SOUTHWEST OHIO REGIONAL TRANSIT AUTHORITY
TRANSIT AUTHORITY OF NORTHERN KENTUCKY
BUTLER COUNTY REGIONAL TRANSIT AUTHORITY

ALTERNATIVE FUEL STRATEGY
ZERO EMISSION VEHICLE
TRANSITION PLAN

FINAL REPORT

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ACRONYMS

AC: Alternating Current
ADA: Americans with Disabilities Act
AFLEET: Alternative Fuel Life-Cycle Environmental and Economic Transportation
APTA: American Public Transportation Association
BCRTA: Butler County Regional Transit Authority
BEB: Battery Electric Bus
BESS: Battery Electric Storage System
BIL: Bipartisan Infrastructure Law
BRT: Bus Rapid Transit
CalACT: California Association for Coordinated Transportation
CARB ICT: California Air Resources Board Innovative Clean Transit
CCI: Construction Cost Index
CCW: Custom Coach Works
CDL: Commercial Driver's License
CIG: Capital Investment Grant
CMAQ: Congestion Mitigation/Air Quality
CNG: Compressed Natural Gas
CO: Carbon Monoxide
CO2: Carbon Dioxide
COTA: Central Ohio Transit Authority (Columbus, Ohio)
CIP-U: Consumer Price Index for Urban Consumers
DC: Direct Current
DERG: Diesel Emissions Reduction Grant
DGE: Diesel Gallon Equivalent
EPA: Environmental Protection Agency
EV: Electric Vehicle
FCEB: Fuel Cell Electric Bus (hydrogen)
FDC: Fire Department Connection
FHWA: Federal Highway Administration
FTA: Federal Transit Administration
FTE: Full Time Equivalent
FY: Fiscal Year
G: Gram
GGE: Gasoline Gallon Equivalent
GH2: Gaseous Hydrogen
GHG: Greenhouse Gas
GVWR: Gross Vehicle Weight Rating
H2: Hydrogen
HVAC: Heating, Ventilation, Air Conditioning
HYB: Hybrid
ICEB: Internal Combustion Engine Bus
IFC: International Fire Code
IIJA: Infrastructure Investment and Jobs Act
IMC: International Mechanical Code
IndyGo: Indianapolis Public Transportation Corporation
Kg: Kilogram
KVA: Kilovolt-Amps
KW: Kilowatt
KWHr: Kilowatt Hour
LFP: Lithium-Iron-Phosphate
LH2: Liquid Hydrogen
LoNo: Low or No Emission Vehicle Program

LTO: Lithium-Titanium-Oxide
MPG: Miles per Gallon
MPO: Metropolitan Planning Organization
MTD: Champaign-Urban Mass Transit District
MVA: Mega Volt Amp
MW: Megawatt
NFPA: National Fire Protection Association
NMC: Nickel-Manganese-Cobalt
NMTC: New Markets Tax Credit
NOFO: Notice of Funding Opportunity
NOx: Nitrogen Oxide
O&M: Operating and Maintenance
OCTA: Orange County Transportation Authority (California)
ODOT: Ohio Department of Transportation
OEM: Original Equipment Manufacturer
Ohio EPA: Ohio Environmental Protection Agency
OKI: Ohio Kentucky Indiana Regional Council of Governments
OSHA: Occupational Safety and Health Administration
PM: Particulate Matter
PPE: Personal Protective Equipment
PRI: Producer Price Index
PS: Power Source
PSI: Pounds per Square Inch
RAISE: Rebuilding America's Infrastructure with Sustainability and Equity Program
SARTA: Stark Area Regional Transit Authority (Canton, Ohio)
SMART: Strengthening Mobility and Revolutionizing Transportation Program
SoC: State of Charge
SMR: Steam Methane Reformation
SORTA: Southwest Ohio Regional Transit Authority
SOx: Sulfur Oxide
STBG: Surface Transportation Block Grant
TAM: Transit Asset Management
TANK: Transit Authority of Northern Kentucky
TARC: Transit Authority of River City (Louisville, Kentucky)
TIF: Transportation Infrastructure Fund
TRAC: Transportation Review Advisory Council
US DOE: U.S. Department of Energy
US DOT: U.S. Department of Transportation
USDT: U.S. Department of the Treasury
USEIA: US DOE Energy Information Administration
US EPA: U.S. Environmental Protection Agency
VMT: Vehicle Miles Traveled
VOC: Volatile Organic Compound
YOE: Year of Expenditure
ZEB: Zero Emission Bus

EXECUTIVE SUMMARY

Introduction

The three major transit authorities serving the Greater Cincinnati-Northern Kentucky region, through a joint effort, initiated an Alternative Fuel Strategy in 2022. The Southwest Ohio Regional Transit Authority (SORTA), which serves Hamilton County, Ohio; the Transit Authority of Northern Kentucky (TANK), serving Boone, Campbell, and Kenton counties in Kentucky; and the Butler County Regional Transit Authority (BCRTA), serving Butler County, Ohio, currently operate internal combustion engine buses (ICEBs)- carbon-emitting diesel and gasoline-fueled buses. The authorities are seeking a thorough assessment of zero emission (ZE) technologies -specifically battery electric buses (BEBs) and fuel cell electric buses (FCEBs, powered by hydrogen) – by providing the essential data and experience by which each will determine its path forward to a ZE future. This report focuses on BCRTA.

State of the Practice

Alternative fuels are fuels or propulsion systems that are not petroleum-based. They include, but are not limited to, natural gas, electricity, and hydrogen. These alternative fuels can be produced domestically and produce less pollution than diesel.

Buses with an electric and/or hydrogen-based fuel are known as zero-emission buses (ZEBs). ZEBs are buses with a drivetrain that produce zero local tailpipe emissions. In the existing market, the two most prevalent ZEB technologies are battery-electric buses (BEB) and fuel cell electric buses (FCEB), both of which are propelled by an electric motor.

Battery Electric Buses

BEBs use onboard batteries to store and distribute energy to power an electric motor and other onboard systems. As with many other battery-powered products, BEBs must be charged for a period of time to be operational. BEBs can be "depot-charged" at a storage facility when not in service, typically overnight or midday, or "opportunity charged" while in service, typically at a layover point or transit center. A depot charging strategy typically consists of buses with high-capacity battery packs that are charged for several hours in conjunction with "slow" chargers. An opportunity charging strategy typically consists of buses with lower-capacity battery packs that are charged for short periods of time with "fast" chargers. BEBs can be charged via several dispenser types (conductive and inductive) and orientations (overhead or ground-mounted). Figure E-1 illustrates various methods to dispense electricity to a BEB: from left to right, plug-in, overhead (inverted) pantograph, and inductive, described as follows.

Plug-In: The plug-in charger consists of cables and a plug which can be manually inserted into a BEB charging port. Plug-in charging is typically used in bus depot (garage) applications. Plugs are connected as dispensers in 2:1 or 3:1 configuration to a single depot charging station. Pantographs are also used, more typically, as high voltage opportunity chargers.

Conductive-Inverted Overhead Pantograph: The inverted overhead pantograph is an infrastructure-mounted, retractable device with electrical contacts that engage a contact bar on the roof of the bus. The operator uses visual indicators to ensure that the BEB is aligned with the pantograph. This charging strategy automates the initiation of charging, reducing the risk of user error. Inverted overhead pantograph charging can be used for both opportunity and depot charging. Depot pantographs can be connected as dispensers in 2:1 or 3:1 configurations to a single depot charging station. Pantographs are also used, more typically, as high voltage opportunity chargers.

Figure E-1. Battery-Electric Bus Charging Methods

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

Inductive - Wireless Charging: Inductive chargers rely on inductive charging pads- one installed in the ground or floor and the other on the BEB. Powering the induction coil in a ground-mounted pad creates an alternating electromagnetic field which induces current in the induction coil on the BEB, which charges the battery. It requires no labor for external connections and requires no loose electrical cords. Induction plate technology involves a substantial capital investment, and only two manufacturers currently provide equipment. However, once installed, it is the most flexible and, operationally, the least labor intensive of the three different types of charging. Induction charging can be used for both opportunity and depot charging.

COSTS

The cost of an individual BEB varies based on battery capacity, vehicle length, customizations (software/hardware, trimmings, etc.), bulk orders, and warranties. For that reason, it can be difficult to accurately estimate costs until entering a contract with an original equipment manufacturer (OEM). Based on current procurements nationwide, the full cost of a BEB acquisition, including charging infrastructure, is approximately $1.4 million per bus.

INFRASTRUCTURE

Infrastructure components are required to sufficiently and safely charge a BEB include:

- Charging cabinet – dispenses power and, in most cases, converts power from alternating current (AC) to direct current (DC)
- Transformer – steps down electricity to a safe and suitable value for equipment
- Switchgear – distributes power and allows for the isolation of equipment

Other components can also be considered, such as battery storage, photovoltaics (solar panels), and backup generators. The equipment to support BEBs can take up considerable space. Therefore, considerations of safety and reduction of impacts to existing operations must be carefully reviewed and assessed. Due to the potentially high-power demand of charging several BEBs at once, and the limited spare capacity available in existing circuits, expanded or new electrical service is usually required to support BEBs.

RANGE

The range of a BEB does not currently equal that of a standard diesel bus. In terms of a total fleet, BEB may not be able to replace diesel buses on a 1:1 basis. However, the majority of operating blocks at most transit agencies are within current battery ranges; the remaining blocks are either re-blocked. The introduction of BEBs is relatively recent enough so that large agency fleets converting to BEBs have not yet reached 100 percent. In the meantime, battery range has improved every year since their introduction in the last decade and additional improvement in range is expected to continue.

Fuel Cell Electric Buses

FCEBs store compressed gaseous hydrogen which is distributed to onboard fuel cells that combine the hydrogen with ambient air to produce electricity to power an electric motor and other onboard systems. The fuel cell is generally used in conjunction with a low(er)-capacity battery, which stores electricity and supplements the fuel cell's power during peak loads.

Hydrogen is a colorless, odorless gas. Unlike CNG, which is odorized as a safety precaution so that leaking CNG can be detected by smell the same as natural gas used for home heating, hydrogen used in FCEBs is not odorized. Therefore, hydrogen requires hydrogen gas sensors to detect and alert operators to the presence of the odorless, colorless, gas.

PRODUCTION AND STORAGE

The process, operations, and equipment used for FCEBs are similar to lighter-than-air fuels such as CNG. Hydrogen is generated via steam methane reforming (SMR) or electrolysis. SMR, the most common method of producing hydrogen, uses high-pressure steam to produce hydrogen from a methane source, such as natural gas. Electrolysis, on the other hand, uses an electric current to decompose water into hydrogen and oxygen. After the hydrogen is produced, it can be delivered to the site via pipeline or as a gas or liquid by truck. Hydrogen is then stored, vaporized (if delivered as a liquid), compressed, and dispensed to FCEBs on site. Depending on space availability and resources, some agencies can also produce hydrogen on site—most commonly via electrolysis.

COSTS

The capital costs associated with on-site hydrogen production is typically more expensive than the comparable lifecycle costs for delivered hydrogen; however, the hydrogen fuel price savings from on-site production may make it a more cost-effective solution than delivery depending on future pricing conditions. The costs per kilogram of hydrogen for delivered hydrogen are currently around $8-12 per kilogram, as it must be transported with specific tanker truck equipment and the generation costs incurred by the producer, along with a margin, are passed through to the end user.

RANGE

The range of FCEBs is comparable to that of diesel buses. Conversion to FCEBs can be accomplished on a 1:1 replacement ratio.

Peer Agency Experience

Six peer agencies were analyzed to determine their experiences with ZEB technology and implemtnation:

- Orange County Transportation Authority (OCTA), Santa Ana, California
- Stark Area Regional Transit Authority (SARTA), Canton, Ohio
- Champaign-Urbana Mass Transit District (MTD), Urbana, Illinois
- Central Ohio Transit Authority (COTA), Columbus, Ohio
- Indianapolis Public Transportation Corporation (IndyGo), Indianapolis, Indiana
- Transit Authority of River City (TARC), Louisville, Kentucky

These agencies operate a either BEBs or FCEBs; one agency- OCTA in California, currently operates a small number of both. Indianapolis has the largest ZEB fleet, with 43 BEBs; the rest currently operate 15 or fewer buses of either technology. Lessons learned and feedback from the peer agencies is summarized in Table E-1.

Table E-1. Peer Agency ZEB Lessons Learned and General Feedback

BEB	FCEB
• Set parameters for the blocks that the BEBs can operate on. • Implement the buddy system which requires a secondary technician be present for safety. • Consider "what if" scenarios and plan for these scenarios with your safety department. • Recommend having bus storage walls be poured concrete instead of traditional block walls. • All vehicle maintenance and bus storage should plan to have an overhead-rated fire door to close in the event of a fire. • Have more distance between buses. • Have one main Fire Department Connection (FDC) hook up or a dedicated fire pump placed in areas where electric buses are stored. • Have first responders walk through the facility to understand any changes to the bus electric emergency response plans. • Identify a subject matter expert on electric bus technology. • All bus equipment should also have an onboard fire suppression system .	• Keep expectations reasonable early on, first year requires working through kinks, but things normalize in second year. • Install hydrogen leak detectors on buses early. • Uncertainty in fuel cost and availability is big concern. • Anticipate expanding facility to accommodate equipment. • Recommend reading H2 at scale from the Department of Energy to learn about supplemental use cases. • Recommend coordinating between vehicle and fueling manufacturers to ensure compatibility across equipment. • Consider specifying a faster fueling option (perhaps 3.5 kg/min). MTD's equipment is closer to 2.5 kg/min.

