Whatcom Transportation Authority
Zero Emissions Bus Transition Study

July 2023

Prepared by:

transpogroup
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Introduction

The transportation sector accounts for the majority of greenhouse gas emissions in the United States. The primary source of carbon emissions is the use of fossil fuels in traditional combustion engine vehicles. Public transportation agencies, as providers of essential transportation services in communities, play a critical role in the transition to a more sustainable future.

Whatcom Transportation Authority (WTA) is committed to meeting carbon reduction mandates at the state, federal, and local levels. This commitment will be accomplished primarily by converting their bus fleet to zero-emission vehicles. The bus fleet conversion replaces traditional diesel or gasoline-powered buses with electric or hydrogen-powered buses, which emit no tailpipe emissions and produce no greenhouse gas emissions.

There are many complex issues to consider when transitioning to a zero-emission bus fleet, but it is a critical step in mitigating climate change and improving urban air quality. The transition necessitates careful planning and consideration of factors such as funding, infrastructure requirements, and operational logistics.


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Report Organization

1
Existing Transit Service Conditions

CHAPTER 1 of this report summarizes the existing transit services provided by WTA in order to establish the level of service required by any new technology.

2
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CHAPTER 2 provides a current snapshot of the zero-emission transit industry, including available technologies, costs, and operational considerations.

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CHAPTER 3 describes the policies at the local, state, and federal levels that are driving the transition to zero-emission buses and identifies potential funding sources.

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CHAPTER 5 discusses the effects of a zero-emission fleet on WTA's existing facilities.

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CHAPTER 6 outlines three potential paths that WTA could take to operate a fully zero-emission fleet by 2040, as well as summarizing the costs, site plan implications, and associated GHG emissions for each option.

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Future Planning

CHAPTER 7 looks ahead to the future of zero-emission technology and how it will affect WTA's transition to a zero-emission fleet.

Chapter 1 Existing Transit Service Conditions

This chapter describes the existing bus fleet, transit services, and operating conditions of WTA. Details about the service area, daily runs, length of the runs, and driver route are provided.

Current Fleet

Whatcom Transportation Authority's fixed-route fleet currently includes 62 buses of 35 and 40 feet in length. Sixty of these buses run on diesel fuel (52 diesel only and 8 hybrids). WTA has 2 battery electric buses in service since 2021. The fleet ranges in age from 1 to 11 years.

WTA also runs paratransit services and has 45 existing paratransit vehicles. 23 of these vehicles are gas-powered while the other 22 run on propane. These buses range from 3 to 9 years.

WTA has 19 vanpool vehicles, all of which run on gas. These vehicles are 3 to 11 years old.

WTA has 46 additional support vehicles, such as Dodge Caravans, Toyota Prius', Ford Escapes, and Chevy Silverados. All support vehicles run on gas (or hybrid electric gas such as the Chevy Volt) except for one diesel-powered Ford F-450.

WTA is seeking to understand the state of the zero-emission vehicle market and plan for how they might transition to a zero-emission fleet. A more detailed investigation of the existing transit operations has been conducted to determine the feasibility of converting the entire WTA fleet to zero-emission.

Transit Operations

Table 1 summarizes WTA's routes' service areas, operating hours, and runs per day as of January 2023.

As shown in Table 1, WTA provides fixed route service that generally operates within the greater Bellingham area. Fixed route service extends as far north as Sumas and Blaine, as far east as Kendall and Sudden Valley, and travel as far south as Mt. Vernon. WTA's existing fixed-route service is shown on Figure 1.

For passengers whose disability prevents them from riding WTA's fixed route bus system, WTA's paratransit service offers curb-to-curb (and, if necessary, door-to-door) transportation. The service area and operating times for paratransit are generally the same as for fixed routes.

WTA's paratransit service generally functions within a 3/4 mile buffer of fixed route service. In addition, WTA provides additional paratransit services to several 'zones' in the greater Bellingham Area on specific days of the week, as shown on Figure 2.

WTAs CURRENT FLEET

Fixed Route Vehicles

52
diesel

8
hybrid-diesel

2
battery electric

Paratransit

23
gas-powered

22
propane-powered

Vanpool

19
gas-powered

Support Vehicles

39
gas-powered

6
hybrid

1
diesel-powered

Table 1 – Existing Transit Routes – Service Areas, Operating Hours, and Runs per Day

Route	Area Served	Approx. Operating Hours	Runs / Day
1	Fairhaven <-> Downtown Bellingham	6 a.m. – 10:30 p.m. (Weekdays)	46 (Weekdays)
		8 a.m. – 10:30 p.m. (Saturdays)	29 (Saturdays)
		7:30 a.m. – 9:30 p.m. (Sundays)	26 (Sundays)
3	Airport/Cordata <-> Hospital/Downtown	6:30 a.m. – 7 p.m. (Weekdays)	13 (Weekdays)
		7:30 a.m. – 6 p.m. (Saturdays)	11 (Saturdays)
4	Hospital/Cordata <-> Hospital/Downtown	7 a.m. – 7 p.m. (Weekdays)	12 (Weekdays)
		8 a.m. – 6 p.m. (Saturday)	10 (Saturdays)
14	Fairhaven <-> Downtown Bellingham	6:30 a.m. – 10:30 p.m. (Weekdays)	28 (Weekdays)
		8 a.m. – 10:30 p.m. (Saturdays)	25 (Saturdays)
		8 a.m. – 9:30 p.m. (Sundays)	14 (Sundays)
15	Cordata/Whatcom Community College <-> Downtown Bellingham	6:30 a.m. – 10 p.m. (Weekdays)	28 (Weekdays)
		8 a.m. – 10 p.m. (Saturdays)	25 (Saturdays)
		9 a.m. – 8 p.m. (Sundays)	12 (Sundays)
24	Cordata	7 a.m. – 9:30 p.m. (Weekdays)	27 (Weekdays)
		8 a.m. – 9:30 p.m. (Saturdays)	25 (Saturdays)
		9:30 a.m. – 8:30 p.m. (Sundays)	12 (Sundays)
26	Lynden <-> Cordata/ Whatcom Community College	6:30 a.m. – 8:30 p.m. (Weekdays)	15 (Weekdays)
		8 a.m. – 7 p.m. (Saturdays)	12 (Saturdays)
		8 a.m. – 7 p.m. (Sundays)	11 (Sundays)
27	Ferndale <-> Cordata/ Whatcom Community College	6:30 a.m. – 9:30 p.m. (Weekdays)	15 (Weekdays)
		7:30 a.m. – 6 p.m. (Saturdays)	11 (Saturdays)
		8:30 a.m. – 6:30 p.m. (Sundays)	8 (Sundays)
29	Cordata/Kline	7 a.m. – 6:30 p.m. (Weekdays)	13 (Weekdays)
		8 a.m. – 6:30 p.m. (Saturdays)	11 (Saturdays)
		8:30 a.m. – 7 p.m. (Sundays)	11 (Sundays)
48	Cordata/Whatcom Community College <-> Bakerview Spur	6:30 a.m. – 4 p.m. (Weekdays)	3 (Weekdays)
		10 a.m. – 5:30 p.m. (Saturdays)	2 (Saturdays)
49	Downtown Bellingham <-> Bakerview Spur	1 p.m. – 6 p.m. (Weekdays)	5 (Weekdays)
		10 a.m. – 6 p.m. (Saturdays)	3 (Saturdays)
50	Gooseberry Point <-> Downtown Bellingham	6 a.m. – 8 p.m. (Weekdays)	9 (Weekdays)
		7:30 a.m. – 6 p.m. (Saturdays)	7 (Saturdays)
		8:30 a.m. – 5:30 p.m. (Sundays)	6 (Sundays)
71X	Everson/Nooksack/ Sumas <-> Cordata / Whatcom Community College	6 a.m. – 7:30 p.m. (Weekdays)	5 (Weekdays)
		8:30 a.m. – 7 p.m. (Saturdays)	3 (Saturdays)
72X	Kendall <-> Downtown Bellingham	6 a.m. – 7:30 p.m. (Weekdays)	8 (Weekdays)
		7:30 a.m. – 7 p.m. (Saturdays)	4 (Saturdays)
		7:30 a.m. – 7 p.m. (Sundays)	4 (Sundays)

Route	Area Served	Approx. Operating Hours	Runs / Day
75	Blaine/Birch Bay – Downtown Bellingham	6 a.m. – 7 p.m. (Weekdays)	12 (Weekdays)
		7:30 a.m. – 6:30 p.m. (Saturdays)	4 (Saturdays)
80X	Downtown Bellingham – Lincoln Creek – Alger – Burlington – Mount Vernon	6:30 a.m. – 7 p.m. (Weekdays)	9 (Weekdays)
		9 a.m. – 6 p.m. (Saturdays)	5 (Saturdays)
		9 a.m. – 6 p.m. (Sundays)	5 (Sundays)
105	Fairhaven <-> Downtown Bellingham	7:30 a.m. – 10:30 p.m. (Weekdays)	16 (Weekdays)
		8:30 a.m. – 10:30 p.m. (Saturdays)	15 (Saturdays)
		8:30 a.m. – 9 p.m. (Sundays)	13 (Sundays)
107	Western Washington University/ Samish	6:30 a.m. – 6 p.m. (Weekdays)	12 (Weekdays)
		8:30 a.m. – 6 p.m. (Saturdays)	10 (Saturdays)
108	Samish/ Western Washington University	7 a.m. – 5:30 p.m. (Weekdays)	21 (Weekdays)
		8:30 a.m. – 6 p.m. (Saturdays)	10 (Saturdays)
190	Lincoln St <-> Downtown	7 a.m. – 11 p.m. (Weekdays)	21 (Weekdays)
		8:30 a.m. – 11 p.m. (Saturdays)	20 (Saturdays)
		8:30 a.m. – 8:30 p.m. (Sundays)	24 (Sundays)
196	Western Washington University/ Lincoln Creek	7 a.m. – 6:30 p.m. (Weekdays)	12 (Weekdays)
		9 a.m. – 6:30 p.m. (Saturdays)	10 (Saturdays)
197	Lincoln Creek/ Western Washington University	7 a.m. – 7 p.m. (Weekdays)	12 (Weekdays)
		7 a.m. – 6 p.m. (Saturdays)	11 (Saturdays)
232	Cordata/Whatcom Community College <-> Downtown Bellingham	6:30 a.m. – 10:30 p.m. (Weekdays)	52 (Weekdays)
		8 a.m. – 10:30 p.m. (Saturdays)	46 (Saturdays)
		8 a.m. – 8 p.m. (Sundays)	24 (Sundays)
331	Cordata/Whatcom Community College <-> Downtown Bellingham	6:30 a.m. – 10:30 p.m. (Weekdays)	52 (Weekdays)
		8 a.m. – 10:30 p.m. (Saturdays)	45 (Saturdays)
		8 a.m. – 8 p.m. (Sundays)	24 (Sundays)
512	Sudden Valley <-> Downtown	6:30 a.m. – 10 p.m. (Weekdays)	16 (Weekdays)
		8:30 a.m. – 10 p.m. (Saturdays)	14 (Saturdays)
		8:30 a.m. – 8 p.m. (Sundays)	12 (Sundays)
525	Barkley <-> Downtown Bellingham	7:30 a.m. – 7:30 p.m. (Weekdays)	13 (Weekdays)
		8:30 a.m. – 7 p.m. (Saturdays)	11 (Saturdays)
		9 a.m. – 7:30 p.m. (Sundays)	11 (Sundays)
533	Yew St <-> Downtown	7 a.m. – 6:30 p.m. (Weekdays)	12 (Weekdays)
		8 a.m. – 5:30 p.m. (Saturdays)	10 (Saturdays)
540	Sunset <-> Downtown	7 a.m. – 6:30 p.m. (Weekdays)	12 (Weekdays)
		9 a.m. – 6:30 p.m. (Saturdays)	10 (Saturdays)

