voltage (MV) switchgear. Dominion Energy would provide primary service with the point of interconnection at the main MV switchgear. However, the final design is subject to change and larger transformer and switchboard sizes may be used depending on the design engineer's preference.

In the future, if DASH wants to increase the number of fleet chargers, the agency can install new bays in the MV switchgear and increase their service in subsequent years. With a 6 MW service, the expanded DASH facility will be able to accommodate a total of 36 chargers and 72 dispensers. If DASH's charging infrastructure is limited to 48 dispensers starting in FY 2029, DASH will face operational challenges, as the planned number of BEBs in that year is 64, meaning that certain buses will need to be shifted in order that they be charged fully prior to service. The number of BEBs is planned to increase continually until the entire fleet is transitioned, compounding the challenge. Prior to FY 2029, DASH should explore options to move buses non-manually to address charging needs or consider increasing the number of dispensers available.

The existing electrical service and infrastructure will not be able to support the new anticipated loads for the BEB charging equipment, therefore DASH will need to request new medium voltage service from Dominion Energy consisting of at least one feeder. The project team recommends requesting two new feeders for improved resiliency due to limited space onsite. The cost for these upgrades is estimated to be on the order of $5.4M for the first feeder and $4.5M for a redundant feeder excluding the cost of facility improvements needed. Dominion Energy does not currently offer incentives that could benefit DASH's electrification plan, but this is subject to change in the future.

5.4 Conclusion

During the Low or No Emission Grant Program application process in March 2022, a preliminary load letter and high-level concept design were provided to Dominion Energy for the cost analysis exercise. DASH will need to submit a formal application in the future once the final load numbers are known. The plans and single line diagrams provided by WSP were concept-level designs which are not suitable for construction, bid, or permit. The engineer of record will need to perform detailed design, determining system details such as final transformer sizes, equipment ratings, and on-site service voltage. The engineer of record will need to coordinate new primary service with Dominion Energy and finalize the service application process prior to construction.

6 Maintenance Assessment

This section provides an assessment of the DASH ZEB program's maintenance needs. It also provides recommendations for workforce development strategies, including training and recruitment, to ensure that DASH has the necessary operations and maintenance capabilities for a ZEB fleet.

6.1 Introduction

This section provides a high-level review of multiple requirements that will be needed to ensure that DASH is ready to maintain its future 100% ZE fleet in a safe and reliable manner. BEBs are still considered an emerging technology and historical data is limited, as well as industry best practices. The details below include recommendations that were developed using available data and practices employed by peer transit agencies to prepare and operate BEB units.

6.1.1 Purpose and Approach

Figure 15. A BEB undergoing maintenance

Source: WSP

While fully transitioning to a ZEV fleet, several operational processes will require adjustment. Employee training will need to adjust to the technology currently deployed and adjust as technology continues to evolve. The conversion to ZE technology is a more complex adjustment for technicians, specialized mechanics, and operational staff. To prevent maintenance staff from losing its competences DASH will need to schedule a proper amount of refresher sessions annually. Employee refresher training topics should focus on high-voltage awareness, proper use of personal protective equipment (PPE), and safety procedures.

6.1.2 Structure

This section provides an assessment of the ZEB maintenance program DASH should pursue, including infrastructure and equipment requirements, and identifying staff training. The assessment includes analyses that focus on different aspects of the technology transition. These analyses include a conditions and training assessment, infrastructure and equipment requirements, and workforce development.

6.2 Methodology

WSP has assessed DASH's procurement plan and reviewed the maintenance requirements necessary when procuring an eventual 134-bus fleet to develop the recommendations for a successful BEB fleet deployment.

6.3 Assessment

A transition from working with ICE vehicles to ZEBs does not require a significant change in the job duties and job descriptions of the technicians and operators. Technicians are still responsible for providing preventive maintenance per a predesigned checklist. They are still required to troubleshoot a vehicle's issues and to fix them using safety protocols, per training. Operators will still operate the buses on the same routes, utilizing the same bus stops and customer service protocols. However, the skills needed to perform these tasks will change. For example, the job description of the service attendant, including the core standard operating procedures that process a bus at the end of the day, will need to be revised to assign responsibility for charging. Currently, during fueling, most agencies direct the service attendant to sweep the bus, clean, probe and empty the farebox, and record the mileage and other data required (if this is not done electronically). The ZEB transition will provide an opportunity for agencies to rethink how the vehicles are serviced, since the "fueling" of the bus is now either a plug-in or pantograph charger, located well away from the rest of the service activities. DASH may also take this time to reexamine the best time of the day to probe buses. Some could be probed at midday, or activities could be split in different ways throughout the day. outlines the approximate impact that the transition to ZEB vehicles is anticipated to have on different job classifications.

Table 14: Zero-Emission Bus Impacts to Staff Responsibilities

Position	Job Impact
Bus Operations Supervision	Medium
Cleaners	Low
Control Center	Low
Dispatchers	Low
Facility Technicians	Medium
Maintenance Supervision	High
Operators	Low
Safety	Medium

Position	Job Impact
Schedulers/Planners	Low
Technicians	High
Training Instructors	High
Transit Field Supervisors	Medium

Source: WSP

6.3.1 Training

Every bus operator must be properly trained prior to new buses being deployed into revenue service. Refresher training should provide each employee with both academic and behind-the-wheel experience. Topics covered should include awareness of high voltage, dashboard controls and indicator lights, specific start-up and shut-down procedures, and defensive driving safety. This training should meet state of Virginia and federal regulatory requirements. As DASH currently operates 14 BEBs, the agency should consider expanding its current training offerings to ensure that all operators are comfortable with BEBs and understand BEB operational concepts such as conserving battery life, degradation, and daily wear and tear. ZEB technology will continue evolving over time, and each vehicle purchase or upgrade will require a proper reevaluation of DASH's current BEB training program. Refresher training should be provided annually as well.

Technicians, mechanics and maintenance supervisors comprise the roles most affected by the transition to ZEB. As the DASH workforce will understand through its current BEB maintenance work, most job functions will remain unchanged (brakes, farebox, and low voltage systems of the bus function in the same way as on a diesel bus). However, BEBs provide a significant change in terms of the propulsion system. BEBs as well as charging infrastructure are also equipped with new software technology. It is recommended for DASH to assess if technicians, mechanics and maintenance supervisors require additional training to become more comfortable using these systems and electronics. Technicians and mechanics need to be proficient to efficiently us diagnostic tools to monitor operation levels, run in-depth diagnoses to identify faults, and resolve operating problems without physically removing components. To ensure that technicians, mechanics and maintenance supervisors complete their daily tasks safely, both roles will receive basic medium/high voltage refresher training, and revisit how to properly use receive specialized personal protective equipment (PPE). As with operator training, DASH should ensure that its maintenance staff training courses are updated with every new bus or charging equipment purchase.

The following table provides a list of employee categories which will require refresher training through the conversion process of ZEVs:

Table 15. Required Training Knowledge by Position

Positions	Required Training Knowledge
Bus Operators and Supervisors	Bus operators and field supervision must prove to be familiarized with the safety of bus and charger operations.
Facilities Maintenance Staff	Maintenance staff will need to prove to be familiarized with scheduled and unscheduled repairs, high-voltage systems, and the specific maintenance and repair of equipment.
First Responders	Local first responders will need to be familiarized with the new buses and supporting facilities.
Tow Truck Service Providers	Tow truck providers will need to be familiarized with the new buses and proper procedures for towing these vehicles.
Mechanics and Technicians	Mechanics and technicians will need to be familiarized with the safety-related features and other components of ZEVs.
Instructors	Maintenance and bus operator instructors will need to understand all aspects of the transition of ZEVs to train others.
Utility Service Workers	Staff will become familiarized with proper charging protocol and procedures that are ZEV-specific.
Management Staff	Maintenance and Operations managerial staff will be familiarized with ZEV operations and safety procedures.