Transit Fleet and Operations

Blocking Analysis

An analysis of transit operations is an important consideration when considering BEBs given current limitations on range. Evaluating bus blocks for compatibility with BEB conversion provides an idea of the possible impacts on scheduling, including block length and bus pull-out location. Analysis of the weekday blocks (vehicle itineraries) from recent service schedules indicated that all BCRTA blocks fall within the general range of BEBs.

Current Fleet and Replacement Schedules

BCRTA's existing fleet consists of 56 vehicles, with a mix of 15 35-foot buses, 26 cutaway buses, 11 vans, and one trolley bus. BCRTA has 12 vehicles on order (2021 replacement) and seven vehicles scheduled for procurement (2022 replacement). This was considered in the following replacement schedule. A 12-year useful life threshold was used for buses and a five-year useful life threshold was used for cutaway buses.

Facility Analysis

The BCRTA bus maintenance and administrative office facility at 3045 Moser Court in Hamilton was constructed in 2000. A bus parking garage building was constructed on the site at a later time. The facility was constructed for maintenance of diesel and gasoline vehicles. BCRTA is currently in advanced design of a new maintenance and operating facility in Oxford that will have the capability of housing the entire fleet.

The main bus storage building is capable of storing approximately 24 40-ft vehicles. There is a generous aisle space between each vehicle door and at each end, north and south. Buses enter and exit from vehicle doors on the west side of the storage facility (no through traffic) through six coiling doors, two bus aisles per door.

The facility reports a monthly fuel consumption of 10,856 gallons of gasoline and 1878 gallons of diesel fuel.

The facility has a main 480-volt switchboard rated for 800 amps. Locally, it was observed that there are three available switches on the switchboard. Standby power is provided only for emergency loads with a 40 kW natural gas generator on the south side of the administration building and east side of the maintenance building.

According to record drawings, the garage location is served by a 500 kVA transformer by the City of Hamilton. The utility pad transformer is located at the entrance, near the street and is fed from an overhead 13.2 kV line on Moser Court. Actual transformer rating is 300 kVA; this, in effect, throttles the available current to the 800-amp switchboard to 361 amps.

The new Oxford facility is being designed to accommodate either a 100% BEB fleet or a 100% FCEB fleet. It will also include an outdoor passenger transfer facility that can be equipped with overhead BEB charging equipment.

The Hamilton facility can accommodate a 100% BEB or 100% FCEB fleet with appropriate modifications. The new Oxford facility will also be able to accommodate a 100% BEB or FCEB fleet.

Lifecycle Cost Analysis: Baseline and ZEB Scenarios

The purpose of the lifecycle cost analysis is to provide in-depth analyses on the lifecycle costs for the fleet transition effort. The lifecycle cost estimation includes cash and non-cash costs. Cash costs consist of vehicle and infrastructure capital costs, operating and maintenance costs, and disposal costs. Non-cash costs consist of environmental costs and benefits.

WSP is actively engaged with fuel providers, agencies operating zero-emission buses, and vehicle manufacturers to understand technology and cost trends in the industry. This information is utilized to inform assumptions on the availability and pricing of vehicles and supporting infrastructure. The values presented are subject to change and are based on the most current information available at the time of this analysis (mid-2022).

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

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

The structure of the lifecycle cost modeling includes the assessment of capital, operating, disposal, and monetized environmental costs associated with the transition of existing vehicles under a **Baseline Scenario** and **ZEB scenarios**, defined as:

- **Baseline Scenario** - Continued operation of the current diesel, clean diesel, and diesel-electrichybrid vehicles with replacement by similar models at the end of the assumed vehicle service life
- **BEB Scenario** - Replacement of current vehicles with BEBs at the end of the assumed vehicle service life
- **FCEB Scenario** - Replacement of vehicles with FCEBs at the end of the assumed vehicle service life

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

BEBs and FCEBs and facilities may offer the opportunity for the authorities to lower some operations and maintenance costs; however, other costs will increase. Similar to conventionally fueled vehicles, BEB and FCEB operations and maintenance costs are highly dependent on the size and complexity of the vehicle fleet. Additionally, an electrification strategy would shift the authorities' primary fuel source for core bus operations from diesel to electric power, which would subject the agency to very different energy pricing structures and exposure to energy price volatility.

Table E-2 outlines the major cost categories evaluated as part of the lifecycle analysis.

Table E-2. Primary Cost Categories

Cost Type	Cost Category	Cost Variable
Cash Costs	Capital	Vehicle
		Vehicle modifications and contingency
		Facility costs for charging or fueling Infrastructure
		Major component replacement
	O&M	Vehicle maintenance, tools, training, and equipment
		Tire replacement costs
		Vehicle fuel/energy costs
		Charging and fueling infrastructure maintenance costs
		Training costs
	Disposal	Bus disposal costs or salvage value
Non-Cash Costs (Benefits)	Environmental	Vehicle emissions (including tire and brake wear)
		Upstream emissions

Cost Type	Cost Category	Cost Variable
		Noise impacts

Source: WSP

Lifecycle Cost Results

The lifecycle cost results are summarized in Tables E-3 and E-4, presenting the outcomes in 2022 dollars and year of expenditure (YOE) dollars, respectively.

The full lifecycle cash cost of a transition to BEBs and FCEBs is higher than the continued reliance on IFCBs (diesel). While the initial capital and operating costs are higher for ZEBs, there are opportunities for some savings in fuel costs. Additionally, operating cost benefits are highly dependent on factors that are continually evolving as BEBs and FCEBs are deployed in greater numbers across the U.S.

The analysis also shows that the Baseline scenario would result in a large emission generation over the lifecycle of diesel operations in comparison to the Build scenarios. The large vehicle emission difference between the two replacement scenarios was expected, as the technology in the BEBs are aimed to reduce GHG emissions, particularly for carbon emissions.

The comparison of BEBs and FCEBs indicate that BCRTA may benefit from pursuing hydrogen over electricity. BCRTA's relative small size, the flexibility of the Hamilton facility and planned Oxford facility, are amng the factors that lean in that direction.

Table E-3. Lifecycle Cost Analysis Results (2022$ Millions)

Scenario		**BASELINE**	**BEB**	**FCEB**
Capital	VEHICLE PURCHASE PRICE	$13	$27	$27
	MODIFICATIONS & CONTINGENCY	$2	$3	$3
	CHARGING/FUELING INFRASTRUCTURE	$0	$13	$9
	COMPONENT REPLACEMENT	$1	$0	$1
	TOTAL CAPITAL COSTS	**$16**	**$43**	**$39**
Operating	VEHICLE MAINTENANCE	$16	$23	$15
	VEHICLE TIRES	$0	$0	$0
	VEHICLE FUEL COSTS	$9	$15	$12
	CHARGING/FUELING INFRASTRUCTURE	$1	$2	$2
	TRAINING COSTS	$0	$0	$1
	TOTAL OPERATING COSTS	**$25**	**$40**	**$31**
Disposal	BATTERY DISPOSAL	$0	$0	$0
	BUS DISPOSAL	$0	-$1	$0
	TOTAL DISPOSAL COSTS	$0	-$1	$0
Total Cash Costs		**$40**	**$83**	**$69**
Comparison to Base	*DOLLARS*	*$0*	*$42*	*$29*
	PERCENT	-	*105%*	*71%*
Total Cash Cost per Mile		**$1.99**	**$3.33**	**$3.39**
Environmental	$2	$1	$0	$1
	$1	$0	$0	$1
	$1	$1	$1	$3
	$4	$2	$2	**$5**
Total Cash and Non-Cash Costs		**$45**	**$85**	**$71**
Comparison to Base	*DOLLARS*	*$0*	*$40*	*$26*
	PERCENT	-	*90%*	*59%*
Total Cash and Non-Cash Costs per Mile		**$2.20**	**$3.42**	**$3.48**
Total Mileage (million miles)		*20*	*25*	*20*

Source: WSP

Table E-4. Lifecycle Cost Analysis Results (YOE$ Millions)

Scenario		BASELINE	BEB	FCEB
Capital	VEHICLE PURCHASE PRICE	$20	$41	$41
	MODIFICATIONS & CONTINGENCY	$2	$5	$4
	CHARGING/FUELING INFRASTRUCTURE	$0	$19	$12
	COMPONENT REPLACEMENT	$1	$0	$1
	TOTAL CAPITAL COSTS	**$24**	**$65**	**$58**
Operating	VEHICLE MAINTENANCE	$23	$35	$22
	VEHICLE TIRES	$0	$1	$0
	VEHICLE FUEL COSTS	$13	$22	$18
	CHARGING/FUELING INFRASTRUCTURE	$1	$3	$3
	TRAINING COSTS	$0	$0	$1
	TOTAL OPERATING COSTS	**$37**	**$61**	**$44**
Disposal	BATTERY DISPOSAL	$0	$0	$0
	BUS DISPOSAL	-$1	-$1	-$1
	TOTAL DISPOSAL COSTS	**-$1**	**-$1**	**-$1**
Total Cash Costs		**$60**	**$126**	**$102**
Comparison to Base	*DOLLARS*	$0	$66	$42
	PERCENT	-	111%	70%
Total Cash Cost per Mile		**$1.95**	**$2.94**	**$5.07**
Environmental	EMISSIONS - TAILPIPE	$3	$1	$1
	EMISSIONS - REFINING/UTILITY	$1	$0	$0
	NOISE	$2	$2	$2
	TOTAL ENVIRONMENTAL COSTS	$6	$3	$3
Total Cash and Non-Cash Costs		**$66**	**$129**	**$104**
Comparison to Base	*DOLLARS*	$0	$63	$38
	PERCENT	-	95%	58%
Total Cash and Non-Cash Costs per Mile		**$3.25**	**$5.19**	**$5.11**
Total Mileage (million miles)		20	25	*20*

Source: WSP

Potential Risks

A transition to alternative fuels and ZEBs, as with the introduction of and major change to capital infrastructure and operating procedures, entails some level of risk. The Lifecycle Cost Analysis identifies the cost implications of a transition to alternative fuels. The identification of potential risks – for both a transition to BEBs and FCEBs – along with an identification of potential risks if a transit agency does not elect to transition to alternative fuel/ZEBs is designed to further help BCRTA in determining a path forward.

The identification of risks is not considered a benefit-cost analysis. Risks are identified to help inform decision-makers with the various issues that are associated with the various technologies, primarily from the standpoints of technology, reliability, cost, and safety, but also in terms of the political and public considerations that come with a major change in infrastructure, agency policy, and carbon mitigation along with major expenditure of public dollars. Risks involve buses, charging and fueling infrastructure, facilities and maintenance, fuel and power supply, and funding. Potential risks are summarized in Table E-5.

Table E-5. Summary of Potential Risks

BEBs	FCEBs	Diesel / Diesel Electric Hybrids
Although new federal programs are designed to expand BEB technology, and availability, high demand for BEBs has the potential to slow production and delivery of BEBs and associated parts and infrastructure.	Relative newness of FCEB technology, limited industry experience to date and ongoing improvements may result in unachieved performance levels and render components or buses obsolete.	Contribution to climate change.
Battery fire may occur and spread to surrounding materials and adjacent buses at Bus Operating Facility.	High demand may significantly slow production and delivery of FCEBs and associated parts and infrastructure.	Nationwide shift to cleaner and renewable energy may result in fewer refineries and capacity.
Relative newness of BEB technology and ongoing improvements may render components or buses obsolete.	Equipment may fail and result in hydrogen leaks creating a potential fire hazard.	Nationwide shift to cleaner and renewable energy along with increased environmental regulations and government policy may reduce capacity.
A loss of cooling liquid causes arcing, heating the cells and causing thermal runaway.	Hydrogen is highly flammable; static electricity can cause sparks.	Price swings due to infrastructure issues, weather, international conditions, etc.
Crashes put mechanical strain on the batteries; cells can come lose from the vehicle and spread around the crash site.	Limitation on adequate and safe location of fueling facilities may restrict the ability to convert 100% of the fleet to FCEB, resulting in a mixed fleet.	Erosion of public and government support for the agency. Public relations issues.
Potentially subject to cyberattacks.	The increasing frequency of severe weather, such as flooding, high winds, and severe lightning, poses a threat to maintaining power supply.	Reduced funding for diesel buses.
Monitoring system transmitting telemetry data can fail on a mechanical or software platform.	Equipment malfunction or force majeure at production facility interrupts hydrogen deliveries. Limited number of suppliers in area.	Shift by manufacturers to ZEB production may reduce ability to replace buses or expand fleet.
First responders to a battery-related combustion incident may be at the risk of harm when subject to a volatile and dangerous environment	Pipeline availability may be limited and subject to strict regulation, delaying or precluding direct service to a Bus Operating Facility.	
Use of lithium batteries propagates the unregulated mining of materials in developing countries.	Insurers may increase rates due to the publicity on the volatility of hydrogen.	
Unregulated manufacturing plants often release harmful organic electrolytes and requires high energy consumption	Fueling, maintaining, and operating FCEBs requires significant and on-going training, resulting in increased costs; agency reliance on	

BEBs	FCEBs	Diesel / Diesel Electric Hybrids
	manufacturer for training may cause delays and erosion of quality of training; employee turnover can also impact training costs and effectiveness.	
Insurers may increase rates due to the publicity on the volatility of batteries.	Local fire and emergency personnel may not be familiar with and/or adequately training in safety and hazard mitigation procedures.	
The increasing frequency of severe weather, such as flooding, high winds, and severe lightning, poses a threat to maintaining power supply.	Manufacturer assistance or warranty services may be delayed.	
Charging, maintaining, and operating BEBs requires significant and on-going training, resulting in increased costs; agency reliance on manufacturer for training may cause delays and erosion of quality of training; employee turnover can also impact training costs and effectiveness.	On-site production of hydrogen is relatively expensive and requires additional outdoor space.	
Local fire and emergency personnel may not be familiar with and/or adequately training in safety and hazard mitigation procedures.	Limited number of hydrogen suppliers may impact supply reliability	
Manufacturer assistance or warranty services may be delayed.		
Preferred site may have inadequate power access or neighborhood opposition.		