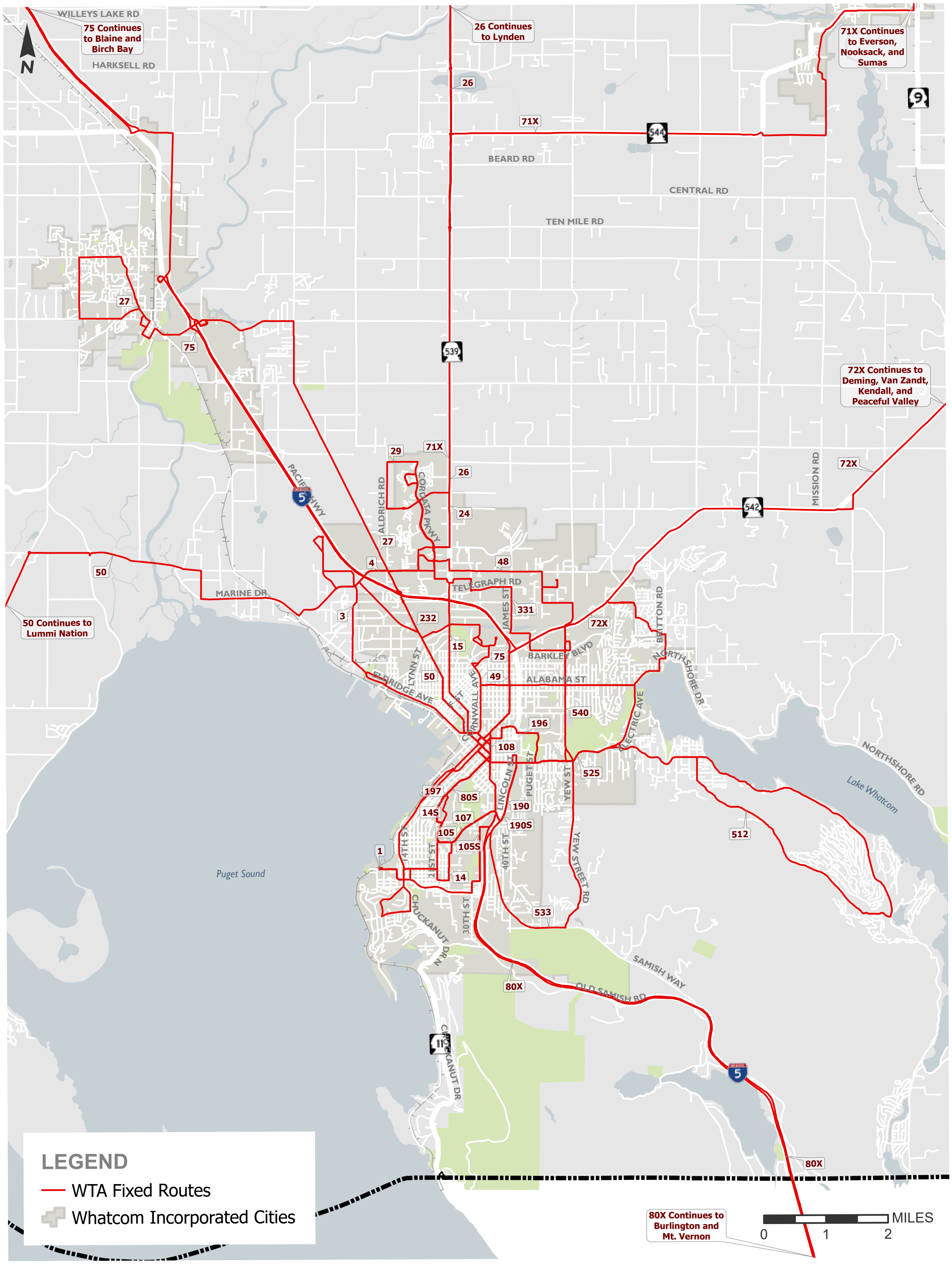


Figure 1 – WTA's Fixed Route Service

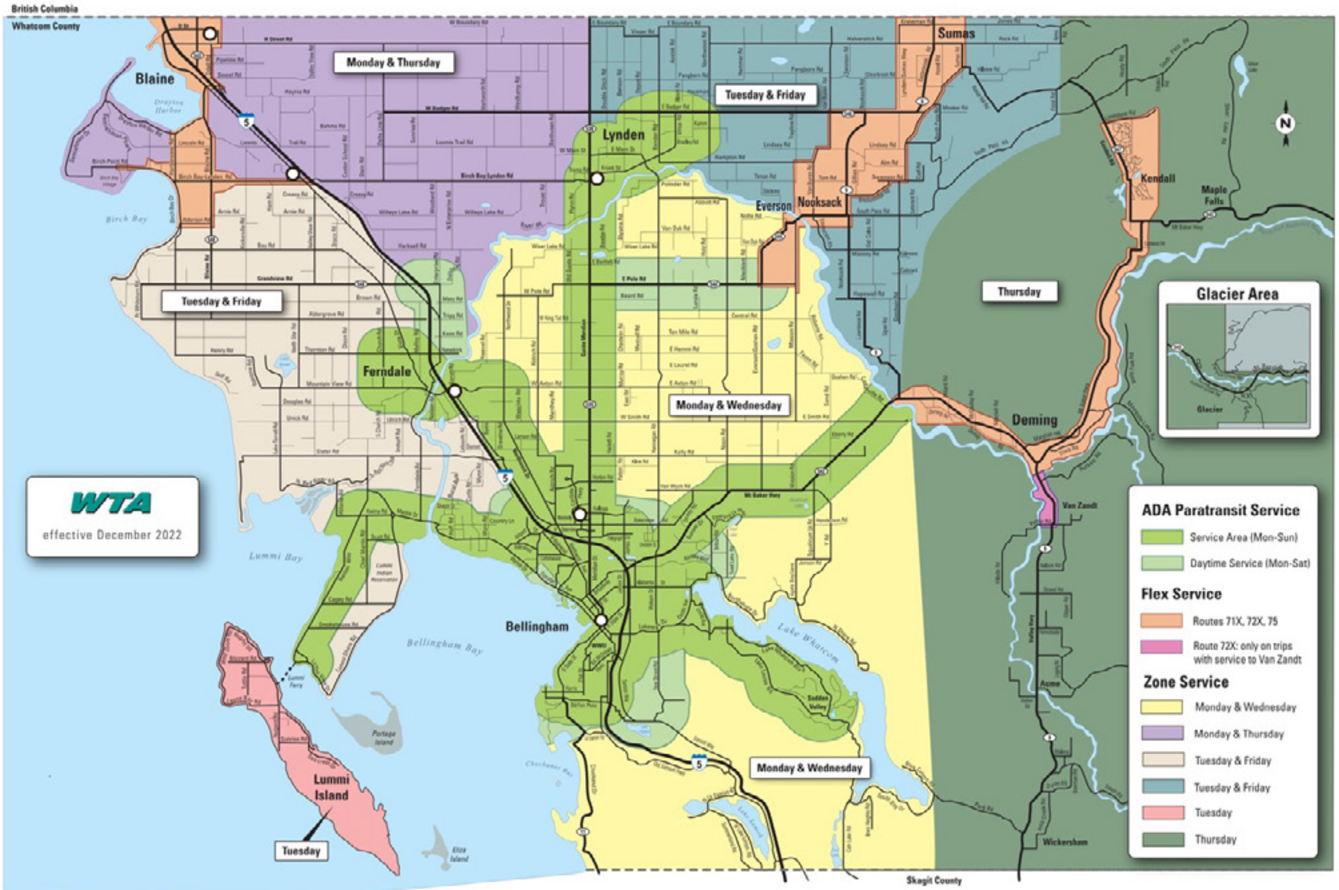
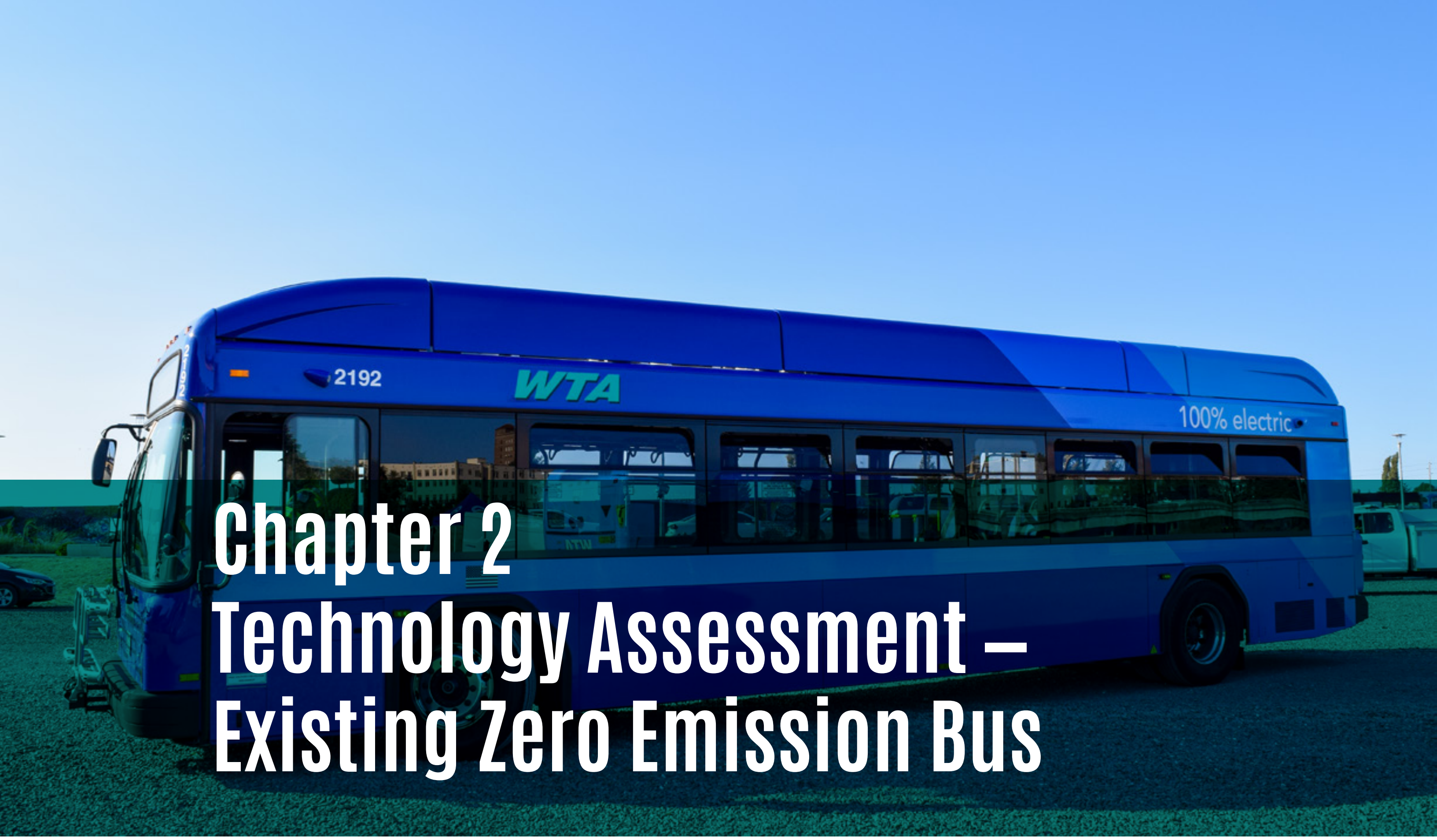


Figure 2 – WTA Paratransit, Flex and Zone Service Map



Chapter 2 Technology Assessment – Existing Zero Emission Bus

Battery Electric Buses (BEBs) and Fuel Cell Electric Buses (FCEBs) are the two main types of zero-emission bus (ZEB) technology.

BEBs store electrical energy in battery packs which power the drivetrain. BEBs charge at stations rather than refueling with liquid or gaseous fuels like traditional internal combustion engine-equipped buses. In the United States, three types of charging are currently used for BEBs: plug-in charging, overhead conductive charging, and wireless inductive charging.

FCEBs store gaseous hydrogen fuel in onboard tanks, which the fuel cell uses to generate electricity, which powers the drivetrain propulsion system. FCEB buses also have a battery pack system, but the energy storage capacity is much lower than that of a BEB battery pack. FCEB battery packs supplement the energy generated by the fuel cell and recover regenerative braking charge energy.

All major North American bus Original Equipment Manufacturers (OEMs) have developed ZEB offerings in various sizes for full-size transit bus operations. Since the first BEB was introduced nearly two decades ago, this competition has significantly reduced vehicle pricing. Unfortunately, in the paratransit vehicle industry, this competition does not currently exist. The current price of zero-emission paratransit vehicles is twice that of comparable internal combustion engine paratransit vehicles. The price differential is expected to change with the upcoming introduction of zero-emission vehicles from Ford, General Motors, and Dodge. As a result, zero-emission paratransit vehicle purchase prices will gradually decrease, similar to transit buses.

The following section summarizes the available ZEB technologies in 2023, the date of this report. These technologies were compiled from the consultant team's previous experience working with manufacturers and from the Federal Transit Administration (FTA).

BEB Technologies Defined

Battery Capacity and State of Charge

This document addresses both "nominal" battery capacities and "service energy". The nominal battery capacity refers to the amount of total energy storage capacity, expressed in kilowatt-hours (kWh). The "service energy" refers to the amount of energy that can be used on a regular basis. Service energy, like nominal battery capacity, is expressed in kWh, but the value is significantly lower because not all battery capacity can (or should) be used daily. The industry standard reduction for usable service energy is 20 percent, and therefore, only 80 percent of the nominal battery capacity is available as service energy.

Rechargeable batteries also degrade over time due to changes in chemical composition that affect storage capacity, power delivery, and the ability to accept a charge. Manufacturers generally indicate that at the end of its useful life, a battery can retain 80 percent of its maximum capacity. This degradation in capacity typically occurs over a six-year period. However, the rate and extent to which the battery degrades is largely determined by the amount of stress the battery experiences during use and charging. Therefore, the indicated State of Charge (SOC) of a battery does not always correspond to the same amount of energy stored. SOC is the BEB equivalent of a traditional ICE vehicle's fuel gauge.

Figure 3 shows the service energy available for 40-ft Gillig BEB that has a nominal battery size of 588 kWh when new. A 40-ft Gillig BEB's service energy decreases to 376 kWh at the end of its life, which serves as the basis of the WTA operation modeling discussed in Chapter 4.

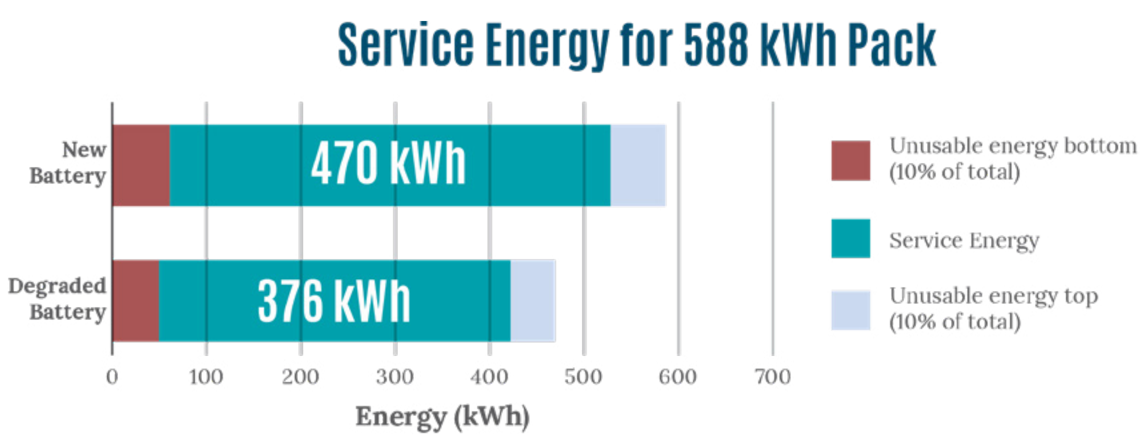


Figure 3 - Nominal Battery Capacity vs Service Energy at Beginning and End of Life of a 40-ft BEB

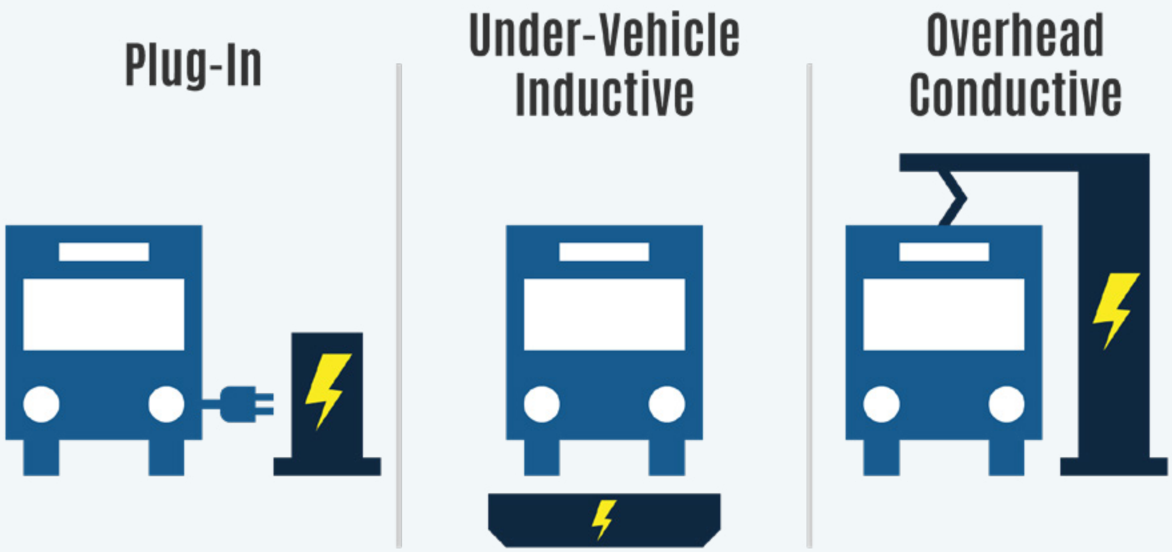


Figure 4 – Three Primary Methods of Bus Charging

Future Battery Capacity

As the BEB market has developed, the energy density of batteries has greatly improved. WTA's first two BEBs acquired in 2020, along with the two being delivered in 2023, have a nominal battery capacity of 440 kWh. The next eight BEBs that WTA will obtain in 2024 will have a nominal battery capacity of 588 kWh, a 33 percent increase in energy density in four years. While the industry does not expect such rapid advances each year, it is anticipated that battery energy density will continue to steadily improve. For the purpose of this report, a future nominal battery capacity of 800 kWh is assumed to exist in the foreseeable future. This future 800 kWh battery would have a service energy of 640 kWh. Chapter 4 examines the impact that future battery capacities will have on WTA's operations.

Charging Infrastructure

In the United States, three types of BEB charging are currently in use: plug-in conductive charging, overhead conductive charging, and wireless under-vehicle inductive charging. The standard electric charging options are depicted on Figure 4, with descriptions of each type provided in the following sections.

Plug-In Charging

The most common method of charging a vehicle is by plugging it into a power source and leaving it to charge while not in use. Plug-in charging can be done at various power levels, changing the rate at which a battery is charged by using a variety of voltages and electric currents. A charger with a higher power output (measured in kilowatts, or kW, a unit of electrical power) will charge faster. Electric buses are designed to handle varying levels of charging, with each manufacturer establishing a maximum number of kW that a vehicle's battery can receive. Commercial plug-in charging units typically range from 20 kW to 200 kW. WTA's existing plug-in chargers have a capacity of 156 kW (with two dispensers each) and can fully charge their current BEBs in 4-5 hours.

Advantage

The primary advantage of plug-in charging is cost. Plug-in charging is the least expensive charging type. A plug-in charger typically costs approximately $1,000 per kW of charging capability. A 150-kW charger would cost approximately $150,000. Design and installation fees can add an additional 170 percent to the cost of a plug-in charger.

Disadvantage

The main disadvantages of plug-in charging are labor and safety. Plug-in charging necessitates WTA staff plugging vehicles into chargers and manually unplugging them before operation. WTA employees require instruction and training to use and store charging cables. Charging cables, for example, must be properly reconnected to their chargers when not in use so that no high-voltage cables are left lying around.

Overhead Conductive Charging

Overhead conductive charging is accomplished by attaching a motorized pantograph mechanism to an overhead gantry that powers the bus. This mechanism connects a pair of charging rails to the bus's roof charging rails. This charging method has some of the fastest charging speeds available, reaching up to 600 kW. This charging rate can reduce bus charging times by over 75 percent compared to plug-in chargers. These chargers are typically installed at the end of a bus route where there may be a layover or at an established stop within a bus route where the stop duration exceeds 5-10 minutes.

Advantage

For BEBs, overhead conductive charging provides the fastest charging speeds. Overhead charging minimizes the need for in-pavement infrastructure and reduces the number of obstacles that drivers must avoid. Furthermore, the gantry system can automatically connect overhead chargers (charging rails are lowered onto the bus) and does not require the bus driver to exit the bus to charge.

Disadvantage

Overhead conductive chargers have the most expensive installation costs. According to the National Renewable Energy Laboratory, an overhead conductive charger capable of delivering 600 kW of power can cost up to $750,000 depending on the installation site and local conditions.

Under-Vehicle Inductive Charging

Inductive charging requires the installation of in-pavement induction coils, which emit an electromagnetic field and wirelessly transfer energy to the vehicle's battery via an additional induction receiving plate installed on the bus's bottom. Wireless charging solutions are the least common of the three charging types, but they are gaining popularity. A new installation in Wenatchee, Washington, can charge at rates of up to 200 kW. Transit Cooperative Research Program Report 219 (Guidebook for Deploying Zero-emission Transit Buses, 2021) estimates

WTA Plug-in Charging Station

the cost of inductive chargers to be between $200,000 and $500,000 per charger (including installation).

Advantage

Under-vehicle inductive charging is similar to overhead conductive charging in that drivers do not need to be present to enable charging. This system also reduces the amount of at-grade infrastructure drivers must avoid.

Disadvantage

Because more than 10% of the energy is 'lost' during the wireless transfer, and charging speeds are typically slower than plug-in charging, this technology has historically been less efficient than traditional plug-in or overhead conductive charging. Since inductive charging is a much less common method of bus charging, the industry has not standardized the process.

On-Route Charging

When a bus's service block exceeds its usable onboard energy supply, on-route charging can quickly add energy into the battery to extend the range of a BEB.

All current on-route charging options necessitate stopping the bus. For on-route charging, buses would need to be stopped for at least 5 minutes per charge cycle. Driver disembarkation, charging equipment manipulation, battery load testing and assessment sequence performed by the charger, spool-up, run, and cool-down times, charger disengagement, driver re-board, checks, and bus mobilization are all included in this time. Even in an ideal scenario, the bus would take on approximately 20 kWh of energy with

Example of Overhead Charging

Photo courtesy of Momentum Dynamics

Example of Under-Vehicle Inductive Charging

a 450-kW charger during a 5 minute stop (with approximately a 3-minute total charge time at full rate). The additional 20 kWh of energy would be enough to drive an additional 5 to 8 miles. Despite the apparent benefit of a high-speed charger in extending range, this type of charging generates a significant amount of heat in the battery system, which has been shown in some applications to reduce long-term battery service life and performance.

On-route high-capacity pantograph chargers necessitate significant investments in additional equipment, such as on-bus hardware, increasing bus weight and electricity consumption. Furthermore, large and noisy cooling systems are required for high-capacity pantograph chargers to ensure that heat generated by the charger is adequately controlled, which means it may be unsuitable for certain locations due to customer and driver comfort concerns.

The other primary method of on-route charging is inductive charging. Inductive charging, as opposed to pantograph charging, is a newer technology that is still expensive and has yet to be widely tested in the field. In addition, there is a scarcity of manufacturer support and competing systems. Non-depot high-speed charging options, in general, necessitate additional equipment on the bus and complicate operations.

Bus Manufacturer Battery Options

Several manufacturers offer a variety of BEBs. Table 2 summarizes the various bus lengths, battery sizes, estimate range, and cost of today's electric buses.

Most manufacturers anticipate a 12-year service life for the bus's batteries, with some requiring an extended warranty to meet this expectation. Battery warranties vary, but most guarantee a certain percentage of original battery life for the life of the bus. Many buses also provide battery lease options, which reduce the initial cost of the bus purchase while adding a rental fee for

Table 2 - Existing Battery Electric Bus Manufacturers and Battery Capacities

Manufacturer	Model	Length (ft)	Battery Capacities	Cost ($ millions)	Procurement Lead Time
GILLIG	EBUS	40	440, 588, up to 686 kWh	$1.15	Approx. 24 months
PROTERRA	ZX5	40	225, 440, up to 675 kWh	$1.25	Approx. 24 months
		35	up to 450 kWh	$1.15	Approx. 24 months
NEW FLYER	Xcelsior Charge NG	35	350, 440 kWh	$1.15	Approx. 24 months
		40	350, 440, 525 kWh	$1.25	Approx. 24 months
		60	525 kWh	$1.4	Approx. 24 months
NOVA BUS	LFSE+	40	up to 564 kWh	$1.25	Approx. 24 months

Buses Currently Available that have passed Altoona testing and are available for FTA funding

the batteries (similar to purchasing daily fuel for a diesel bus). This rental is included to alleviate vehicle operators' concerns about battery degradation.

FCEB Technologies Defined

Battery-Dominant vs. Fuel Cell Dominant Configurations

There are two types of Fuel Cell bus propulsion systems. In their design, these are either battery-dominant or fuel cell-dominant.

In a battery-dominant design, the primary energy source is the battery energy storage system. During operation, the fuel cell provides a continuous charge to the batteries. The fuel cell operates to achieve maximum peak efficiency in order to provide the vehicle with the longest range possible.

In a fuel cell dominant design, the battery supplements the fuel cell during brief surges in power demand, such as when the bus exits a stop. The constant cycling of the fuel cell output causes inefficiencies. As a result, this system is rarely used in bus propulsion.

Fuel Storage On-board

The electrical energy in an FCEB is derived from hydrogen. Onboard the bus, the hydrogen is stored in cylindrical tanks similar to those used in current compressed natural gas (CNG) bus systems. The FCEB differs in that the hydrogen is stored at a significantly higher pressure of more than 5000 PSI. FCEBs typically weigh slightly less than their BEB counterparts.

