PLANNING DEPLOYMENT OF ZERO-EMISSION BUS FOR WILLIAMSBURG AREA TRANSIT AUTHORITY (WATA)

OCTOBER 2022

the heartbeat of HAMPTON ROADS TPO
Transportation Planning Organization

T22-08

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ABSTRACT
Zero-Emission Bus (ZEB) deployment is one approach to decarbonizing the transportation sector and reducing air pollution. This report reviews: the ZEB deployments in Virginia, WATA's existing conditions, capital costs and funding, battery-electric bus technology, training, route assignment and future considerations. Finally, the report outlines the HRTPO staff's recommendations for WATA's first ZEB deployment and additional deployments.

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Prepared by:

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TRANSPORTATION PLANNING ORGANIZATION

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INTRODUCTION

In the United States in 2020, the transportation sector was responsible for 27% of the greenhouse gas (GHG) emissions (US EPA, 2020). Moreover, more than 25% of transportation-related emissions came from the medium and heavy-duty vehicle markets (US EPA, 2020). Alternative fuels such as compressed natural gas (CNG) and liquid natural gas (LNG) were one of the approaches to addressing urban air quality degradation until the emergence of electric powertrain configuration. In "partial" mode, the vehicle would have some tailpipe emissions, while in "full-electric" mode, the vehicle would have no emissions. Deploying zero-emission transit buses (ZEBs) is one approach to decarbonizing the transportation sector and reducing air pollution. By electrifying transportation, a portion of energy demands shifts from petroleum products traded in the global market to local electricity generation, which is much less likely to depend on petroleum fuels. This shift reduces domestic dependence on the oil market and lowers exposure to the risks of oil volatility (Bordoff, 2019).

The Williamsburg Area Transit Authority (WATA) is interested in procuring one zero-emission bus as a pilot project, thus obtaining real-world experience with ZEBs before deciding how to pursue decarbonization and reducing GHG in their transportation sector in the long run.

The purpose of this study is to assist WATA in the deployment of Zero Emission Bus.

WATA currently provides public transportation services to James City County, the City of Williamsburg, the Bruton District of York County, the College of William and Mary, and the Colonial Williamsburg Foundation. Furthermore, a route extends to Newport News (Gray Line to Lee Hall) to connect with Hampton Roads Transit (HRT), and a route extends to Surry County via Jamestown-Scotland Ferry.

This report is organized as follows:

- Review of ZEB deployments in Virginia – summarizes experience and recommendations from Virginia transit agencies who deployed ZEBs.
- Existing conditions – reviews service area and fleet characteristics.
- Capital costs and funding – outlines funding opportunities that WATA could pursue for future ZEB purchases and costs associated with ZEB technology.
- Battery electric bus technology description – explores the components of this technology:
    - Bus itself
    - Battery system
    - Charging infrastructure
- Training – reviews best practices and recommendations for training on concepts and details of ZEB technology.
- Route assignment – assesses factors affecting route choice and outlines analysis conducted to determine the best route for Battery Electric Bus (BEB).

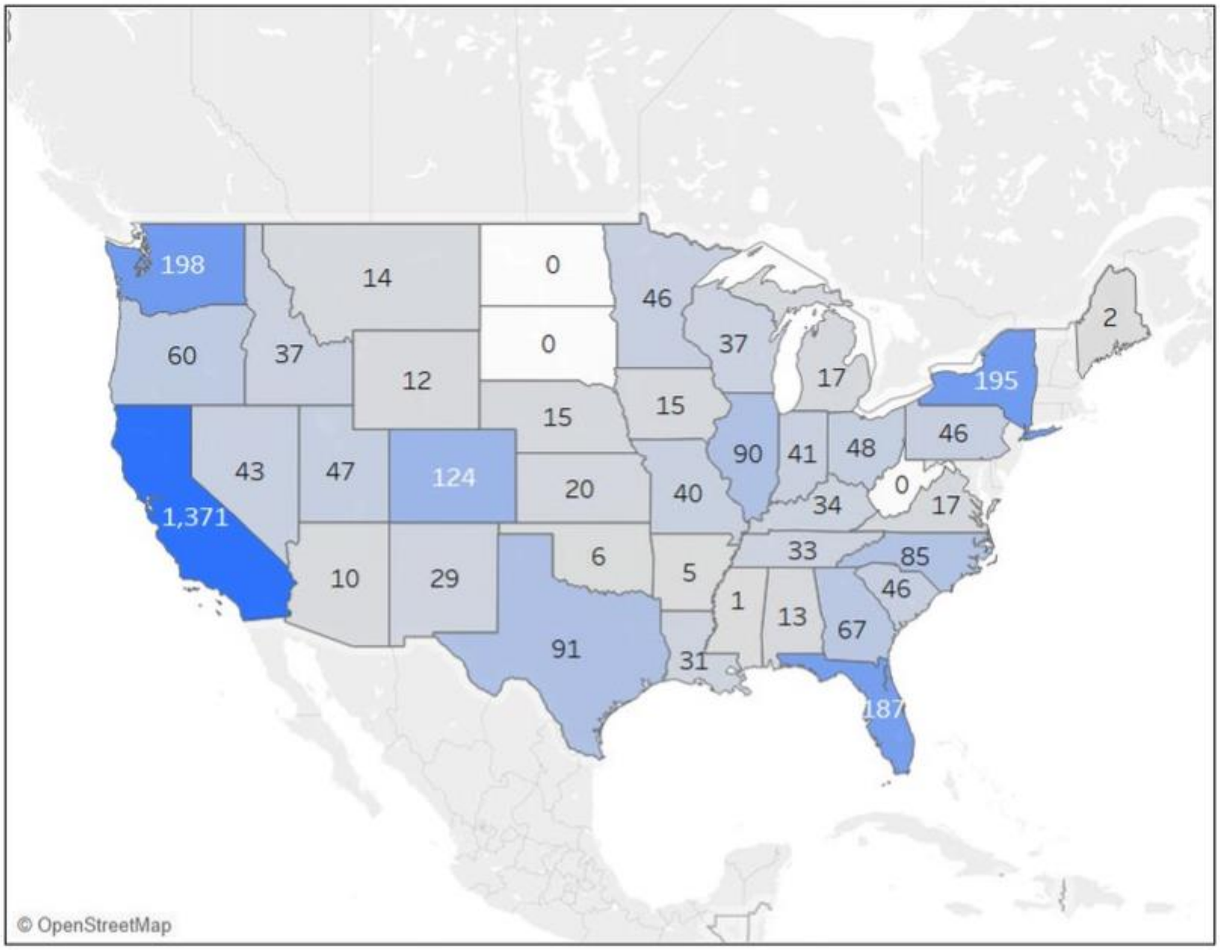
- Future considerations – indicates acceptance and validation testing, inspection, deployment and data monitoring and evaluation.
- Conclusion – provides a summary of the report and bulleted recommendations for WATA's first BEB deployment.

REVIEW OF ZEB DEPLOYMENTS IN VIRGINIA AND US

Two early BEB studies—the Center for Urban Transportation Research's "Realizing Electric Bus Deployment for Transit Service" (1998) and the Federal Transit Administration's "Analysis of Electric Drive Technologies for Transit Applications: battery-electric, hybrid-electric, and fuel cells," (2005)—provide information about early BEB experience. The first study indicates that electric buses can significantly positively impact the environment. The maintenance and driver training must be delivered timely to be effective, and trouble-shooting instructions must be direct and consistent. Moreover, the study asserts that the battery was the weak link at the time. Following specific charging procedures may eliminate most of the problems associated with the battery. A general lack of working experience for all stakeholders involved (transit agency, utility providers, consulting agency) is the major cause of the problems encountered. "There may never be a future for big electric buses because of their power requirements, but it could work well for the smaller ones" (Lisa, 2005).

The first BEB program in the Hampton Roads region was the Norfolk Electric Transit program (NET), introduced in the late 1990s as a free circulator in Downtown Norfolk. The electric vehicles for the service were purchased with a federal grant. The vehicles caused maintenance and operating challenges for HRT from the start. The technology required swapping out the chassis of the batteries every few hours. Luckily, the route was close to HRT's maintenance headquarters in Norfolk (18th Street and Monticello Avenue) since the vehicles had to return several times during the day for the swap. The introduction of light rail through Downtown Norfolk in 2011 led to the ending of the NET shuttle. BEB technology has evolved significantly, judging by the number of BEB models available and the number of BEB deployments. Transit agencies' experience with the technology has grown exponentially since these two studies and the NET program.