While there are several risks associated with both BEBs and FCEBs, the risk may be greater with FCEBs due to three basis conditions:

- The number of BEBs in service and on order far exceeds FCEBs.
- The number of OEMs producing BEBs exceeds FCEBs.
- Federal funding programs favor BEBs.

Implementation

The estimated lifecycle costs of FCEBs are slightly lower than BEBs, but the difference is minimal. BCRTA's Hamilton and planned Oxford facilities can be modified to accommodate either technology. However, between BEBs and FCEBs, the most significant risk factors and considerations focus on the relatively minimal industry experience with FCEB versus BEBs. There is still, at this point, no indication that FCEBs will eventually comprise a major market share that will eventually result in the moderating trend of capital costs – or downward pressure on price - thay typically arises from a new technology that becomes standard technology. Grant availability is another factor. While hydrogen technology is eligible under various funding programs, the current federal emphasis is on BEBs.

Regional Network Benefits

Benefits of all three authorities pursuing the same ZEB technology are speculative at this time. Potential network benefits of BEBs appear minimal primarily because each authority has its own contract and arrangements with its local utility. Shared opportunity charger locations are also limited. Interface locations between BCRTA and SORTA are highly limited and not a significant potential network benefit factor.

FCEB technology may offer potential network benefits involving the production and procurement of hydrogen. A regional commitment of the authorities to hydrogen may encourage the development of providers, which are currently very limited.

It is theoretically possible for one authority to arrange with another to fuel at their facility. In terms of infrastructure, this is dependent on the ability of a hydrogen facility to store enough H2 for a large number of buses. Even if this should occur, the practicality of one authority sending its buses every day or night to a fuelding facility several miles away would create major logistical issues and operating cost increases, such as those involving extensive deadheading.

Network benefits can extend beyond the transit authorities. For example, other major public entities that desire to convert large fleets to ZE may team work with one of more of the authorities to help encourage available supply of hyrdrogen. At this time, however, the region's largest public entity, the City of Cincinati, has expressed minimal interest in hydrogen and intends to pursue electric.

Timeline

A transition timeline is divided up into three components: utilities, facilities, and vehicles.

Utility and facility development would prepare the authorities to accept BEBs or FCEBs and infrastructure through their transition periods. Utilities application, design, and construction can take up to 36 months, although this timeline is shorter or longer depending on the utility and power required. It is paramount that the authorities complete infrastructure to support vehicles before vehicles arrive onsite.

The facilities timeline is based upon a design-bid-build strategy. While the lengths of time required for each stage of this process depends heavily on internal procurement and design procedures of each authority, the assumptions shown below provide a rough estimate based on experience with other agencies.

These assumptions take into account a preliminary procurement schedule, and two rounds of bus production extending into 2025. It is assumed that the authorities will not go out for bid in successive years for vehicles, but instead exercise options off existing procurement contracts for several years before going out for bid. It is also assumed that chargers will be purchased with BEBs, and/or hydrogen fueling stations purchased with FCEBs.

Training

Transitioning to ZEBs requires training employees to keep pace with changing technologies. BCRTA provides operational training for its bus operators, mechanics, and other support employees. The emphasis for ZEBs is primarily on mechanic training, however. The shift from ICEBs and propulsion technologies to ZEB systems is more complicated for mechanics than it is for bus operators.

Training will be required prior to deployment of ZEBs into revenue service. It should be provided by bus OEMs and coincide with pre-production activities. Training should be coordinated with OEMs and internal stakeholders for authority employees to attend OEM familiarization and safety orientation sessions. Of utmost importance in training awareness of high voltage conditions including "lock out/tag out" procedures and other safety considerations.

Training must also be refreshed on a regular basis, for new employees and refresher training for existing employees on a quarterly basis. While new technology requires strong partnerships with OEMs and sub-component suppliers, the ultimate goal of the authorities is to reduce reliance on OEMs in the long term and bring ZEB training in-house. Classes can be taught by staff on the array of essential topics including safety awareness for high voltage and high-pressure hydrogen, operational start-up/shut-down and emergency procedures, familiarization with the location and function of fuel cell and battery electric components, fueling, and charging.

All training, for operators, mechanics, supervisors, and others, would typically be scheduled through an agency-based learning management system. This can take the form of an intranet site that serves as the primary portal for the authorities' transportation and maintenance departments to access course and course schedules. It also allows the authorities to track training complianece for each employees and is essential to tracking training progress and results.

Operators: Operator training should include both academic (classroom) and behind-the-wheel experience. Training topics include dash controls, indicator lights, specific start-up and shut-down procedures, and defensive driving safety.

Mechanics: For mechanics and others, familiarization and safety orientation is an OEM-led class. Content includes high voltage safety awareness, personal protective equipment (PPE), safety measures, and preventive maintenance. Training sessions would be conducted for each shift upon ZEB delivery. In addition to mechanics and service employess, maintenance supervisory staff and maintenance trainers would be require the same training.

Additional topics that OEMs would provide training for include air systems, brakes, steering/suspension, electrical systems, computer diagnostic systems, energy storage systems, fuel cell systems, and troubleshooting.

Lessons Learned

Work with transitioning agencies around the country has resulted in a variety of lessons learned for both procurement and incorporation of ZEB technology into a fleet. The following considerations should be made in developing a full fleet transition:

- Facility construction and infrastructure installation should complete before buses arrive onsite. This will ensure that vehicles can be used when they arrive and prevent warranty delays.
- The authorities may consider "evergreen battery warranties" to ensure performance for the lifetime of a vehicle. Adding warranty language to bus contracts will allow authorities to maintain their fleet performance as batteries age, for example.
- The authorities should engage a facility designer to perform 100% designs. Regardless of technology choice, a facility designer will enable each authorities to best optimize its facility(ies) to fit new technology with minimal impact to ongoing operations.

Equity

Equity is an important consideration in an Alternative Fuel strategy in terms of facilities and deployment of vehicles. In terms of bus operating facilities, equity considerations should be minimal. SORTA's, TANK's, and BCRTA's facilities are generally located in industrial or industrial park areas with little or no residential land use in the immediate vicinity.

When an authority's first ZEBs are deployed, equity considerations are a greater factor. For BCRTA, a somewhat robust equity analysis may be required prior to implementation given the contrasts between areas that require equity consideration, such as in portions of Hamilton and Middletown, and those that do not.

Funding Sources

The federal government, which is a primary funding source for bus procurements, is heavily promoting the transition from carbon-emitting vehicles, such as diesel buses, to alternative fuels and clean technologies such as BEBs and FCEBs. It is also incentivizing transit agencies to make this transition by providing substantial funding.

The Infrastructure Investment and Jobs Act (IIJA or "Act") was signed into law in 2021. Now formally known as the Bipartisan Infrastructure Law (BIL), the Act contains $550 billion in new spending over five years. The BIL also provides $113.3 billion in advance general fund appropriations to allow agencies to begin funding infrastructure improvements before the fiscal year (FY) 2022 appropriations process is completed. Table E-6 summarizes the ZEB programs funded through the Federal Transit Administration (FTA).

Table E-6. Potential FTA Funding Sources Summary

FTA Funding Program	Program Type	Eligibility			Funding Amount (FY 22 – FY 26)
		Alt Fuel Vehicle/ZEB Purchase	Vehicle Charging Infrastructure	Facility Capital Investments	
Bus and Bus Facilities Program, both formula and discretionary	Formula and Discretionary	✓	✓	✓	$ 5.1 B
Low or No Emission Vehicle Program	Discretionary	✓	✓	✓	$ 5.6 B
Urbanized Area Formula Grants	Formula	✓	✓	✓	$ 33.5 B
Capital Investment Grants (CIG) – Small Starts	Discretionary	✓	✓	✓	$ 23 B
FTA Section 5310: Enhanced Mobility of Seniors & Individuals with Disabilities	Formula	✓	✓		$ 2.2 B

1 INTRODUCTION

The three major transit authorities serving the Greater Cincinnati-Northern Kentucky region, through a joint effort, initiated an Alternative Fuel Strategy in 2022. The Southwest Ohio Regional Transit Authority (SORTA), which serves Hamilton County, Ohio; the Transit Authority of Northern Kentucky (TANK), serving Boone, Campbell, and Kenton counties in Kentucky; and the Butler County Regional Transit Authority (BCRTA), serving Butler County, Ohio, currently operate internal combustion engine buses (ICEBs)- carbon-emitting diesel and gasoline-fueled buses. The authorities are seeking a thorough assessment of zero emission (ZE) technologies -specifically battery electric buses (BEBs) and fuel cell electric buses (FCEBs, powered by hydrogen) – provide the essential data and experience by which each will determine its path forward to a ZE future. This report focuses on BCRTA.

Figure 1-1: Zero Emission Buses and Infrastructure

Source: Capitol GCS, King County Metro, Mass Transit, Intelligent Transport

The objectives of the Strategy include:

- Provide a baseline summary of key authority metrics.
- Take into consideration city/county/state zero/reduced emission goals.
- Summarize relevant considerations for developing a ZEB fleet.
- Assess the currently regulatory and funding framework.
- Determine facility conditions, constraints, and opportunities.
- Identify implementation and ongoing procedures.

The development of the Strategy begins with a review of industry and peer agency experience. As relatively new technologies, BEBs and FCEBs are used in limited, but growing, quantities throughout the U.S. BEB technology has been around longer than FCEB; it is in part for this reason that the use of BEBs are currently more widespread than FCEBs. In Ohio and Kentucky, agencies such as the Central Ohio Transit Authority (COTA) in Columbus, the Stark Area Regional Transit Authority (SARTA) in Canton, and the Transit Authority of River City (TARC) in Louisville have already introduced BEBs and FCEBs into revenue service. Their experiences, while generally positive, provide examples of lessons learned that can be applied to the Greater Cincinnati-Northern Kentucky authorities.

Figure 1-2. Zero Emission Buses in Columbus, Canton, and Louisville

Source: COTA, SARTA, Green Car Congress

The ability of each of the authorities to transition to ZEBs has a significant financial impact. ZEBs are more expensive than ICEBs, new charging and/or fueling infrastructure must be added, current operating blocks may be impacted, and new training programs must be implemented. Federal funding, however, if available to offset some of these costs through the recent Bipartisan Infrastructure Bill's Low-No Emissions Grant Program. To be eligible for funding under this program, the authorities must develop a Transition Plan, which this Alternative Fuel Strategy will comprise. Additional potential funding sources at the federal, state, regional, and local levels are also identified and addressed for the relevance and potential to help with the transition to ZE.

A major factor in the decision of which path to follow is the design, layout, location, and condition of its bus operating facilities. In addition to its existing facility in Hamilton, BCRTA is currently in final design, and has secured funding and a site for a new facility in Oxford. Through an analysis of the existing facility and available plans for the new Oxford facility, it can be determined if and how each can accommodate BEBs and or/BEBs, and to what extent.

Figure 1-3. BCRTA, SORTA, and TANK Bus Operating Facilities

A Lifecycle Cost Analysis is developed using available agency and utility data, to estimate the costs of a transition to BEBs and FCEBs. The analysis takes into account vehicle replacement schedules, buses currently on order, utility requirements, facility modifications to accommodate either technology (including additional power needs, charging equipment, and fueling stations), current and anticipated vehicle costs, training, and emissions. Estimated costs are projected out to the middle of the next decade, allowing for a potential 100 percent transition to ZEBs, and shown in current year and year of expenditure dollars.

As with the introduction of any new technology, especially after a nearly a century of operating ICEBs, risks are involved. A register of risks highlights the various issues relating to each technology in terms of safety, availability, complexity, and cost. Risks are somewhat subjective but must be taken into account in concert with the Lifecycle Cost Analysis. Together, the results provide BCRTA with the essential information from which to make an informed decision on their path forward.

2 STATE OF THE PRACTICE

Alternative fuels are fuels or propulsion systems that are not petroleum-based. They include, but are not limited to, natural gas, electricity, and hydrogen. These alternative fuels can be produced domestically and produce less pollution than diesel.

Buses with an electric and/or hydrogen-based fuel are known as zero-emission buses (ZEBs). ZEBs are buses with a drivetrain that produce zero local tailpipe emissions. In the existing market, the two most prevalent ZEB technologies are battery-electric buses (BEBs) and fuel cell electric buses (FCEBs), both of which are propelled by an electric motor.