Source: WSP

6.3.2 Infrastructure and Equipment Requirements

While mechanics, technicians, and maintenance staff might require classroom with every new bus purchase training, active learning will also be important through the ZEB transition. Training aids such as display panels of bus body parts will allow maintenance staff to have continued hands-on experience in a safe manner. Other training aids that are recommended acquiring with a new vehicle purchase include basic and advanced drivetrain mock units, a multiplex simulator to help technicians and mechanics become familiar with the new vehicles' communication signals transmission method, and a battery pack mockup in case module's structure changed. DASH should ensure that its workforce has access to enough training aids to support the continued learning process.

Further recommendations beyond ensuring mechanics and technicians have access to all required training aids include guaranteeing that training materials arrive before the first bus delivery. This will allow supervisors and trainers to become familiar with the new equipment before arrival.

DASH should also work with the OEM after every vehicle purchase to develop a list of recommended special tools that will be required with each order DASH should also request a list of recommended spare parts, such as items that are either frequently replaced or difficult to acquire.

All staff working with high or medium voltage (HV/MV) electrical equipment will have to ensure having the appropriate PPE. Each technician and mechanic working on ZEBs should receive their own set of PPE as well as refresher training on how to properly use and care for it. Table 16provides detail on the PPE that DASH staff should always have access to for working on HV equipment.

Table 16. Personal Protective Equipment

Tool	Recommended Quantity	Notes
Arc-rated long sleeve shirt and long pants	Ample supply for each ZEB technician and mechanic that could be working on a ZEB at any given time. Assigned to employee.	Arc-rated overalls are also acceptable.
Arc-rated balaclava	Ample supply for each ZEB technician and mechanic that could be working on a ZEB at any given time. Assigned to employee.	
Arc-rated flash suit hood or face shield	Ample supply for each ZEB technician and mechanic that could be working on a ZEB at any given time. Assigned to employee.	
Hard hat (Class E or G)	Ample supply for each ZEB technician and mechanic that could be working on a ZEB at any given time. Assigned to employee.	
Safety glasses or googles	Ample supply for each ZEB technician and mechanic that could be working on a ZEB at any given time. Assigned to employee.	
ASTM Class 0 insulated gloves (red label)	One pair, properly sized for each ZEB technician and mechanic.	
Leather gloves to be worn over ASTM insulated gloves	One pair, properly sized for each ZEB technician and mechanic.	Insulated gloves need to be tested and replaced every six months.
Leather footwear	One pair, properly sized for each ZEB technician and mechanic.	Certified ASTM F2413-17 for electrical hazard that can withstand 18,000 volts at 60 Hz for one minute.
Arc-rated hard hat liners (as needed)	Ample supply for each ZEB technician and mechanic that could be working on a ZEB at any given time. Assigned to employee.	

Source: (International Transit Learning Center, 2022)

Fall Protection

As most of DASH's BEBs complete their second year in service, vehicles may require technicians and mechanics to complete repairs and battery evaluation on the roof, DASH should consider fall protection methods to ensure the safety of its maintenance personnel. In a maintenance building servicing BEBs, a minimum of two dedicated maintenance bays should provide BEB roof access with fall protection. For every four lift bays, one jib crane should be available to hoist material. There are three approaches to fall protection that could be considered for addition to DASH's maintenance facility:

- Monorail with fall protection harness
- Portable scaffolding
- Fixed catwalk

A monorail with a fall protection harness is the most common solution, as it is the least costly and takes up the smallest amount of space. Peer transit agencies have found such equipment cumbersome, however. Other options include portable scaffolding or a fixed catwalk system, often found in light rail and streetcar maintenance facilities.

Safety

Safety is paramount for BEB units as the risk of injury or serious injury is exponentially increased with these technologies compared to conventional buses. After every new bus or charging infrastructure purchase basic safety protocol requirements as well as specific safety and maintenance standards should be reviewed for DASH BEB facilities.

Lockout and Tagout Procedures

While utilizing dangerous machinery and industrial equipment, lockout and tagout procedures help manage the safety controls this equipment is designed with. The lockout/tagout standard establishes the agency's responsibility to protect employees from hazardous energy sources on machines and equipment during service and maintenance. Employees should receive refresher training annually to ensure they know, understand, and follow the applicable provisions of hazardous energy control procedures. The procedures include the following eight steps.

1. Find the procedure to be used
2. Notify anyone affected by the lockout/tagout
3. Locate all listed energy sources
4. Shut down the machine or equipment
5. Lockout and tag all energy isolating devices
6. Release any stored energy (steam, hydraulic, electric etc.)
7. Return controls to off position
8. Maintain and test safety critical systems

For DASH to be compliant with lockout/tagout standard, all employees must prove to be familiar with the precautions and actions necessary to avoid emergencies and/or what the protocol is during an emergency, such as locations of emergency of shut-offs. Some transit agencies have found that there is a shortage of technicians and mechanics with the required skillsets for electric powertrains and high-voltage servicing. The industry is addressing this need by working with community colleges and technical schools to add required courses to keep ZEV technicians and mechanics updated on the latest technologies.

6.3.3 Staff Training and Workforce Development

Maintenance

ZEVs have different components and controls compared to traditional diesel buses. Bus performance also differs. It is recommended for DASH to provide annual refresher training to ensure its operators continue to be proficient on the differences and efficient operation of the buses. Refresher training should be conducted on all emergency and safety procedures. Maintenance staff should be trained to service and troubleshoot all vehicle and auxiliary systems, how to work with onboard diagnostic systems, and be trained in safe work practices for high-voltage. Operations staff should be briefed on any expected range or endurance limitations (including seasonal variations) of the BEBs as well as expected recharging times. Safety training is critical for all staff involved supporting ZEV deployments (some transit agencies train managers and non-operational/administrative staff on vehicle safety fundamentals).

Each repair or service procedure that is completed by a technician or mechanic should be verified and inspected using a stringent QA/QC process to ensure that the repairs are completed to OEM specifications and all equipment is secured before the unit is returned to service.

Maintenance Training

While operator training is necessary, maintenance training is far more critical because technicians and mechanics regularly work directly with ZE systems. While an operator may have around eight hours of training to operate these vehicles, mechanics will need upwards of 200 hours before they are qualified to work on high voltage electrical systems. The main differences involved in transitioning from diesel fleet to BEB fleet maintenance are the electrical systems and charging monitoring/communication system. These additional services require an on-staff electrician when maintaining the electric propulsion or charging system.

With ongoing development of ZEV technology, training programs are constantly updated to comply to the bus technology being released. Table 17 provides a ZEB course catalog recently developed by a peer agency to produce high-level understanding. The training time for each course is an approximation.

Table 17. Sample ZEB Course Catalog

Course	Hours	Fleet
Digital Multimeter (Distance Learning)	4	ZEBs/Hybrid
High Voltage Electrical Safety – ZEB (Vendor)	8	BEB

Course	Hours	Fleet
High Voltage: Awareness and Safety (Distance Learning)	3	VH/New Flyer BEBs
High Voltage FC Safety and Familiarization – ZEB	8	VH/New Flyer BEBs
New Flyer BEB Orientation – ZEB (Vendor)	3	ZEBs/Hybrid
New Flyer BEB Service/Maintenance – ZEB (Vendor)	24	New Flyer BEB
New Flyer FC Orientation – ZEB (Vendor)	3	New Flyer BEB
Siemens ELFA – ZEB (Vendor)	8	VH/New Flyer BEBs
XALT Battery – ZEB (Vendor)	16	New Flyer BEBs

Source: AC Transit

6.4 Maintenance Costs

Maintenance costs for BEBs are expected to be higher than those for conventional buses. Additionally, training costs are expected to be higher for BEBs, as the entire workforce, as well as local first responders, should be trained on the unique aspects of operating, maintaining, and staying safe around BEBs. WSP estimated that a fully transitioned fleet would lead to maintenance costs of $117 million (over the 12 years of useful life for each vehicle), opposed to an estimated $91 million maintenance cost for the existing fleet. See section 7.5 for more discussion of estimated vehicle maintenance costs.