ZEBs nationally have grown by 24% (from 2,790 to 3,533 vehicles) from 2020 to 2021 (Hannah Hamilton, 2021). The West Coast (Washington State, California, Oregon) has the most buses, with well over a third of all ZEBs in the U.S. deployed in that region alone. Deployed ZEBs have increased by 78% (565 vehicles) from 2020 to 2021 (Hannah Hamilton, 2021). Map 1 provides a breakdown of the number of ZEBs by state across the U.S.



Map 1 Transit ZEBs funded, ordered, delivered or deployed within the United States (updated September 2021)
Source: Hannah Hamilton, 2021

The oldest implementation of ZEB is 1991 for Santa Barbara BEBs. Table 1 presents a timeline of Battery Electric Buses across the U.S. transit agencies.

Table 1 Timeline of BEB fleet across the U.S.
Source: HRTPO analysis of data, 2022

Agency	Buses	Deployed since
Antelope Valley Transit Authority (CA)	41	2014
Capital District Transportation Authority (NY)	1	2016
Central Contra Costa Transit Authority (CA)	8	2016
Chicago Transit Authority (IL)	6	2014
Clemson Area Transit (SC)	10	2014
Dallas Area Rapid Transit (TX)	7	2015
Foothill Transit (CA)	31	2010
Indianapolis Public Transportation Corporation (IN)	21	2013
King County Metro (WA)	84	2017
Lexington-Fayette Urban County (KY)	6	2015
Los Angeles County Transportation Authority (CA)	5	2017
Pioneer Valley Transit Authority (MA)	3	2017
Regional Transportation Commission Washoe (NV)	4	2010
Santa Barbara MTD (CA)	30	2002
Shreveport Area Transit (LA)	5	2017
Southern Pennsylvania Transportation Authority (PA)	25	2015
Springfield Area Transit Company (MA)	3	2016
Star Metro Transit (FL)	6	2010
Stanford University (CA)	39	2010
University of California Los Angeles (CA)	2	2016
Utah Transit Authority (UT)	6	2015
VIA Metropolitan Transit (TX)	3	2017
Washington Metropolitan Area Transit Authority (DC)	1	2015
Worcester Regional Transit Authority (MA)	7	2017

An agency can obtain real-world experience by taking advantage of bus demonstrations on their local routes and planning one or more pilot programs using relatively small bus deployments to gain experience in operating these buses.

All transit agencies that deployed ZEBs experienced challenges in implementing the new technology. Most agencies encountered more issues than expected at the initial deployment, including bus components, such as doors and the wheelchair lift.

According to the Virginia Department of Rail and Public Transportation (DRPT), there are 2,168 transit buses in Virginia (DRPT, 2022):

- Diesel Buses (53%)
- Gasoline (32%)
- Compressed Natural Gas (CNG) (13%)
- Battery Electric (1%)
- Other (1%)

This section delves into the feedback for WATA based on ZEB deployments at the following transit agencies:

- WMATA (Washington Metropolitan Area Transit Authority)
- Jaunt
- Blacksburg Transit (BT)
- DASH (Alexandria Transit Company)
- Hampton Roads Transit (HRT)

The Washington Metropolitan Area Transit Authority is a tri-jurisdictional government transit agency that serves the Washington Metropolitan Area. In June 2021, the WMATA unanimously approved a new Sustainability Vision and Guiding Principles and established new goals for transitioning the Metrobus fleet to zero-emission vehicles.

From WMATA's experience, WATA should initiate an internal opportunities analysis to assess BEB technology, service, infrastructure requirements, and costs for the first BEB deployment. HRTPO and WATA staff are already applying this by doing this study.

From WMATA's experience, for 2^{nd}+ BEB deployment WATA should:

- Conduct further research and feasibility study
- Adopt clear goals to transition its fleet to zero-emission

For every BEB deployment, from WMATA's experience, WATA should:

- Revise fleet management plan to take into account BEB deployment.
- Launch a BEB test and evaluation procedure
- Establish ongoing engagement with regional utilities, other transit agencies, and stakeholders to identify opportunities. HRTPO staff contacted HRT to obtain more experience with BEB deployment.

Jaunt is a transit agency providing curb-to-curb demand response service in Albemarle County, Buckingham County, Charlottesville, Fluvanna County, Green County, Louisa County and Nelson County. Since January 2020, Jaunt has been operating one electric Ford Transit 350 HD passenger van, which is fully accessible and can accommodate ten passengers and two wheelchairs. On a single charge, it can travel up to 120 miles. Jaunt paid $185,000 for the van (approximately $140,000 more than its gasoline-powered equivalent). However, operational costs are 0.08 cents/mile compared to 0.15 cents/mile for the gasoline counterpart (Entzminger, 2020). Additionally, it will produce fewer emissions, which is a step towards Jaunt being fully decarbonized by 2050. Jaunt plans to convert six more of its 78 on-demand transit vehicles, and by 2030, Jaunt hopes that most of its fleet will run on electricity. From Jaunt's experience, WATA can see a higher upfront cost of the electric vehicle. However, this higher cost is offset by savings in operational costs.

Blacksburg Transit (B.T.) is the public transportation provider for Blacksburg, Virginia Tech, Christiansburg, and Montgomery County in southwest Virginia. The services include:

- Fixed routes
- Demand response
- Event shuttles

- Community events shuttles

B.T. launched five battery-electric buses in April 2021 that replaced five conventional diesel-powered buses. Per B.T. director Tom Fox, "our goal is that half of the entire fleet will be electric in three to four years, and we will be 100% electric in about ten years, depending on funding. This launch is a large step towards reducing our carbon footprint while also reducing our dependence on fossil fuels" (Blacksburg Transit, 2022). Three buses are 35-foot, and two are 60-foot buses. B.T. reported that a 35-foot BEB is about 50% more expensive than its typical diesel counterpart. However, B.T. anticipated savings of approximately $125,000 in operating and maintenance costs over the 12-year life span of an electric bus. The DRPT and the Department of Environmental Quality (DEQ) provided funding to purchase the five buses and infrastructure. DRPT provided 57% of the project funding, DEQ accounted for 41%, and Virginia Tech contributed the local matching funds of 2%. The total project cost was $6.9 million. (Blacksburg Transit, 2022). From Blacksburg Transit's experience, WATA may find, as from Jaunt's experience, a significant saving in operating and maintenance costs over the life span of a vehicle.

DASH is the city bus system for Alexandria, Virginia, operated by the Alexandria Transit Company, a non-profit service corporation owned by the City of Alexandria. As part of their overall long-term fleet policy planning, DASH has engaged the Center for Transportation and the Environment (CTE) to perform a zero-emission bus fleet feasibility and planning study (Center for Transportation and the Environment, 2019). From DASH's experience, for additional BEB deployment, WATA should conduct further research and feasibility analysis to assess current and projected route structures and estimate the capability of an electric fleet to meet those requirements, given the current technology capabilities in the industry. WATA should also consider hiring a consultant with experience in ZEB deployment studies in case of additional ZEB deployments.

Hampton Roads Transit operates six all-electric, zero-emission buses from Proterra (440 kWh of energy) on its routes. Recharging stations were installed at HRT's 18th Street maintenance shop. HRT deployed these zero-emission buses in 2020. This project was prioritized through DRPT's MERIT prioritization program and funded by various sources, including the Virginia DEQ's Clean Transportation Voucher Program, the Volkswagen Environmental Mitigation Trust, and the Federal Transit Administration Low- or No-Emission program. According to HRT, replacing a diesel bus with a BEB reduces CO_2 emissions by 230,000 pounds annually.

HRTPO staff and Zach Trogdon (executive director of WATA) met with Dan Good, Manager of Maintenance Training at HRT, to exchange BEB experience. Mr. Good showed the layout of the charging stations and electric buses and shared their experience, which can be summarized as follows:

- When procuring BEB, it is recommended that WATA pay close attention to the width of the bus. If the bus is wider, it will be easier to install a ticketing system next to the driver, making more space for the driver.
- HRT runs its buses for approximately between 3 and 4 hours, which brings the battery's charge level to 60%, after which they bring the buses back to recharge, which takes about 2-3 hours.

- Little maintenance is required, apart from lubricating the suspension system.
- HRT recommends that WATA pay close attention to the outside weather (temperature), which heavily affects the battery levels because the HVAC system runs more during colder periods.
- WATA will see the positive effect of regenerative braking on the battery charge level.
- HRT recommends that WATA order spare parts, maintenance tools, and personal protective equipment (PPE) with the bus to avoid delays in maintenance which will cause the bus to stay off the route. (PPE is for protection against power surges.)