It is important to monitor and understand these alternative fuel bus technologies and characteristics as their markets are rapidly changing. The following subsections provide an overview of BEB and FCEB technologies.

2.1 BATTERY ELECTRIC BUSES

BEBs use onboard batteries to store and distribute energy to power an electric motor and other onboard systems. As with many other battery-powered products, BEBs must be charged for a period of time to be operational. BEBs can be "depot-charged" at a storage facility when not in service, typically overnight or midday, or "opportunity charged" while in service, typically at a layover point or transit center. A depot charging strategy typically consists of buses with high-capacity (kilowatt-hour [kWh]) battery packs that are charged for several hours in conjunction with "slow" chargers, usually rated with less than 150 kilowatts (kW). An opportunity charging strategy typically consists of buses with lower-capacity battery packs that are charged for short periods of time with "fast" chargers, usually in excess of 150 kW. BEBs can be charged via several dispenser types (conductive and inductive) and orientations (overhead or ground-mounted). Figure 2-1 illustrates various methods to dispense electricity to a BEB: from left to right, plug-in, overhead (inverted) pantograph, and inductive.

Figure 2-1. Battery Electric Bus Charging Methods

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

2.1.1 PLUG-IN

The plug-in charger consists of cables and a plug which can be manually inserted into a BEB charging port. Charging connectors are subject to misalignment errors. Mismanaged cables are subject to damage because of their proximity to bus lanes while bulky cables must be managed in close proximity to bus lanes. Plug-in charging is typically used in bus depot (garage) applications. Plugs are connected as dispensers in 2:1 or 3:1 configurations to a single depot charging station. Pantographs are also used, more typically, as high voltage opportunity chargers.

An example of dispenser and charger cabinets, for Knoxville Area Transit supplied by the manufacturer Heliox, is shown in Figure 2-2.

Figure 2-2. Dispenser and Charger Cabinets, Knoxville Area Transit

Source: Heliox

2.1.2 CONDUCTIVE - INVERTED OVERHEAD PANTOGRAPH

The inverted overhead pantograph is an infrastructure-mounted, retractable device with electrical contacts that engage a contact bar on the roof of the bus. The operator uses visual indicators, such as lighting or painted markings, to ensure that the BEB is aligned with the pantograph. The operator then lowers the pantograph from a switch on the bus using RFID (radio frequency identification) or wireless technology; the charge automatically starts once the pantograph has engaged the contacts on the bus. This charging strategy automates the initiation of charging, reducing the risk of user error.

Inverted overhead pantograph charging can be used for both opportunity and depot charging. Depot pantographs can be connected as dispensers in 2:1 or 3:1 configurations to a single depot charging station. Pantographs are also used, more typically, as high voltage opportunity chargers.

Figure 2-3 shows an example of on-route overhead charging in Los Angeles. An example of indoor bus garage charging in Edmonton, Canada, is shown in Figure 2-4.

Figure 2-3. On-Route Overhead Charging, Los Angeles Metro

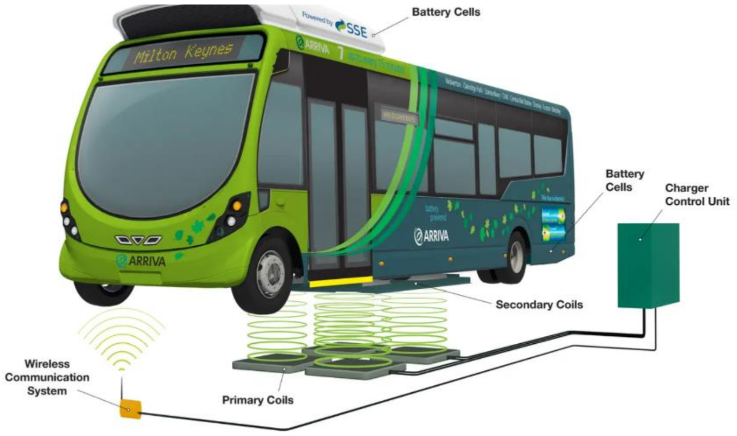
Figure 2-4. Bus Operating Facility, Overhead Pantograph Chargers, Edmonton Transit

Source: Sustainable-Bus.com

2.1.3 INDUCTIVE - WIRELESS CHARGING

Inductive chargers rely on inductive charging pads- one installed in the ground or floor and the other on the BEB. Powering the induction coil in a ground-mounted pad creates an alternating electromagnetic field which induces current in the induction coil on the BEB, charging the battery. The process is illustrated in Figure 2-5. The induction charger system brings some significant advantages to the charging operation. Foremost, no system connections are exposed, reducing corrosion from water or the salt and chemicals used to de-ice roads. In addition, the system needs no physical plug and unplug activity, thereby eliminating issues related to wear and tear. It requires no labor for external connections and requires no loose electrical cords. Buses equipped for induction charging have visual indicators to provide the vehicle operator with visual cues to precisely align the induction charging plates for efficient charging. More sophisticated (and expensive) systems provide steering assist for the driver to align charging surfaces.

Figure 2-5. Induction Charging Process



Source:https://techxplore.com/news/2014-01-electric-buses-wireless-uk-milton.html

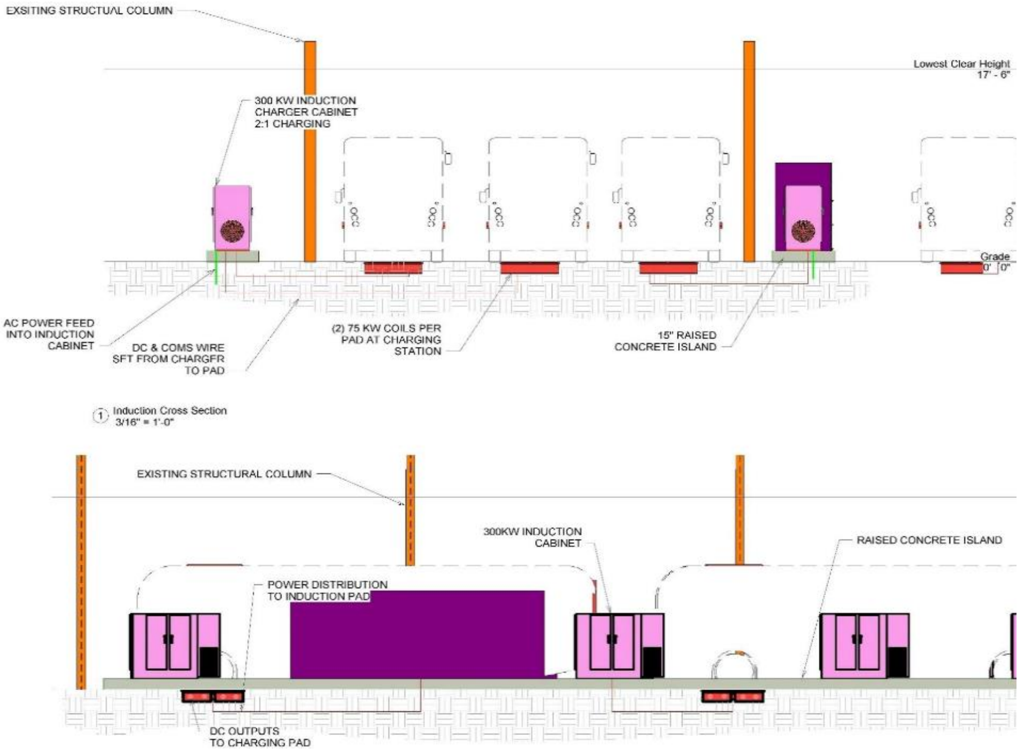
Induction plate technology involves a substantial capital investment, and currently, only two manufacturers currently provide equipment. Electrical feeders between the direct current (DC) charger and the streetside induction plate are subsurface, requiring extensive excavation. In addition, BEBs must be specially equipped with matching induction coils and supporting electronics to be compatible with this charging method. It is the most expensive installed alternative. However, once installed, is the most flexible and, operationally, the least labor intensive of the three different types of charging. Induction charging can be used for both opportunity and depot charging.

An example of on-route induction charging, from Link Transit in Wenatchee, Washington and provided by the supplier, Momentum Dynamics, is shown in Figure 2-6. Induction charging in a bus operating facility is illustrated in Figure 2-7.

Figure 2-6. On-Route Induction Charging, Link Transit, Wenatchee, Washington

Source: Momentum Dynamics

Figure 2-7. Conceptual Bus Operating Facility Induction Charging



2.1.4 OPERATING RANGE

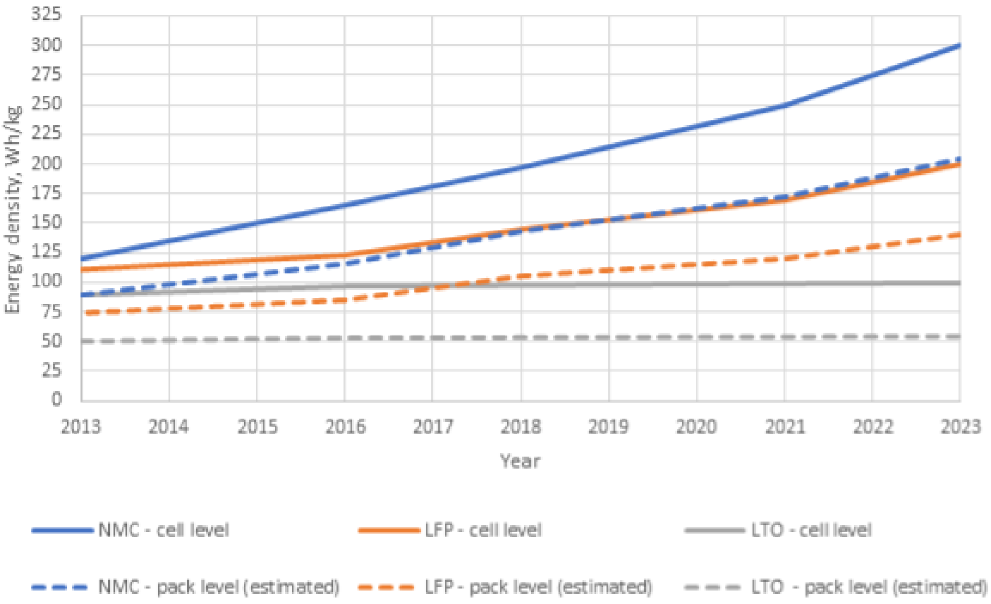
Under existing conditions, BEBs cannot meet the operating ranges that internal combustion engine buses (ICEBs) can. The specific range is dictated by multiple factors including temperature and heating, ventilation, air conditioning (HVAC) usage, driving behavior, and topography. For this reason, if a duty cycle cannot be completed with a single BEB, other capital-intensive strategies must be considered to meet range requirements, including, but not limited to, service changes, additional BEBs, opportunity charging infrastructure, or a mixed-fleet strategy with the incorporation of FCEBs. BEBs, as with other battery-based products, experience battery degradation over time, meaning that the usable capacity, and thus range, will be reduced over the lifecycle of the battery. Therefore, it is important to understand, plan for, and mitigate degradation and its impact on the overall range of the BEB. Accordingly, additional warranties (including battery replacement) or operational changes will need to be considered.

2.1.5 BATTERY PERFORMANCE

There are several advancements in battery technology being researched that aim to improve energy densities, lifespans, and reduce weight. Additional research is being conducted to reduce the cost and time required to manufacture these batteries as well as increase the cycle life.

The most significant advances are in energy density improvements resulting in reductions in battery weight. Anticipated breakthroughs within battery performance will address many of the limitations existing today in terms of range capability, weight, life expectancy and degradation. As an example, for a bus with a 450-kWh battery, an increase of energy density from 150 Wh/kg to 300 Wh/kg could reduce bus battery weight by up to 3000 pounds. This weight reduction would allow for additional kWh of battery capacity added or an overall reduction in bus weight.

Figure 2-8: Lithium-Ion Battery Technology Progression



Source: Sustainable Bus

Since lithium-ion batteries have high energy and power densities, they are the preferred technology for electric vehicles. The three most widely used types of lithium-ion batteries are lithium-titanium oxide (LTO), lithium-ion-phosphate (LFP), and nickel-manganese-cobalt (NMC). These batteries have high specific power and/or specific energy, and high thermal and safety performance.[1] As shown in Figure 2-8, these types of lithium-ion batteries have been increasing in energy density and are expected to continue increase over time.[2] The U.S Department of Energy (DOE) is currently providing funding to various companies to focus on the manufacture of batteries and increase of storage capacity. Due to the growing research in battery technology, improvements in BEB range and cost are

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[1] Redesigning European Public Transport: Impact of New Battery

[2] Sustainable Bus

anticipated. New battery cell chemistries such as solid-state batteries are also anticipated to be introduced into the market by 2026. Anticipated new manufacturing process are also expected to reduce battery cost.