6.5 Recommendations

The following sections include recommendations related to maintenance refresher training and future procurements for charging infrastructure.

6.5.1 Troubleshooting Training

The arrival of the new BEBs, added new daily responsibilities for technicians and mechanics. Charger usage familiarization is now required to perform preventive maintenance and corrective maintenance on BEBs. DASH should plan to provide refresher training with every new purchase so its mechanics can continue to efficiently troubleshoot and repair any issues related to charging infrastructure without relying on the OEM.

Mechanics also require a deep understanding of how to service and troubleshoot all electric propulsion systems as well as all parts associated to BEBs. Although mechanics might currently be familiar with ZEB dashboard controls and warning signals this role might need to be retrained on how to address each technical issue. It is important to understand that such training and competence standards require technicians and mechanics to be literate in computer systems, electronics, and electricity in general. In the case DASH decides to acquire updated BEB model, both technicians and mechanics will need to be trained and become fluent in troubleshooting the new system's components, as they will need to continue running computer-based diagnosis.

To keep troubleshooting skills updated, technicians and mechanics will require a combination of classroom hours and access to training aids. The latter will allow them to successfully learn how to troubleshoot any new components in the propulsion and Energy Storage Systems (EES) in a safe manner.

6.5.2 OEM Training

Prior to every new purchase, DASH should look for a BEB OEM that can effectively support its fleet transition. With every purchase, the OEM is expected to provide basic BEB training for operations and maintenance staff and first responders. This includes courses from the introductory level, such as Operator and Maintenance BEB Orientation, to more complex and advanced courses such as Propulsion & Energy Storage System (ESS) Familiarization and High Voltage Safety.

DASH may wish to utilize an OEM field support mechanic for the first year of service of the new vehicles. These OEM technicians can provide support and training in the shop, mentor DASH's mechanics as they continue developing competencies with ZE technologies and provide any of the OEM training modules to DASH's staff as requested. It is recommended for DASH to request this service as a separate line item in every procurement with a one-year timeline, as well as a one-year option to be exercised at the request of DASH if needed.

6.5.3 Interoperability

Bus manufacturers encourage their customers to use their charging systems. It is recommended that DASH assess current and future operations requirements and depot conditions to determine if integration of a new charging system will best meet its needs. Many agencies choose to add inverted pantographs but an equal or greater number choose to continue using CCS1 plug-in charging. Other agencies have decided to invest in a remote multi-dispenser architecture that offers significant cost and space advantages over the all-in-one options usually available in the market today.

6.6 Conclusion

It is imperative that the agency understands the significant endeavor of fully transitioning to a zero-emission fleet. Zero-emission buses are a mere fraction of the overall requirements to support transit fleet electrification, workforce is a critical component as well. DASH will evaluate its current training plan and assess its workforce readiness prior to receiving further BEB deliveries. With the acceleration of state-level mandates for the adoption of ZEBs, early and robust planning to address the capital costs, infrastructural requirements, and operational limitations of ZEBs is recommended.

Maintenance of the BEBs may have fewer moving parts, however they still require highly specialized technicians with different skillsets than technicians who work on ICE vehicles. Operational costs related to implementation of charge management strategies, utility upgrades, and battery storage can be reduced through strategic partnerships. Developing key partnerships with the local utility company and bus OEMS can additionally promote the exploration of innovative solutions, such as the creation of a distributed generation micro-grid at the bus depot.

7 Total Cost of Ownership

This section provides a total cost of ownership evaluation of the DASH ZEB program, from developing the vehicle replacement timeline to calculating capital costs, vehicle maintenance costs, disposal costs, and non-cash environmental costs by scenario and sensitivity test.

7.1 Introduction

7.1.1 Purpose and Approach

The purpose of the lifecycle cost analysis is to define the incremental cost attributed to both purchasing and operating vehicles and supporting infrastructure investments over their useful life and under various transition scenarios. The lifecycle analysis is conducted using a tool referred to as PRISM. The PRISM model is designed to evaluate both cash and non-cash (such as emissions and noise) costs for the No Build and ZEB Transition Plan scenario and identify the specific variance in costs. The PRISM model is also designed to transition from evaluation to funding using input factors and model structure as recommended by USDOT, the primary administrator of national funding programs. The model provides benefit cost analysis using DOT guidance on factors including greenhouse gas and vehicle emissions, the impacts of noise, and residual values of included assets.

PRISM outputs can be directly leveraged to react to various levels of governments that offer funding programs to help offset the incremental costs attributed to purchasing and operating BEB vehicles and upgrading supporting vehicle charging infrastructure. Both formula funds and discretionary grant funds were identified and reviewed to help align specific projects with funding programs.

7.1.2 Structure

This section is organized into the following primary sub-sections:

1. Introduction – Overview of the report's purpose, approach, and structure.
2. Methodology – Overview of the modeling process, including inputs, assumptions, and approach.
3. Vehicle Fleet Transition – Overview of Vehicle replacement timeline for the No Build baseline and alternative ZEV scenario.
4. Capital Cost – Overview of capital costs including vehicle purchase cost, vehicle mid-life overhaul costs, and facility improvement costs.
5. Vehicle Maintenance Costs – Overview of vehicle maintenance cost categories and methodology including vehicle annual operating mileage assumptions, annual maintenance cost, tire costs and training costs required for the conversion to ZE technology.
6. Operational Costs – Overview of operating costs such as fuel and energy costs.
7. Disposal Cost – Overview of residual value/disposal cost assumptions for vehicles and batteries, where applicable.

8. Environmental Non-Cash Costs – Overview of approach used to monetize non-cash costs including noise, tailpipe emissions, and upstream emissions.
9. Lifecycle Cost Results – Overview of lifecycle cost results by scenario and sensitivity test including annualized costs and cost risks and opportunities.
10. Recommendation and Conclusion – Presents recommended next steps for implementation and concludes the section.

7.2 Methodology

The following section provides an overview of the inputs (data and assumptions), methodology, and outputs used to determine the viability of operating electric buses based on DASH's existing service schedules.

DASH is actively engaged with fuel providers, agencies operating ZEBs, and vehicle manufacturers to understand technology and cost trends in the industry. This information is utilized to inform assumptions on the availability and pricing of vehicles and supporting infrastructure. The values presented are subject to change and are based on the most current information available at the time of this analysis in mid-2023.

Compared to conventional diesel vehicles, ZEVs incur different capital and operating costs. For example, in the case of BEBs, the cost to install and maintain utility and charging infrastructure will differ in both the magnitude and the types of resources required in comparison to existing diesel storage and fueling facilities. Other examples include battery replacement schedules, vehicle components requiring mid-life overhaul, and disposal values for the vehicles and batteries.

The total cost of DASH's transition will be contingent upon its specific fleet size, bus acquisition plan, facility sizes, charging strategy, construction schedule, and pursuit of applicable grant and funding programs, among other details.

The structure of the lifecycle cost modeling includes the assessment of capital, operating, disposal, and monetized environmental costs associated with the transition of DASH's existing vehicles under a No Build and a Build Scenario (as developed in Section 3 Full Fleet Assessment), defined as:

- No Build Scenario – DASH continues to operate its current fleet (replacing all diesel vehicles with similar diesel vehicles and BEBs with similar BEBs) and operating them until the end of their useful life.
- Build Scenario 3, 134 vehicles (DASH's alternative ZEB transition) – The existing diesel vehicle fleets are replaced with BEBs after the vehicle useful life at a higher replacement ratio to account for range limitations.