Fuel Dispensing

FCEB's daily refueling is also similar to that of a current CNG bus. The same process is used to dispense hydrogen fuel in a gaseous state into the bus by attaching a nozzle to the bus. The system is programmed to monitor the bus onboard storage level and shuts down when the temperature compensated fill volume reaches 5000 PSI.

Liquid hydrogen storage tank

While CNG and FCEB refueling are very similar, the method of delivering and storing hydrogen to the bus fueling facility differs greatly. Currently, hydrogen is only available in large quantities as a gas or a liquid.

The gaseous delivery is typically made via a tube trailer that is linked to the bus facility fueling station and remains connected until the trailer storage is fully dispensed into the FCEB fleet. There are usually several trailers on-site to ensure continuous FECB refueling operations. When a trailer is completely depleted, another is sent to the bus terminal to replace the empty one.

The liquified hydrogen delivery system functions similarly to the diesel delivery systems that have been in use for decades. A trailer loaded with liquid hydrogen arrives at the bus terminal. The truck driver would then connect a hose to dispense the hydrogen between the trailer and a stationary storage tank. This system has the advantage of requiring a much smaller footprint at the bus terminal. It also provides resilience due to its ability to store quantities sufficient to sustain multiple days of transit operation.

There is an advantage to this system because it requires a much smaller footprint at the bus facility. It also provides resiliency with its ability to be designed to store quantities to sustain multiple days of transit operation.

Hydrogen Types and Availability

There are three main types of hydrogen production in use today: Grey Hydrogen, Blue Hydrogen and Green Hydrogen. These types of hydrogen differ in terms of their production methods and their environmental impact.

Grey hydrogen is the most common type of hydrogen produced today. It is produced from natural gas using a process called steam methane reforming (SMR). During SMR, natural gas is mixed with steam and heated in a reactor to produce hydrogen and carbon dioxide. Grey hydrogen is considered “grey” because the carbon dioxide produced during SMR is typically released into the atmosphere, contributing to greenhouse gas emissions.

Blue hydrogen is produced in a similar way to grey hydrogen, but with an added step to capture and store the carbon dioxide produced during SMR. This process is called carbon capture and storage (CCS). Blue hydrogen is considered more environmentally friendly than grey hydrogen because the carbon dioxide emissions are mostly captured and stored, reducing the impact on the environment.

Green hydrogen is produced through the electrolysis of water using renewable electricity, such

	Grey Hydrogen	Blue Hydrogen	Green Hydrogen
Process	**Reforming or gasification**	**Reforming or gasification with carbon capture**	**Electrolysis**
Energy Source	**Fossil fuels**	**Fossil fuels**	**Renewable electricity**
Estimated Emissions from Production Process (lbs of CO2e/kg of hydrogen)	**Reforming: 9-11** **Gasification: 18-20**	**0.4-4.5**	**0**

Selected color-coded typology of hydrogen production

as solar, wind or hydropower. This process splits water molecules into hydrogen and oxygen, with the hydrogen being collected and used as fuel. Green hydrogen is considered the most environmentally friendly form of hydrogen production because it does not produce any greenhouse gas emissions. However, it is typically more expensive than grey or blue hydrogen due to the amount of electricity required.

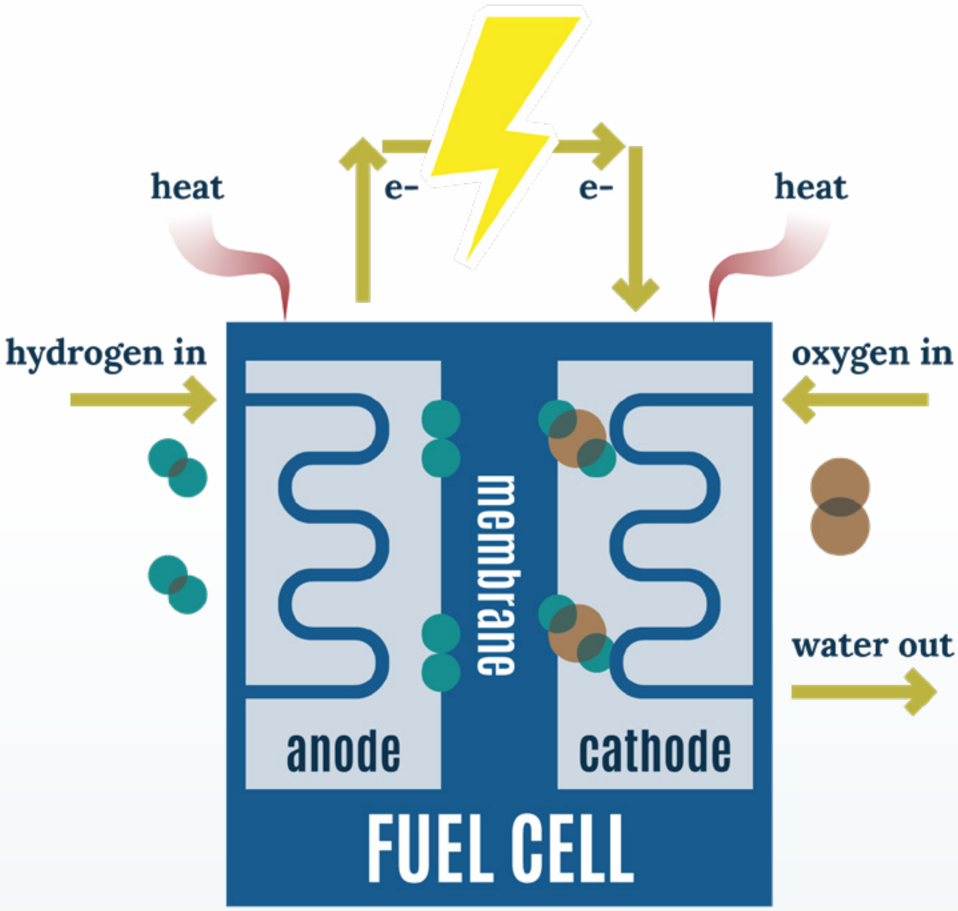
Commercial hydrogen currently has very limited availability. Hydrogen has a minimal number of commercial applications (fossil fuel processing, food refinement and fertilizer production). Hydrogen is currently being produced by two companies in Washington State:

» BP West Coast Products LLC

» Air Liquide in Kalama, WA

Additionally, The Douglas County Public Utility District is currently constructing a green hydrogen plant in East Wenatchee, which is expected to open soon. The plant's electrolyzers will be powered by dams on the Columbia River, producing green hydrogen, and have the capacity to accommodate up to 80 MW of green hydrogen production.

However, in the near term, hydrogen generation and distribution facilities are likely to remain scarce, posing obstacles to widespread adoption of FCEBs. Identification of a reliable, nearby source of hydrogen, such as the plant in East Wenatchee, will be critical to potential adoption of FCEBs. Transporting hydrogen over long distances is expensive and will limit WTA's ability to operate FCEBs. While WTA could theoretically build an electrolyzer on site to generate their own hydrogen, this was not examined



1. **Hydrogen atoms enter the anode**
2. **Atoms are stripped of their electrons in the anode**
3. **Positively charged protons pass through the membrane to the cathode and the negatively charged electrons are forced through a circuit, generating electricity**
4. **After passing through the circuit, the electrons combine with the protons and oxygen from the air to generate the fuel cell's byproducts: water and heat**

Figure 5 - How a Fuel Cell Works

in detail within this report due to the vast capital expense required.

Fuel Cells

The fuel cell system on an FCEB is typically sized for the duty cycle of the bus as it is intended to be operated. Buses that are used in city service would typically utilize a larger fuel cell due to the constant stop start operation. Buses that are primarily dispatched for highway operations such as express would not require a design that matches the constant speed operations of these service types. Figure 5 shows a description of how a fuel cell operates.

Table 3. Existing Fuel Cell Electric Bus Manufacturers

Manufacturer	Bus Model	Bus Length	Fuel Cell Power	Battery Capacity	OEM-Advertised Range	Cost
ENC	Axess-FC	35’	100kW	Not provided	225+ mi	$1.15 M
		40-ft	100kW	Not provided	260+ mi	$1.25 M
NEW FLYER	XcelsiorCHARGE H_2	40-ft	160kW	150kWh	350	$1.25 M
		60’	320kW	150kWh	300	$1.55 M

Battery Packs

The high-voltage battery stores energy generated by the fuel cell and regenerative braking, which powers the electric traction motor as well as all onboard electrical components such as the HVAC system, air compressor system for brakes and suspension, steering, lighting, and numerous other accessory systems. The battery is designed similarly to that found in BEBs. The FCEB design has a slightly different usage cycle. The SOC rarely falls below 50 percent and then recharges at a moderate rate. This recharging reduces battery degradation and significantly increases the life of this component. Table 3 summarizes the current FCEB offerings by manufacturer, price, and advertised range.

Table 4. Summary of ZEB Adoption and Operational Challenges

Challenges to Adoption and Operation*	Battery Electric Buses	Fuel Cell Electric Buses
Vehicle Cost	~ 2X diesel bus	More than 2X diesel bus
Infrastructure Cost	Very High	Very High
Range	Less than ½ of diesel bus	¾ of diesel bus range
Fueling Logistics	Hours to Charge	Minutes to Fuel
Available Fuel Source	Electricity not constrained	Lack of Available H_2

Limited to no impact to WTA funding or operation

Large impact on WTA funding or operation

**Not all challenges to adoption are equally important.*

Challenges to Zero-Emission Bus Adoption

There are several difficulties to consider with the adoption and operation of a fully zero-emission fleet. First and foremost, the cost of ZEBs and the required infrastructure upgrades is significantly higher than the cost of purchasing internal combustion engine (ICE) buses.

ZEBs have driving ranges shorter than ICE buses. On average, a BEB has less than half of the range of a diesel bus. While FCEBs have significantly more range than BEBs, they do not yet have equivalent ranges to diesel buses. In addition to range constraints, recharging a BEB takes hours. Plug-in depot charging, like those that WTA currently uses, can take 3 to 5 hours to charge a bus. High power pantograph chargers can recharge buses significantly faster, but have much larger capital costs.

Finally, FCEB are powered by hydrogen, which at the time of this report the supply of hydrogen, whether generated on-site or off-site, remains very limited and requires significant upfront costs. Electricity availability is not likely to be a constraint for WTA, but bulk power delivery from PSE will likely require additional infrastructure upgrades. Table 4 summarizes the existing barriers to adoption and operation of a fully zero-emission fleet for both BEB and FCEBs.

Chapter 3
Policy and Strategy Summary

The purpose of this section is to summarize the federal, state, and local policy and statutory requirements for adopting zero-emission vehicle technologies. Local community interest, policy requirements and WTA's own sustainability goals are the foundation of WTA's interest in pursuing a zero-emission fleet.

This section also outlines potential funding sources for WTA to procure a fleet of ZEBs.

Funding Assessment

WTA allocates funds based on an established procurement timeline determined by the useful life of its buses. Transitioning to a zero-emission bus fleet increases overall fleet costs because of the incremental cost of zero-emission buses, the installation of new infrastructure, and required modifications to maintenance facilities. The current market cost of zero-emission buses is between $850,000 and $1,400,000, which is approximately $250,000 to $700,000 more expensive than diesel buses. Additionally, the necessary infrastructure to support these zero-emission buses adds to the financial burden of transitioning to a zero-emission fleet. The added infrastructure costs vary by propulsion type. BEBs require chargers which can cost between $150,000-$750,000 per charger depending on capacity and configuration. FCEBs require the installation of an onsite liquified hydrogen tank that costs approximately $4.5 million and would support up to 50 FCEBs.

For this Zero-Emission Fleet Study, vehicle and infrastructure costs are assessed individually in Chapter 6. The results of those cost assessments are compiled here as total costs and then compared to WTA's budget to better understand funding gaps and needs.

WTA's Funding Needs

To achieve WTA's goals and move towards a successful deployment of zero-emission buses, WTA will require an estimated $175 million in funding to cover the procurement of vehicles and infrastructure during the transition time period.

WTA already operates two battery electric buses. Over the course of the transition period, WTA plans to deploy 71 additional 40-ft zero-emission buses (total of 73 ZEBs in operation by 2040, which includes both replacement and estimated expansion vehicles.) WTA plans to deploy additional zero-emission cutaways and other service vehicles. Depending on the ZEB technology of choice, WTA may deploy up to 60 additional chargers, incurring an additional 1.5 megawatts of electricity demand by 2040.

Available Funding Resources & Resulting Funding Shortfalls

WTA has maintained adequate cash flow due to larger than anticipated sales tax revenue and federal relief packages despite reduced ridership and being fare-free during much of the pandemic. WTA has reserves for unexpected operating expenses, fleet replacement and expansion, and other capital projects. However, WTA is currently not able to fund the entire capital cost needed to support the transition to a 100 percent zero-emission fleet.

Based on the funding needs identified above and an assessment of WTA's current projections, WTA must identify resources to cover this funding gap. As done for diesel vehicle replacements, traditional federal formula funding can be applied to the cost of zero-emission vehicle replacements, but it is unlikely that the formula grants will be available to cover the full cost of zero-emission technology and associated infrastructure improvements. Additional sources of funding beyond WTA and formula grants will be needed to make the transition.

WTA plans to pursue funding opportunities at the federal, state, and local levels, as available and sequenced with bus replacement needs.

Federal Funding sources WTA is considering include:

United States Department of Transportation (USDOT)

Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Grants

This program was formerly known as Better Utilizing Investments to Leverage Development (Build) and Transportation Investment Generating Economic Recovery (Tiger), and it was first created in the 2009 Recover Act. The RAISE program provides a unique opportunity for the USDOT to invest in road, rail, transit, and other projects that aim to achieve national goals.

Federal Transportation Administration (FTA)

Bus and Bus Facilities Discretionary Grant

The Grants for Buses and Bus Facilities Competitive Program allocates federal funding to states and direct recipients for purposes of replacing, rehabilitating, and purchasing of buses and equipment, including technological improvements and innovations to modify low or no (Low-No) emission vehicles or facilities. The funding is available through competitive grants and formula allocations.

Low-or No-Emission Vehicle Grant

The Low or No Emission competitive program is available to help modernize bus fleets and bus facilities across the nation. Transit agencies can use this grant to purchase or lease low- or no- emission vehicles that use advanced technologies to fight against climate change and improve air quality. They can also be used for the purchase, construction, and leasing of required supporting facilities. WTA has received funding for buses and charging equipment from this source.

Urbanized Area Formula Grants

The Urbanized Area Formula Funding program makes federal resources available to urbanized areas and to governors for transit capital and operating assistance for transportation-related planning. Funds are apportioned based on legislative formulas.

State of Good Repair Grants

The State of Good Repair Grants Program offers capital support for high-intensity fixed guideway and bus system maintenance, replacement, and rehabilitation projects, to help transit agencies keep their assets in good conditions. Funds are apportioned based on statutory formulas

Flexible Funding Program – Surface Transportation Block Grant Program

Provides funding that states and municipalities can utilize for a variety of surface transportation projects such as highway, transit, intercity, bus, bicycle, and pedestrian projects, in order to maintain and enhance their performance.

Environmental Protection Agency (EPA)

Environmental Justice Collaborative Problem-Solving (EJCPS) Cooperative Agreement Program

The EJCPS Cooperative Agreement Program offers financial support to qualifying organizations working on or planning to work on initiatives that address local environmental and/or public health challenges in their communities. In order to create solutions that will significantly address environmental and/or public health issues at the local level, the program helps recipients form cooperative partnerships with other stakeholders (such as local businesses and industry, local government, medical service providers, academia, etc.) Additionally, the EJCPS Program requires a number of applicants or recipients to use the EPA's EJCPS Model as part of their projects.

Washington State Department of Transportation

Green Transportation Capital Grants

The Green Transportation Capital Grants help transit agencies with funding assistance for cost-effective capital projects that reduce the carbon intensity of the Washington transportation system. It is anticipated that $12 million and up to $50 million in state funding will be available for this program in the 2023-2025 biennium. Any transit agency in Washington State is an eligible applicant. Electrification of vehicle fleets, such as battery and fuel cell operated electric vehicles is one of the eligible capital projects for this type of grant. WTA received approximately $2 million in 2020 towards electric buses and chargers from this source.

Public Transit Rideshare Grant

The Public Transit Rideshare grant program–formerly the Vanpool Investment Program–supports rideshare programs at transit agencies across Washington.

Transit agencies use these grant funds to expand rideshare fleets, replace aging rideshare vehicles, and provide incentives to employers to increase ridership. The funding allows transit agencies to purchase rideshare vehicles with alternative fuel types, including low-emission plug-in hybrids and zero-emission all-electric vehicles. WSDOT anticipates awarding up to $10 million during the 2023-2025 biennium.

City of Bellingham

Transportation Levy Fund

The Transportation Fund (TF) is specific to transportation improvement projects in Bellingham and comes from two-tenths of one percent (2/10ths of 1 percent) sales tax on all consumer goods bought within the limits of the City of Bellingham. This voter-approved TF sales tax can generate over $5 million dollars over the course of a year. Up to $500,000 is earmarked for Climate Action Plan and Transit Capital projects.

Policy Assessment

As efforts to de-carbonize the transportation sector expand, policies and regulations supporting the transition to zero-emission are proliferating. WTA is keeping an eye on the implementation of relevant policies and legislation. While relevant funding programs are considered in the Funding Needs Assessment above, this section considers policies and regulations that direct aspects of zero-emission transit deployments other than funding. Throughout the fleet transition, WTA will continue to thoroughly assess all relevant policies and legislation.

Alignment with Federal Priorities and Policies

With the passage of the Bipartisan Infrastructure Law and Executive Order 14008: Tackling the Climate Crisis at Home and Abroad, the federal government has set a renewed focus on zero-emission transit. WTA's goal to deploy zero-emission buses supports the Federal Transit Administration's priorities of safety, modernization, climate, and equity for public transportation. In Whatcom County, 60 percent of people living in poverty live within a quarter mile of a WTA bus stop. Transitioning to electric buses will reduce air and noise pollution, especially for people who live, work or recreate along a transit corridor.

Washington State Policies & Goals

The State of Washington has enacted numerous pieces of legislation and regulations that target emissions reductions both statewide and in specific sectors. The state requires reductions in overall greenhouse gas (GHG) emissions, with the goals of 25 percent below 1990 levels by 2035 and 50 percent below 1990 levels (or 70 percent below the state's expected emissions that year) by 2050. In 2019, Governor Inslee signed the Clean Energy Transformation Act into law, committing utilities within the state to produce electricity that is free of GHG emissions by 2045.

Clean Fuel Standard

In 2021, the state legislature passed the Clean Fuel Standard, which orders the development of rules to reduce the overall carbon intensity of transportation fuels used in the state by 20 percent below 2017 levels by 2035. Under the Clean Fuel Standard, fuels will be assessed to determine their carbon intensity. Cleaner fuels, those with a carbon intensity below the standard, will generate credits that can be kept or sold to producers of high-carbon fuels. Fuels with a carbon intensity above the standard will generate deficits. Those producers must then buy enough credits to meet the carbon-intensity reduction for that year. The requirement to reduce carbon intensity increases over time, making sure all transportation fuels decrease their emissions.