HRTPO staff had another meeting with Sibyl Pappas (HRT's Chief Engineering and Facilities Officer) regarding HRT's experience from the planning and engineering perspective. HRT's BEBs are currently being used on Route 20, from Norfolk to Virginia Beach Oceanfront. It is the longest and busiest HRT route. Typically, round trip time takes about 60 minutes because of the high number of stops on the route. Ms. Pappas' main concern was the range discrepancy:

- Proterra's modeled range: 225 miles
- HRT's actual range: 100 miles

The discrepancy between the two values was seen in colder months. Because Route 20 has a lot of bus stops, every time the bus opens the door, the temperature decreases in the bus; thus, the power is drained to heat the bus. Moreover, drivers used the defroster excessively to heat the bus, affecting the battery. HRT will purchase auxiliary diesel heaters with the next BEB purchases for these situations. WATA could consider doing the same. Ms. Pappas shared other HRT experiences that WATA could apply, which can be summarized as follows:

- WATA could contact its utility provider to check if any upgrades are needed because of the additional power required to charge the bus overnight. In the case of HRT, Dominion Energy had to significantly upgrade the network, which took 12-14 months (before the COVID-19 pandemic). Ms. Pappas recommended that WATA account for 20% longer times for each stage of ZEB deployment because of the COVID-19 pandemic.
- WATA could explore multiple Original Equipment Manufacturers (OEMs). Proterra's buses had body issues. The bus body represents the portion of the bus that encloses the bus's occupants' space (body shells, doors, doors, hatches). Specifically, Ms. Pappas shared an experience from Philadelphia's transit agency where a bus body manufactured by Proterra experienced significant cracking.
- WATA could pay close attention to costs because they are changing more frequently than before (resulting from the current world situation and the pandemic).
- With all its preparation and planning, Ms. Pappas shared that ZEB deployment was a heavy lift for HRT as a transit agency. WATA could expect some hurdles and issues in the first couple of months of deployment (i.e., the bus did not connect to chargers). According to Ms. Pappas, WATA could expect a very steep learning curve.

WATA EXISTING CONDITIONS

To prepare for making informed recommendations, HRTPO staff explored existing conditions of the WATA transit network, mainly:

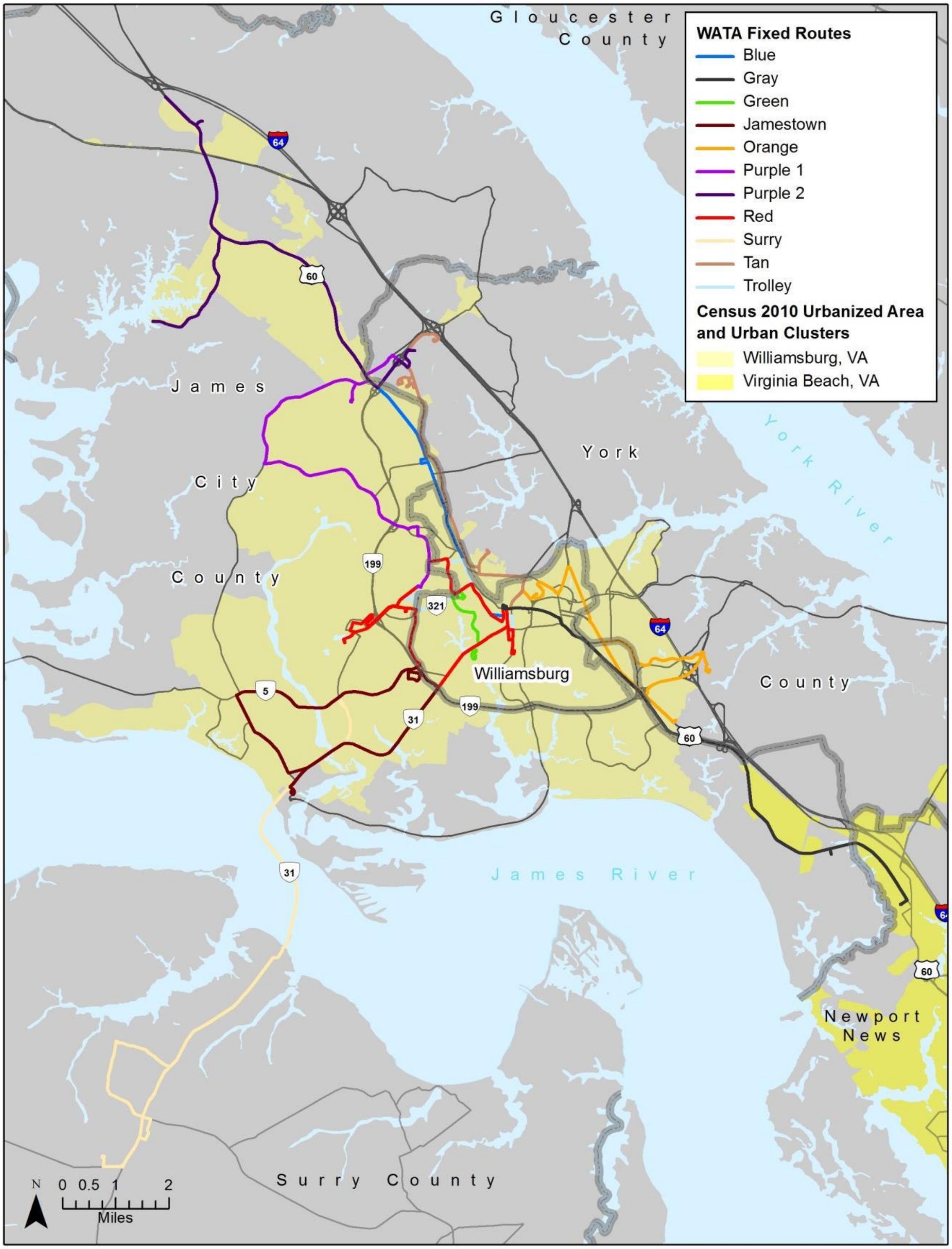
- Transit services and areas served
- Fleet

Eight routes comprise the core year-round fixed-route transit network for WATA, which operate Monday through Saturday from 6:00 am to 9:00 pm, and Sundays from 8:00 am to 6:00 pm, which is shown on Map 2 (KFH Group, 2019):

- **Blueline** – Route 60 West
- **Gray Line –** Route 60 East
- **Jamestown Line** – Colonial Parkway (at The Settlement) / N. Boundary St. (at Williamsburg Transportation Center)
- **Orange Line** – Route 143/Merrimac Trail
- **Purple 1 Line –** Longhill Road
- **Purple 2 Line –** Route 60 Far West
- **Red Line –** South Williamsburg
- **Tan Line –** Mooretown Road

Moreover, three routes within the WATA route network operate on significantly different schedules than the eight-core fixed routes and serve different markets (shown on Map 2) (KFH Group, 2019):

- **Green Line** is geared to the transportation needs of the College of William & Mary community during the fall and spring semesters. Points along the route include Ludwell Apartments, Morton Hall, Campus Center, Marshall-Wythe School of Law, Merchants Square, Sadler Center, Williamsburg and Monticello Shopping Centers, William & Mary School of Education, William & Mary Hall, Commons Dining Hall, and the parking deck adjacent to Police and Parking Services.
- **Surry Line** provides service between Surry County and the Williamsburg Transportation Center via the Scotland/Jamestown Ferry. Five daily trips connect Surry Village, Lebanon Village, Smith's Park and VDOT Park and Ride (Rt 31 and Rt 637) to Jamestown, Five Forks, and the Williamsburg Transportation Center.
- **Williamsburg Trolley** is a 30-minute counter-clockwise loop connector between New Town, the College of William & Mary, Merchants Square, Williamsburg Shopping Center and the High Street development.



Map 2 WATA Route Network
Source: KFH Group, 2019

WATA's fleet comprises vehicles operated by WATA directly and vehicles purchased through WATA and operated by its partners (Colonial Williamsburg Foundation (CWF) and York County). Directly operated vehicles include (KFH Group, 2019):

- Six 30-foot diesel buses
- Fourteen 35-foot buses
- Five body-on-chassis vehicles
- Three diesel trolleybuses
- Seven operational support vehicles

CWF vehicles that are part of the WATA vehicle fleet are (KFH Group, 2019):

- Sixteen Orion 40-foot compressed natural gas (CNG) buses
- One support vehicle

York County operates two trolleybuses that are also part of the WATA vehicle fleet.