The lifecycle costs are assessed over the vehicles' operating years to account for their full operating costs over 12 years.

BEB facilities offer the opportunity for DASH to lower some operations and maintenance costs; however, other costs will increase. Like conventionally fueled vehicles, BEB operations and maintenance costs are highly dependent on the size and complexity of the vehicle fleet. Additionally, an electrification strategy would shift

DASH's primary fuel source for core bus operations from diesel to electric power, subjecting the agency to very different energy pricing structures and exposure to energy price volatility.

Table 18 outlines the major cost categories evaluated as part of this analysis.

Table 18. Primary Cost Categories

Type	Cost Components Attributed to Lifecycle Analysis
Capital	Vehicle Purchase Price
	Modifications & Contingency
	Charging or Fueling Infrastructure
	Major Component Replacement
Maintenance	Vehicle Annual Mileage
	Vehicle Maintenance, Vehicle Tools, and Equipment
	Tire Replacement Costs
	Fueling or Charging Infrastructure Operational Costs
	Training Costs
Operational	Vehicle Fuel or Energy Costs
Disposal	Battery Disposal Cost or Salvage Value
	Bus Disposal Cost or Salvage Value
Environmental	Vehicle Emissions
	Upstream Emissions
	Noise

Source: WSP

7.3 Vehicle Fleet Transition

Two main factors are considered with vehicle procurement: timing and quantity. The number of vehicles being procured is determined by how many vehicles can be accommodated at each facility and the quantity needed to maintain services.

The procurement timeline should align with facility enhancements and is subject to considerations such as the useful life of the vehicles and any established procurement goals. The lifecycle model assumes that the buses will be retired after 12 years.

For both the No Build and ZEB Transition scenarios, eight new BEBs enter service in FY 2023. Vehicle purchases between FY 2024 and 2038 are assumed to all be diesel vehicles in the No Build scenario, and all BEBs in the ZEB Transition scenario. Over the analysis period the no-build scenario assumes all diesel or BEB vehicles are replaced by similar vehicles and the build scenario assumes that all vehicles are replaced by electric models. The build scenario assumes an increase in fleet to 134 buses versus 119 buses in the no-build scenario to accommodate the shorter range of BEBs versus conventional buses.

Table 19 depicts the new fleet acquisition in the No Build scenario and Table 20 depicts the new fleet acquisition in the Build or ZEB Transition scenario. These tables are focused on the year of delivery which is assumed to occur approximately two years after purchase.

Table 19. New Fleet Acquisition – No Build

	FY 23	FY 24	FY 25	FY 26	FY 27	FY 28	FY 29	FY 30	FY 31	FY 32	FY 33	FY 34	FY 35	FY 36	FY 37	FY 38
Electric 35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electric 40	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electric 60	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clean Diesel 35	-	-	-	4	4	11	-	3	13	9	3	-	-	-	-	3
Clean Diesel 40	-	-	-	-	10	1	12	6	-	5	8	3	-	-	-	16
Purchase by Year	**8**	**-**	**-**	**4**	**14**	**12**	**12**	**9**	**13**	**14**	**11**	**3**	**-**	**-**	**-**	**19**

Source: DASH

Table 20. New Fleet Acquisition – Build

	FY 23	FY 24	FY 25	FY 26	FY 27	FY 28	FY 29	FY 30	FY 31	FY 32	FY 33	FY 34	FY 35	FY 36	FY 37	FY 38
Electric 35	-	-	-	5	5	13	-	4	14	10	3	-	-	-	-	4
Electric 40	4	-	-	-	12	1	14	7	-	5	9	3	-	-	-	17
Electric 60	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clean Diesel 35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clean Diesel 40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Purchase by Year	**8**	**-**	**-**	**5**	**17**	**14**	**14**	**11**	**14**	**15**	**12**	**3**	**-**	**-**	**-**	**21**

Source: WSP

7.4 Capital Cost

This section outlines the capital cost assumptions for the lifecycle cost analysis. Capital costs of vehicles are sourced from the base vehicle prices provided through a contract from Virginia's Department of General Services State that is active from January 11, 2023 to January 10, 2025.[8] The additional costs of battery extended warranties were applied to the capital costs of BEBs. Vehicle costs represent the cost of replacing the existing vehicle fleet and do not consider incremental vehicle requirements due to potential range reductions from the transition to BEBs. Capital costs of vehicles are incurred based on the fleet replacement plan developed by the Project Team in support of lifecycle cost analysis. The fleet replacement plan is based on the current operations of DASH, with the assumption that BEB and related infrastructure costs will be incurred during the applicable vehicle transition timeframe and will correspond to completion of facility transition and electrification. Vehicle purchases for BEB and conversion may not fully align with the current vehicle fleet due to other operational considerations. Additionally, capital costs of vehicles are incurred two years prior to operational start date to account for delivery lag and acceptance testing.

Bus capital costs are based on standard vehicle purchase prices, after-market equipment, and allowances for contingency. Supporting infrastructure costs include fueling or charging supply integration and storage and any associated periodic replacement costs over the analysis period.

7.4.1 Vehicle Purchase Cost

Vehicle purchase costs include the standard purchase price and additional options and charges as shown in Table 21. The values provided exclude sales tax costs.

Table 21. DASH Vehicle Purchase Price Assumptions (2022 dollars)

Bus Type	Bus Cost Estimate	Additional Options and Charges	Total Vehicle Purchase Costs
35ft BEB	$918,571	$155,593	$1,074,164
40ft BEB	$928,571	$155,593	$1,084,164
60ft BEB	$1,419,654	$155,593	$1,575,247
35ft DSL	$477,690	$155,593	$633,283
40ft DSL	$482,690	$155,593	$638,283

Source: Virginia Contract

8 *Contract: CTR010079-2 - Vehicle: Low Floor Transit Buses, Commuter Coach Buses, and Trolleys Heavy Duty, 12 Year (29 ft. – 60 ft. sizes) Amendment #2: Virginia.* [online] Available at: https://procure.cgieva.com/page.aspx/en/ctr/contract_manage_public/17105 [Accessed 10 Oct. 2023].

7.4.2 Vehicle Mid-Life Overhaul Costs

Overhaul costs apply to diesel and electric vehicles. Based on DASH's operational experience, major component replacement is assumed at $60,000 for diesel buses.

For BEBs a cost of $240,000 per vehicle is assumed for 35 ft and 40 ft models in year 6 to cover the full replacement cost of the battery. For 60 ft BEBs, battery replacement is estimated to cost $280,000. The battery replacement is assumed necessary to maintain vehicle operational range through retirement. While there are no examples of agencies in the U.S. replacing a battery outside of the warranty period the cost estimates are based on current battery prices for New Flyer bus and assumed labor costs based on experience with the replacement of bus batteries and additional contingency to account for the larger battery size and potential complexities with a BEB battery replacement.

7.4.3 Facility Improvement Costs

Facility improvement costs are based on cost estimates from the City of Alexandria's Approved FY 2024 - FY 2033 Capital Improvement Program. Facility improvement costs are taken into account for both diesel buses and BEBs. These estimates are to account for costs such as utility upgrades and any other supporting infrastructure costs including chargers and dispensers. Facility improvement costs in the No Build Scenario include costs such as underground tank replacement costs for diesel buses. For the Build Scenario, facility improvement costs of $11.9 million for 38 buses from the Approved FY 2024 – FY 2033 Capital Improvement Program have been incorporated into the model and has been scaled to the size of the fleet in the Build Scenario.