Puget Sound Energy

Puget Sound Energy is under mandate from Washington State Law to reduce greenhouse gas emissions from electricity generation. The Clean Energy Transformation Act (CETA) commits all utilities within Washington State to GHG-free electricity generation by 2045. The current mix of power sources generating PSE electricity is summarized in Figure 6.

WA State Climate Commitment Act

The Climate Commitment Act (CCA) caps and reduces greenhouse gas (GHG) emissions from Washington's largest emitting sources and industries, allowing businesses to find the most efficient path to lower carbon emissions. This program works alongside other critical climate policies to help Washington achieve its commitment to reducing GHG emissions by 95 percent by 2050. This program works by setting an emissions limit, or cap, and then lowering that cap over time to ensure Washington meets the GHG reduction commitments set in state law.

ZEV Infrastructure Partnership Program (ZEVIP)

The Zero-Emission Vehicle Infrastructure Partnerships (ZEVIP) is a Washington State Department of Transportation (WSDOT) grant that provides funding for the installation of new electric vehicle charging equipment and hydrogen fueling infrastructure along priority corridors. Priority corridors for EV charging infrastructure include only state routes. For EV charging, stations should be located at least every 50 miles and within one travel mile of the priority corridor. Priority corridors for hydrogen fueling infrastructure include Interstates, U.S. routes, and state routes. Hydrogen stations should be located at least every 150 miles and within five travel miles of the priority corridor. Nonprofit organizations, tribes, and state and local government agencies such as cities, towns, counties, and districts are eligible to apply. Potential grant recipients must partner with private-sector organizations to develop and implement their projects.

2021 PSE Mix

Hydroelectric	24%
Wind	9%
Solar	1%
Nuclear	<1%
Coal	23%
Natural Gas	27%
Other	1%
Unspecified	14%
Total	**100%**

renewable energy

CO2 FREE

2045 PSE Mix

100% Carbon-free electric supply

Figure 6 - PSE Energy Mix

Washington State Bill 5910

SB 5910, "Accelerating the availability and use of renewable hydrogen in Washington State" was signed on March 31, 2022. SB 5910 was designed to help Washington become a "national and global leader" in the production and use of renewable hydrogen. The bill created an Office of Renewable Fuels within the Washington State Department of Commerce to advance the production and use of fuels made from renewable resources.

WTA's Transition Study considers these goals and aims to contribute to both local and statewide emission reduction efforts.

Support for Local Policy Goals

City of Bellingham's Climate Protection Action Plan

The City of Bellingham's 2018 Climate Action Plan Update includes six core strategies. Under 'Transportation,' switching from fuel powered vehicles to electric vehicles is named as a primary measure. Section 5 of the Council Resolution identifies the following as greenhouse gas (GHG) reduction ambitions: 100 percent renewable energy for community heating and transportation by 2035.

The City of Bellingham aims to further reduce municipal greenhouse gas emissions to 85 percent below 2000 levels by 2030 and 100 percent below 2000 levels by 2050 – making the city government carbon neutral. The new community emissions targets are 70 percent below 2000 levels by 2030 and 85 percent by 2050.

Whatcom County Climate Action Plan

The 2021 Whatcom County Climate Action Plan has a goal in the Transportation Chapter to "Reduce transportation-related GHG emissions 45 percent below 1990 levels by 2030, including eliminating fossil fuels from County government transportation operations where technology permits, while ensuring climate-resilient transportation systems.

WTA 2040

WTA 2040, WTA's long range transit plan, established three priorities for the agency: Equity, Efficiency and Environment. Goal #4 of the Plan states that WTA will serve as stewards of the environment, and that it will decrease carbon emissions from their transit operations, partner with others in local and regional carbon-reduction efforts, and work to improve the viability and attractiveness of walking, rolling, biking and transit. A key strategy is to "Pursue grant funding to support the transition to a zero-emission fleet by 2040."

WTA Sustainability Plan

The WTA Sustainability Plan lays out four key goals and eighteen strategies to help WTA reduce their carbon footprint. Goal #3 is "transition to zero emission fleet and facilities."

City of Bellingham Climate Protection Action Plan

Chapter 4
Route Planning and Analysis

A Performance and Evaluation of Electric Bus Routes (PEER) Analysis and Modeling simulation was run to estimate the energy required to service WTA's existing routes. Assuming an all-electric bus fleet, this simulation was performed on all weekday transit service blocks. This simulation will aid in operational and financial decisions during fleet electrification, including planning, staging, and phasing.

In this report, only the highlights and key takeaways of the PEER analysis are presented. A full technical report is found in Appendix A.

The project team analyzed WTA routes and OEM bus specifications and ran simulations on Gillig 40-ft buses at various ambient temperatures to compare energy consumptions per route, analyzed overall block completions, and remaining SOC while operating on existing service schedules. The team also calculated the power needed to recharge a fully electric fleet at MOAB.

Table 5 - Percent of WTA Blocks that can be completed with a new 40-ft Gillig BEB'

Winter (no added diesel heater)	Winter (with diesel heater)	Spring/Fall	Summer
67%	81%	90%	89%

Table 5 provides an overview of the completion rates for WTA's existing schedule under four different temperature scenarios, using the specifications of a Gillig 40-ft bus with a new 588 kWh battery. The completion rate is defined as the percent of WTA's existing block schedule that can be completed using a BEB. A block is what a bus is scheduled to do during a given driver shift.

Table 5 shows that the simulation performed during Fall/Spring (at 59°F) yields the best completeability results due to the lowest load on the HVAC system and thus more energy being available for the traction motor. In contrast, simulations performed during the winter with no additional diesel heater (11°F to simulate worst case winter conditions, with typical winter conditions being warmer) have the lowest completeability. Without additional diesel heaters, the heating load on the HVAC system in the winter greatly diminishes the buses range.

Assuming charge management to level demand, the maximum load at MOAB was calculated to be 1,560 kW. This load assumes WTA's future fixed route BEB fleet will have adequate battery capacity to function as a one-to-one replacement for existing diesel buses. Future battery capacity assumptions are summarized in Chapter 2.

Assumptions

The analysis model simulates whether currently available battery-electric buses have sufficient range to complete each block in the current service schedule.

The following is a list of inputs that have been used to perform the PEER modeling and simulation:

» Elevation and location of each bus stop
» Passenger loads
» Four different ambient temperature profiles
  - 91°F ambient temperature for summer operation
  - 59°F ambient temperature for typical spring/fall operations
  - 41°F ambient temperature to simulate winter operation with a diesel fueled heater
  - 11°F ambient temperature to simulate winter operation without a diesel fueled heater
» 68°F as the interior desired temperature
» 40-foot bus technical characteristics
» GTFS file provided to match current schedules, blocks, routes, and operating environment, as well as supplementary data indicating block lengths and deadhead distances
» New, degraded, and estimated future batteries.

Bus Types Considered

Since WTA's fleet consisted predominantly of 40-ft buses, the following specification of a 40-ft bus was used.

- *40-ft bus with a battery capacity of 588 kWh (e.g., Gillig BEB 40-ft specifications)*
- *40-ft bus with an assumed future battery capacity of 800 kWh (e.g. future Gillig BEB 40-ft specifications)*

Ambient Temperature's effect on BEBs

The interior heating requirement has not been a problem for many decades due to the abundance of waste heat available from the internal combustion engine and transmission systems that propelled the bus. With the introduction of all-electric propulsion, the resource to heat the bus interior must now be obtained using systems and components that require electrical energy to maintain the bus interior temperature. When compared to summertime operations, this significantly reduces the bus's operating range. The simulation tool calculates the total energy requirement by using historical ambient temperatures for the WTA service region and desired bus interior temperatures as inputs.

In the simulations, the highest ambient temperature of 91°F was used as a worst-case scenario for the needs of cooling the bus interior. The lowest ambient temperature used, on the other hand, is 11°F to estimate worst case conditions without the use of additional diesel heating. It is critical to understand the bus's operating range on the most extreme days, as this will determine whether the bus can be used consistently throughout the year.

Use of Diesel Fueled Heaters

For winter operations, electric buses are typically equipped with a diesel fueled heater (DFH) that activates when the ambient temperature is 41° F or lower.

At ambient temperatures of 41°F or higher, the electric heater is typically used in a BEB. When the ambient temperature falls below 41°F, the DFH is activated. As a result, when the DFH takes over from the electric heater, a BEB with a DFH will consume more battery energy above 41°F than it would at 41°F and lower.

The analysis in this report considers two winter operating scenarios. The first scenario involves a bus that lacks a DFH. The simulation for this scenario is run at Winter ambient temperature of 11°F. The simulation at this temperature is meant to demonstrate the relative importance of using a DFH and the viability of eliminating it in the future as battery technology advances, despite temperatures rarely reaching 11°F in WTA's service area.

The second winter operating simulation scenario is run at 41°F to capture the worst electrical energy consumption that a DFH-equipped bus will experience. Because DFHs will

Table 6. WTA Block completion Summary for 40-ft Bus

Temperature Scenario	Number of Blocks	New Battery		Degraded Battery	
		Blocks Completable	Completion Percentage	Blocks Completable	Completion Percentage
Winter w/o DFH	72	48	67%	41	57%
Winter w/ DFH	72	58	81%	50	69%
Spring/Fall	72	65	90%	57	79%
Summer	72	64	89%	54	75%

almost certainly be used to increase range during the winter, this scenario is more realistic for the near term and the current level of battery energy capacity. It's important to note that even though the simulation is run at 41°F for this scenario, the results are still valid for lower temperatures because the heat required is provided by the DFH and does not increase the electrical load on the battery.

Simulation Results

PEER, as stated in the introduction, models how well BEBs can complete blocks under various operating scenarios. A block is completed when a BEB has enough stored battery power to leave MOAB, travel to its starting point, finish all assigned work, and return to MOAB.

The PEER model was used by the project team to assess how well different battery capacities, using winter heating solutions, could complete WTA's 2021 block schedule.

Block and Range Analysis - New vs Degraded Battery

Table 6 shows the number and percentage of existing WTA weekday block assignments that could be completed with a 588 kWh Gillig 40-ft BEB with both a new battery and a degraded battery during four ambient temperature scenarios.

The best completability is observed during Spring/Fall temperatures, due to the lower load on the HVAC system. Conversely, peak winter temperatures have the lowest completability due to the high demands of the HVAC system on the battery.

As described in Chapter 2, battery degradation "removes" 20 percent of the available energy. As shown in Table 6, the number of completable blocks during Winter with DFH conditions decreased by 8 blocks, or 12 percent. For the purposes of route planning with BEBs, it is critical to plan for this expected worst case scenario so that buses are not assigned to routes that they will not be able to complete during winter months and/or when their batteries degrade.

Block Combination Analysis

To more accurately capture WTA operational requirements, WTA blocks were combined into block combinations. A block combination is equivalent to what a bus does on any given day. One bus will likely run multiple routes, and complete multiples blocks during the course of it's daily operation.

WTA blocks were combined based on each bus's availability and charge status at the end of an existing block. Based on its mileage, energy consumption, start time and end time, the analysis determined whether a block could be combined with a later block. Incomplete blocks are still counted in the total number of weekday block combinations.

Figure 7 depicts the number and length of weekday blocks operated by WTA. The schedule derived from the GTFS data is depicted on the left. The combined block schedule is depicted on the right. Blue represents time spent servicing a block, while yellow represents time spent at MOAB, where the bus receives a mid-day charge. Red represents time where the range needs of the block could not be met (i.e. the bus ran out of charge).

Given the 72 individual blocks on WTAs schedule (left), they can be combined into a schedule of 49 combined blocks (right). The number of combined blocks determines the number of buses needed to operate on a day-to-day basis (not including spare ratio buses). Figure 7 shows that 27 of the 49 combined blocks would be completable with existing 40-ft BEB technology with a degraded battery.

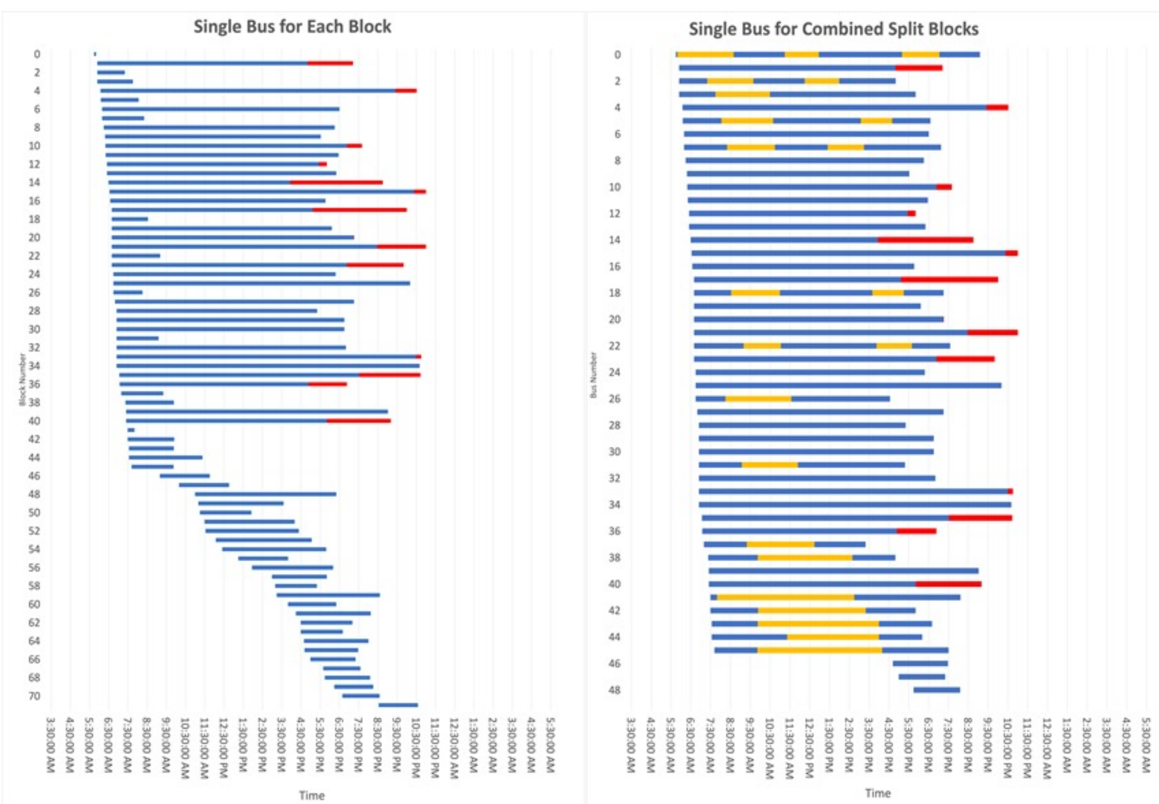


Figure 7 - WTA Original Block Schedule (left) and Combined Block Schedule (right)

LEGEND

- Bus in operation
- Time charging
- Incompletable portion

Future Battery Technology

The PEER system-wide analysis was also performed for future battery technology (800kWh) as described in Chapter 2. Table 7 compares the number and percentage of WTA's existing weekday block combinations that could be completed in winter with DFH conditions for both existing and future battery scenarios.

The results shown in Table 7 indicate that 47 of 49 block combinations would be completable with a future nominal battery capacity of 800 kWh. Table 8 shows the specific blocks that cannot be completed, even with expected future battery technology.

These incompletable blocks require either a future battery capacity of more than 800 kWh, a schedule change, on route charging, or a combination of multiple buses serving the block.

The project team completed a re-blocking analysis to check the theoretical possibility of recombing block schedules to mitigate the two incompletable blocks. To do this, the two incompletable blocks were split into four shorter blocks. With the additional blocks, WTA's weekday schedule would have 74 blocks to be combined into block schedules. The re-blocking analysis was used again on the theoretical 74 blocks. The results found that WTA would be able to complete all 74 blocks in 49 combined block schedules, or with 49 buses. This block recombination process is summarized on Figure 8.

Table 8. WTA Incompletable Routes for 40-ft Bus

Block ID	Route ID(s)	On-Route Travel Before Failure (miles)	Miles needed to complete block (after battery dies)
WM-2	26, 29	191.43	97.19
512-1	512	190.64	89.16

The block recombination results suggest that with minor schedule tweaks and no additional vehicles in operation, WTA would be able to meet all of its fixed route service needs with a future battery capacity of 800 kWh.

Table 7. Existing Battery vs Future Battery Completable Block Combinations (Winter w/ DFH)

Battery Type	# of Block Combinations	Blocks Combinations Completable	Completion Percent-age
Existing (588 kWh) Degraded Battery	49	27	55%
Future (800 kWh) Degraded Battery	49	47	96%

72 Scheduled Blocks *(Existing Schedule)*		**74 Theoretical Blocks** *(Completable Schedule)*		**49 Block Combinations** *(Minimum Required Fleet Size)*	
# of Blocks	72 (70/2)	# of Blocks	72 (+2)	# of Vehicles	49 (+0)
Combinations	49 (47/2)	Completable	**100%**	Completable	**100%**

Figure 8. Block Recombing with Future 800 kWh nominal battery capacity

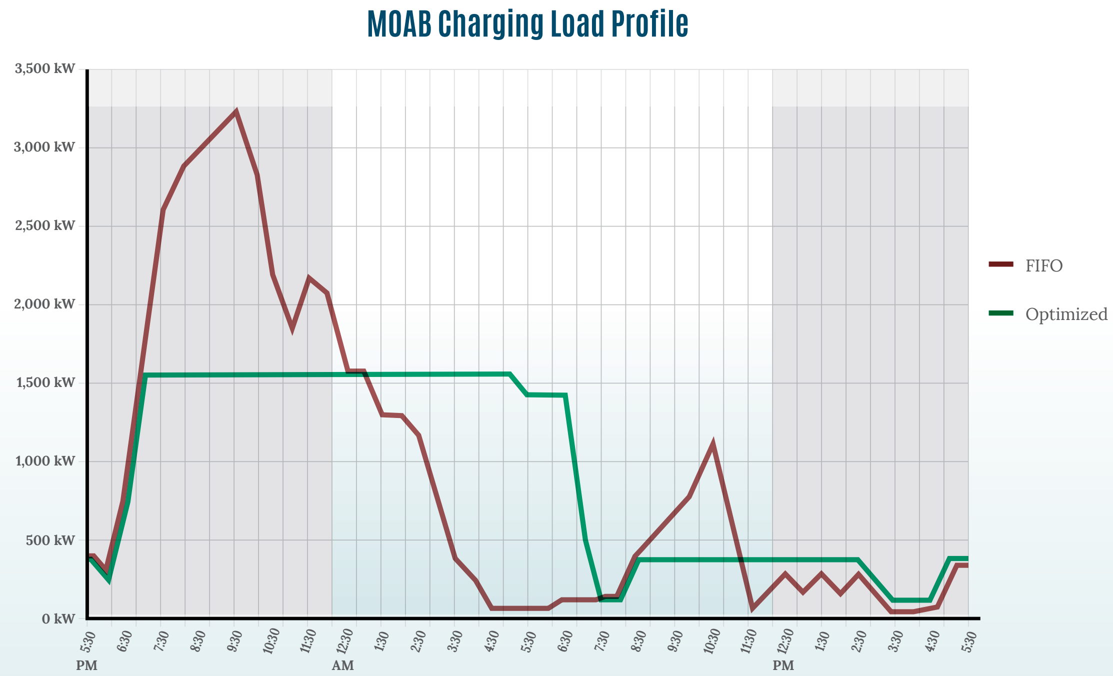


Figure 9 - MOAB Charging Load Profile (Assuming 100% BEB Fleet)

The load is based on an assumed 130 kW charge rate for WTA buses. In reality, the bus's charge acceptance rate will be determined by factors such as onboard OEM software, battery SOC, charger capability, and the batteries themselves.