WATA operates at 7239 Pocahontas Trail. This facility contains administrative, operations offices, and a maintenance facility (Figure 1).

Figure 1 Overview of WATA Bus Facility
Source: Google Maps

Williamsburg Transportation Center (Figure 2), located at 468 North Boundary Street in the City of Williamsburg, is the agency's main transfer hub. It is a multi-modal center served by Amtrak, Greyhound, HRT, WATA, and taxis (KFH Group, 2019).

Figure 2 Williamsburg Transportation Center
Source: HRTPO staff

CAPITAL COST AND FUNDING OPPORTUNITIES

Capital costs are one of the biggest obstacles facing the current ZEB market. For the first ZEB deployment, anticipated capital costs are related to:

- Vehicle costs
- Charging equipment and installation costs
- Electric utility upgrades
- Maintenance facility modifications

The costs will be agency-specific and based on the different configurable options of the buses, the size of deployment, required facility upgrades and fueling approach. The following funding opportunities can help offset the cost of ZEB procurement, including:

- Federal funding – the following programs are available through the Federal Transit Administration (FTA) that can help transit agencies deploy ZEBs:
    - **The Low or No (Low-No) Emission Vehicle Program** in the Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Bill (Transportation House, n.d.).
    - **Bus and Bus Facilities Program** provides funding for capital projects to replace, rehabilitate, purchase buses and construct bus-related facilities.
- State funding
    - **MERIT (Making Efficient and Responsible Investments in Transit)** is the Virginia Department of Rail and Public Transportation's (DRPT) statewide public transportation grant program. The MERIT program consists of the following individual grant programs:
        - Operating Assistance
        - Capital Assistance
        - Demonstration Project Assistance
        - Technical Assistance
        - Public Transportation Intern Program
    - **SMART SCALE –** VDOT's primary program for funding transportation projects in Virginia. It evaluates potential transportation projects based on key factors like how they improve safety, reduce congestion, increase accessibility, contribute to economic development, promote efficient land use, and affect the environment (SMART SCALE, n.d.)
    - **V.W. Mitigation Trust –** The replacement of transit vehicles is an eligible mitigation activity under the consent decree that governs this trust that made funding available to all 50 states, Puerto Rico and the District of Columbia (VW Diesel Emission Environmental Mitigation Trust, n.d.)
- Regional funding
    - **Congestion Mitigation Air Quality Improvement Program (CMAQ)** provides over $8.1 billion in funds to State DOTs and MPOs for transportation projects designed to reduce traffic congestion and improve air quality.
    - **Regional Surface Transportation Program (RSTP)**. RSTP provides flexible funding in Virginia that may be used for projects to improve and preserve

conditions and performance on federal-aid highways, public bridges and tunnels, bicycle and pedestrian infrastructure, and transit capital projects.

Eligible recipients of CMAQ and RSTP funds in Hampton Roads include the localities and portions of localities within the MPA, Hampton Roads Transit (HRT), Williamsburg Area Transit Authority (WATA), Suffolk Transit, the Virginia Department of Transportation (VDOT), the Virginia Department of Rail and Public Transportation (DRPT), the Virginia Port Authority (VPA), and the HRTPO.

Electric utilities across the country are offering electricity rates or infrastructure incentives to support the deployment of electric vehicles. In Virginia, the Smart Charging Infrastructure Pilot (SCIP) Program from Dominion Energy supports electric vehicle adoption. This program provides rebates for qualifying charging stations, charging infrastructure and installation, and network fees. For transit, these rates are as follows (Dominion Energy, n.d.):

- Utility infrastructure (per site): $35,000
- Customer infrastructure (per site): $33,000
- Network fee (per charger): $5,000
- Equipment (per charger): $53,000
- Limit number of stations: 60

WATA obtained funds from Congestion Mitigation and Air Quality (CMAQ) federal program (allocated by HRTPO) that they plan to use to purchase one 35-foot zero-emission bus and deploy it on one of WATA's routes.

In the following chapter, HRTPO staff explores BEB technology and its challenges.

BATTERY ELECTRIC BUS TECHNOLOGY DESCRIPTION

This chapter is concerned with reviewing the challenges of BEB technology and its components. Challenges for BEB deployment are as follows:

1. **Economic Challenges** (Alexander Kunith, 2016):
   a. **Upfront cost**: "A typical 40-foot diesel bus cost about $445,000 while BEB of similar length went for $770,000" (Nunno, 2018). In June 2021, the cost of BEB was $887,000 (Bellon, 2021).
   b. **Charging infrastructure**: Additional funding is needed to install charging stations (cost of the charging equipment, installation, and coordination with the utility and other project partners) (Alana Aamodt, 2021). Prices can range from $2,000 to $64,000 for depot charging and $50,000 to $400,000 for on-route charging (Caley Johnson, 2020).
   c. **Grant dependence**: BEB investments in the U.S., and other countries, are subsidized to overcome the high upfront costs. This dependence could negatively affect deployment scalability.
2. **Planning challenges**:
   a. **The BEB range** is heavily impacted by ambient temperature, road grade, and operator driving style, affecting BEB range projections. Local conditions and driver training are critical considerations for planning the BEB range.
   b. **Novelty of BEB technology**: As a less established and more rapidly evolving technology sector, there is a higher risk of unknowns associated with BEB component manufacturing and model-specific maintenance services. Moreover, since BEBs have less established performance records than internal combustion engine buses, prospective funders of BEB deployment could be hesitant to invest.

Battery electric bus (BEB) technology is composed of three main components:

- Bus itself
- Battery system which is used to power the bus
- Charging infrastructure is a stationary system separate from the bus designed to connect the BEB to external electricity sources, supplying power to charge the bus battery

Bus

BEBs are powered by electric motors rather than internal combustion engines. Electric motors are simpler and rely on electrically powered onboard magnets to directly convert electrical energy into mechanical rotational energy (Alana Aamodt, 2021). Electric vehicles (EVs) have a high energy conversion efficiency, transferring between 72% and 94% of the input electrical energy into motion, dramatically more than the 12% to 30% of gasoline energy converted into movement by internal combustion engine vehicles.

EVs also use regenerative braking, which can make a large, positive impact on fuel efficiency. "Regenerative braking allows electric motors to recover some of this kinetic energy by switching to "generator mode" during gradual braking. In generator mode, the spinning wheels power the drivetrain in reverse, storing energy in the battery" (Alana Aamodt, 2021).

A typical diesel bus has an FTA-required life of 12 years but often lasts 15 years (Richard Laver, 2007). BEBs have a predicted lifespan of 12 years (Leslie Eudy M. J., 2017), but—given changing technology—actual life may differ.

The electric propulsion system within BEBs relies on magnetic induction rather than combustion, resulting in less vibration and a smoother, quieter ride (Alana Aamodt, 2021).

Battery system

Lithium-ion batteries are used by modern BEBs because of their high energy densities and good power densities compared to earlier battery technologies. Batteries are typically described by their energy capacity (kWh) and power (kW). Power (kW) describes instantaneous work performed by the battery and can be compared to horsepower in Internal Combustion Engines (ICE). Energy capacity (kWh) is the exercise of that power over time, compared to the fuel tank size of diesel buses.

The amount of energy left in a battery is called the state of charge (SOC) (Alana Aamodt, 2021). In theory, SOC may vary from 0% to 100% full. However, the SOC has a minimum and maximum limit to protect the battery's long-term useful life (Figure 3).

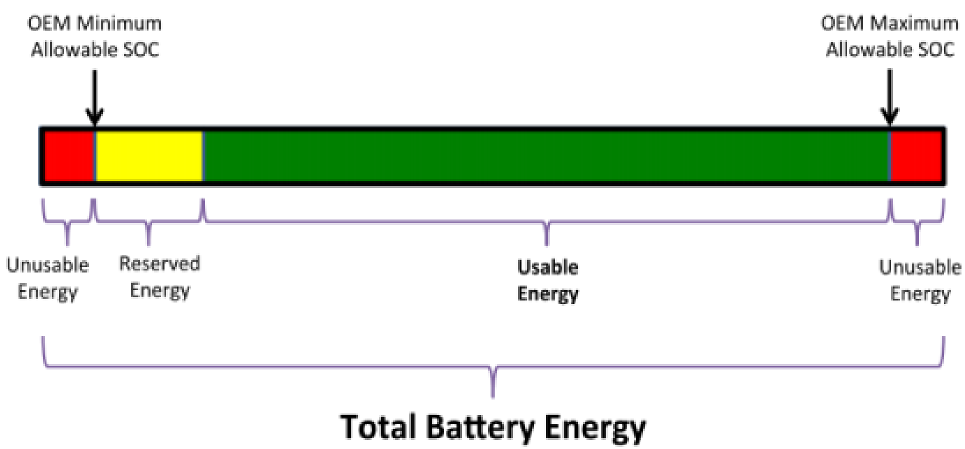


Figure 3 Beginning of life for BEB batteries
Source: Bigelow, 2017

The lower limit of SOC is above 0% to minimize battery performance degradation (Alexander Kunith, 2016). Additionally, energy is reserved (yellow) for emergencies and unforeseen delays, ranging from 15% to 35%. The upper margin (typically between 10% and 25%) ensures fast chargers do not exceed the maximum storage capacity (Alexander Kunith, 2016). The expected usable energy is around 70% of the theoretical battery capacity at the beginning of life (Matthias Rogge, 2015).