7.5 Vehicle Maintenance Costs

Operating and maintenance costs are evaluated on a cost per mile basis and applied to the average vehicle mileage over the lifecycle of BEBs. The operating life of the vehicles is assumed to be 12 years. The average mileage of each vehicle type is determined based on the odometer for each vehicle. Values on operating costs per mile are sourced from the operating experience of peer agencies. Fuel costs (electricity) are based on the utility tariffs of local utilities VEPGA. Diesel fuel costs are based on Energy Information Administration (EIA) price forecasts. Disposal costs are based on the current Federal Transit Administration (FTA) guidance.

Vehicle operations and maintenance (O&M) costs include general vehicle maintenance costs, tire service costs, fueling infrastructure annual maintenance costs, fuel or energy costs, and bus disposal and retirement costs. Vehicle O&M costs are specific to the vehicle types and the length of the vehicles. Overall O&M costs are influenced by the operating costs per mile of each vehicle and annual mileage, both direct inputs into the lifecycle cost model.

7.5.1 Average Mileage Per Vehicle

Average miles per vehicle are estimated using the odometer for each vehicle. Vehicle life was assumed based on the DASH's operational experience. Average mileage and useful life for each fleet type are shown in Table 22.

Table 22. DASH Average Mileage per Vehicle and Useful Life

Scenarios	Average Vehicle Mileage	Useful life
35-ft BEB	25,421	12
40-ft BEB	22,767	12
60-ft BEB	22,767	12
35-ft DSL	26,808	12
40-ft DSL	23,072	12

Source: FTA NTD Agency Profile (avg. 2019-20), DASH

7.5.2 Annual Maintenance Cost

General vehicle maintenance costs are provided in Table 23. Data from DASH and peer agency were applied for diesel and electric vehicles using the average cost per mile values for the agencies. As actual 60-foot BEB maintenance experience is limited to a few years on initial pilot deployments at the time of the analysis, future costs curve values were informed by a combination of 40-foot BEB values and differentials for other technologies between 40-foot and 60-foot models. BEB costs rise over time due to higher training costs after the first three years of the Build Scenario.

Table 23. DASH – Vehicle Annual Maintenance Costs (2022 $/mile)

Year	BEB 35’	BEB 40’	BEB 60’	DSL 35’	DSL 40’
Year 1	$0.29	$0.33	$0.28	$0.36	$0.41
Year 2	$0.26	$0.30	$0.25	$0.38	$0.43
Year 3	$0.26	$0.30	$0.25	$0.45	$0.51
Year 4	$0.59	$0.67	$0.68	$0.52	$0.60
Year 5	$0.52	$0.59	$0.81	$0.46	$0.53
Year 6	$0.66	$0.75	$1.07	$0.59	$0.68
Year 7	$0.60	$0.69	$0.98	$0.54	$0.62
Year 8	$0.58	$0.67	$0.95	$0.52	$0.60
Year 9	$0.56	$0.64	$0.92	$0.50	$0.58
Year 10	$0.62	$0.71	$1.01	$0.56	$0.64
Year 11	$0.57	$0.65	$0.93	$0.51	$0.59
Year 12	$0.54	$0.62	$0.88	$0.48	$0.56

Source: DASH, Peer Agency

7.5.3 Tire Costs

Tire replacement costs are provided in Table 24. Tire costs for BEBs are higher than for diesel vehicles as BEBs weigh more, leading to a higher frequency of replacement.

Table 24. DASH – Vehicle Tire Replacement Costs for ZEV Transition Plan and No Build Scenario (2022 $/mile)

	BEB 35'	BEB 40'	BEB 60'	DSL 35'	DSL 40'
Tires ($/mi)[9]	0.072	0.074	0.112	0.065	0.065

Source: Peer Agency

7.5.4 Training Costs

Total incremental and ongoing training costs for maintenance staff, first responders, and operators are documented as O&M costs.

Initial maintenance staff training costs assume 0.62 FTEs based on current Bus Maintenance staffing, with 121 hours of training assumed per full-time equivalent (FTE). Ongoing training costs assume the same 0.62 FTEs will need to be trained approximately 30 hours per year over the assumed life of the vehicles, aside from original equipment manufacturer (OEM)-provided training that will be included with DASH's procurements of BEBs.

Initial first responder staff training costs assume an average of 0.05 FTEs based on a single point of contact and oversight, with eight hours of initial training. Ongoing training costs assume the same single FTE will need to be trained approximately 2 hours per year over the assumed life of the vehicles.

Initial operator staff training costs assume an average of 1.2 FTEs per bus based on operations staffing levels at peer agencies, with nine hours of initial training. Ongoing training costs assume the same staffing levels as initial training and that they will need approximately one hour of training per year, per FTE, over the assumed life of the vehicles.

7.6 Operational Costs

7.6.1 Fuel and Energy Costs

Fuel costs are based on average 2022 prices through June, escalated using the EIA 2022 Annual Energy Outlook Reference Case Scenario price forecast. The EIA price forecast is referenced as annual percent increases which are applied to the 2022 price baseline. Prices for electric vehicles are based on Dominion utility and EIA's five-year historical utility rates. **Error! Reference source not found.** summarizes the energy cost assumptions. Demand charges are rounded to the nearest thousands.

[9] Tire replacement costs are based on peer agency provided costs for BEBs. The higher costs for BEB can be primarily attributed to the higher weight of the vehicle and changes in operator behavior primarily related to braking.

Table 25. DASH – Fuel/Energy Cost per Bus (2022 $ Values)

Measure	Electricity			Diesel	
Fuel/Energy Cost	$0.0046/kWh			$4.44/gal[10]	
Demand Charges ($/kW)	$26.50			N/A	
Vehicle Type	35’	40’	60’	35’	40’
Vehicle Fuel Efficiency Diesel Equivalent (MPGDE)	17.48	17.48	11.35	5.14	4.50
Vehicle Fuel Efficiency (kWh/mi)	2.3	2.3	2.7	-	-
Average Annual Miles	25,421	22,767	22,767	26,808	23,072
Total Fuel/Energy Costs per Year per Bus	$5,355	$5,327	$5,369	$23,157	$22,764
Fuel/Energy Costs per Year per Bus per Mile	$0.21	$0.23	$0.24	$0.86	$0.99

Source: DASH, Dominion Energy Provider, and US EIA Escalation

7.7 Disposal Cost

It is assumed that at the end of the vehicle life, DASH will sell the vehicle. Vehicle sales pricing is assumed to be $5,000 per vehicle as any sales above that value must be returned to FTA.

7.8 Environmental Non-Cash Costs

Environmental costs consist of direct vehicle emissions, upstream emissions, and noise. The analysis converts these non-monetized values to cash costs using monetization factors shown in Table 25. The environmental costs are measured in dollars per mile and the total cost calculations are driven by vehicle annual mileage. Total emissions values are calculated for each bus fleet per year, converted from grams to metric tons, assuming 1.1015 short tons per metric ton, and multiplied by monetized emissions values. Monetized emissions values are sourced from USDOT benefit-cost analysis guidance as of March 2022 for all emissions with the exception of volatile organic compounds, which is not available through USDOT and sourced from the California Department of Transportation benefit-cost analysis tool. Table 25 provides monetized emissions values for 2022, and future years 2030 and 2040.

[10] 2022 existing value based on January 2022 MSE901 rates and quantities of $2.02 per gallon, adjusted for diesel prices through August from EIA compared to EIA January 2022 prices, which resulted in a 1.33 multiplier for 2022 average prices.