Power and Energy Requirements

The PEER simulation provides information on each bus's remaining SOC when it returns to MOAB after completing daily operations. Based on the needed energy to reach 100 percent charge, the total power requirements (kWh) can be estimated for the entire WTA bus fleet. These arrival and departure times can then be used to determine the available charging time at the depot and the number of buses at the depot that require charging simultaneously.

Figure 9 depicts MOAB's electrical load profile (assuming an all-electric fleet) on a typical winter day (with DFH) for a weekday schedule assuming future batteries. This chart is meant to show the maximum anticipated power demand at MOAB if WTA procures an all BEB fleet.

Figure 9 shows two charge scenarios, first-in first-out (FIFO) and optimized. Under the FIFO condition, buses will begin charging when they return to MOAB and will charge until completed. The optimized scenario attempts to group bus charging so that all charging takes place during off-peak hours and to minimize demand peaks by load levelling. Load levelling reduces electricity demand charges from PSE and may also reduce the electrical infrastructure upgrades required. This load levelling can be accomplished automatically

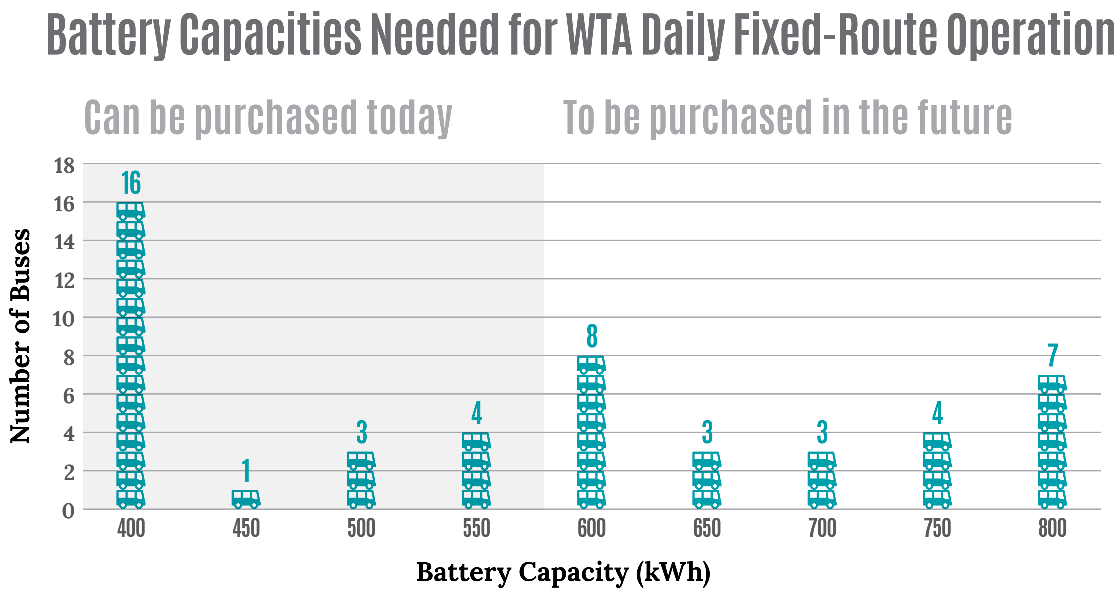


Figure 10. Buses by Battery Capacity needed for Daily Operation

through charge management software. WTA has already purchased ViriCiti, a charge management software, for their existing BEBs.

WTA is also installing a plug-in charger at its Cordata Station, and is planning to install an additional charger at the Bellingham Station as part of the ongoing station expansion. These additional chargers will provide range boosts to routes that layover at either of these two locations. However, any mid-day charging at these locations was not included in the PEER modeling to add additional conservatism.

Conclusion and Recommendations

The PEER modeling results showed that existing battery technology can meet approximately 50 percent of WTA's current needs. These results are for typical winter conditions with a degraded battery. The modeling results also showed that for a future nominal battery capacity of 800 kWh, 96 percent of WTA's existing block schedules could be operated by BEBs with no impact to schedule or fleet size. However, with minor schedule adjustments all of WTA's fixed route needs could be met with an 800 kWh nominal battery size. Figure 10 shows the breakdown of required battery capacities to meet all of WTA's fixed route needs.

49 buses are currently required to meet WTA's daily operational needs.

Figure 10 shows that 24 buses could be operated with existing BEB technology. Future battery improvements are needed for WTA to replace the other 25 diesel and hybrid buses with BEBs at a one-to-one ratio.

Given these results, WTA could continue procuring BEBs until approximately 50 percent of their fixed-route fleet was BEB with existing technology. Based on WTA's current replacement schedule, this would not occur until approximately 2033. By 2033 it is anticipated that BEB technology will have improved, allowing WTA to either continue procuring BEBs with the higher energy densities or begin procuring FCEBs.

Unless FCEBs gain significant advantages in the next few years (commercialized cheap hydrogen) it is anticipated that WTA will expand its BEB fleet first to meet its goals.

To meet the needs of an expanding BEB fleet, site upgrades will be needed at MOAB. These site updates primarily include:

» **Ensure electrical capacity up to 2 MW**. The MOAB load curves in Figure 9 showed that with proper charge management, WTA would need a theoretical maximum 1.56 MW peak load. However, it is recommended that WTA build in some additional capacity so no future grid enhancements are necessary.

» **Additional charging infrastructure**. Additional BEBs will require additional chargers. WTA will need to add either plug-in, overhead pantograph, or induction chargers to MOAB.

» **Backup Generators**. In case of power outages, WTA will need backup generators to charge their fleet. Generators will be needed once WTA does not have enough spare diesel and hybrid buses to meet daily operational needs, assuming the BEB fleet is completely unavailable (i.e. when WTA does not have 49 diesel and/or hybrid buses).

Further detail about site upgrades and additional considerations are discussed in Chapter 5.

Chapter 5 Facility Needs

On August 17, 2022, the project team visited the Maintenance/ Operations/Administration Base (MOAB) and associated Midway and North Lot sites to assess current facility conditions and how these facilities may be impacted by the transition to a zero-emission fleet. The site visit and evaluation focused on the yard, maintenance facility, and service lanes. We recognize that additional administrative and operational space is required, but this was not considered as part of this study.

The MOAB facility, which was built in the early 2000s, has been maintained in excellent condition. The facility modifications required for ZEB implementation will be determined by the propulsion system or systems of choice. Both propulsion types will require staff training in addition to infrastructure upgrades. Staff training needs are discussed at the end of this chapter.

BEB Infrastructure Needs

Bus Chargers and Electrical Infrastructure Upgrades

The most significant infrastructure upgrades required for BEB deployment are chargers and associated electric equipment. It is anticipated that WTA would install DC to DC rectifier systems to provide DC current directly to bus chargers. These DC to DC rectifier systems are based on traction power

Pantograph bus charging example

systems used in light and heavy rail (subway) transportation systems. Several manufacturers are currently marketing or will soon be marketing DC to DC rectifier systems. These systems operate at medium voltage (12kV - 70kV) and significantly reduce the utility company's hardware needs. The system is metered at this "primary" voltage and then distributed directly to unitized systems throughout the site. These systems are installed as large containers.

The charging container is made up of a transformer, a DC rectifier, and several modular charging blocks, the number of which depends on the desired output. DC power is then distributed directly to the charging technology of choice (plug-in, overhead pantograph or under-vehicle inductive). Current systems have a 3MW capacity, enough to charge up to 20 BEBs at 150kW simultaneously. Charging rates can be further customized using a charge management system so WTA could charge more buses at a lower rate. Full buildout of the site would likely require between two and four DC to DC rectifier systems, depending on WTA's charging requirements. A DC to DC rectifier system is recommended because they largely eliminate the need for switchboards and transformer installations/upgrades on the utility side, as well as reduce switchgear on the WTA side of the utility meter.

It is recommended that DC power distribution from the charging container to the pantograph or plug-in chargers be overhead. As pantographs require an overhead gantry for support, the gantry becomes a conduit or cable tray for accessible cable distribution. Running the power overhead allows for modifications and keeps workers above and out of the way of vehicles traversing the site.


Hitachi ABB DC Rectifier System

Maintenance Bay Changes

Site improvements include modifications to the repair bays to facilitate access to the bus's roof within the repair bays. BEB batteries are often housed on the bus's roof. The rooftop-mounted equipment necessitate more frequent roof access for inspections and maintenance. WTA's maintenance facility currently has a movable gantry crane that could be used for this purpose and to replace air conditioning units. However, installing a 1-ton monorail crane in one bay would be safer and more efficient. Fall protection, visible in one existing bay, should be added to another for the current fleet size. The existing rolling stair should be supplemented with another unit.

It is also recommended that low-power plug-in chargers be available at every other repair bay and placed so the two bays can share the charger.

Resiliency Needs

Operating a BEB fleet requires near constant access to large electricity loads to ensure BEBs can charge as needed. WTA will need to work closely with PSE to coordinate any infrastructure upgrades required for this power delivery. It is expected that power cuts to MOAB will happen at some point, however infrequently. While PSE generally repairs power outages quickly, power outages during key charging times will impact WTA's ability to meet daily service needs or regional needs, especially in the event of a disaster.

To mitigate the effect of unforeseen outages, WTA will need a backup system to ensure their buses can be charged. The two primary options are a large-scale battery energy storage system (BESS) or diesel/natural gas generators. While BESS storage systems (often combined with on-site solar photovoltaic power generation) theoretically looks like an appealing option, in reality generating and storing the multiple megawatts of electricity required to meet WTA's needs is impractical and extremely expensive. This impractical storage is especially true in long duration power outages. It is therefore recommended that WTA procure large diesel or natural gas-fired generators.

A single fixed medium voltage generator capable of providing up to 3MW of power is recommended. This generator could power 20 buses at 150kW and, depending on SOC, could prepare far more for morning roll-out. The generator could be natural gas-fired, with connections ready for the BEB fleet's facility improvements. These generators are typically located adjacent to the shop building or elsewhere on the site where they do not interfere with operations.

BEB Safety Needs

Fire protection is the next most critical factor associated with BEB safety. The market's current state does not adequately address fire suppression within a lithium-ion battery "thermal event". When a stressed or damaged battery reaches 300° F, a lithium-ion thermal event becomes a runaway event. Because the degeneration of the lithium produces oxygen, the resulting fire is self-sustaining. It is anticipated that the National Fire Protection Association (NFPA) will develop specific standards to address electric vehicle facilities in the foreseeable future. Current best practice is to isolate the bus from other assets or remove other assets from the vicinity of the engaged bus. The second strategy is to "surround and drown" by using higher-than-normal fire sprinkler discharge, which is typically double the standard hazard group established by municipal code. Local fire department training and awareness will also be critical to ensuring safety and effective emergency preparedness. As a result, increased fire flows and the resulting structural load must be considered at MOAB.

FCEB Infrastructure Needs

Hydrogen Storage and Delivery System

If hydrogen fuel cell technology is chosen as a preferred propulsion system, additional site modifications, such as locating a suitable location for the fueling infrastructure, will be required. A system capable of fueling up to 50 buses over a five-day period would require approximately 3,500 square feet of hydrogen system-related equipment. A liquid H_2 tank, pumps, dryers, valve and other control panels, compressed air equipment, electrical switchgear, and most likely, a new utility-side transformer comprises the base system. The hydrogen would be pumped into the current fueling lanes. This equipment is most likely to be found in the site's northwest corner, north of the diesel storage tanks. Appropriate fire separations would be required around any H_2 tanks.

Maintenance Bay Upgrades

Maintenance Bay upgrades for FCEBs would generally be similar to those required for BEBs. These upgrades would primarily entail modification to the repair bays to more easily facilitate access to the bus's roof, as

WTA Maintenance Bay

FCEBs (like BEBs) generally contain their batteries on the roof of the bus.

FCEB Safety Needs

The safety modifications necessary for operation of FCEBs are more complicated than those required for BEBs. When in a gaseous form (as on-board a FCEB) hydrogen is a lighter-than-air gas that is odorless, colorless and highly flammable. As a results, the primary concern with introduction of gaseous hydrogen is the potential for explosions. The NFPA 70 National Electrical Code requires no sources of ignition in the upper 18" of the roof. It is recommended that WTA (or a specialist) model a potential hydrogen leak to determine likely zones of trapped gases. All electrical and communications conduits, lighting, motors, and other potential ignition sources must be relocated outside the zone.

A new, explosion-proof exhaust system and a gas detection system will be required. This system would be able to exhaust any trapped hydrogen if detected. Several motorized roll-up doors should be linked to this system and automatically open to provide outside air when higher levels of hydrogen are detected. Finally, the detection system will communicate with a monitored alarm system, activating audible and visual alarms.

FCEBs, like BEBs, have large batteries and as a result the fire sprinkler system should be upgraded to double the standard municipal code (as described in the BEB Safety Needs).

ZEB Workforce Training

The transition to a ZEB fleet will require significant changes to WTA's daily operations. Transitioning will require training employees to understand and safely operate new and changing technologies. WTA will need to provide operational training for bus operators, mechanics, and other support employees.

Maintenance Training Plans

Transitioning to a fleet of FCEBs and/or BEBs requires coordination with internal stakeholders and OEMs, as well as prioritizing training sessions for specific employees based on high voltage and/or H_2 exposure levels. The following outlines a general maintenance training plan for WTA staff as they transition to a ZEB fleet.

Familiarization and Safety Training

Bus manufacturers will need to provide bus familiarity and safety orientation for the delivery of all new buses. This is a standard, scheduled first-step practice when receiving any new bus (not just ZEBs). This basic training course would be for mechanics and service employees (i.e., any WTA employee who fuels, operates or cleans the vehicle). This orientation should be led by a representative from the bus manufacturer and content should include high voltage safety training, personal protective equipment (PPE), safety measures, and preventive maintenance. This course should be presented to each shift at each affected operating division upon delivery of the bus. In addition to mechanics and service employees, maintenance supervisory staff and maintenance trainers should attend.

Bus Systems Training

Additional training should be provided by the OEM for all WTA mechanics, maintenance trainers and supervisors to ensure familiarity with all bus components and their operations. These training sessions should include, but not be limited to, air systems, brakes, steering/suspension, door operations, electric systems, computer and diagnostic systems, basic troubleshooting. These training sessions will likely need to be repeated as OEM components are likely to change with updated bus models. WTA should schedule these with OEM on an as needed basis.

Table 9 Summary of Site Upgrades Needed by Propulsion Technology

Upgrade Type	BEB	FCEB
Fueling	• Chargers • Electrical Upgrades (DC to DC rectifier system, or switch gears and service panel upgrades, possible utility transformer improvements)	• Hydrogen Storage and Delivery System • Possible Electrical Upgrades
Maintenance	• Repair bay upgrades for better bus rooftop access (battery access) • Low-power plug-in chargers at every other bay	Repair bay upgrades for better bus rooftop access (battery access)
Safety	Upgraded Fire Suppression	• Upgraded Fire Suppression • H_2 Detection Alarms • Increased Ventilation
Other	Staff Training (safety, bus systems, advanced training)	Staff Training (safety, bus systems, advanced training)

Note: Discussion of infrastructure costs are summarized in Chapter 6.

Advanced Training

As bus OEMs supply parts from other manufacturers, these specific component manufacturers should provide advanced training to WTA maintenance staff. These advanced training sessions may include (but not be limited to): battery-energy storage systems, electric-propulsion motors, or fuel-cell systems. These trainings would likely be scheduled with the bus OEM and should be repeated periodically as necessary.

WTA Training Programs

While the adoption of new technologies often comes with a steep learning curve, the goal of these training programs should be for WTA to reduce reliance on OEMs over time. WTA should identify key maintenance staff who could become internal subject matter experts. These key staff members could begin teaching some of the training courses to other WTA staff as knowledge with new technologies increases. While increased internal familiarity with new ZEB technologies will reduce reliance on OEMs over time, WTA should maintain frequent communication with bus OEMs to minimize bus down-time and stay up to date on ZEB best practices.

Summary

Table 9 summarizes the site upgrades needed at MOAB by propulsion technology.

Chapter 6 ZEB Transition Options

While WTA is firmly committed to transitioning to a fully zero-emission fleet, the team recognizes that ZEB technology is changing quickly.

WTA already has two BEBs in operation, has ten more BEBs on order (for delivery in early 2023/2024), and has been earmarked for congressional funding via Transportation, Housing and Urban Development (THUD) appropriation for three more ZEBs (for delivery after 2025).

At this point, WTA's fixed route fleet will be over 20 percent ZEB. When WTA took delivery of their first BEBs in 2020, they had a nominal onboard energy storage of approximately 440 kWh. The eight 40-ft BEBs to be delivered in 2024 will have a nominal onboard energy storage of at least 588 kWh, a 33 percent increase in energy storage in approximately four years. Additionally, the ZEB industry is working on expanding the production of FCEBs and increasing the availability of hydrogen fuel while reducing its cost.

The evolving nature of ZEB technology and the large investment required to purchase zero-emission buses and install infrastructure requires a thoughtful strategy to bridge the gap between near term procurement needs and longer term opportunities. WTA's near term strategy is to procure hybrid buses for fixed route bus replacements between 2024 and 2027. This procurement strategy will give the WTA team additional time to plan and develop additional ZEB infrastructure and monitor technology changes. For this reason, this ZEB transition study presents three options for WTA to achieve a fully zero-emission fleet by 2040.

1. WTA procures all BEBs after 2027
2. WTA procures all FCEBs after 2027
3. WTA procures a combination of BEBs and FCEB after 2027

The following sections detail the implications and each option available to WTA. A summary is provided at the end of the chapter discussing the difference in costs, site impacts, and expected greenhouse gas emissions for these three options to achieve a full ZEB fleet.

Cost Assumptions

The assumptions made in the cost estimates for the transition to a fully zero-emission fleet and the corresponding infrastructure adoption are summarized below. WTA finance staff directed the project team to use a 5 percent annual increase, which has been applied to all future year cost estimates.