Figure 4 shows the SOC limits near the end of its life.

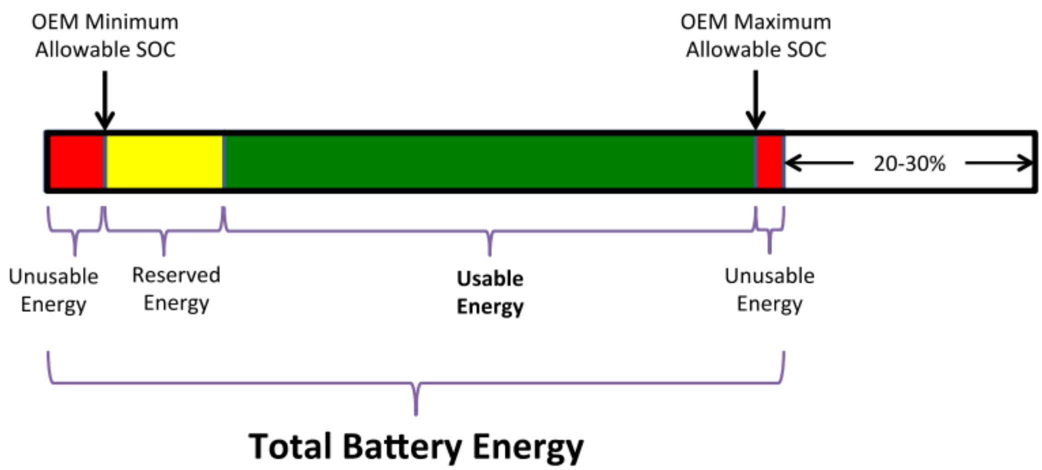


Figure 4 End-of-life batteries
Source: Bigelow, 2017

The battery capacity (total battery energy) declines with age, regardless of use, but high usage increases the degradation rate. The loss of battery capacity with age is represented by the white area in Figure 4 (between 20 and 30%). Battery life is uncertain, but all major bus OEMs offer 12-year warranties on their batteries. While the minimum allowable SOC is highly similar to a new battery, the battery capacity has diminished significantly compared to Figure 3.

High outdoor temperature can also accelerate the natural battery aging process, shortening battery life. Moreover, keeping batteries at a high SOC accelerates battery degradation. Battery life can be extended by (Alana Aamodt, 2021):

- Cycling the battery at lower SOCs when possible
- Avoiding high SOC when the BEB is not in use
- Decreasing the upper SOC limit

Charging infrastructure

Battery charging infrastructure is critical for battery-electric bus implementations. It affects the driving range of the bus and, in turn, bus routing and charging infrastructure placement and cost. There are three charging approaches (Figure 5):

- **Depot charging (plug-in charging)–** is typically scheduled during extended periods of non-operation while the battery-electric buses are stationed at their depot. This type of charging occurs by physically plugging the charger into a charging port on the battery-electric bus. The process can take between one to eight hours, but most buses can fully charge in five hours (Transit Cooperative Research Program, 2018). Depot charging is often preferred for smaller-scale deployments because the infrastructure is less expensive than on-route charging. Advantages of depot charging are (Alana Aamodt, 2021):
    - Schedules do not need to change to allow on-route charging
    - Off-peak charging is cheaper
    - Simpler grid connection and more centralized charging equipment.
    - Less infrastructure and installation.
    - Charging is handled by maintenance staff.

  Some disadvantages of depot charging are as follows (Alana Aamodt, 2021):
    - Longer charging time.
    - The depot requires more space and chargers to charge many buses at once.
    - High grid impact if all buses charge at once at the same place.
    - Midday charge might be necessary/more buses might be necessary.
    - It cannot be in service while charging.
- **Conductive charging** - uses, on average, 250 kW across bus manufacturers, allowing for a range of 20 to 30 miles on a 5-to-20-minute charge. Conductive charging employs a movable pantograph mounted on the vehicle's roof (Alana Aamodt, 2021). Pantographs serve as a temporary connection at specific charging locations. As a BEB approaches an overhead conductive charger, the bus communicates with the station to engage in automatic docking (Alana Aamodt, 2021). Once in place, the pantograph rises from the bus to make the connection. The BEB begins to charge while the passengers board and exit the bus. Charge power can range from 175-500 kW and take 5-20 minutes (Transit Cooperative Research Program, 2018).
- **Inductive charging** - uses a higher charging power (400 to 500 kW), such that a 15-second charge can add 12 miles (Moataz Mahmoud, 2016). Inductive charging occurs wirelessly, without any physical connection, through inductive charging coils buried beneath the street level at bus stops. Typically, inductively charged buses are paired with medium-sized battery packs and possess a medium range (Transit Cooperative Research Program, 2018).

  The advantages of conductive and inductive charging are as follows (Alana Aamodt, 2021):
    - Faster charge time.
    - It can run 24 hours with no long break for charging.

- One fast charger can serve multiple routes.
- Traffic flow at the depot is similar to diesel and would not require reconfiguration.

Disadvantages, on the other hand, are as follows (Alana Aamodt, 2021):

- Faster charging requires high power = high impact on the energy grid; thus, high demand charges.
- Less flexible: BEBs must stay on the route with charging access. Charging locations make it hard to adjust routes in the future.
- Expensive charging infrastructure.
- Daytime charging uses daytime electricity, which may cost more per kW.
- A transit agency may not own land use/rights; therefore, it must be obtained at charging locations.

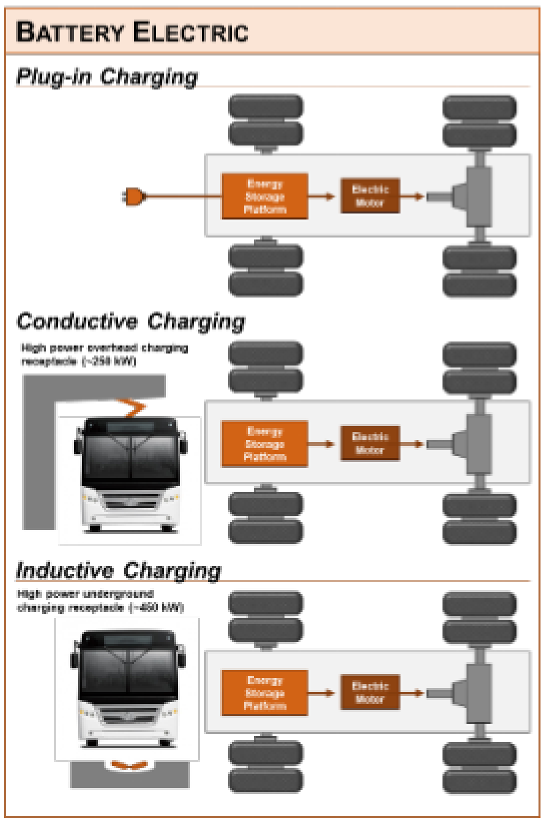


Figure 5 Overview of BEB charging methods
Source: Deliali, 2018

The HRTPO staff recommends depot charging for WATA's first BEB deployment because:

- The bus will be charged overnight (off-peak); therefore, charging will be cheaper.
- Better for smaller-scale deployment (i.e., first BEB deployment) because of:
  - Simpler grid connections and more centralized equipment
  - Less infrastructure and installation
  - Charging is handled by maintenance staff

Technology costs

The price of the bus is impacted by the battery size, bus size, charging type, charging location, electricity cost, and maintenance cost. Table 2 provides agency examples of costs for BEB deployment from 2019.