Table 25. Monetization Factors for Emissions (YOE $ per metric ton)

Emission	2022	2030	2040
Nitrogen Oxides (NO_x)	$16,811	$20,483	$26,220
Sulfur Oxides (SO_x)	$45,007	$54,837	$70,196
PM-10	$177,202	$215,903	$276,374
Volatile Organic Compounds (VOC)	$1,506	$1,834	$2,348
PM2.5	$810,342	$987,324	$1,263,858
GHG (CO_2 equivalent)	$59	$84	$126

Source: All values except VOC - USDOT BCA Guidance March 2022 (Revised) Escalated to 2022 dollars using BEA GDP and escalated by 2.5% in future year. VOC derived from Cal Trans BCA Model Assumptions - McCubbin and Delucchi, 2021.

7.8.1 Upstream Emissions

Table 26 provides the lifecycle GHG emissions based on current diesel production and energy sourced from Dominion grid source.

Table 26. DASH – Upstream GHG Emissions (g/VMT)

Emission	BEB 35'	BEB 40'	BEB 60'	DSL 35'	DSL 40'
GHG (CO_2 equivalent)	379	433	600	2,730	2,730

Source: Diesel Based on EPA Factors and BEB based on Dominion

7.8.2 Vehicle Emissions

The analysis applies the average annual mileage and the tailpipe and greenhouse gas emissions of grams of CO_2 equivalent per millijoule per mile to estimate the lifecycle emissions in the ZEV Transition Plan and No Build Scenarios. Table 27 outlines the vehicle emissions in grams per vehicle mile traveled (VMT) (g/mi) calculated by the AFLEET analysis and by the EPA MOVES 2014b model. In the case of BEBs, fine particulate matter ($PM_{2.5}$) and coarse particulate matter (PM-10) emissions are attributed to tire and brake wear.

Table 27. DASH – Vehicle Tailpipe/Pollutants Emissions (g/VMT)

Emission	BEB 35'	BEB 40'	BEB 60'	DSL 35'	DSL 40'
GHG (CO_2 equivalent)	-	-	-	1.52	1.52
Nitrogen Oxides (NO_x)	-	-	-	2.58	2.58
Sulfur Oxides (SO_x)	-	-	-	0.02	0.02
PM-10	0.11	0.11	0.11	0.20	0.20
Volatile Organic Compounds (VOC)	-	-	-	0.50	0.50

Emission	BEB 35’	BEB 40’	BEB 60’	DSL 35’	DSL 40’
$PM_{2.5}$	0.01	0.01	0.01	0.03	0.03

Source: AFLEET Analysis and EPA MOVES 2014 Model

7.8.3 Noise

Table 28 provides noise emissions costs sourced from Altoona testing.

Table 28. DASH – Noise Cost (2022 $/VMT)

Emission	BEB 35’	BEB 40’	BEB 60’	DSL 35’	DSL 40’
Noise	0.046	0.049	0.074	0.067	0.067

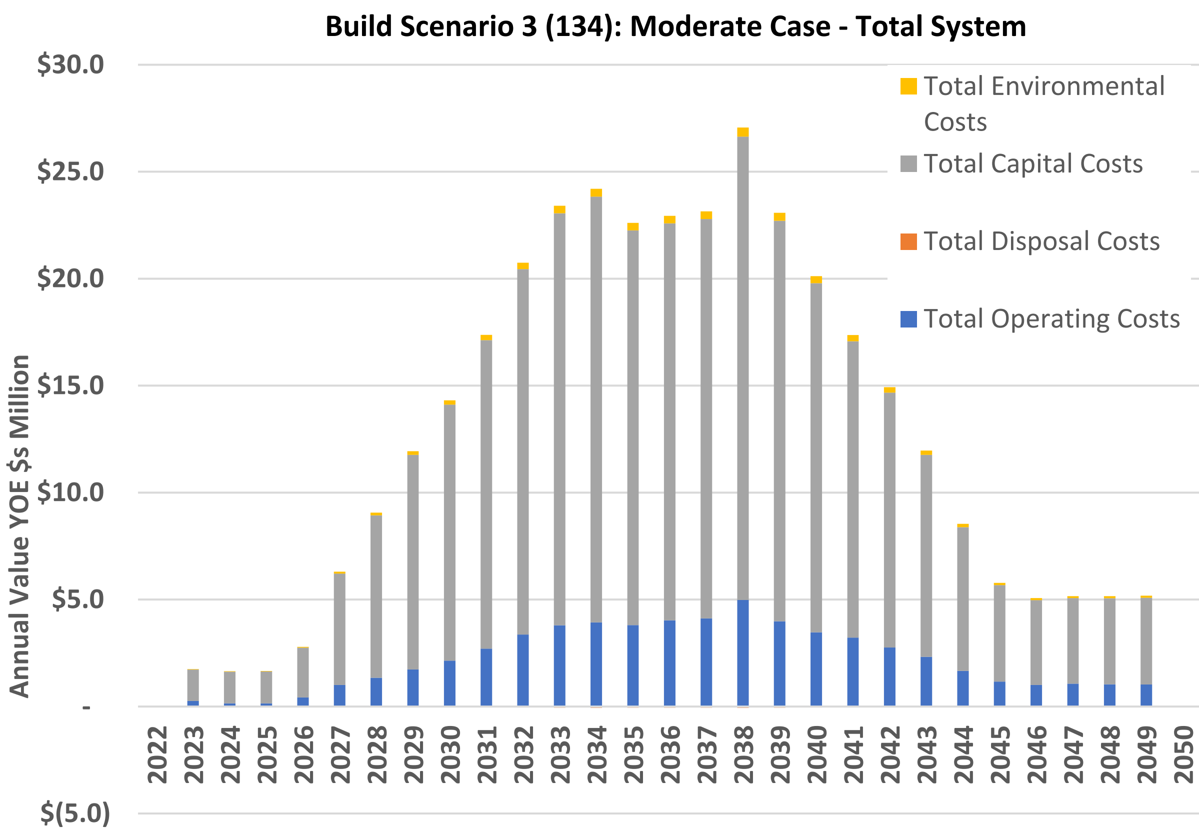
Source: Altoona Testing

7.9 Lifecycle Cost Results

7.9.1 Annualized Costs

Lifecycle cost analysis is provided for the conditions outlined in this section. Figure 16 provides the annual costs for the three primary cash cost categories and environmental costs under the ZEB Transition Plan. Disposal costs of the buses are negligible in comparison to the primary cost projections.

Figure 16. Cost Drivers ZEB Transition Plan*



Source: WSP
*Disposal costs are negative

The full lifecycle cash cost of a transition to BEBs is $141 million higher than the continued reliance on diesel engines. While the initial capital and maintenance costs are higher for ZEVs, there are opportunities for some savings in fuel costs. Additionally, maintenance cost benefits are highly dependent on factors that are continually evolving as battery-electric buses are further deployed in transit services. As depicted in Table 29, the analysis also shows that the No Build Scenario would result in a large amount of emissions generated over the lifecycle of diesel operations in comparison to the ZEV Transition Scenario. The difference in vehicle emissions between the two replacement scenarios was expected, as the technology in the BEBs is aimed to reduce GHG emissions, particularly for carbon emissions. Table 29 shows the overall estimated cash and non-cash costs in YOE$ for the system.