Capital Costs

	Bus Cost	Charging/Fueling
BEB	$1,100,000	$200,000/bus[1]
FCEB	$1,250,000	$4.5m/50 FCEB
Diesel	$520,000	0

Maintenance Costs[2]

BEB	$0.45 per mile
FCEB	$0.42 per mile
Diesel	$0.35 per mile

Fuel Costs

BEB	$0.113/kWh + $21.48/kW peak
FCEB	$7/kg hydrogen
Diesel	$3.25/gallon of diesel[3]

1. *Estimated cost for plug-in chargers. If WTA selects pantograph chargers, cost will increase.*
2. *Estimatesfrom National Renewable Energy Laboratory research and Transit Coorperative Research Program Report 219*
3. *Most recent 6-month average price paid by WTA for diesel*

Greenhouse Gas Estimate Assumptions

Each ZEB transition plan option changes the rate at which WTA's operations emit greenhouse gases (GHG). To estimate the rate of emissions, the project team conducted research into GHG emissions from transit operations and combined that with local energy mix information.

The following summarizes the assumptions that form the basis of the GHG calculations:

Diesel

» 1 gallon of diesel produces ~22.46 lbs CO_2e (CO_2 equivalent)
  - carbon emissions for refining and transporting diesel fuel, which would increase the GHG impact of diesel is not included

» WTA fuel consumption is expected to increase proportionally with fleet size

Electricity

» 1 kWh of electricity from Puget Sound Energy (PSE) produces approximately 0.8986 lbs CO_2e

» PSE to produce 100 percent carbon free electricity in 2045
  - The analysis assumed a linear relationship between 2022 carbon emissions and 2045 carbon emissions per kWh of electricity generated
    - 2040 estimate for 1 kWh of electricity = 0.19 lbs CO_2e

H2

Hydrogen

» 1 kg of hydrogen currently produces approximately 20.5 lbs CO_2e via the Steam Methane Reforming process (which accounts for 99 percent of hydrogen generated in the US)
  - This emissions rate of hydrogen generation is assumed to be reduced by 50% by 2040, linearly each year.

» Hydrogen is assumed to be trucked to the WTA facility, where it would be stored as a liquid in tanks before undergoing compression and pumping into the FCEB. This compression is assumed to require ~1kWh per kg of hydrogen

Note: While the upstream emissions for WTA's operations do not reach net-zero for any transition plan option (i.e. the generation and transportation of hydrogen and/or electricity is not assumed to be fully renewable by 2040) each transition plan option results in WTA operating a fully zero-emission fleet by 2040.

Option 1 - All BEB

WTA procures all BEBs after 2027 in the first transition option. The fixed route fleet composition between 2023 and 2040 is shown on Figure 11.

Under this option, WTA would cease operations of diesel only vehicles in 2036, and would remove their last hybrid powered buses from operation in 2039, at which point they would operate a fully BEB fleet. This option assumes that battery technology improves such that WTA can purchase and operate BEBs at a one-to-one ratio with existing diesel buses.

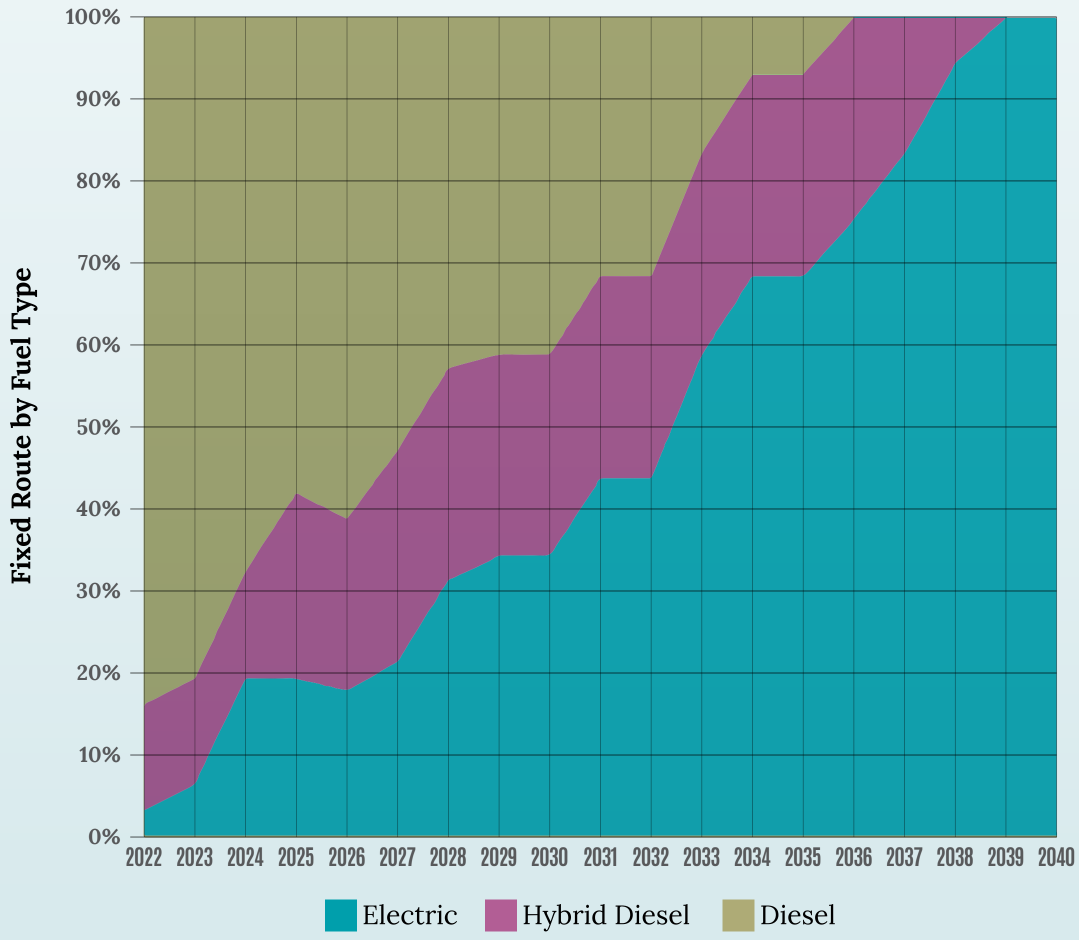


Figure 11 - Fixed Route Fleet Composition - BEB Option

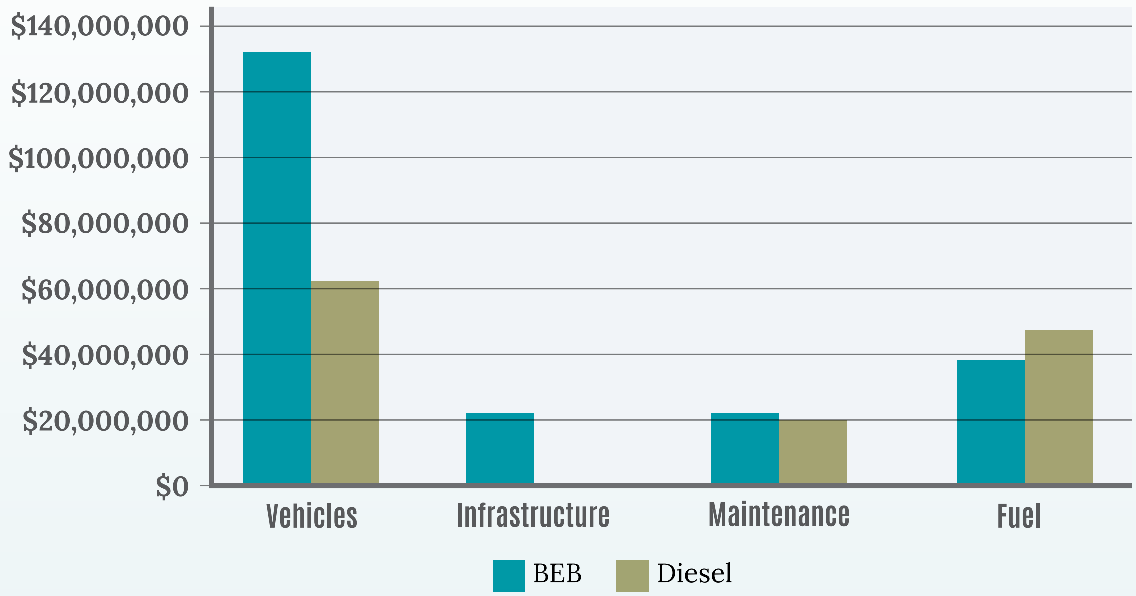


Figure 12 - Total Cost of Ownership - BEB Option (2022-2040)

Cost

The total cost of ownership (purchase, operation, maintenance) of WTA's fixed-route fleet between 2022 and 2040 for a fully electric fleet and continued operation of a diesel fleet is shown on Figure 12.

Total cost of transitioning to and operating a fully BEB fleet is expected to cost approximately $215 million between 2022 and 2040. For reference, operation of a fully diesel fleet for these years is expected to cost $130 million. The premium for going fully electric is expected to be $85 million, with most of the cost difference expected to be in the purchase price of the vehicles and installation of charging infrastructure. While this cost is high, it does not factor into account the receipt of any funding (federal, state or local). WTA has, to date, received grant funding for 15 BEBs and associated charging infrastructure. WTA will likely not receive grant funding for all future ZEBs, but it is important to note that the increased cost burden is unlikely to be WTA's sole responsibility.

The cost estimates for the BEB option also do not include any utility upgrades that would be necessary for MOAB to accommodate the high electrical loads. These costs are currently being investigated internally by WTA in collaboration with PSE.

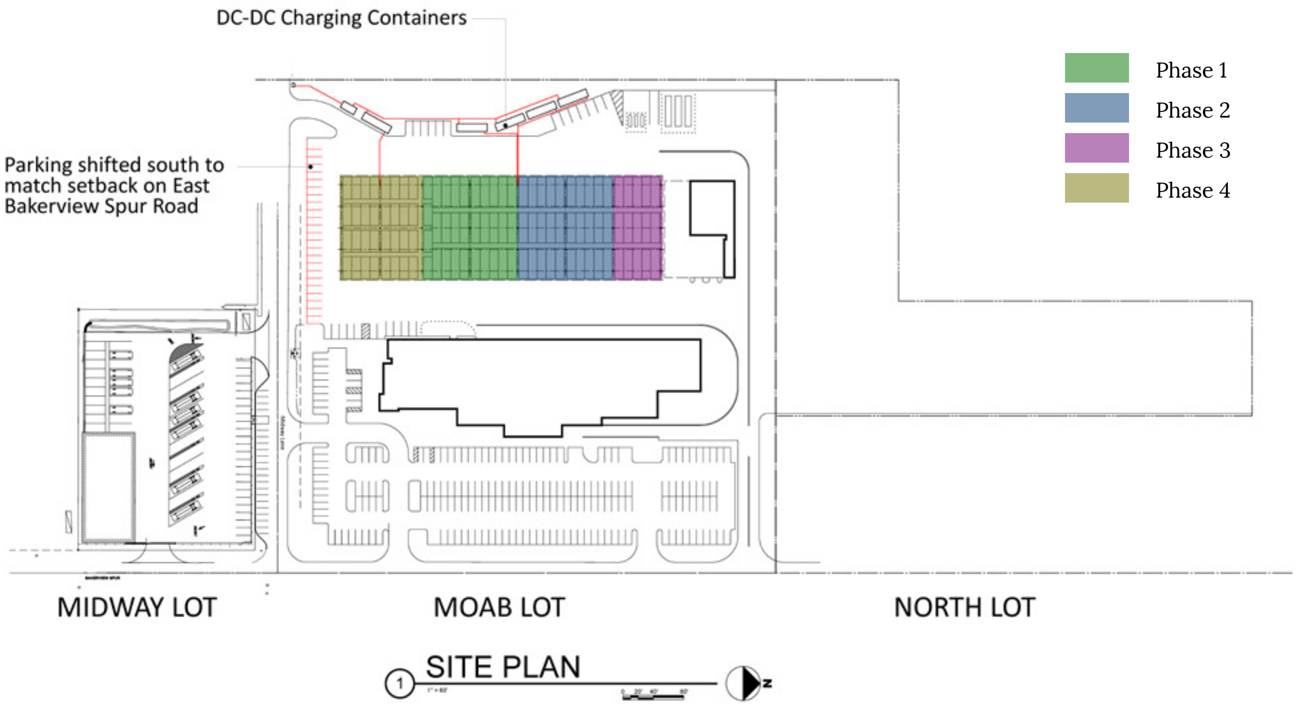


Figure 13 - All BEB Site Plan Layout

Site Plan and Phasing

Implementing BEBs on the MOAB lot would likely occur in four or more phases. The buildout of the charging infrastructure is conceived to impose minimally on WTA operations and employ an overhead distribution network mounted on a canopy. The concept is based upon 3MW DC-DC chargers and their capacity to charge up to 20 BEBs at 150kW each. Phase 1 (green) would be centrally located within the BEB parking area and can charge 30 - 40 buses. Phase 2 and 3 (blue and purple) expansions would occur in segments to the north. Based on the spatial constraints of the site, Phase 4 (yellow) would require a second conduit (overhead or underground) extending from the west landscaped area to the overhead canopy. Up to 84 40-foot equivalent BEBs could be accommodated in the parking area as shown on Figure 13.

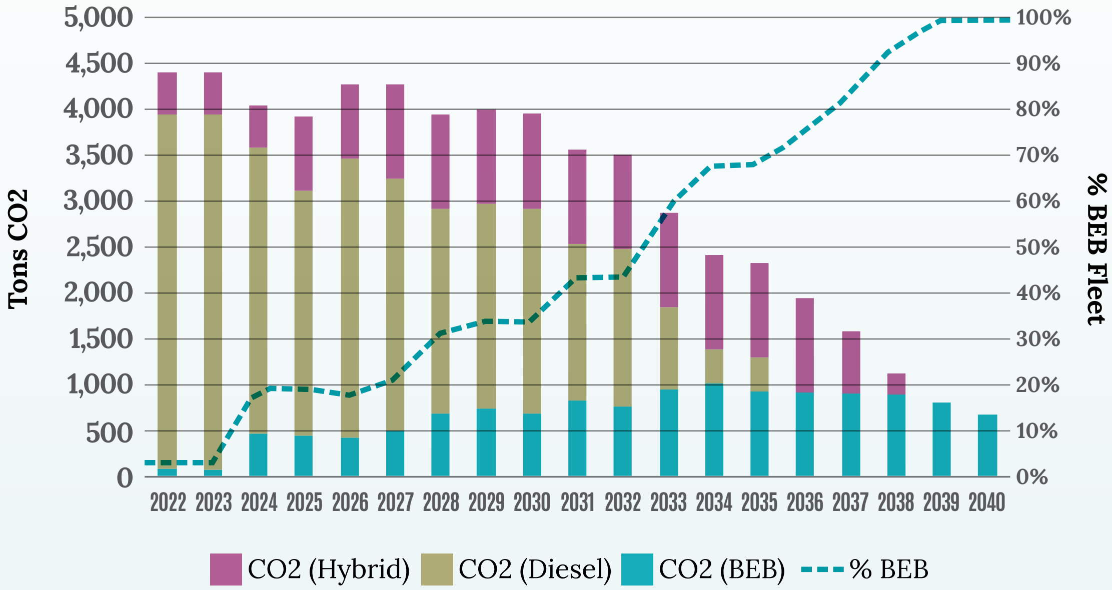


Figure 14 - BEB Option GHG Emissions

Greenhouse Gas Emissions Estimates

Figure 14 summarizes the annual GHG emissions forecasts between 2022 and 2040, assuming the adoption of all BEBs after 2027.

Annual emissions under this scenario are expected to decrease by approximately 80 percent between 2022 and 2040. While WTA would operate a fully zero-emission fleet in 2039, WTA would be expected to hit net-zero emissions in 2045, because PSE is expected to continue generated electricity from sources that emit carbon until 2045. The estimated total emissions from WTA fixed-route operations between 2022 and 2040 is 64,000 tons of CO_2e. For comparison, the continued operation of a diesel-powered fixed route fleet would result in 97,000 tons of CO_2e emitted during the same time period.

Option 2 - ALL FCEB Option

WTA procures all FCEBs after 2027 in the second transition option. The fixed route fleet composition between 2022 and 2040 is shown on Figure 15.

Operations of diesel buses and existing BEBs would cease in 2036. WTA would retire their last hybrid powered buses from operation in 2039, when they would operate a fully FCEB fleet. This option assumes that FCEB technology can meet WTA's route needs such that WTA can purchase and operate FCEBs at a one-to-one ratio with existing diesel buses.

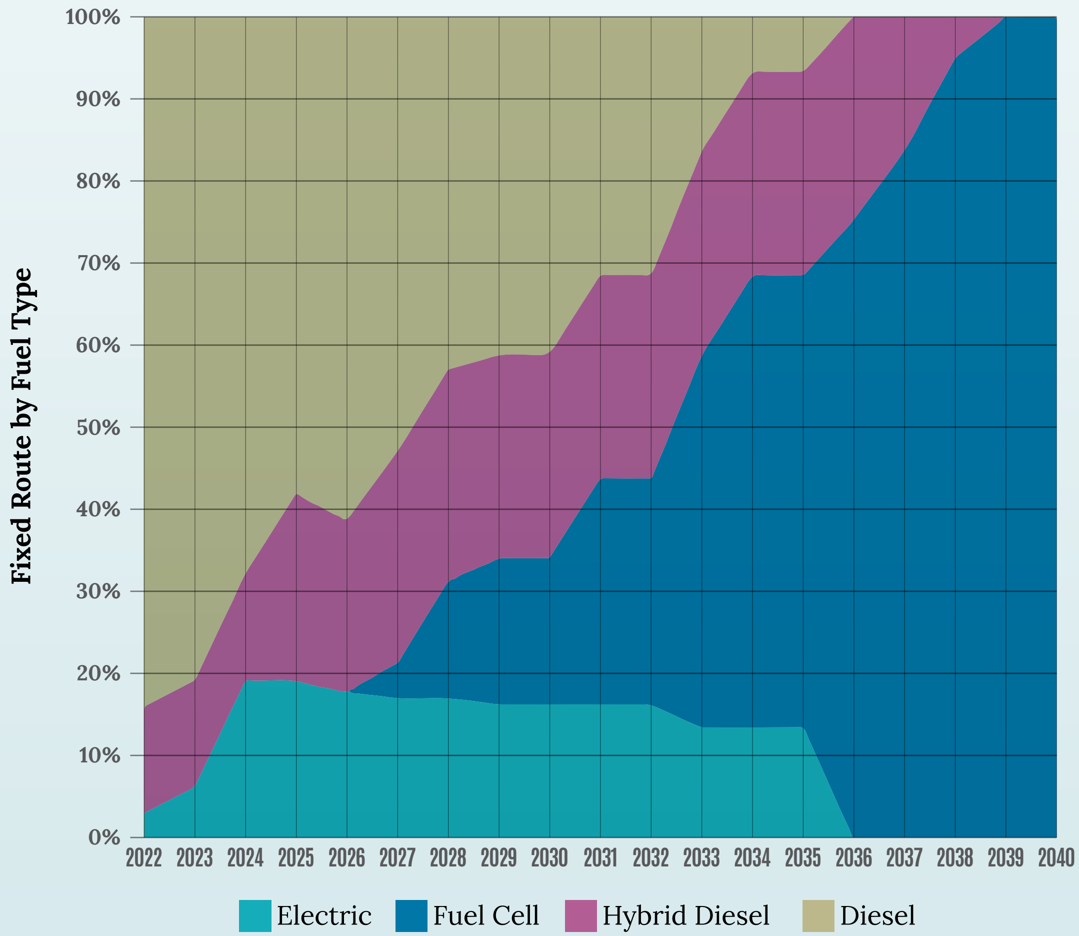


Figure 15 - Fixed Route Fleet Composition - FCEB Option

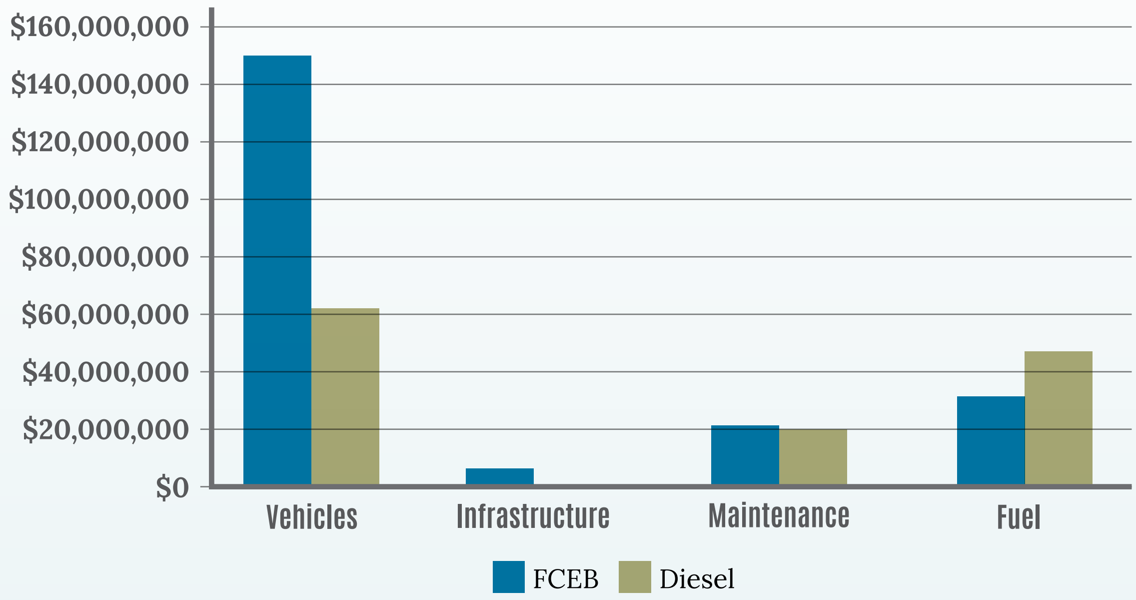


Figure 16 - Total Cost of Ownership - FCEB Option (2022-2040)

Option 2 Cost

The total cost of ownership (purchase, operation, maintenance) of WTA's fixed-route fleet between 2022 and 2040 for a FCEB fleet and the continued operation of a diesel fleet is shown on Figure 16.