Table 2 Agency examples of technology costs

Source: Center for Transportation and the Environment, 2019

	Antelope Valley Transit Authority (CA)	King County Metro (WA)	City of Seneca (SC)	Foothill Transit (CA)	IndyGo (IN)
BEB OEM	BYD	Proterra	Proterra	Proterra	Complete Coach Works
Year deployed	2014	2016	2014	2014	2015
Number of BEBs	40' (2)	40' (3)	35' (5), 40' (1)	35' (15), 40'(2)	40' (21)
Number of depot chargers	1	1	1	0	22
Number of on-route chargers	2 (50 kW inductive)	1 (overhead conductive)	2 (overhead conductive)	2 (overhead conductive)	0
BEB cost (per bus)	$770,000	$797,882	$950,000	$789,000 base $823,000 with add-ons	$597,000
Depot charge equipment cost (per charger)	$19,000	$60,000	$60,000	n/a	$10,000
Depot charge installation cost (per charger)	$55,000	Included	$8,000	n/a	$5,000
On-route charger equipment cost (per charger)	$350,000	$600,000	$600,000	$5,000,000	n/a
On-route charger installation cost (per charger)	$250,000	$241,510	$225,000	$200,000	n/a

Costs can be categorized as follows:

1. The BEB procurement costs – costs associated with the purchase of BEB. These costs range between $597,000 and $950,000, depending on the bus and battery size determined by the charging infrastructure (Deliali, 2018).
2. Infrastructure cost – the cost is mainly determined by the charging method. A generalized battery charging station with a plug-in charger consists of the following parts: grid, transformer, switchgear, charger, and dispenser. The infrastructure costs vary from agency to agency.
3. Electricity costs – Table 3 shows the fuel cost for battery-electric buses deployed in various transit agencies. HRTPO staff recommends that WATA estimate total electricity costs, including energy charges, demand charges, time of use rates and other surcharges. This analysis should be conducted in the early planning process to allow for operational adjustment. The impact of demand charges can be most acute when fleets have a small number of electric vehicles, and charging causes large, relative spikes in electricity demand.

Table 3 Fuel cost per mile for battery-electric buses ($/mile)
Source: Deliali, 2018

Transit Agency	Fuel Cost per mile ($/mile)	
	Battery Electric	Conventional
Clemson Area Transit (SC)	0.26	0.66
Foothill Transit (CA)	0.39	NR
King County Metro (WA)	0.18	0.44
Los Angeles MTA (CA)	NR	NR
Regional Transportation Commission Washoe (NV)	NR	NR
Santa Barbara MTD (CA)	NR	NR
Spokane Transit Authority	0.37	0.59

4. Maintenance cost – the cost depends on the manufacturer's availability of parts and whether the bus is under warranty. Battery electric buses have extended maintenance intervals, fewer fluids, fewer moving parts, and decreased emissions than conventional diesel buses (Center for Transportation and the Environment, 2019). Regenerative braking systems reduce brake wear and expensive brake repair. In most cases, maintenance is done in-house. The maintenance cost per mile for BEBs was reported as 11% lower than CNG buses (Leslie Eudy R. P., 2016) and 80% lower than diesel buses (Moataz Mahmoud, 2016). The average maintenance cost was 0.16-0.21 $/mile/bus for BEBs, while the average maintenance cost for the conventional bus was 1.15 $/mile/bus (Leslie Eudy R. P., 2016). Another author reported an average maintenance cost of $0.64/mile for BEBs, compared with $0.88/mile for traditional diesel buses (Caley Johnson, 2020).

The next chapter is concerned with the best practices of training.

TRAINING

BEBs have many new components and operations that operators, maintenance staff, and facilities staff may be unfamiliar with. Training must be provided to transit agency staff on the safe and efficient operations of ZEBs. Bus procurement contracts should include requirements for the OEM to provide sufficient training to the staff. Moreover, contract specifications should include training hours, aids, materials, tools and diagnostic equipment requirements.

The operator's compartment may have different gauges or displays than conventional buses. Therefore, an overview of the dashboard controls and warning signals for all drivers and maintenance staff and training on the correct procedure when a warning signal appears on the dashboard is needed.

FTA recommends training on concepts, working principles, and details of regenerative braking, mechanical braking, hill holding, and rollback (Meredith Linscott, 2021). Training on the difference between regenerative braking and conventional friction braking is highly suggested.

Driving habits can significantly affect BEB efficiency and performance. Drivers must be trained on optimal driving habits, such as the recommended levels of acceleration and deceleration, to maximize efficiency (Meredith Linscott, 2021).

ZEBs operate with much less noise. Drivers should be aware and properly trained on the risks silent operations pose to pedestrians and bicyclists.

American Public Transportation Association (APTA) recommends that any staff responsible for ZEB operation and maintenance be familiar with processes, procedures, and hazards associated with the charging process (Meredith Linscott, 2021). Moreover, APTA recommends that the transit agency staff responsible for specific tasks associated with BEB charging should receive additional training on the safe operation of BEB chargers.

Thorough safety training is critical for all staff involved in supporting ZEB deployments. Safety training should include (Meredith Linscott, 2021):

- Overview of hazards associated with battery chargers
- Safe handling and deactivation of high-voltage components, including required personal protective equipment (PPE) for different tasks and capacitor discharger timing
- Lockout and tagout procedures for working on energized components and systems, as specified in *The Control of Hazardous Energy (Lockout/Tagout), title 29, CFR Part 1910.147 (OSHA, 2002)*.
- Battery-specific safety hazards, such as electrocution, arcing, and fires from short circuits
- Locations of emergency cut-off switches and fire response equipment
- Actions to take to avoid an emergency and what to do in an emergency
- Maintenance and testing of safety-critical systems like ground-fault detection

Emergency response guides for battery-electric bus manufacturers—including Proterra, Nova Bus, BYD, and GILLIG—are available on the National Fire Protection Association (NFPA) website (National Fire Protection Association, n.d.).

APTA recommends that bus operators be periodically re-trained based on the operator's performance. When monitoring bus data, transit agencies may be able to identify less energy-efficient drivers and suggest additional training to improve performance.

The following chapter reviews various factors that affect route choice. HRTPO staff also recommends which route should be served by BEB in the following chapter.

ROUTE ASSIGNMENT

The BEB range must be properly matched to bus route length and characteristics to achieve acceptable service levels. This chapter outlines the range and various factors that affect route choice. These factors are as follows (Meredith Linscott, 2021):

- Daily route length: A bus's physical distance to complete a daily route varies based on roundtrip length (short neighborhood routes vs. longer commuter routes) and the number of roundtrips per day. Daily route length has implications for the selection of charging strategies.
- Grade: the incline of the road impacts the BEB range. Overcoming steeper grades requires more power and drains the bus's batteries quicker than flat road transit. This effect is shown in the study concerned with the Foothill Transit agency (Leslie Eudy R. P., 2016). Figure 6 shows the effect of elevation change on battery state of charge (SOC). The blue line shows the battery SOC over time. The battery drain rate has two distinct areas in Figure 6 within the North loop. The steep discharge is approximately between 4:18 pm and 4:38 pm due to the bus climbing 300 ft of elevation over about 7.7 miles. The second portion of the north loop shows a slower battery discharge rate, indicated by the small negative slope after 4:38 pm. Agencies looking to implement BEBs on hilly routes should be aware of these demands and adjust battery size or charging frequency. Additionally, agencies deploying BEBs for the first time may want to avoid large elevation changes to simplify fleet configurations and reduce risk.

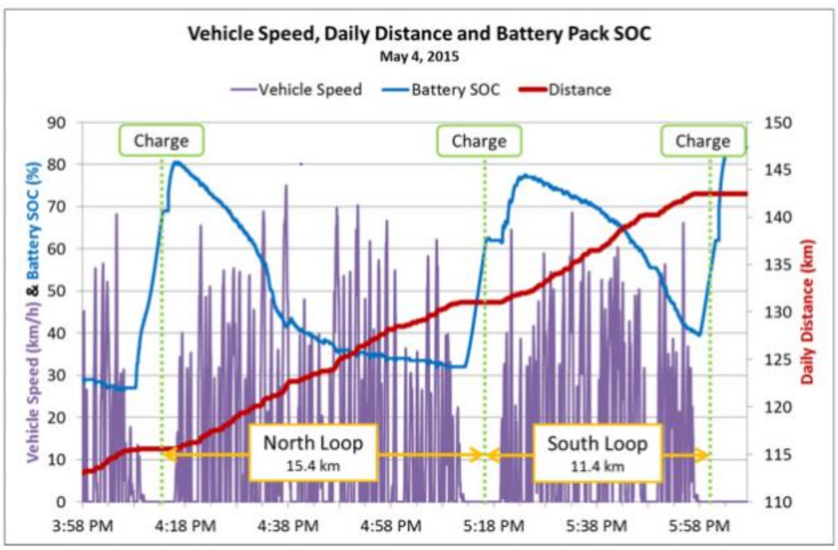


Figure 6 Effect of elevation change on battery SOC
Source: Leslie Eudy R. P., 2016

- Bus speeds: BEBs demonstrate the largest energy efficiency advantage over diesel vehicles at lower average speeds (EPA, 2017).
- Passenger capacity/bus ridership: buses filled are heavier and require more energy from the battery reducing the BEB range.