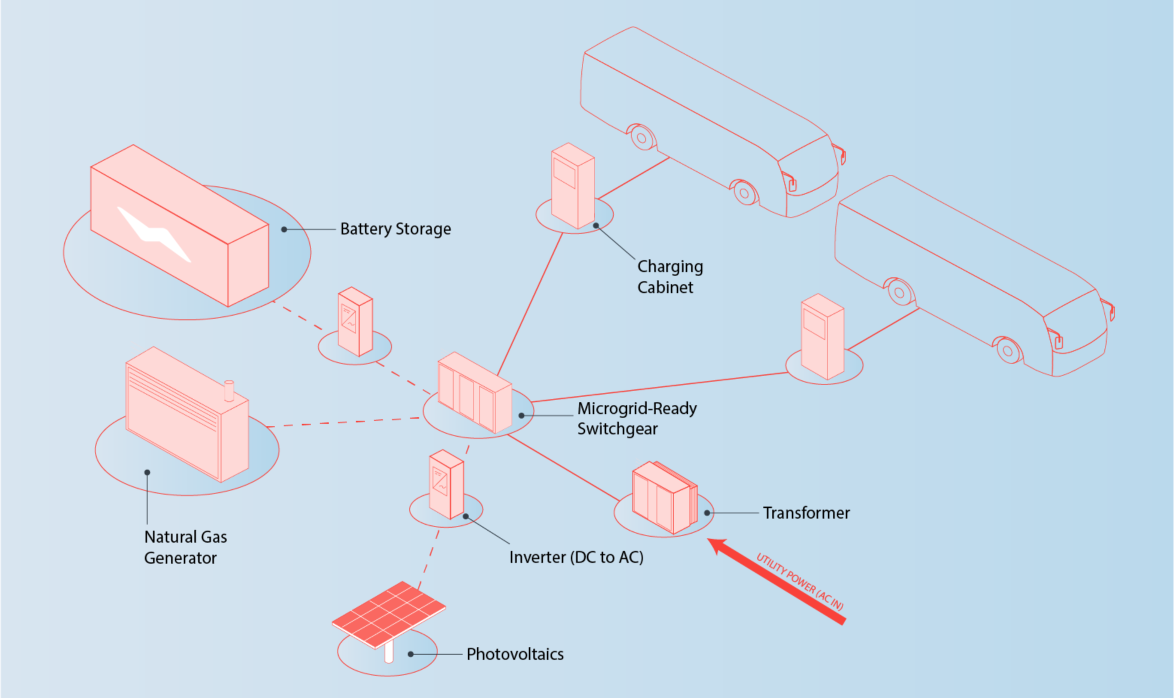
2.1.6 INFRASTRUCTURE

The following infrastructure components are required to sufficiently and safely charge a BEB:

- Charging cabinet – dispenses power and, in most cases, converts power from alternating current (AC) to direct current (DC)
- Transformer – steps down electricity to a safe and suitable value for equipment
- Switchgear – distributes power and allows for the isolation of equipment

Other components can also be considered, such as battery storage, photovoltaics (solar panels), and backup generators. The equipment to support BEBs can take up considerable space. Therefore, considerations of safety and reduction of impacts to existing operations must be carefully reviewed and assessed. Due to the potentially high-power demand of charging several BEBs at once, and the limited spare capacity available in existing circuits, expanded or new electrical service is usually required to support BEBs. Figure 2-9 illustrates the infrastructure that comprises a typical BEB charging system.

Figure 2-9. Typical Battery Electric Bus Charging Infrastructure



Source: WSP

2.1.7 SWITCHBOARD

To accommodate BEBs, new charging capacity would need to be supplied using a 2000-amp, 480/277-volt, three-phase, four-wire, double-ended switchboard that makes use of molded-case breaker technology. The “double-ended” switchboard is characterized by two independent main copper “buses,” each with its own main breaker. (A switchboard “bus” does not refer to a transit vehicle but is a feature that distributes power from incoming cable boxes to branch circuits. They are either made of copper or aluminum.) The switchboard architecture would feature an interconnecting copper bus with a normally open breaker that would close automatically in the event either incoming feeder is interrupted. In addition, the main breaker affected by the outage would open. This "automatic throwover" mechanism would permit any one of the chargers on the affected copper buses to continue operation, although at half capacity - since both ends of the switchboard would temporarily have to share a single remaining transformer - When power is restored, automatic mechanisms reverse the sequence to restore breakers to normal—isolated—operation.

2.1.8 CHARGING INFRASTRUCTURE MARKET AVAILABILITY

Several charger OEMs offer conductive chargers that comply with standards established by the Society of Automotive Engineers. However, there are currently no standards for inductive charging, so adopters of a single OEM (e.g., WAVE) are unable to operate with the other OEM's equipment (e.g., Momentum). Table 2-1 summarizes the various charger OEMs and their current offerings. It should be noted that these represent DC chargers that are compatible with all bus OEMs.

Table 2-1. Available Chargers in the U.S. Market

Manufacturer	Charging Type	Power (kW)
ABB	Plug-in Combined Charging System (CCS)	100 – 350
ChargePoint	Plug-in CCS	62.5 – 350
Hitachi - ABB	Plug-in CCS	50 – 150
Heliox	Plug-in CCS	180
Momentum Dynamics	Inductive - Wireless	50 – 300
Siemens	Plug-in CCS	100 – 400
Tritium	Plug-in CCS	50 – 175
Wave	Inductive - Wireless	350

Source: WSP, OEM Websites

As BEB technologies advance, interconnectivity between software, hardware, and BEB-supporting infrastructure is imperative for the successful implementation and operation of a fully electrified fleet.

2.1.9 COSTS

The cost of an individual BEB varies based on battery capacity, vehicle length, customizations (software/hardware, trimmings, etc.), bulk orders, and warranties. For that reason, it can be difficult to accurately estimate costs until entering a contract with an original equipment manufacturer (OEM). Based on current procurements nationwide, the full cost of a BEB acquisition, including charging infrastructure, is approximately $1.4 million per bus[3].

2.2 FUEL CELL ELECTRIC BUSES

FCEBs store compressed gaseous hydrogen which is distributed to onboard fuel cells that combine the hydrogen with ambient air to produce electricity to power an electric motor and other onboard systems. The fuel cell is generally used

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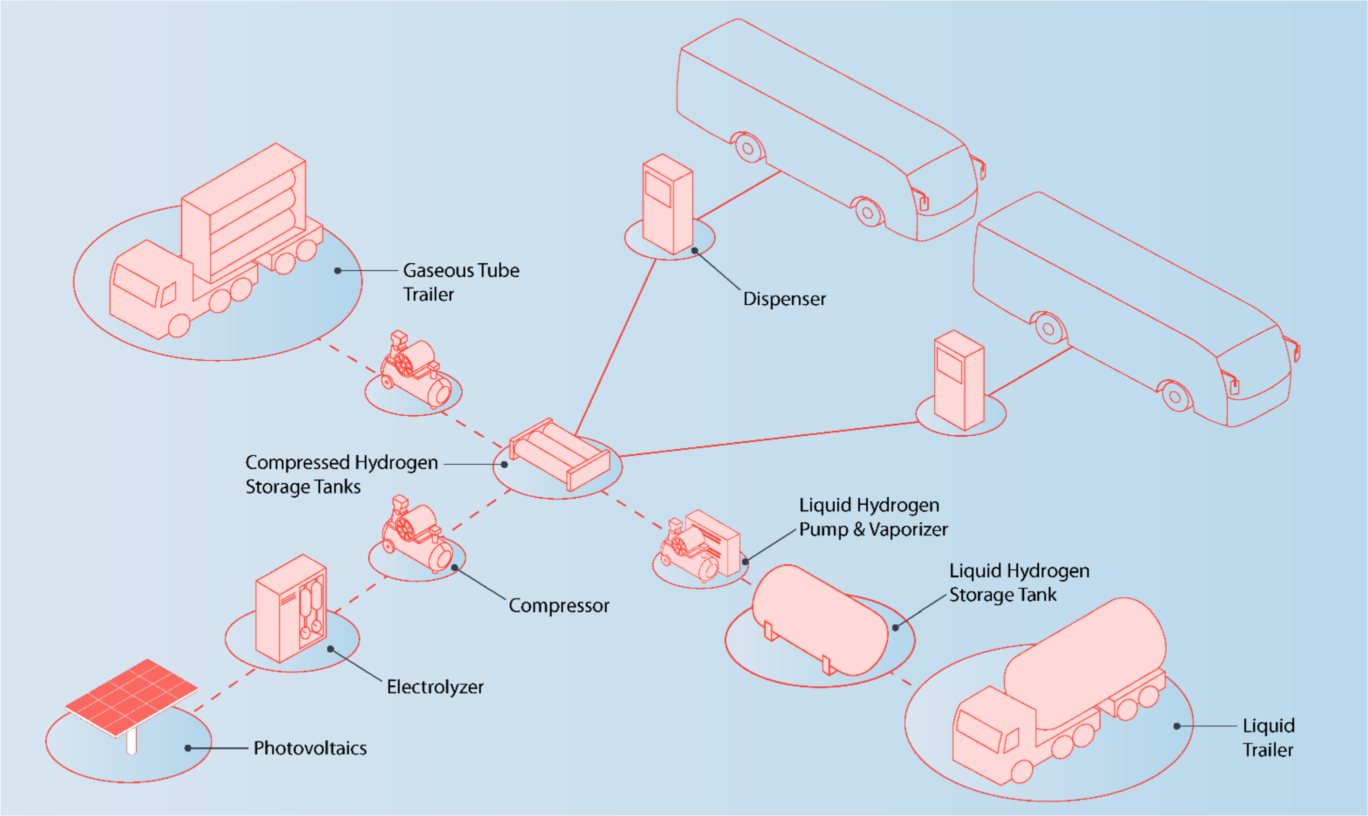
[3] Based on procurement through the State of Georgia contract for 14 40-foot Proterra ZX5s and 15 ABB chargers for delivery in 2023. Price includes vehicles, battery packs, options, warranties, training, manuals, software license, spare parts, and delivery.

in conjunction with a low(er)-capacity battery, which stores electricity and supplements the fuel cell's power during peak loads. FCEB infrastructure and the fueling process are illustrated in Figure 2-10.

Figure 2-10. Typical Fuel Cell Electric Bus Fueling Infrastructure and Process



Source: WSP

Given that hydrogen is lighter than air and has a higher ignition temperature than gasoline or diesel fuel, it naturally rises, dissipates in open air, and is more difficult to ignite than gasoline or diesel vapors.

Hydrogen is a colorless, odorless gas. Unlike CNG, which is odorized with mercaptan as a safety precaution so that leaking CNG can be detected by smell the same as natural gas used for home heating, hydrogen used in FCEBs is not odorized. Because of the buoyancy of hydrogen, 2.5 times the odorant would be required to effectively odorize hydrogen than to odorize natural gas. In addition, the odorants used to odorize CNG contaminate the catalysts used in hydrogen fuel cells. Therefore, hydrogen is not odorized and requires hydrogen gas sensors to detect and alert operators to the presence of the odorless, colorless, gas.

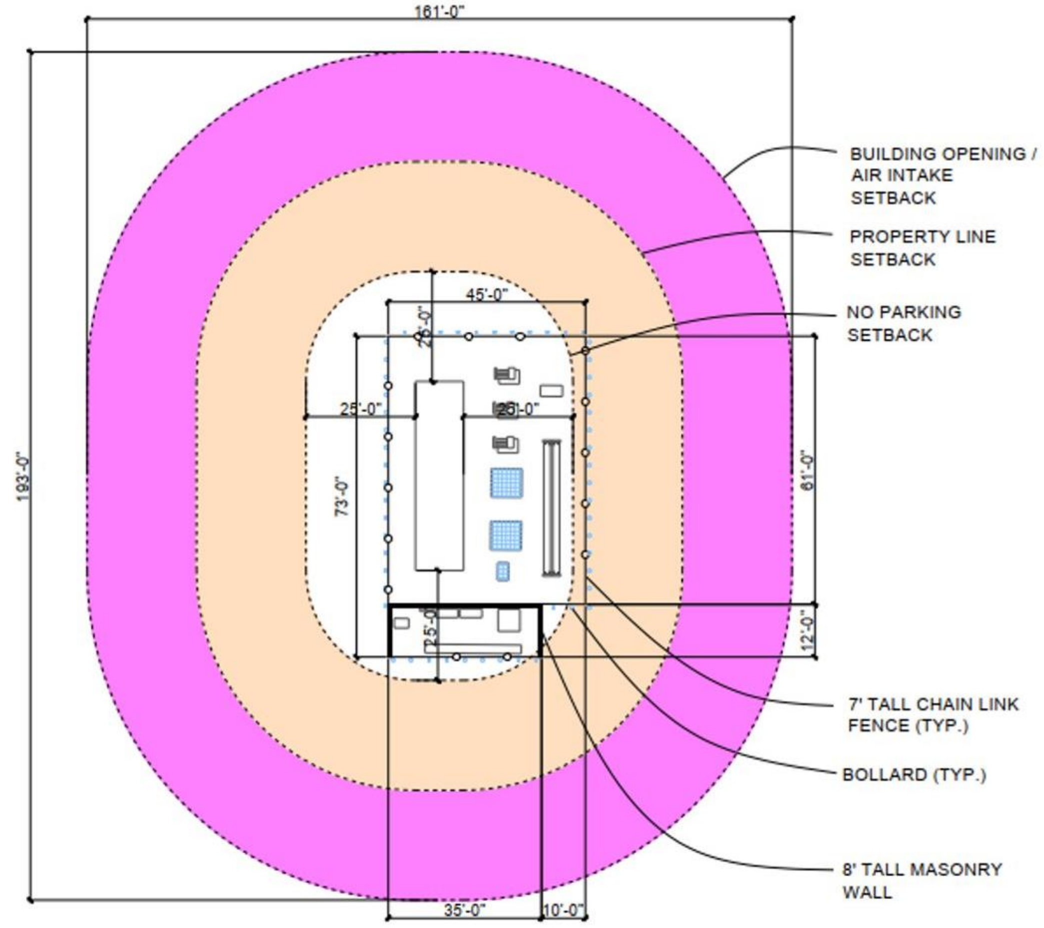
2.2.1 PRODUCTION, STORAGE, AND FUELING

The process, operations, and equipment used for FCEBs are similar to lighter-than-air fuels such as CNG. Hydrogen is generated via steam methane reforming (SMR) or electrolysis. SMR, the most common method of producing hydrogen, uses high-pressure steam to produce hydrogen from a methane source, such as natural gas. Electrolysis, on the other hand, uses an electric current to decompose water into hydrogen and oxygen. After the hydrogen is produced, it can be delivered to the site via pipeline or as a gas or liquid by truck.