Table 29. Summary Lifecycle Costs for ZEV Transition Plan Scenario (YOE in Millions)

Cost Category/Variable		No Build	ZEB Transition	Incremental Expenses
Capital	Vehicle Purchase Price	$98	$178	$80

Cost Category/Variable		No Build	ZEB Transition	Incremental Expenses
	Modifications & Contingency	$13	$28	$15
	Charging/Fueling Infrastructure	$1	$41	$40
	Vehicle Mid-Life Overhaul	$11	$40	$30
	Total Capital Costs	*$122*	*$287*	*$165*
Maintenance	Vehicle Maintenance	$27	$30	$3
	Vehicle Tires	$3	$4	$1
	Charging/Fueling Infrastructure	$10	$7	-$2
	Training Costs	$1	$12	$11
	Total Maintenance Costs	*$40*	*$53*	*$13*
Operational	Vehicle Fuel/Energy Costs	$44	$7	-$37
	Total Operational Costs	*$44*	*$7*	*-$37*
Disposal	Battery Disposal	$0	$0	$0
	Bus Disposal	-$1	-$1	$0
	Total Disposal Costs	*-$1*	*-$1*	*$0*
Total Cash Costs		***$206***	***$347***	***$141***
Comparison to Base	*Dollars*	$0	$141	*$141*
	Percent	-	68%	*68%*
Total Cash Cost per Mile		***$6***	***$9***	***$3***
Environmental	Emissions - Tailpipe	$5	$1	-$4
	Emissions - Refining/Utility	$10	$2	-$8
	Noise	$3	$3	-$1
	Total Environmental Costs	*$18*	*$6*	*-$13*
Total Cash and Non-Cash Costs		***$224***	***$352***	***$128***
Comparison to Base	Dollars	$0	$128	$128
	Percent	-	57%	57%
Total Cash and Non-Cash Costs per Mile		***$7***	***$9***	***$3***
Total Mileage (million miles)		***34***	***37***	***3***

Source: WSP

7.9.2 Cost Risks and Opportunities

A transition to alternative fuels and ZEBs, including the introduction of a major change to capital infrastructure and operating procedures, entails some level of risk. The Lifecycle Cost Analysis identifies the cost implications of a transition to BEB technology using generally conservative assumptions on anticipated capital expenditures and vehicle operating costs relative to existing technology. The identification of potential risks—for both a transition to BEBs—along with an identification of potential risks if a transit agency does not elect to transition to alternative fuel/ZEBs is designed to further help DASH in determining a path forward.

Risks are identified to help inform decision-makers with the various issues that are associated with the technology including reliability, cost, and safety, but also in terms of the political and public considerations that come with a major expenditure of public dollars. Risks involve buses, charging and fueling infrastructure, facilities and maintenance, fuel and power supply, and funding.

- Although new federal programs are designed to expand BEB technology, and availability, high demand for BEBs has the potential to slow delivery of BEBs and associated parts and infrastructure which could result in increased costs over what is assumed for vehicle purchase and operations.
- Relative newness of BEB technology and ongoing improvements may render components or buses obsolete, increasing the cost of spare parts inventory and staff training as well as potential requirements to replace initial capital investments.
- Insurers may increase rates due to the publicity on the volatility of batteries.
- Manufacturer assistance or warranty services may be delayed or in some cases removed, such as the current trend on removing extended 12-year battery warranties which were offered as extensions of standard 6-year battery warranties.
- Charging, maintaining, and operating BEBs requires significant and on-going training, resulting in increased costs; agency reliance on manufacturer for training may cause delays and erosion of quality of training; employee turnover can also impact training costs and effectiveness.
- Battery disposal costs are largely unknown due to the relatively limited experience with disposing of large scale BEB batteries. While the assumption is that most of the components can be recycled helping to offset or more than offset the cost of disposal, that may not materialize based on market conditions and changes in technology.
- BEB maintenance costs continue to be higher than conventional diesel technology. Similar to continued higher diesel-hybrid maintenance costs, there is a potential that BEB maintenance may not decrease over time and maintain a significant premium over conventional technology.
- Value of environmental benefits, specifically emissions and noise, may be partially or fully offset by the environmental costs attributed to battery and component production and disposal, and unregulated manufacturing plants that often release harmful organic electrolytes and requires high energy consumption.

Opportunities are identified to help inform decision-makers with the additional benefits that may be realized with the technology including eventual cost savings, resiliency, and reduced exposure to volatility in market prices.

- The transition to an electric engine from a diesel engine should result in lower bus maintenance costs, similar to what is generally the experience with the transition to EV passenger vehicles from gasoline engines. While lower costs have not been fully realized in initial deployments of BEBs, primarily due to the reliability of the vehicles, with further advancements in the design, production, and technology there is anticipation that costs will eventually match, if not provide a discount, to diesel buses.

- Significant volatility in diesel prices resulting from global conflicts, refinery outages, and reliability and capacity limitations of the primary pipelines supplying the Washington DC metro area, are anticipated to increase over time with further aging of critical assets and potential downturn in demand and production with transition of the general U.S. vehicle fleet to zero emissions technology. By comparison utility rates are strongly regulated and tend to be fixed for longer durations reducing volatility in pricing.
- In addition to reduced exposure to diesel price fluctuations the utility grid tends to be resilient with opportunities to maintain backup generators in the event of a significant power outage and supplement grid sourced energy with on-site photovoltaic production. By comparison refinery or pipeline outages tend to be longer durations with higher costs associated to resiliency strategies including sourcing from other markets and increases in localized market prices.
- Similar to California, Oregon, and Washington, other markets in the U.S., or the federal government, may start to implement carbon pricing systems that will increase the cost of procuring diesel. Often revenue generated by carbon tax or credit system is available as a cost offset to zero-emissions fuels, further reducing the fueling/charging cost differential between BEBs and conventional fuel vehicles.
- Current federal and state programs are helping to offset the capital costs for making the transition to zero emissions technology, including grants and credits for vehicles and charging infrastructure. While there is a risk that funding may be reduced or removed through future legislative action, there may also be increased opportunities if existing programs receive increases in funding or additional programs are implemented.

7.10 Recommendations and Conclusions

The transition to ZEBs is currently anticipated to increase overall capital and maintenance costs compared to existing technology. Higher purchase price of vehicles, and equipment and infrastructure and higher maintenance and employee training costs for ZEBs are expected to respectively drive the increased capital and maintenance costs for the transition of DASH's fleet to ZEBs. Table 30 shows the overall costs in the existing No Build scenario and the total costs in the ZEB Transition Build scenario.

Table 30: Total Costs in No Build and ZEB Transition Scenarios (in millions of YOE $s)

Cost Category/ Variable	No Build	ZEB Transition	Incremental Expenses
Total Capital Costs	$122	$287	$165

Total Maintenance Costs	$40	$53	$13
Total Operational Costs	$44	$7	-$37
Total Disposal Costs	-$1	-$1	$0
Total Cash Costs	$206	$347	$141
Total Cash Cost per Mile	$6	$9	$3
Total Environmental/Non-Cash Costs	$18	$6	-$13
Total Cash and Non-Cash Costs	$224	$352	$128
Total Cash and Non-Cash Costs per Mile	$7	$9	$3

With limited experience in BEB production for the legacy OEMs, and new ZEB focused OEMs, there will likely be continued operational issues for both charging infrastructure and vehicles. Primary issues to date with initial vehicle and infrastructure deployments have largely been addressed through warranty coverage and additional OEM support. As the technology is still relatively nascent purchasing available warranties and extended warranty options is recommended to avoid unexpected costs that may be realized with additional operations of the vehicles and infrastructure.

Beyond enhanced warranty coverage DASH should continue to monitor their experience with initial vehicle deployments and coordinate with other agencies to learn from their experiences with similar or alternative technologies and OEMs. Interoperability capabilities of charging infrastructure and charge management solutions will be instrumental in allowing for DASH to introduce and evaluate alternative equipment with future deployments. Interoperability and industry standards should be considered during initial procurements with anticipation of further fleet transition to ZEBs.

With continued expansion of DASHs ZEB fleet there will be increasing reliance on utilities such as Dominion Energy for power supply and exposure to utility rates. DASH should continue to coordinate with Dominion on optimizing load use and prioritizing off-peak rates, or help define EV specific tariffs for public entities, to help stabilize or lower the cost of electricity for DASH.