- Deadhead is the distance a bus must travel while not in service to return to the bus depot and travel at the beginning of the shift. Deadhead must be considered when analyzing if the bus will work on the route (cover the daily route length).
- External temperature patterns: HVAC demand has the largest impact on usable battery range (Bigelow, 2017). Seasonal HVAC loads affect energy consumption; the energy consumption model by the Center of Transportation and the Environment showed a BEB with an average number of passengers uses 2% more energy in the summer (for cooling) and 28% more energy in the winter (for heating) compared to autumn operation (Bigelow, 2017).

Table 4 shows WATA routes, first stop, last stop, roundtrip miles and daily miles.

Table 4 WATA routes
Source: HRTPO analysis of WATA data

Route Number	Route Name	First Stop	Last Stop	Roundtrip (miles)	Daily (miles)
Rt 1	Lee Hall	N. Boundary St. at Williamsburg Hub (1000)	Elmhurst St. at Lee Hall Transfer (1060)	21	319
Rt 2	Richmond Rd	N. Boundary St. at Williamsburg Hub (1000)	E. Rochambeau Dr. at Walmart (1256)	15	221
Rt 3	Merrimac Trl	N. Boundary St. at Williamsburg Hub (1000)	Tam-O-Shanter Blvd. at Merrimac Trl. (1107)	16	234
Rt 4	Longhill Rd	New Town Ave. at Velocity (1128)	E Rochambeau Dr. at Walmart (1256)	20	297
Rt 5	Monticello	N. Boundary St. at Williamsburg Hub (1000)	Steeplechase Dr. at Steeplechase (1222)	12	180
Rt 6	Jamestown	N. Boundary St. at Williamsburg Hub (1000)	Colonial Pkwy at The Settlement (1303)	19	291
Rt 7	Mooretown Rd	N. Boundary St. at Williamsburg Hub (1000)	E Rochambeau Dr. at Walmart (1256)	16	245
Rt 8	William & Mary (loop)	S Henry St at WM Grad Plex (1089)	S Henry St at WM Grad Plex (1089)	6	125
Rt 9	Toano	Barhamsville Rd at LaGrange Pkwy (1171)	E Rochambeau Dr. at Walmart (1256)	24	353
Rt 11	Lackey	Battery Blvd at Riverside Hospital (1292)	Barham Blvd at Rivermeade (1329)	27	244

HRTPO staff contacted several Original Equipment Manufacturers (OEMs) of Battery Electric Buses to obtain battery capacity, range and model name, as shown in Table 5. Because the BEB range depends on different factors (discussed above), OEMs listed range values in the form of a minimum and maximum values. The operating range listed on OEM brochures for different models is approximated from simulation based on Altoona testing results at Seated Low Weight. The operating range will vary with route conditions (route length, grade, start/stop frequencies), weather, vehicle configuration and driver behavior, and traffic patterns (peak hours).

Table 5 OEM Battery Electric Bus specifications
Source: HRTPO analysis of data

OEM	Model Name	Battery Capacity (kWh)	Range (miles/bus)
PROTERRA	ZX5+	450	172-240
GILLIG	N/A	588	180-200
NEW FLYER	XCELSIOR CHARGE NG	440	220

Staff calculated the distances (in miles) that buses must travel from WATA's depot (located at 7239 Pocahontas Trail) to the first and last stop for every WATA route, shown in Table 6.

Table 6 Distances from WATA depot to first/last stop (in miles)
Source: HRTPO data analysis

	7239 Pocahontas Trail, WATA depot
Elmhurst St at Williamsburg TC (1060)	8
N Boundary St at Williamsburg TC (1000)	3
E Rochambeau Dr at Walmart (1256)	10
Tam-O-Shanter Blvd at Merrimac Trl (1107)	2
New Town Ave at Velocity (1128)	6
Steeplechase Dr at Steeplechase (1222)	7.5
Colonial Pkwy at The Settlement (1303)	9
E Rochambeau Dr at Great Wolf Lodge (1257)	10
S Henry St at WM Grad Plex (1089)	3
Barhamsville Rd at LaGrange Pkwy (1171)	18
Barham Blvd at Rivermeade (1329)	11
Battery Blvd at Riverside Hospital (1292)	0.5

HRTPO staff calculated deadhead with the following equation:

$$Deadhead_i = d_{first\ stop_i} + d_{last\ stop_i} + d_{safety\ margin}$$

Where:
$d_{first\ stop_i}$ = distance from the depot to the first stop on route *i* (miles),
$d_{last\ stop_i}$ = distance from the depot to the last stop on route *i* (miles),
$d_{safety\ margin}$ = safety margin distance (miles), the HRTPO staff assumed 2 miles

For example, for Route 1 (Lee Hall), HRTPO staff calculated deadhead as follows:

$$Deadhead_1 = d_{first\ stop_1} + d_{last\ stop_1} + d_{safety\ margin} = 3 + 8 + 2 = 13$$

Where:

$d_{first\ stop_1}$ = distance from depot to N. Boundary St. at Williamsburg Hub (1000), which is 3 miles (Table 6)

$d_{last\ stop_1}$ = distance from depot to Elmhurst St at Lee Hall Transfer (1060), which is 8 miles (Table 6)

$d_{safety\ margin}$ = safety margin, which is 2 miles

Next, the HRTPO staff calculated the Necessary Range by adding Daily miles and Deadhead (Table 7).

Table 7 Deadhead and daily miles with deadhead traveled for each route
Source: HRTPO analysis of data

Route Number	Route Name	First Stop	Last Stop	Roundtrip (miles)	Daily (miles)	Deadhead (with safety margin)	Necessary Range
Rt 1	Lee Hall	N. Boundary St. at Williamsburg Hub (1000)	Elmhurst St. at Lee Hall Transfer (1060)	21	319	13	332
Rt 2	Richmond Rd	N. Boundary St. at Williamsburg Hub (1000)	E. Rochambeau Dr. at Walmart (1256)	15	221	15	236
Rt 3	Merrimac Trl	N. Boundary St. at Williamsburg Hub (1000)	Tam-O-Shanter Blvd. at Merrimac Trl. (1107)	16	234	12	246
Rt 4	Longhill Rd	New Town Ave. at Velocity (1128)	E Rochambeau Dr. at Walmart (1256)	20	297	18	315
Rt 5	Monticello	N. Boundary St. at Williamsburg Hub (1000)	Steeplechase Dr. at Steeplechase (1222)	12	180	13	192
Rt 6	Jamestown	N. Boundary St. at Williamsburg Hub (1000)	Colonial Pkwy at The Settlement (1303)	19	291	14	305
Rt 7	Mooretown Rd	N. Boundary St. at Williamsburg Hub (1000)	E Rochambeau Dr. at Walmart (1256)	16	245	15	260
Rt 8	William & Mary (loop)	S Henry St at WM Grad Plex (1089)	S Henry St at WM Grad Plex (1089)	6	125	8	133
Rt 9	Toano	Barhamsville Rd at LaGrange Pkwy (1171)	E Rochambeau Dr. at Walmart (1256)	24	353	30	383
Rt 11	Lackey	Battery Blvd at Riverside Hospital (1292)	Barham Blvd at Rivermeade (1329)	27	244	14	257

HRTPO staff calculated the necessary number of buses to cover daily miles with deadhead on each WATA route with the following equation:

$$Number\ of\ Buses = \frac{Necessary\ Range}{Bus\ range}$$

Table 8 shows the required number of buses to cover daily miles with a deadhead.