Hydrogen fuel is typically stored on-site in liquid form in large storage tanks. As an example, Figure 2-11 illustrates an on-site hydrogen fueling yard capable of fueling 50 vehicles, as well as setbacks required by National Fire Protection

Association (NFPA) 2, Hydrogen Technologies Code. The NFPA required distance from outdoor bulk hydrogen systems to various exposures is dependent on the storage tank size and type of exposure. Certain setback distances may be reduced by use of fire barrier walls at the fueling yard.

Figure 2-11. FCEB Fueling Infrastructure Template



Source: WSP

The use of mobile fueling stations is a recent introduction for FCEB applications. Mobile fuelers can provide up to 4,500 kg of storage, As liquid hydrogen (LH2) tanker trucks hold 3,400 kg of LH2, about 15-16 buses could be fueled with one tanker delivery a week (at 30 kg/bus/day). A mobile fueler can have two pumps, each of which can dispense 150 kg/hr – enabling the 15-16 buses to be fueled in an hour and a half.

In contrast, permanent stations can hold up to 18,000 gallons (3,300 kg) of storage and dispense 150 kg/hr with two pumps. A single permanent station could fuel 100 (30 kg/bus fill) in a ten-hour fueling window. This would require six tanker deliveries a week – essentially one a day, although this frequency is not out of line compared to large scale diesel bus facilities.

KH2 has to be vaporized, compressed, and chilled/dispensed. As with permanent facilities, buffers are required for mobile fuelers resulting in an overall footprint that is similar to permanent stations. Based on the footprint and buffer requirements, along with their fueling capacity, mobile fuelers may be more appropriate for pilot FCEB applications.

Figure 2-12. Mobile Hydrogen Fueling Station, Canton, Ohio

Source: Stark Area Regional Transit Authority

An example of mobile hydrogen supply, in Canton, Ohio, is shown in Figure 2-12. Hydrogen is then stored, vaporized (if delivered as a liquid), compressed, and dispensed to the FCEBs on site. Depending on space availability and resources, some agencies can also produce hydrogen on site—most commonly via electrolysis.

2.2.2 OPERATING RANGE

FCEBs typically can replace an ICEBs at a 1:1 replacement ratio without significant changes to operations and service. However, some of the most pressing challenges for FCEB operations include the limited supply of hydrogen and the amount of energy, physical space requirements, and high capital costs required to isolate, compress, and store hydrogen, Also, if renewable natural gas - such as methane capture from organic matter – is not used as an alternative to natural gas during SMR operations, there are concerns that FCEBs may not be the most sustainable vehicle to achieve greenhouse gas (GHG) reduction targets due to high methane emissions attributed to natural gas production and distribution. Alternatively, electrolysis relies upon an electric current and offers the potential to provide fully renewable hydrogen. However, on-site electrolysis presents challenges in high upfront costs, space requirements, and scalability. Hydrogen's high flammability is also a concern regarding fire and safety requirements. In short, implementation of hydrogen at a site presents new complexities that often require specific site and operations analyses to assess.

2.2.3 HYDROGEN FUEL SUPPLY AVAILABILITY

When operating a FCEB fleet, hydrogen can be sourced one of several ways: Gaseous hydrogen (GH2) delivered via a high-pressure tube trailer or mobile refueler, liquid hydrogen (LH2) delivered via a tanker, GH2 or LH2 delivered by pipeline, or on-site production of GH2 via SMR or electrolysis

All forms of hydrogen, whether GH2 or LH2, must have adequate and safe on-site storage. Access to inexpensive hydrogen fuel remains a challenge for FCEB operators as the industry works to increase in scale. For this reason, the long-term costs of hydrogen sourcing should be carefully considered. In addition, resiliency should be considered for all technologies in case of equipment failure. Table 2-2 shows some of the national suppliers of hydrogen fuel and their distribution options.

Table 2-2. Distribution Options of National Hydrogen Fuel Suppliers

Supplier	LH2 or GH2 Deliveries	Pipeline	On-Site Production
Air Liquide	✓	✓	✓
Air Products	✓	✓	✓
Linde Gas	✓	✓	✓
Messer	✓	⊘	⊘

Source: WSP, OEM Websites

2.2.4 COSTS

The capital costs associated with on-site hydrogen production is typically more expensive than the comparable lifecycle costs for delivered hydrogen; however, the hydrogen fuel price savings (per kilogram) from on-site production may make it a more cost-effective solution than delivery depending on future pricing conditions. The costs per kilogram of delivered hydrogen is more expensive, currently around $8-12 per kilogram, as it must be transported with specific tanker truck equipment and the generation costs incurred by the producer, along with a margin, are passed through to the end user. Transit agencies and other operators of FCEBs across the nation are exploring the viability of scaling up from hydrogen delivery to on-site production (via an electrolyzer or SMR) to gradually ease into costly capital investments.

While both BEB and FCEB technologies provide zero emission benefits, the feasibility and viability of their application is largely based on an agency's service and operational parameters.

2.3 ZE VEHICLE AVAILABILITY

The following subsections provide an overview of current market availability.

There are various BEBs and FCEB options available to transit agencies. These vehicles offer a range of battery capacities to support a range of duty cycles. Table 2-3 summarizes the 40-foot alternative fuel buses available in the U.S. market.

Table 2-3. Available 40-Foot Alternative Fuel Buses in the U.S. Market

OEM	Model(s)	Technology	Capacity (kWh)
BYD	K9M and K9MD	BEB	313 and 446
El Dorado National	Axess – FCEB	FCEB	Not listed.
	Axess – BEB	BEB	Not listed.
GreenPower	EV350	BEB	400
Gillig	Battery-Electric	BEB	490, 588, and 686
New Flyer	Xcelsior CHARGE NG	BEB	350, 440, and 525
	Xcelsior Charge H2	FCEB	700 (equivalent)
Nova	LFSe and LSFSe+	BEB	Up to 564
Proterra	ZX5, ZX5+, and ZX5 MAX	BEB	225, 450, and 675

Source: WSP, OEM websites

Bus procurements with individual OEMs can be very time consuming and resource intensive. Experience is most extensive in California, which has been a pioneer in ZEB conversion in the U.S. The California Association for Coordinated Transportation (CalACT), a resource primarily for small, rural, and specialized transportation California-based transit providers, has several pre-approved and priced ZEBs that can be purchased to avoid lengthy bid and procurement processes. Table 2-4 presents the current ZEBs and prices that are offered via CalACT.

Table 2-4. Vehicle Base Cost for 40-Foot Buses

Bus Type	Estimated Cost*
BEB	$1,101,000
FCEB	$1,352,000
CNG Bus	$653,000

Source: Peer agency vehicle cost estimates

*Includes estimated vehicle add-ons

3 PEER AGENCY EXPERIENCE

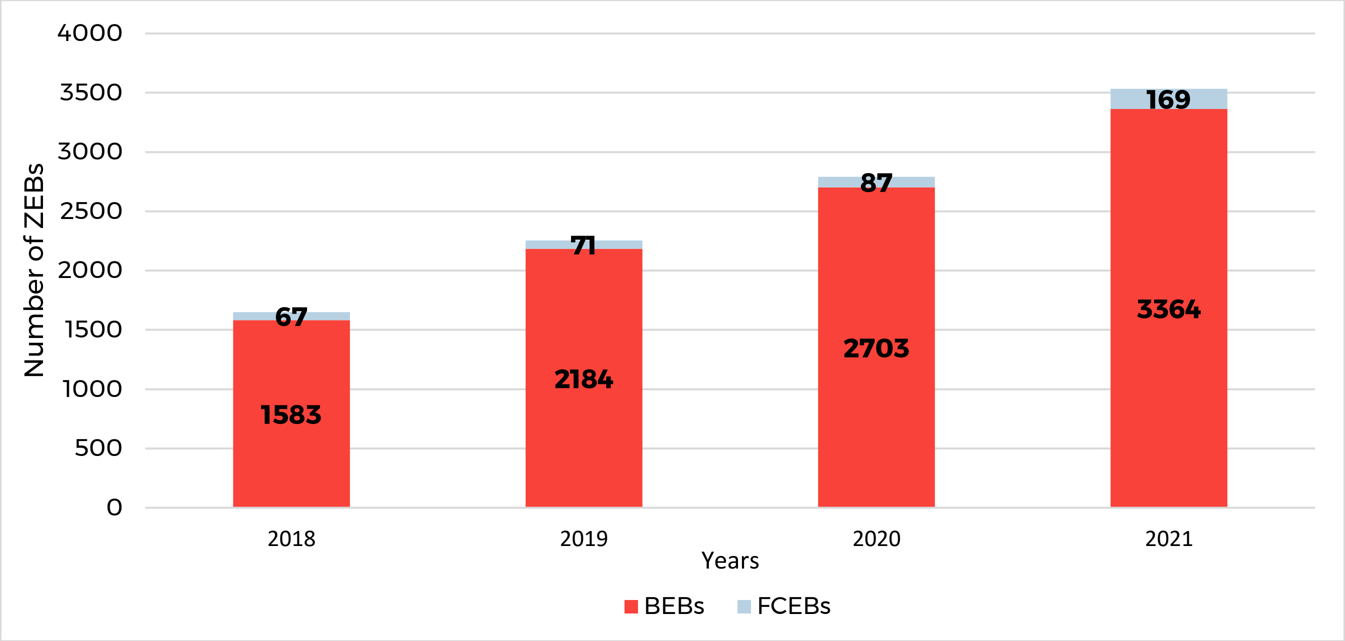
3.1 BACKGROUND

The purpose of this section is to gather and gather the experiences and lessons learned from peer agencies to assist BCRTA with choosing the appropriate alternative fuel technology for its fleet.

In the existing market, the two most prevalent ZEB technologies are BEBs and FCEBs. ZEB technology is rapidly evolving and therefore, it is important to monitor and understand both ZEB technologies and characteristics. California Air Resources Board Innovative Clean Transit (CARB ICT) rollout plans (typically used throughout the U.S. as an industry standard), industry announcements, and peer agency interviews were used to gather and evaluate the experiences of peer agencies operating ZEBs. The gathered information will help inform the authorities of the potential benefits and challenges of implementing a ZEB fleet.

Due to improvements in technology, funding opportunities, and environmental benefits, transit operators are implementing more ZEBs into their fleet. Figure 3-1 shows the number of ZEBs on order or in use in the U.S between 2018 and 2021. As of September 2021, 3,364 BEBs and 169 FCEBs were in use or on order in the U.S.[4] Since both technologies are rapidly changing, it is important to analyze the experiences and lessons learned from peer agencies to determine which technology best fits an agency's needs.

Figure 3-1. ZEBs on Order or in Use in the U.S., 2018-2021



Source: SmartCitiesDive, CALSTART

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[4] Dan Zukowski, More Electric Buses Join Transit Fleets as Costs and Technology Improve. *SmartCitiesDive*. October 3, 2022

3.2 PEER AGENCIES

Based on consultant recommendations and input from the three authorities, six agencies were analyzed to determine their ZEB experience. Table 3-1 provides an overview of these transit agencies and their ZEB fleets.

Table 3-1. Peer Agency ZEBs

Agency	Location	Vehicle Type	Active ZEB Fleet	Total Bus Fleet
Orange County Transportation Authority (OCTA)	Santa Ana, CA	FCEB	10	508
		BEB	2 (pilot)	
Stark Area Regional Transit Authority (SARTA)	Canton, OH	FCEB	15	40
Champaign-Urbana Mass Transit District (MTD)	Urbana, IL	FCEB	2	116
Central Ohio Transit Authority (COTA)	Columbus, OH	BEB	2 (8 planned delivery)	321
Indianapolis Public Transportation Corporation (IndyGo)	Indianapolis, IN	BEB	43	217
Transit Authority of River City (TARC)	Louisville, KY	BEB	6	227

Source: WSP, Transit operator websites

3.2.1 *ORANGE COUNTY TRANSPORTATION AUTHORITY, ORANGE COUNTY, CALIFORNIA*

The Orange County Transportation Authority (OCTA) serves 34 cities and more than 3.2 million residents in Orange County, California with fixed-route and demand service. It currently operates 58 fixed routes with 508 vehicles, most of which run on CNG. OCTA has been operating 10 40-foot FCEBs along with a transit-operated hydrogen fueling station since 2020. As of April 2022, two pilot BEBs have begun operating at OCTA and eight more BEBs were expected to be delivered later in 2022 (Figure 3-2). By operating these two vehicle types, OCTA plans to collect and compare their performance data to help inform future procurements.