The total cost of transitioning to and operating a fully FCEB fleet is projected to cost approximately $211 million between 2022 and 2040. For reference, the operation of a full diesel fleet for these years is expected to cost $130 million. The premium for going fully hydrogen powered is expected to be $81 million, with most of the cost difference expected to be in the purchase price of the vehicles and hydrogen fueling infrastructure. As previously noted, this cost differential does not consider the receipt of any funding (state or federal). WTA likely will not receive grant funding for all future FCEBs, but it is important to note that the increased cost burden is unlikely to be WTA's sole responsibility.

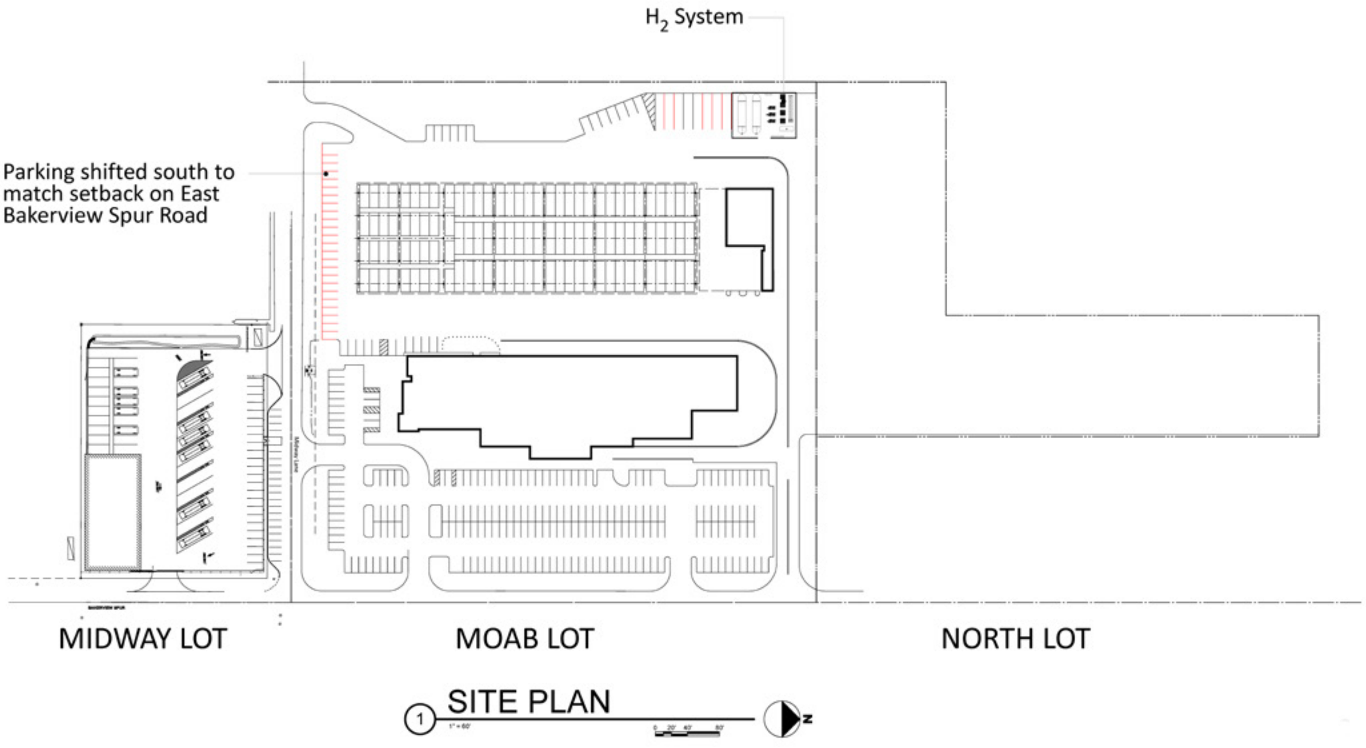


Figure 17 - FCEB Site Plan and Phasing

Site Plan and Phasing

Like the all BEB option, a total of 84 40-foot equivalent FCEBs could be accommodated in the central MOAB bus parking area. FCEB implementation, based upon a truck-delivered, liquid hydrogen system, would require minimal modifications to the existing facilities and would be accomplished in two phases. The first phase would install most hydrogen fueling infrastructure and be capable of fueling up to 50 transit buses. The second phase would add a second hydrogen storage tank, but the rest of the system would be predominantly unchanged. Given a three-pump system for redundancy, fueling up to 100 FCEBs could be accomplished in a seven-hour window.

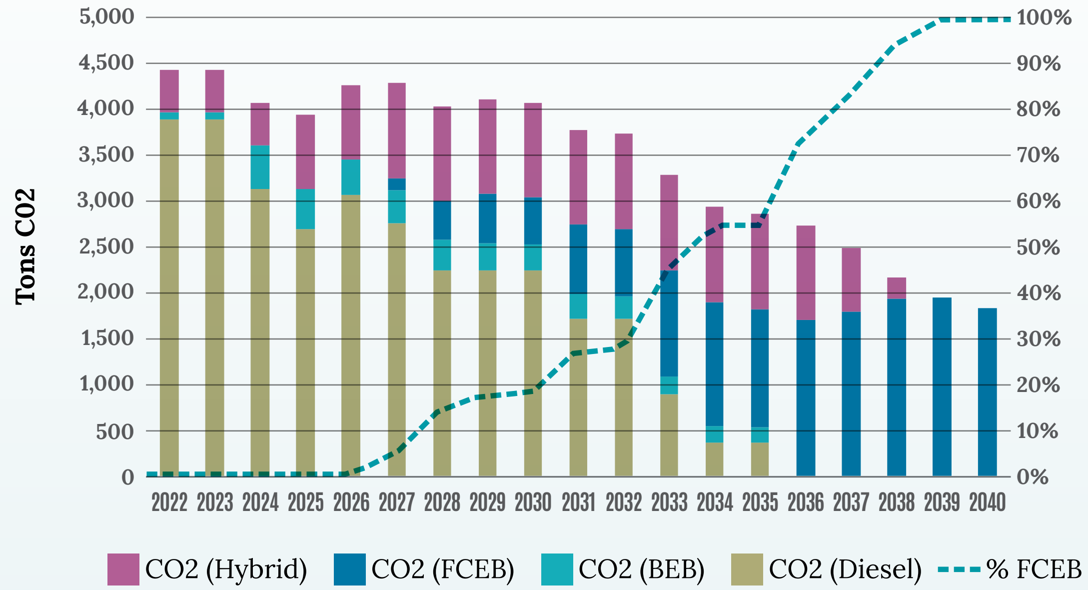


Figure 18 - FCEB Option GHG Emissions

Greenhouse Gas Emissions Estimates

Figure 18 summarizes the annual GHG emissions forecasts between 2022 and 2040, assuming the adoption of all FCEBs after 2027.

Annual emissions under this scenario are expected to decrease by approximately 60 percent between 2022 and 2040. While WTA would operate a fully zero-emission fleet in 2039, WTA would not be expected to hit net-zero emissions in 2040, as hydrogen generation is still expected to involve emitting GHGs. The estimated total emissions from WTA fixed-route operations between 2022 and 2040 is 72,000 tons of CO_2e. For comparison, the continued operation of a diesel-powered fixed route fleet would result in 97,000 tons of CO_2e emitted during the same time period.

Option 3 - BEB / FCEB Option

In the final transition plan option WTA would acquire a mix of BEBs and FCEBs after 2027. Figure 19 depicts the fixed route fleet composition between 2023 and 2040 (assuming an even split of BEBs and FCEBs). It is unlikely that WTA would run an equal number of BEBs and FCEBs. However, the exact breakdown will be determined as each technology matures and a further determination of WTA's specific needs is made. This option assumes WTA can purchase and operate both BEBs and FCEBs at a one-to-one ratio with existing diesel buses.

Figure 19 assumes an equal order of BEBs and FCEBs each year, although this may not occur. WTA may choose to purchase BEBs and FCEBs in bulk, instead of splitting purchase orders to better align with corresponding infrastructure upgrades. WTA would phase out diesel-only vehicles in 2036 and retire their last hybrid-powered buses in 2039, when they would operate a fully BEB/ FCEB fleet. Before the first FCEB is delivered, a hydrogen storage/compression system, in addition to BEB charging infrastructure, would need to be installed.

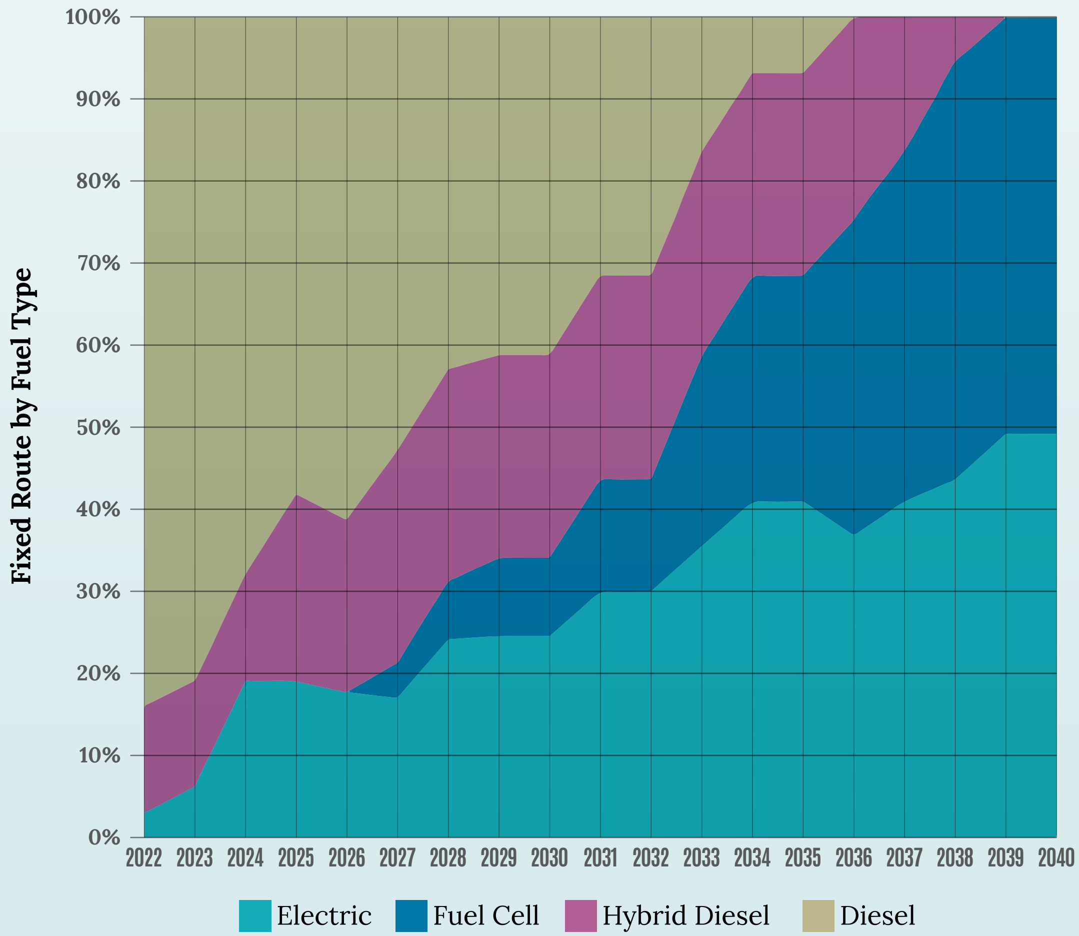


Figure 19 - Fixed Route Fleet Composition – BEB/FCEB Option

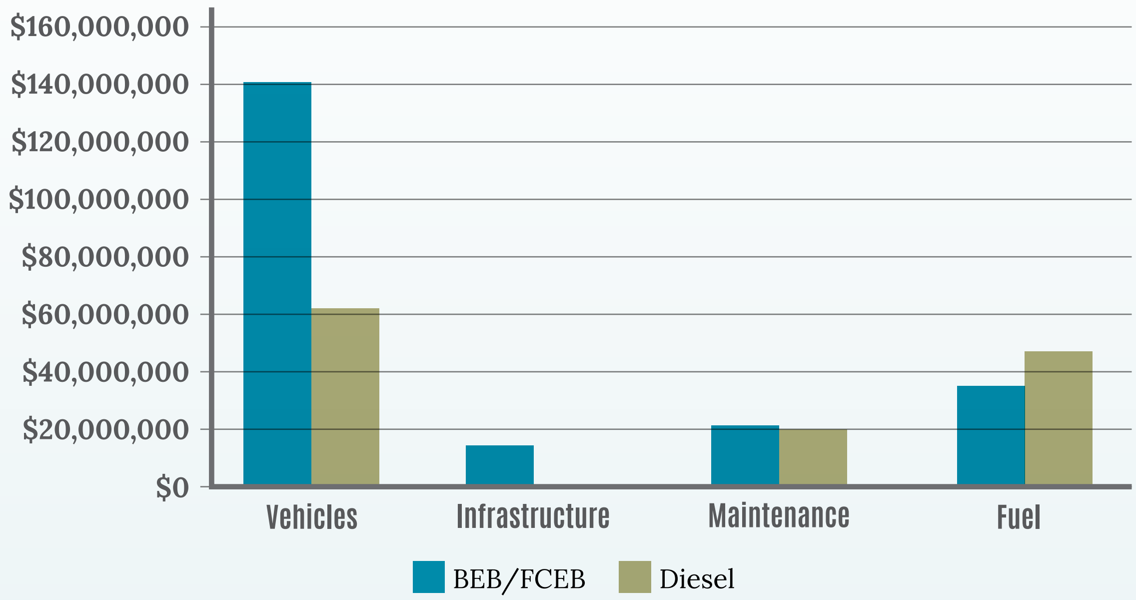


Figure 20 - Total Cost of Ownership – BEB/FCEB Option (2022-2040)

Option 3 Cost

The total cost of ownership (purchase, operation, maintenance) of WTA's fixed-route fleet between 2022 and 2040 for a BEB/FCEB fleet and continued operation of a diesel fleet is shown on Figure 20.

Between 2022 and 2040, the total cost of transitioning to and operating a combined BEB/FCEB fleet is expected to be around $213 million. For comparison, the cost of running a full diesel fleet during these years is expected to be $130 million. Under this scenario, the premium for going ZEB is expected to be around $83 million, with the majority of the cost difference accounted for in the purchase price of the vehicles and required infrastructure. As previously stated, this cost differential does not consider any funding received (state or federal). WTA is unlikely to receive grant funding for all future ZEBs, but the increased cost burden is unlikely to be solely WTA's responsibility.