Table 8 Required number of buses to cover daily miles with deadhead for WATA routes
Source: HRTPO analysis of data

		PROTERRA		GILLIG		NEW FLYER
Route Number	**Route Name**	**Low value (172 miles)**	**High value (240 miles)**	**Low value (180 miles)**	**High Value (200 miles)**	**220 miles**
Rt 1	Lee Hall	1.9	1.4	1.8	1.7	1.5
Rt 2	Richmond Rd	1.4	1.0	1.3	1.2	1.1
Rt 3	Merrimac Trl	1.4	1.0	1.4	1.2	1.1
Rt 4	Longhill Rd	1.8	1.3	1.8	1.6	1.4
Rt 5	Monticello	1.1	0.8	1.1	1.0	0.9
Rt 6	Jamestown	1.8	1.3	1.7	1.5	1.4
Rt 7	Mooretown Rd	1.5	1.1	1.4	1.3	1.2
Rt 8	William & Mary (loop)	0.8	0.6	0.7	0.7	0.6
Rt 9	Toano	2.2	1.6	2.1	1.9	1.7
Rt 11	Lackey	1.5	1.1	1.4	1.3	1.2

From Table 8, we can infer that Route 8 (William and Mary loop) can be served best by the BEB because only one bus will be required. Route 5 (Monticello) can be served second-best by BEB. The range values are approximations from the OEM and will differ in real-life applications. HRTPO staff recommends that WATA conduct test runs before deployment to prepare for the impact of temperature, driver style, route grade, etc.
The next chapter is concerned with key future steps in the deployment of BEB.

FUTURE CONSIDERATIONS

This chapter is concerned with future considerations for WATA as a transit agency: vehicle inspection, acceptance testing, validation testing and data monitoring and evaluation.

Vehicle Inspection, Acceptance Testing, Validation Testing

Before actual BEB deployment, the transit agency should conduct vehicle inspection, acceptance testing, and validation testing.

Vehicle inspection will ensure buses meet the transit agency's specifications and that no damage is done during delivery. Acceptance testing ensures all contractual requirements for bus operations have been met. In conjunction with acceptance testing, validation testing will verify that actual bus performance meets expectations from modeling efforts. These results will support the strategic deployment of the bus.

HRTPO staff recommends that WATA implement these three actions for the first BEB purchase and every subsequent BEB purchase.

Data Monitoring and Evaluation

Data analysis provides insight into how the BEBs perform in the service area and how much they are utilized. Data monitoring and evaluation will allow an agency to understand true costs and benefits, future needs, and utilization. Common Key Performance Indicators (KPIs) for ZEB deployments are (Meredith Linscott, 2021):

- **Fuel cost per mile** – determines whether bus operations align with transit agency's estimates. This is the easiest metric to compare ZEB and non-ZEB vehicles.
- **Energy performance** – (kWh/mile) informs range, identifies any seasonal variability, and identifies energy efficiency trends by route or operator.
- **Availability –** indicates how often the ZEB was available for service.
- **Utilization –** measures the actual usage of ZEB compared to the possible usage. It can be measured by comparing the number of days a bus was put into service to the full days it was available to be put into service.
- **Fleet comparison** – comparison of the costs and performance of ZEB to diesel and CNG buses.
- **Emission reduction** – ZEB eliminates harmful emissions from diesel vehicles. The EPA provides GHG emissions estimated by diesel gallons avoided or miles traveled. In addition to calculating GHG emissions reduction, some agencies calculate the net health benefits of GHG emissions reductions.
- **Maintenance costs** – this information can help inform expectations and prepare for unscheduled maintenance.
- **Ongoing cost analysis –** comparing the actual operating and maintenance costs to the projected costs throughout the fleet's service.

Data could be collected from utility bills, data monitoring services (OEM platforms, third-party platforms), asset management systems, maintenance reporting systems, and operations reporting systems. WATA could identify and coordinate internal and external operations and maintenance data sources. WATA could designate one staff member to collect and evaluate the data. Some agencies use application programming interfaces (APIs) to automatically collect data from I.T. systems and translate the data into a format that can be more easily used. On the other hand, some agencies simply use a spreadsheet to maintain and analyze data.

After deploying the first BEB, WATA could gather data and develop and analyze KPIs. This analysis will help WATA determine the success of the first BEB and inform the purchase and deployment of additional BEBs.

CONCLUSION

Modern Battery Electric Buses are a growing approach used to provide transportation service with many benefits, including lower fuel costs, lower maintenance costs, improved performance, lower emissions, and increased energy security compared to internal combustion buses. Despite these benefits, overcoming the barriers to BEB adoption will require new transit planning and bus implementation approaches. Challenges tied with BEB deployment are financial cost, new planning burdens, BEB ranges heavily influenced by many external factors, and unfamiliarity with BEB technology.

BEBs have high upfront costs compared to diesel buses. Capitals costs associated with BEBs are vehicle costs, fueling equipment costs, infrastructure installation costs, electric utility upgrades, and maintenance facility modifications. The study outlined many funding and financing options that support BEB purchases, including FTA grants, state and regional funds, and utility incentives.

Preparing for BEB deployment can be a lengthy and involved process, but all considerations must be addressed. The HRTPO staff reviewed the experience and recommendations of other transit agencies in the U.S., focusing on Virginia's transit agencies that deployed BEBs: WMATA, Blacksburg Transit, HRT, DASH (Alexandria Transit Authority), and JAUNT. All transit agencies reported a higher upfront cost of vehicles, but agencies also assume they will save hundreds of dollars on maintenance during the vehicle's lifetime.

Existing conditions of WATA's infrastructure were also reviewed in this report, including transit services and areas serviced and fleet composition.

The report outlines BEB technology and its main components: bus structure, the battery storage system, and charging infrastructure. The bus is powered by an electric motor with a currently predicted lifespan of 12 years. The battery system is the second crucial component of this technology; the State of Charge (amount of energy left in the battery) is the important battery parameter. Charging infrastructure is also reviewed, depot charging and on-route charging (inductive and conductive). This report outlined the interrelated nature of these components related to BEB deployment decisions. The battery system and charging strategy are tied together, and charging infrastructure impacts electric utilities and the grid. BEB refueling requires many considerations that affect the electric grid; hence engaging utilities early is critical for successful BEB deployment.

This report also reviewed best practices and recommended training staff to safely and effectively maintain and operate BEB. Safety training topics outlined include codes, standards, regulations, and testing to ensure the well-being of the operator and the public. Operational training is necessary, too, as suboptimal operation of the BEBs can affect the bus range and charging efficiency.

The BEB range must be optimized and properly matched to route length and characteristics to achieve service levels comparable to conventional buses. This entails thorough, location-specific route analysis for viable BEB routes. HRTPO staff obtained range values for BEB from different OEMs. Based on these values, HRTPO staff determined which route would be best served by BEB. Daily miles covered on each route were obtained from WATA. Deadhead with safety margin was added to daily miles, divided by range value from OEM brochure. This value shows how many buses would be needed to cover daily miles on routes. Route 8 (William and Mary) had the lowest value, so the HRTPO staff recommends placing the BEB on this route.

The ZEB industry is still maturing, and technological advancements are frequently emerging. These advancements will improve operational efficiency, vehicle safety, and durability. Moreover, industry innovations will allow a more straightforward replacement of conventionally fueled buses with ZEBs. They will provide the necessary information, tools and resources for transit agencies to support the full fleet of ZEBs.

WATA's current plan is to purchase one BEB and use it as a pilot to obtain experience. WATA's next steps would include stakeholder engagement (utility company, OEMs) followed by bus procurement, bus validation, testing and deployment. After deployment, WATA should collect relevant data and evaluate the performance of the BEB using established KPIs. These data-driven performance measures can be valuable input for future consideration of purchasing additional BEBs.

To conclude, the HRTPO staff's recommendations for WATA are as follows:

- Pay close attention to the outside weather (especially when temperatures are lower), which will result in higher usage of the HVAC system that will drain the battery quicker. Purchasing auxiliary diesel heaters for colder days will be beneficial.
- Contact the utility provider to check if any upgrades are needed; close cooperation is necessary to avoid any setbacks.
- Explore multiple OEMs to determine the best possible vehicle's make and model in terms of battery, range and other transit agencies' experience (refer to HRT's experience regarding Proterra buses discussed in the "Review of ZEB deployments in Virginia and US" chapter).
- Pay close attention to costs that are changing more frequently and abruptly.
- Expect some hurdles and setbacks along the way within months of deployment.
- Compare end-of-life battery specifications from different OEMs to determine the best possible alternative.
- Depot charging is recommended because:
    - The bus will be charged overnight (off-peak); therefore, charging will be cheaper.
    - Better for smaller-scale deployment (i.e., first BEB deployment) because of:
        - Simpler grid connections and more centralized equipment.
        - Less infrastructure and installation.
- Conduct vehicle inspection, validation and acceptance testing before actual deployment.
- After BEB deployment, WATA could start gathering data and developing KPIs to determine the overall utilization of the BEB.

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