To accommodate OCTA's FCEBs, an 18,000-gallon liquid storage tank and a new fuel station (pumps, dispensers, etc.) were installed (Figure 3-3). To mitigate fire related safety risks, OCTA needed to ensure that everything would shut down if either CNG or hydrogen gas was detected. This is designed to help prevent fires from coming into contact with either gas. The hydrogen plant also had to be placed several hundred feet from the fueling station to comply with safety regulations.[5] OCTA invested $5 million for 50 bus capability and $900,000 for shop upgrades to the entire maintenance area (flame detection, hydrogen detection, etc.).

Figure 3-2. OCTA Pilot BEB

Source: OCTA

Figure 3-2. OCTA Hydrogen Tank

Source: California Transit Association

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[5] Hydrogen equipment must comply with safety codes and setbacks as outlined by the National Fire Protection Agency as well as guidelines set by the local fire marshal.

OCTA has provided the following general feedback regarding their FCEBs:

- Keep expectations reasonable early on, first year requires working through kinks, but things normalize in second year.
- Install hydrogen leak detectors on buses early.
- Uncertainty in fuel cost and availability are major concerns.

To help inform future procurements and push toward a 100% zero emission fleet, OCTA will pilot test 10 40-foot plug-in BEBs along with the existing FCEB fleet. Two of the 10 buses have begun operations; the remaining eight were anticipated to be delivered later in 2022.

3.2.2 STARK AREA REGIONAL TRANSIT AUTHORITY, CANTON, OHIO

The Stark County Area Regional Transit Authority (SARTA) operates fixed route services in Stark County, Ohio including the communities of Alliance, Akron, Canton, Cleveland, Hartville, Jackson Township, Louisville, Massillon, North Canton, and Uniontown. SARTA currently operates 20 FCEBs (15 40-foot buses and five paratransit vehicles) and would like to transition all of its buses to hydrogen (Figure 3-4).

SARTA has two types of FCEBs. The first type has a 50 kg tank and a range of 220 miles; the second type has a 60 kg tank and a range of 260 miles. SARTA feels that it has had a positive experience with its FCEBs and has not expressed any major challenges operating a hybrid fleet. SARTA plans on transitioning its entire fleet to hydrogen since it believes there are too many challenges and shortfalls with BEBs (shorter range, longer charge times). However, a few challenges with its FCEBs have been noted. SARTA has stated that its biggest issue is obtaining new parts due to supply chain limitations for FCEBs. It was also noted that in cold and/or snowy weather, the range of FCEBs drops by approximately 7-9%, or more than 20 miles.

Figure 3-4. SARTA Hydrogen FCEB

Source: SARTA

SARTA has also noted some impacts regarding operations and maintenance. Qualified maintainers required high-voltage training. SARTA also provides three to four months of internal training and developed in-house proficiency tests. FCEBs were noted to have a similar preventive maintenance schedule as their other buses but have no oils to change.

SARTA has also not experienced issues with the reliability of hydrogen delivery. Hydrogen is topped off once a week. Since SARTA did not make any investments in pre-cooling to maximize storage capacity, fueling requires approximately 20-25 minutes to allow fuel to cool.

Two 350 bar dispensers and a 2,400 kg tank were installed to accommodate for hydrogen fueling (Figure 3-5). Minimal upgrades to the maintenance facility were made since SARTA was already CNG-ready. However, SARTA had to sacrifice 70 parking spaces to support the hydrogen equipment.

Figure 3-5. SARTA Hydrogen Fueling Station

Source: SARTA

SARTA is satisfied with the operation of FCEBs and anticipates purchasing more in the future. The primary lessons learned from SARTA are:

- Anticipate expanding facility to accommodate equipment.
- Recommend reading hydrogen at scale from the Department of Energy to learn about supplemental use cases.

3.2.3 CHAMPAIGN-URBANA MASS TRANSIT DISTRICT, ILLINOIS

The Champaign-Urbana Mass Transit District (MTD) in Illinois operates two 60-foot New Flyer FCEBs and an on-site electrolyzer powered by solar panels (Figure 3-6). The 1 MW electrolyzer can produce up to 420 kg of hydrogen per day. To accommodate the solar panels that power the elecrolyzer, eight acres of neighboring land were leased. MTD plans to purchase 10 40-foot FCEBs in 2023, four 60-foot FCEBs in 2027, and 10 40-foot FCEBs in 2029. There are also plans to expand its hydrogen station between 2023 and 2027.

MTD chose to implement FCEBs rather than BEBs due to operational and range considerations. FCEBs can typically replace diesel buses at a 1:1 replacement ratio and have a faster refueling time than BEBs. FCEBs refuel in 7-10 minutes while BEBs can take up to six hours to recharge. Also, it was not required to redesign routes or schedules around the FCEBs' capabilities which MTD believes would have been expected with the implementation of BEBs.

In terms of facility upgrades, MTD separated its building into different functional areas; monitoring systems were installed throughout the entire building. MTD lowered everything electrical below ceiling height or placed it in hard conduit. It was noted that the body shop and steam/clean bay were minor repairs. Office and storage areas followed code for parking garage and sensors and ventilation were also installed.

It was also noted that the communication between dispensers and vehicles were a challenge at launch. This was due to the infrared fill emitters and receivers not being properly aligned during fueling and caused MTD's FCEBs to not receive full fills for months.

Figure 3-6. Champaign-Urbana MTD FCEBs

Source: Champaign-Urbana MTD

The primary lessons learned from MTD are:

- Recommend coordinating between vehicle and fueling manufacturers to ensure compatibility across equipment.
- Consider specifying a faster fueling option (perhaps 3.5 kg/min). MTD's equipment is closer to 2.5 kg/min.

3.2.4 CENTRAL OHIO TRANSIT AUTHORITY, COLUMBUS, OHIO

The Central Ohio Transit Authority (COTA) serves the Columbus and Franklin County area with a fleet of 321 vehicles. Of this total, COTA has 251 CNG buses manufactured by Gillig and New Flyer and in operation since 2013. COTA is planning on converting its entire fleet to ZEBs. As such, the agency does not have any CNG buses currently on order or expected for delivery. COTA currently has two 40-foot New Flyer BEBs with eight more on order for the fourth quarter of 2022. The existing BEBs (Figure 3-7) have been in operation for over a year. COTA decided to implement BEBs as part of its sustainability goals for 2035.

Figure 3-7. COTA BEB

Source: COTA

COTA began its transition to alternative fuels with the procurement of CNG buses from Gillig and New Flyer. CNG buses were specifically chosen since it is a greener technology compared to diesel buses with an 80% decrease in fueling costs. The CNG vehicles were recorded to have a range of 250-300 miles and a fuel economy of 4.3 mpg. The miles between road calls were recorded to be 8,075 miles. It was also noted that fueling can take longer in extreme cold weather. To accommodate CNG fueling infrastructure, COTA's two garages have been fully converted with CNG fueling stations. Their electrical infrastructure and safety monitoring equipment have also been modified. COTA is moving towards a zero-emission fleet with a short-term goal of all-electric and a long-term goal of hydrogen electric.

To achieve COTA's short-term goal of procuring all-electric vehicles, COTA currently operates two 40-foot BEBs with eight more on order. When operating the BEBs, COTA did not modify blocks or routes; instead, it set a limit for the blocks that the BEBs can operate on. COTA first limited the BEBs to run on blocks with a duration of six hours or less. After some trials, COTA expanded to less than 170 miles or 13-hour durations. Currently, COTA is running its BEBs on blocks with a distance between 140-150 miles. When temperatures fall below 45°F, it was reported that the cabin heater consumes more energy. However, due to COTA's set parameters, the BEBs can still complete their blocks but return with lower state of charge.

COTA conducted special safety training for those servicing the vehicle and purchased arc flash-rated tooling and clothing. COTA suggests implementing a buddy system which requires a secondary technician be present for safety. COTA has not reported any safety challenges as of September 2022. It has been vigilant about safety by constantly considering "what if" scenarios and planning for those scenarios with its safety department.

COTA uses ABB-manufactured 150 kWh dispensers to charge vehicles and selected staff who were trained on the proper use of charging the buses. Only trained staff are allowed to touch the charging equipment. The most common issue is charging faults which result in the vehicle not charging.

Facility modifications at COTA are currently ongoing. Two chargers are currently online with eight more scheduled for later 2022. Cost and supply chain were reported as the biggest issues. COVID-related issues have also increased prices of materials and labor. The lead time for replacement components ranges from weeks to months.

COTA states that sharing information and asking questions are proving to invaluable. It also noted that COTA documents its experiences with operating BEBs and openly share information when asked.

3.2.5 INDIANAPOLIS PUBLIC TRANSPORTATION CORPORATION, INDIANA

The Indianapolis Public Transportation Corporation (IndyGo) provides both fixed route and ADA paratransit services in Indianapolis and Marion County. IndyGo has 217 buses (135 diesel buses, 39 hybrid buses, and 43 electric buses) comprising its fixed route fleet (Figure 3-8).

IndyGo has documented its ZEB experience with Custom Coach Works (CCW)-converted buses in 2015; these buses cost approximately $500k to convert to battery electric propulsion. They are now near retirement. CCW purchased Gillig diesel buses and converted them to BEBs; however, their performance was below expectations and the rate of failure was high. The rebuilt BEBs have a range of 80-95 miles when fully charged and an energy consumption rate of approximately 2.3 kWh/mile. IndyGo does not plan on purchasing more rebuilt BEBs at this time.

In 2019, IndyGo procured BYD-manufactured AC-charged buses for its new Red Line Bus Rapid Transit (BRT) system. However, the BYD vehicles also did not meet the contractual range requirements and underdelivered on battery performance. The BYD vehicles have a range of 140-185 miles and an energy consumption rate of 2.6-4 kWh/mi. It was noted that the reliability of both the rebuilt BEBs and BYD vehicles depend on the season while the miles between road calls averaged at 2,000 miles. Also, weather impacts the buses' range by approximately 20-30%. The greatest impact is seen during the winter since the heating system is all-electric. Since BYD did not meet the range specifications of 270 miles, IndyGo decided to cancel its BYD order and purchased Gillig electric hybrid buses instead. To meet the contractual range obligations, BYD worked with IndyGo to implement on-route charging.

Figure 3-8. IndyGo BEB

Source: IndyGo

IndyGo has experienced electric bus fires on the road and in its facility building with its BYD buses. To mitigate a reoccurrence, IndyGo is implementing its lessons learned into its future building renovations and a new garage build. The bus storage walls will be poured concrete instead of traditional block walls. The results are expected to include less maintenance, better fire resistance, and better compressive strength for the foundation. All vehicle maintenance and bus storage areas are planned to have an overhead-rated fire door to close in the event of a fire. Buses will have more distance between them to help prevent fire from spreading to other buses and allow space for first responders to work around the bus. One main fire department connection (FDC) hook-up or a dedicated fire pump are planned to be placed in areas where electric buses are stored. IndyGo noted that a designated location should be established away from other buses and property where the bus can be parked after the event of a fire since lithium-ion batteries can re-combust days after the original fire.

IndyGo recommends having first responders walk through the facility to understand any changes to the bus electric emergency response plans. It also recommends identifying a subject matter expert on electric bus technology. All bus equipment should also have an onboard fire suppression system and should be tested regularly as part of the preventive maintenance process.

IndyGo is open to considering different alternative fuels such as hydrogen. In late February 2022, IndyGo performed a week-long trial on a borrowed FCEB from Sunline Transit in California.

3.2.6 TRANSIT AUTHORITY OF RIVER CITY, LOUISVILLE, KENTUCKY

The Transit Authority of River City (TARC) provides service in Louisville and Jefferson County in Kentucky and Clark and Floyd counties in Indiana. TARC's service area encompasses an area of 357 square miles with a population of 806,893. TARC operates a fleet of 227 buses to serve its 31 fixed routes. Of this total, 15 are all-electric (six 40-foot BEBs and nine 35-foot BEBs).

TARC has for years worked to reduce diesel emissions. It first placed diesel-electric hybrid buses in service in 2004 and over the next 10 years acquired 32 hybrid diesel-electric buses. Its ZEB fleet is part of the first generation of buses manufactured by Proterra. TARC's was the first fleet in the region to switch to ultra-low diesel fuel, making that switch three years before the U.S. Environmental Protection Agency (US EPA) mandated the change. In 2015, TARC made its first foray into the world of full BEBs. To date, TARC's experience with charging BEBs is limited to on-route, fast charge systems only, with no depot (garage) charging (Figure 3-9). A "fin blade" is extended from the roof of the bus to an overhead charger. TARC's BEB experience to date has taught the agency about the complexities associated with operating, maintaining, and planning service with range-limited vehicles. TARC is currently, though modestly, expanding its BEB fleets.

TARC's BEB's were used exclusively on a downtown shuttle route. The route was suspended at the outset of the pandemic in March 2020 and has not been reactivated. As a result, its BEB fleet has been out of service for over two years. Proterra's more recent models employ a different charging technology and the company no longer supports the charging technology of TARC's BEBs. This has created contractual issues between TARC and Proterra that have not yet been resolved.

Figure 3-9. TARC BEB

Source: Louisville Courier-Journal

TARC recognizes that current decisions about whether and how much to invest in BEB and/or FCEB technology are largely based on existing infrastructure, system design, and cost. TARC also recognizes that BEB and FCEB technologies are still developing.