The cost of transitioning to ZEVs is anticipated to increase in terms of both capital and operational expenditures in comparison to existing diesel technology. With continued advancements in ZEV technology, additional design and operational experience and expansion of production resulting in economies of scale there should be a trend towards lower costs in the future. DASH will need to continue to evaluate technology options and monitor transition costs for future vehicle replacements. Lifecycle cost analysis should be refined as operational information is available from initial deployments including sensitivity tests on market conditions, including capital and operating costs, cost escalation, and battery and vehicle disposal.

8 Recommendations and Conclusion

This section provides overall next steps for DASH to successfully transition to a 134-vehicle ZE fleet. These recommendations are based on the main takeaways and suggestions outlined in chapters 2 to 7.

8.1 Chapter 2: Current ZEB Fleet Analysis

- At least some of the relative energy savings in Proterra's 42-foot buses versus the 40-foot New Flyer buses derive from the Proterra bus design. The lower bus weight would be expected to result in lower energy use. The project team recommends that DASH continue monitoring energy usage for all subfleets and repeat the analysis after Proterra buses conclude their third year of revenue service.
- Data inconsistencies limited the project team's ability to compare performance across all bus types. The energy usage analysis was focused on the period from November 2021 to June 2022. As more data becomes available, DASH should explore further analyses.

8.2 Chapter 3: Full Fleet Assessment

- DASH should not receive any BEBs before the necessary facilities have charging infrastructure to support them, and existing vehicles should not be replaced until they reach their useful life retirement age.
- Based on workshop discussion, the project team recommends that DASH select Preliminary Scenario 2 and increase its fleet to 134 vehicles, maximum UFL at 12 years, transition by FY 2027.
- It is recommended to maximize dispenser utilization by charging during the day as buses return to the facility, and rotating buses in and out of charging positions throughout the night.
- Assuming that DASH is limited to 46 charging positions for its full fleet, WSP recommends DASH to plan for manual repositioning of buses for charging and evaluate the state of automated solution technology in FY 2027.
- As the DASH BEB fleet expands, it is recommended DASH continue to track vehicle performance and emissions reductions through a validation reporting/KPI program.

8.3 Chapter 4: Energy Assessment

- Overall, in the Typical Winter scenario, 79% of DASH's service is estimated to be achievable by BEBs if the system is operated by only 35-foot buses.
- If DASH were to operate the system with only 40-foot buses, 94% of the service would be achievable by BEBs under the Typical Winter scenario.
- BEB technology will improve over time and has the potential to be able to complete the entirety of DASH's service as currently structured.

- DASH should examine the longer blocks that make up its current service structure and failed the block completion analysis. DASH may wish to collect data on the dwell times and dwell locations of vehicles service these blocks to explore opportunities for opportunity charging during service or consider shortening existing blocks to allow for midday charging of buses at the garage.

8.4 Chapter 5: Utility Grid Assessment

- The existing electrical service and infrastructure will not be able to support the new anticipated loads for the BEB charging equipment, therefore DASH will need to request new medium voltage service from Dominion Energy consisting of at least one feeder. The project team recommends requesting two new feeders for improved resiliency due to limited space onsite.
- In case DASH wants to increase the number of chargers, the project team suggests installing new bays in the MV switchgear and increasing their service in subsequent years.
- With a 6 MW service, DASH can accommodate a total of 36 chargers and 72 dispensers. If DASH's charging infrastructure is limited to 48 dispensers starting in FY 2029, DASH will face operational challenges, as the planned number of BEBs in that year is 64, meaning that certain buses will need to be shifted in order that they be charged fully prior to service. The number of BEBs is planned to increase continually after that time, compounding the challenge.
- The plans and single line diagrams provided by WSP are preliminary engineering level only and not suitable for construction, bid, or permit. It is recommended for the engineer of record to perform detailed design, determining system details; to coordinate new primary service with Dominion Energy and finalize the service application process prior to construction.

8.5 Chapter 6: Maintenance Assessment

- DASH should plan to provide refresher training with every new purchase so its mechanics can continue to efficiently troubleshoot and repair any issues related to charging infrastructure without relying on the OEM.
- Prior to every new purchase, DASH should look for a BEB OEM that can effectively provide basic BEB training for operations and maintenance staff and first responders.
- It is recommended for DASH to request an OEM field support mechanic for the first year of service of the new vehicles with every new purchase. DASH should request this service as a separate line item in every procurement with a one-year timeline, as well as a one-year option to be exercised at the request of DASH if needed.
- It is recommended that DASH assess current and future operations requirements and depot conditions to determine if integration of a new charging system will best meet its needs.
- Operational costs related to implementation of charge management strategies, utility upgrades, and battery storage can be reduced through

strategic partnerships. It is recommended to develop key partnerships with the local utility company and bus OEMs.
- Workforce shortage can be addressed through strategic partnerships as well. DASH should look into lessons learned from peer transit agencies to develop partnerships with local educational institutions.

8.6 Chapter 7: Total Cost of Ownership

- The total cash cost of ownership for a fully-BEB fleet is $347 million in YOE dollars, which includes $287 million for capital costs, $61 million for maintenance and operating costs, and income of $1 million for disposal value.
- The total non-cash cost savings from emissions due to DASH's fleet transition to ZEVs has been estimated to be around $13 million in YOE dollars. The environmental cost of the No Build scenario is estimated to be $18 million whereas that of the ZEV Transition scenario is estimated to be $6 million.
- The full lifecycle cash cost of a transition to BEBs is $141 million higher than the continued reliance on diesel engines. While the initial capital and maintenance costs are higher for ZEVs, there are opportunities for savings in fuel costs. Moreover, as mentioned above, the transition to ZEVs is estimated to result in significant emissions reduction or environmental cost reduction equivalent to a monetized benefit of $13 million in YOE dollars.
- As the technology is still relatively nascent, purchasing available warranties and extended warranty options is recommended to avoid unexpected costs that may be realized with additional operations of the vehicles and infrastructure.
- DASH should continue to monitor their experience with initial vehicle deployments and reach out to peer agencies to learn about their experiences with similar or alternative technologies and OEMs.
- Interoperability capabilities of charging infrastructure and charge management solutions will be instrumental in allowing for DASH to introduce and evaluate alternative equipment with future deployments. Interoperability and industry standards should be considered during initial procurements with anticipation of further fleet transition to ZEBs.
- DASH should continue to coordinate with Dominion on optimizing load use and prioritizing off-peak rates, or help define EV specific tariffs for public entities, to help stabilize or lower the cost of electricity for DASH.

8.7 DASH ZE Transition Timeline

The following timeline provides key fleet, infrastructure, and utilities milestones, with recommended charging capacity.

Table 31. ZE Transition Timeline

Fiscal Year	FY2024	FY2025	FY2026	FY2027	FY2028	FY2029	FY2030	FY2031	FY2032	FY2033	FY2034	FY2035	FY2036	FY2037	FY2038	FY2039	FY2040	FY2041
BEB Vehicle Delivery	5	17	14	14	11	14	15	12	3	8	0	0	26	17	14	14	11	14
Total BEBs	14	14	19	36	50	64	75	89	104	113	113	113	113	113	134	134	134	134
Planned Chargers	6	6	9	18	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Recommended Chargers	6	6	9	18	24	25	31	36	52	57	57	57	57	57	67	67	67	67
Planned Dispensers	12	12	18	36	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Recommended Dispensers	12	12	18	36	48	50	62	72	104	113	113	113	113	113	134	134	134	134
Milestones	Final ICEB procured	Facility expansion				DASH to determine if additional chargers are required or increase yard shifters									100% ZE fleet			