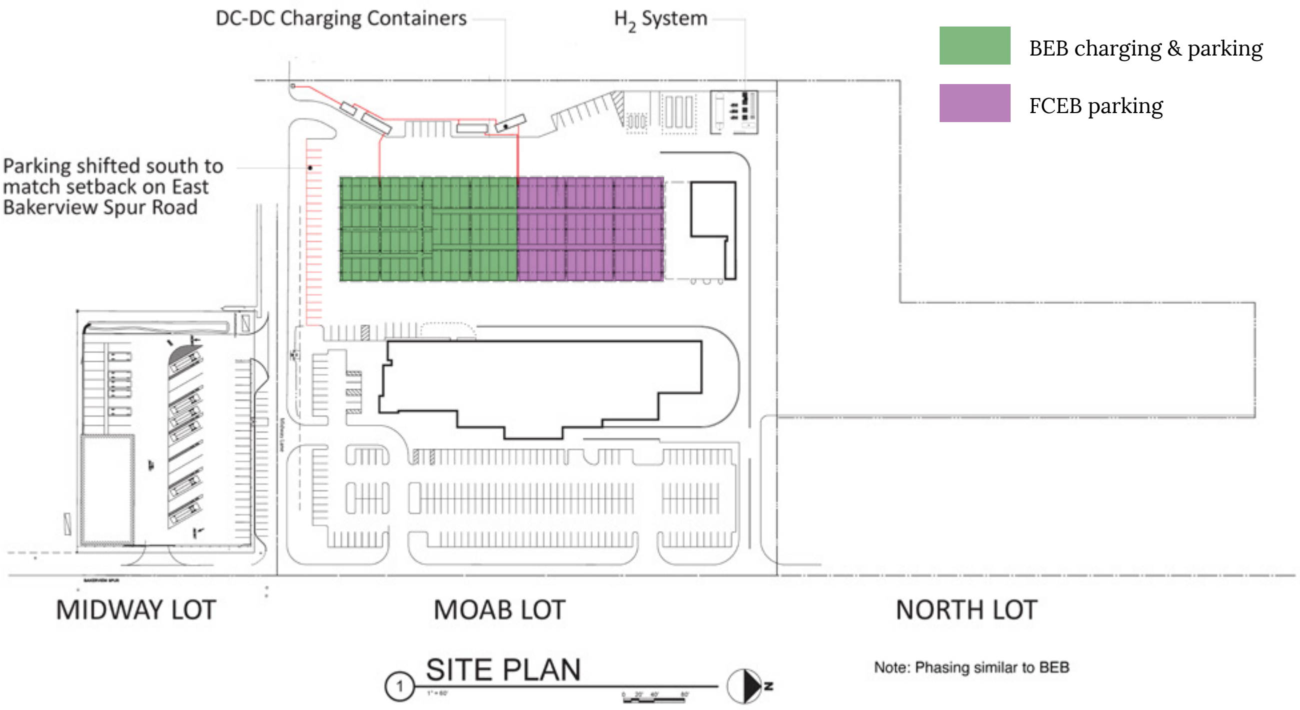


Figure 21 - FCEB / BEB Site Plan and Phasing

Site Plan and Phasing

A blend of BEB and FCEB could be implemented in two ways at the MOAB facility. The first option, entirely on the MOAB site, has the same 84-bus capacity as the previous two options. This option has the highest capital costs due to the infrastructure upgrades required for two fueling types. The fleet's specific composition would determine the charging and hydrogen fueling infrastructure configuration. Figure 21 shows that capacity would be up to 60 BEBs, or 50 FCEBs in a blended fleet of 84 vehicles.

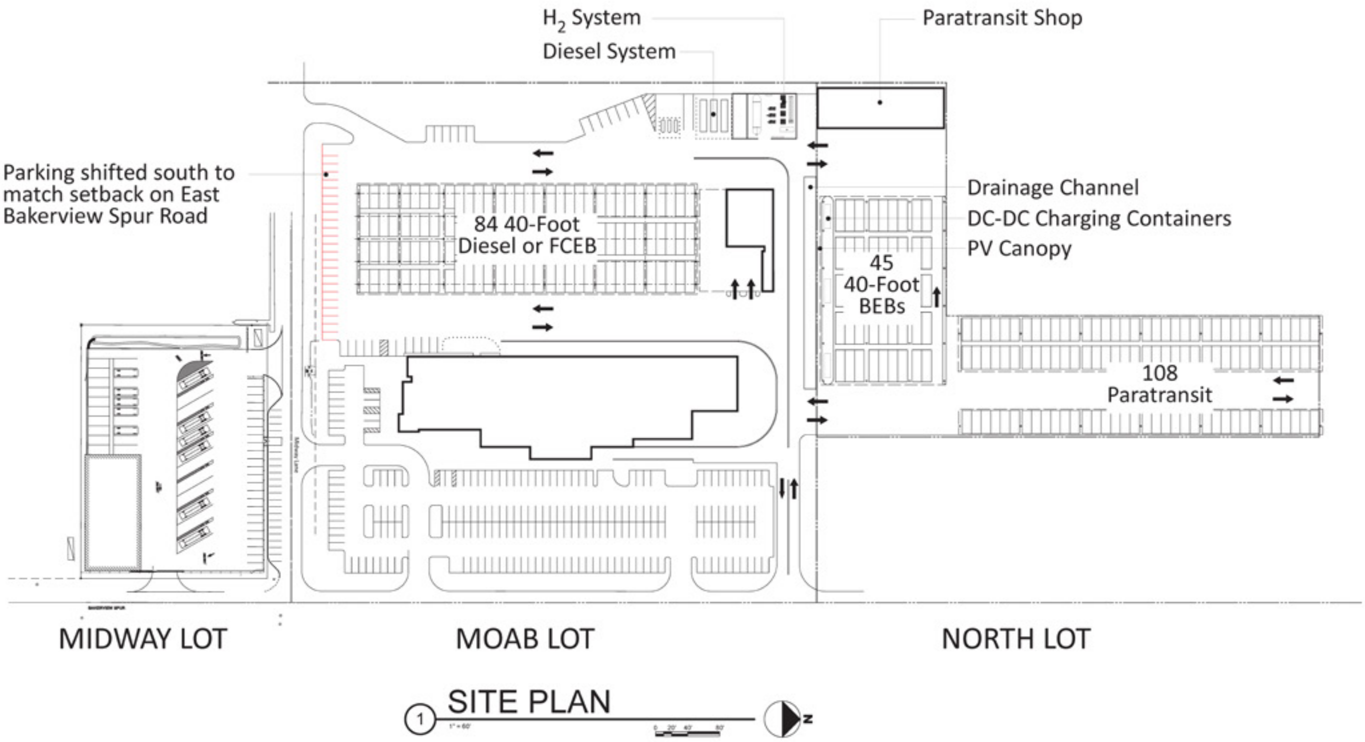


Figure 22 - FCEB/BEB Site Plan and Phasing Option 2

The second option for a blended BEB/FCEB fleet would reserve the MOAB lot for FCEBs while adding 45 BEBs to the fleet on the currently undeveloped North Lot. Figure 22 also depicts the number of paratransit vehicles that could be housed on the North Lot if a dedicated maintenance facility was built.

The buildout of the North Lot could also apply to each of the other transition plan options.

Further discussion on the transition of WTA's paratransit fleet is provided later in this chapter.

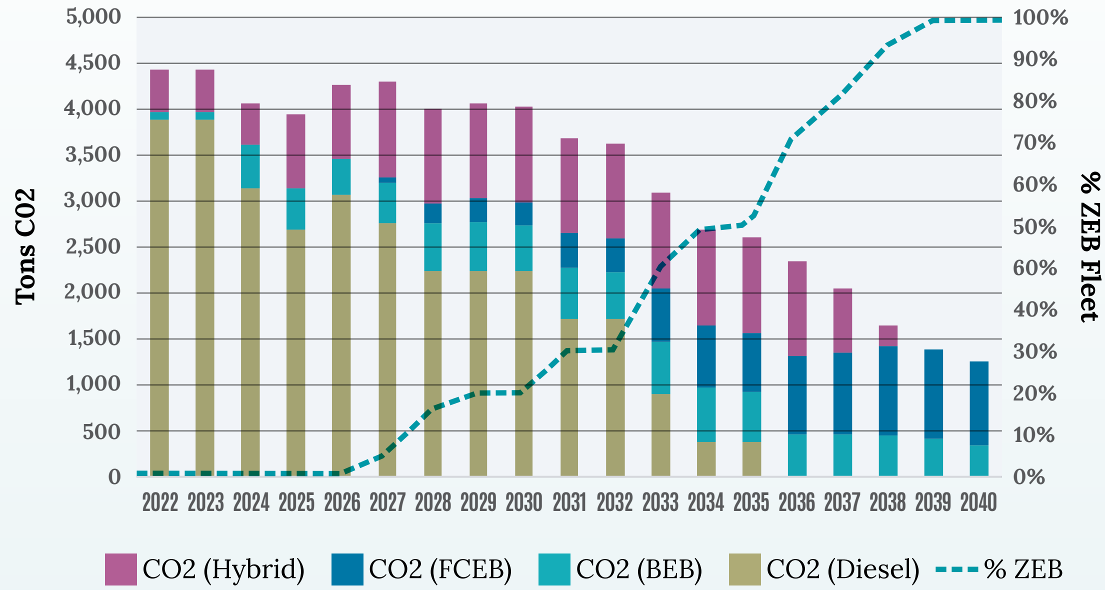


Figure 23 – BEB/FCEB Option GHG Emissions

Greenhouse Gas Emissions Estimates

Figure 23 summarizes the annual GHG emissions forecasts between 2022 and 2040, assuming the adoption of an even number of BEBs and FCEBs after 2027.

Annual emissions are expected to fall by 72 percent under this scenario between 2022 and 2040. While WTA would operate a fully zero-emission fleet in 2039, WTA would not be expected to hit net-zero emissions in 2040, as both hydrogen and electricity generation are expected to involve emitting GHGs. Assuming an even split in BEBs and FCEBs, WTA fixed-route operations are expected to emit 68,000 tons of CO_2e between 2022 and 2040. In comparison, the continued operation of a diesel-powered fixed route fleet would result in the emission of 97,000 tons of CO_2e over the same time period.

Table 10 - Summary of ZEB Transition Options

Options	Pros	Cons
1 – All BEB	• WTA will have working knowledge of BEB operations • Already installed charging infrastructure (not needed for future BEB replacement cycles)	• Range limitations today • Weather can greatly impact performance
2 – All FCEB	• No 'range anxiety' • No need to adjust schedule to match buses with specific routes	• Limited FCEB operation across industry to learn from • Lack of available hydrogen • New technology to learn to operate • Would make BEB chargers already purchased useless at end of BEB lifecycle
3 – Combination	• Flexibility to meet route needs • Can leverage existing BEB chargers	• Requires two types of infrastructure

Summary of Transition Plan Options for Fixed Route Fleet

The three options for WTA to transition to a zero-emission fixed route fleet are:

1. All BEBs after 2027
2. All FCEBs after 2027
3. Combination of BEBs and FCEBs after 2027

The pros and cons of each transition plan option are summarized in Table 10.

The life cycle costs and GHG estimates for continued operation of a diesel fleet, the transition to an all-electric fleet and an all FCEB fleet are summarized on Figure 24.

	Diesel Only	All BEB	All FCEB
Capital Costs			
Buses	$62.4m	$131.9m	$149.9m
Infrastructure	-	$22.3-43.5m	$7m
Operating Costs			
Fuel	$47.5m	$38.6m	$31.9-39.6m
Maintenance	$20.5m	$22.4m	$21.8m
Total Costs			
Life Cycle	$130.4m	$215.2-236.4m	$210.6-218.3m
GHG Emissions (Tons)			
2022-2040 Total Emissions	97,700 tons CO2e	64,000 tons CO2e	72,000 tons CO2e
2040 Annual Emissions (compared to 2022 levels)	20% increase	85% decrease	60% decrease

Figure 24 – Life Cycle Cost Comparison by ZEB Type

WTA Paratransit Bus

Transition Plan for Paratransit Fleet

As previously stated in Chapter 2, zero-emission paratransit vehicle deployment is still in its early stages, with a limited number of zero-emission paratransit vehicles available for purchase. However, the number of paratransit vehicle manufacturers is expected to grow. This increased competition is expected to lower the price of this vehicle type. When combined with anticipated advancements in zero-emission propulsion technology, a fleet transition for these vehicles may be considered in the future to fully capitalize on these significant milestones.

The WTA's 2022 Transit Asset Management Plan forecasts the rate at which paratransit vehicles will be replaced through 2040.

WTA's current paratransit fleet replacement schedule is shown on Table 11.

WTA is well positioned to purchase zero-emission paratransit vehicles in 2027 in a more mature and competitive market. Additionally, WTA should combine their infrastructure upgrades at MOAB for their fixed route fleet with upgrades to charge or fuel their paratransit fleet.

Between 2023 and 2027, WTA is expected to continue purchasing gas-powered paratransit vehicles. WTA may also want to consider purchasing one electric paratransit vehicle to test before making bulk purchases to familiarize operators and maintenance crews with the technology.

Charging paratransit vehicles will be much easier because they do not require the same level of on-board energy storage as a 40-ft BEB. WTA can obtain and install standard 'level-2' plug-in vehicle chargers, which typically

Table 11 - WTA Paratransit Fleet Replacement Schedule

Year	# Vehicles to Replace
2023	5
2024	6
2025	0
2026	11
2027 *zero-emission replacement begins*	12
2028	13

provide 25 miles per hour of charging (enough to charge a paratransit vehicle overnight). These chargers could be used to charge paratransit vehicles or other service vehicles. Installing Level-2 chargers is significantly less expensive than installing 40-ft BEB charging infrastructure. Level-2 charging units typically sell for less than $1,000 and require $2,000 to $3,000 in labor costs to install. For budgeting purposes, $5,000 should be assumed to cover the cost of a level-2 charger. It is recommended that the installation of these units be coupled with the more extensive infrastructure upgrades at MOAB that will likely occur between 2025 and 2027, as discussed in Chapter 7.

There is currently a very limited market for fuel-cell paratransit vehicles. One of the first deployments of fuel-cell paratransit vehicles occurred for Stark Area Regional Transit Authority (SARTA) in Ohio. While fuel-cell paratransit van deployments are currently very limited, WTA should periodically review the ZEB market to understand whether the fuel-cell paratransit market is expanding and becoming a viable alternative to battery-electric. At the time of this report, it is still expected that battery-electric propulsion technology will be able to meet the paratransit fleets needs of WTA.

Transition Plan for Other Service Vehicles

In the last five years, the zero-emission vehicle market for non-revenue vehicles has changed dramatically. The number of commercially available battery electric vehicles (BEVs) has grown exponentially, with many automakers now producing multiple BEVs and many more on the way in the coming months. As automakers face increased competition, the prices of these vehicles are expected to continue to decrease.

WTA could most likely replace all of the service vehicles it currently operates with BEVs if sufficient charging infrastructure was in place. WTA should review the availability of BEV replacements as it prepares to replace its service vehicles. These BEV replacements are expected to be slightly more expensive to purchase but significantly less expensive to maintain and fuel.

Transitioning vanpool vehicles to BEVs will be similar to that of other service vehicles. Other transit agencies, such as King County Metro, have experimented with purchasing BEVs like the Nissan Leaf for use as vanpool vehicles. These vehicles do not have the typical seated capacity of a traditional vanpool vehicle, but they would allow WTA to transition its vanpool fleet more quickly if desired. Vehicle manufacturers will almost certainly build battery-powered vans in the coming years. Again, these vehicles may be slightly more expensive to purchase, but they are expected to be less expensive to maintain and fuel.

Chapter 7 Future Planning

Zero-emission bus technologies are expected to evolve and improve over the next ten years. The technologies have been proven in many small-scale deployments, but few transit agencies have deployed them at scale. Each type of ZEB propulsion (fuel-cell and all-electric) has advantages and disadvantages. The current state of the industry throughout the country heavily favors BEBs, with the majority of ZEBs in operation today being BEBs. FCEBs have a significant advantage over BEBs in that their range is much closer to that of a diesel-powered bus. Due to their longer range FCEBs can more easily ‘plug and play’ with existing bus schedules and routes.

FCEBs are more difficult to obtain because fewer bus manufacturers produce them compared to BEBs. Access to reliable hydrogen sources is also severely limited across the industry. In terms of sustainability, hydrogen is almost entirely produced using the Steam Methane Reforming Process, which burns natural gas and emits large amounts of carbon in the process.

PSE’s existing electricity generation emits fewer GHGs than hydrogen generation, and PSE has been mandated by Washington State Law to reduce their carbon intensity to zero by 2045. Hydrogen generation is also likely to emit fewer GHGs in the coming years.

Near Term Transition Plan (2023-2027)

While ZEB technology is at a period of rapid change, WTA is committed to operating a fully ZEB fleet by 2040. Given a fixed-route bus service life of 12 years, WTA must exclusively purchase ZEBs for rollout in 2028 and beyond. The following outlines WTA's approach and timeline to ZEB deployment.

2023-2024

1. **Continue planned BEB deployments in 2023 and 2024.** WTA will be taking delivery of 2 BEBs in 2023, and 8 more in 2024. These additional buses will give WTA operators, technicians and other staff important hands on experience with the latest BEB technology. WTA should operate new BEBs on a variety of routes and schedules and weather conditions to test their functionality.
2. **Explore Charge Management Software Tools.** Assuming WTA continues to operate BEBs for the foreseeable future, the use of a charge management system is recommended. Currently, WTA has purchased and is using ViriCiti, a charge management software that the project team regards highly. As WTA begins taking delivery of additional BEBs, WTA staff should delve deeper in ViriCiti's capabilities to ensure the software can meet WTA's needs.
3. **Proactively Monitor ZEB Industry.** During 2023 and 2024, WTA should continue to review peer agency ZEB deployments and stay current on industry best practices with ZEB technology. The project team expects additional battery density improvements from BEB OEMs during 2023 and 2024 and would also expect improvements from FCEB OEMs.
4. **Procure hybrid electric buses in the interim**.

June 2024

Decide on ZEB Deployment Technology for 2027-2032.

By mid-year 2024, it is recommended that WTA select the propulsion technology of choice for their 2027 bus order.

The primary purpose of giving WTA almost four years of time between technology selection and deployment is to provide adequate time to design, procure and build improvements at MOAB.

For WTA to make final determination of ZEB deployment technology for their next tranche of bus purchases, WTA will need to be able to answer the following questions:

1. Can WTA procure hydrogen reliably at a reasonable cost to ensure potential FCEBs can be fueled?
2. Can WTA procure up to 20 FCEB vehicles reliably?
3. How well are BEBs operating?
4. Has BEB battery capacity continued to expand?
5. What level of electrical improvements are needed to bring additional power to MOAB to charge future BEBs?

2024/2025

Site Design for Selected Technology (BEB or H_2 Fueling Station)

2025/2026

- **Purchase and Installation of Charger or H_2 Fueling Station**
- **Coordinate with PSE on Electrical Service Upgrades (with BEB)**
- **Site Upgrades for Paratransit (purchase level-2 chargers)**

2026/2027

- Additional MOAB Site Improvements (safety systems, maintenance bay upgrades)
- Additional ZEB staff training
- Zero-emission Paratransit Order #1

2027

- ZEB Order #1 (7 ZEBs)
- First Zero-emission Paratransit in Operation

2028-2031

- 13 additional ZEBs
- Continue paratransit ZEB replacements
- Plan for 2032 ZEB technology deployments

Conclusion

Despite careful planning and consideration, the transition to a fully ZEB fleet will still have unknown and unexpected challenges ahead for WTA. The following summarizes the challenges that WTA faces in the transition to a 100 percent zero-emission fleet.

» ZEB technology is changing rapidly, which makes long-term planning difficult.

» ZEB technology is not currently a suitable one-to-one replacement for diesel vehicles in terms of range and operational needs. It is anticipated that this may change over time.

» ZEB technology and the required additional infrastructure adds significant capital costs to WTA's operations.

» Procurement of ZEBs will require careful timing to ensure associated infrastructure projects are finished when ZEBs are to begin operations.

» Transition to new ZEB technologies will require additional staff and safety training.

» ZEB fueling may be constrained by a limited number of providers and will require resiliency planning in case of utility blackouts.

During the course of the transition to a fully zero-emission fleet, WTA will need to coordinate closely with bus OEMs, Puget Sound Energy, and policy makers to help address these challenges.

It is important to note that WTA's plan to transition to a fully ZEB fleet will be subject to frequent change as the ZEB industry continues to evolve. This study provides estimated timelines, infrastructure and vehicle costs, workforce training, and other information based on the best available information. WTA should update this plan for ZEB transition as industry best practices evolve.

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WTA

Prepared by:

transpogroup