TARC recently completed a ZEB Transition Plan that analyzed the agency's potential to covert its entire fleet, as existing buses are retired, to ZEB technology. The plan looked at BEBs and FCEBs. The primary issues involved the physical constraints of its main operating facility and satellite maintenance facility. It was determined that within the constraints of its existing facility and site, TARC is still able to achieve a 100% conversion to BEBs. However, site limitations limit the number of FCEBs to 100, which falls far short of 100% ZEB conversion. As a result, the Transition Plan recommended conversion to BEBs only.

TARC recently received $7.4 million from the Federal Transit Administration (FTA) FY2022 Low or No Emission and/or Buses and Bus Facilities grant. With this grant, TARC plans to purchase six battery electric vehicles, upgrade its existing electrical service, and install charging infrastructure.

3.3 SUMMARY OF FINDINGS

Determining whether an agency should move forward with BEBs, FCEBs, or a mixture of both depends on the individual agency's available space, location, block distances, available funds, etc. BEBs and FCEBs are rapidly changing technologies; therefore, it is important to monitor and understand both technologies. CARB ICT rollout plans, industry announcements, and peer agency interviews were used to gather and evaluate the experiences of peer agencies operating ZEBs.

Both technologies have their advantages and disadvantages when it comes to running a transit fleet. FCEBs can typically replace diesel buses at a 1:1 ratio, have shorter refuel time, and has longer range capabilities than BEBs. However, FCEBs require a considerable amount of space when implementing hydrogen infrastructure. For example, SARTA sacrificed 70 parking spots while MTD leased eight acres of neighboring land. Another prevalent concern is the uncertainty in fuel costs. BEBs, on the other hand, require a smaller footprint and have lower upfront capital costs compared to FCEBs.

Table 3-2 summarizes the lessons learned and general feedback from peer agency transit operators running ZEBs.

Table 3-2. ZEB Lessons Learned and General Feedback

BEB	FCEB
• Set parameters for the blocks that the BEBs can operate on. • Implement the buddy system which requires a secondary technician be present for safety. • Consider "what if" scenarios and plan for these scenarios with your safety department. • Recommend having bus storage walls be poured concrete instead of traditional block walls. • All vehicle maintenance and bus storage should plan to have an overhead-rated fire door to close in the event of a fire. • Have more distance between buses. • Have one main FDC hook up or a dedicated fire pump placed in areas where electric buses are stored. • Have first responders walk through the facility to understand any changes to the bus electric emergency response plans. • Identify a subject matter expert on electric bus technology. • All bus equipment should also have an onboard fire suppression system .	• Keep expectations reasonable early on, first year requires working through kinks, but things normalize in second year. • Install hydrogen leak detectors on buses early. • Uncertainty in fuel cost and availability is big concern. • Anticipate expanding facility to accommodate equipment. • Recommend reading H2 at scale from the Department of Energy to learn about supplemental use cases. • Recommend coordinating between vehicle and fueling manufacturers to ensure compatibility across equipment. • Consider specifying a faster fueling option (perhaps 3.5 kg/min). MTD's equipment is closer to 2.5 kg/min.

4 TRANSIT FLEET AND OPERATIONS

This section identifies fleet inventories and likely replacement schedules for BCRTA. Replacement schedules are necessary to conduct a lifecycle cost analysis that will provide the three agencies with essential information on which to choose a preferred zero emission technology from the standpoint of costs.

To provide for an equal assessment of BEB technologies versus FCEB technology, a status quo fleet size is used over the course of the study timeframe of 12 years starting in 2023.

The lifecycle cost assessment is also based, in part, on the number of buses required to operate existing and committed service levels. The range of FCEBs is similar to diesel buses resulting in a replacement ratio of 1:1. The range of BEBs is more limited. Battery range has improved every year since the introduction of BEBs in the last decade and is expected to continue improving at a similar rate. However, a speculative approach may fall short in terms of determining how many BEBs are needed to replace diesel buses. This analysis identifies the number of bus blocks (vehicle schedules) that are currently within BEB range parameters and those that are not.

4.1 BATTERY-ELECTRIC BUS BLOCKING IMPACT ANALYSIS

Evaluating bus blocks for compatibility with BEB conversion provides an idea of the possible impacts on scheduling, including block length and bus pull-out location.

4.1.1 EXISTING CONDITIONS

To determine the compatibility of current scheduling for BEB conversion, weekday blocks (vehicle itineraries) from recent service schedules (May 2022) were examined.

For this analysis, BEB compatibility is determined by time, rather than distance. An estimate of 12 hours was set as the maximum time a fully charged BEB may operate in service before requiring a charge, either by returning to the garage for extended charging or an "opportunity charge" located at the end-of-line. For this initial phase, it is assumed that all charging will occur at the storage facility while the bus is not in service.

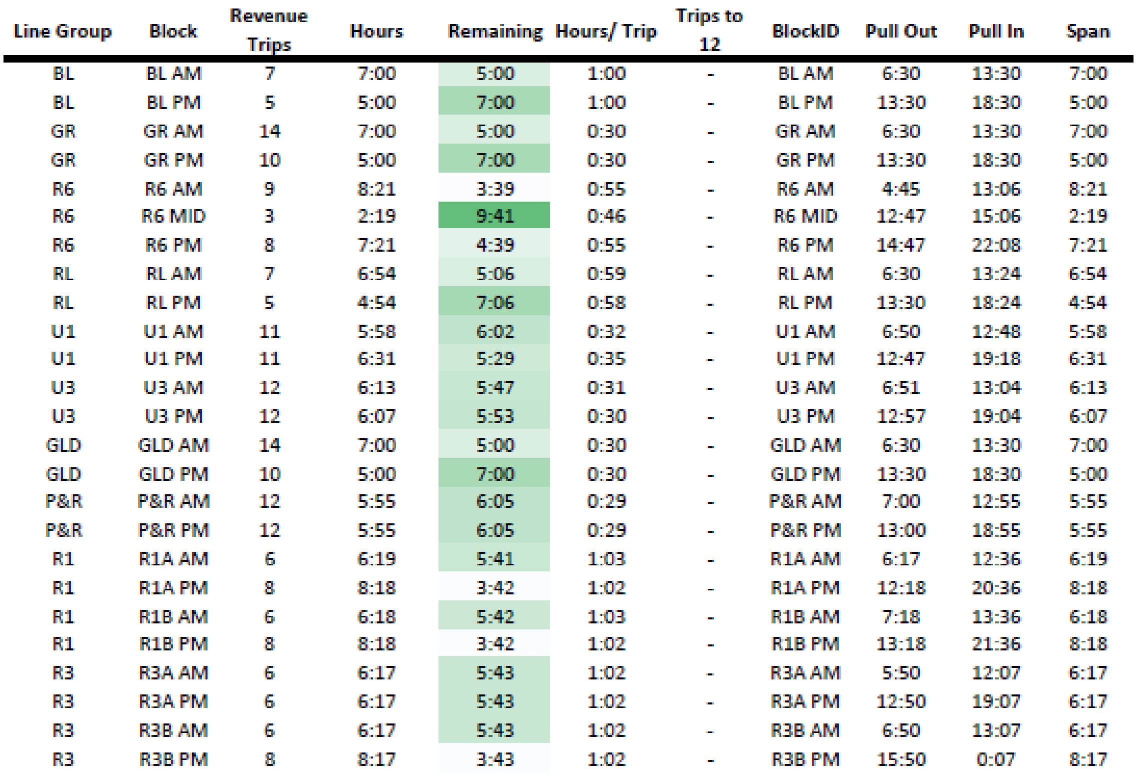
In May 2022, BCRTA operated 25 weekday blocks. The longest block operated for eight hours and 21 minutes, and only four blocks operated over eight hours. All blocks operated on a single shift with the same bus operator departing from and returning to the garage with the same bus.

4.1.2 BEB COMPATIBILITY

Block operating times were calculated from BCRTA's bus paddles. All 25 blocks are 100% BEB compatible based on the 12-hour BEB threshold. The shortest block time span is two hours and 19 minutes on the R6 Midday block and the longest is eight hours and 21 minutes on the R6 AM block. Only four blocks operate longer than eight hours. Even on the longest block, approximately three and a half hours would remain on the BEB range. The May 2022 service period had a peak vehicle requirement of 13 buses. According to the findings described in the previous section, 100% of BCRTA's peak vehicle requirement could be operated with BEBs.

Table 4-1 lists every block and identifies the extent of their BEB compatibility (the darker the green the greater the compatibility).

Table 4-1. Blocking Compatibility for BEB Conversion



Line Group	Block	Revenue Trips	Hours	Remaining	Hours/ Trip	Trips to 12	BlockID	Pull Out	Pull In	Span
BL	BL AM	7	7:00	5:00	1:00	-	BL AM	6:30	13:30	7:00
BL	BL PM	5	5:00	7:00	1:00	-	BL PM	13:30	18:30	5:00
GR	GR AM	14	7:00	5:00	0:30	-	GR AM	6:30	13:30	7:00
GR	GR PM	10	5:00	7:00	0:30	-	GR PM	13:30	18:30	5:00
R6	R6 AM	9	8:21	3:39	0:55	-	R6 AM	4:45	13:06	8:21
R6	R6 MID	3	2:19	9:41	0:46	-	R6 MID	12:47	15:06	2:19
R6	R6 PM	8	7:21	4:39	0:55	-	R6 PM	14:47	22:08	7:21
RL	RL AM	7	6:54	5:06	0:59	-	RL AM	6:30	13:24	6:54
RL	RL PM	5	4:54	7:06	0:58	-	RL PM	13:30	18:24	4:54
U1	U1 AM	11	5:58	6:02	0:32	-	U1 AM	6:50	12:48	5:58
U1	U1 PM	11	6:31	5:29	0:35	-	U1 PM	12:47	19:18	6:31
U3	U3 AM	12	6:13	5:47	0:31	-	U3 AM	6:51	13:04	6:13
U3	U3 PM	12	6:07	5:53	0:30	-	U3 PM	12:57	19:04	6:07
GLD	GLD AM	14	7:00	5:00	0:30	-	GLD AM	6:30	13:30	7:00
GLD	GLD PM	10	5:00	7:00	0:30	-	GLD PM	13:30	18:30	5:00
P&R	P&R AM	12	5:55	6:05	0:29	-	P&R AM	7:00	12:55	5:55
P&R	P&R PM	12	5:55	6:05	0:29	-	P&R PM	13:00	18:55	5:55
R1	R1A AM	6	6:19	5:41	1:03	-	R1A AM	6:17	12:36	6:19
R1	R1A PM	8	8:18	3:42	1:02	-	R1A PM	12:18	20:36	8:18
R1	R1B AM	6	6:18	5:42	1:03	-	R1B AM	7:18	13:36	6:18
R1	R1B PM	8	8:18	3:42	1:02	-	R1B PM	13:18	21:36	8:18
R3	R3A AM	6	6:17	5:43	1:02	-	R3A AM	5:50	12:07	6:17
R3	R3A PM	6	6:17	5:43	1:02	-	R3A PM	12:50	19:07	6:17
R3	R3B AM	6	6:17	5:43	1:02	-	R3B AM	6:50	13:07	6:17
R3	R3B PM	8	8:17	3:43	1:02	-	R3B PM	15:50	0:07	8:17

4.1.3 OPPORTUNITY CHARGING

On-route opportunity charging is a significant investment and consideration should be given to corridors that serve the greatest number of blocks that exceed the estimated 12-hour BEB charging range. Because it is estimated that all BCRTA blocks can be operated with a full overnight charge, opportunity charging facilities are not essential. However, to provide maximum flexibility, consideration can be given to installing opportunity chargers at Butler County's major transfer points, in Middletown and Hamilton. The planned Oxford operating facility is programmed to accommodate opportunity chargers at its passenger bus bays.

4.2 CURRENT FLEET REPLACEMENT SCHEDULE

This section details BCRTA's exiting fleet and anticipated fleet replacement schedule. The fleet replacement schedule outline projects vehicle retirements and purchases through 2035. It does not consider a transition to zero emission buses (ZEBs) but identify how many buses are due for replacements in any given year based on an expected useful life of 12 years.

BCRTA's existing fleet consists of 56 vehicles, with a mix of 15 35-foot buses, 26 cutaway buses, 11 vans, and one trolley bus, as shown in Table 4-2.

Table 4-2. Current Active Fleet

Year	Make	Length	Type	Quantity
2014	Gillig	35-foot	diesel	1
2015	Gillig	35-foot	diesel	11
2015	Ford Transit Van	van		5
2015	Eldorado Aerotech	cutaway		2
2016	Eldorado LTV	cutaway		4
2016	Gillig	35-foot	diesel	3
2010	Ford Econoline Van	van		1
2017	Eldorado Aerotech	cutaway		3
2018	Eldorado Aerotech	cutaway		5
2019	Gillig Trolley	trolley		4
2019	Ford Transit Van	van		5
2020	Eldorado Aerotech	cutaway		12

BCRTA has 12 vehicles on order (2021 replacement) and seven vehicles scheduled for procurement (2022 replacement). This was considered in the following replacement schedule. A 12-year useful life threshold was used for buses and a five-year useful life threshold was used for cutaway buses.

Table 4-3 shows the expected replacement schedule for BCRTA's buses, cutaway buses, and vans through 2035. The fleet is expected to fully turn over by 2032.

Table 4-3. Current Fleet Replacement Schedule

Year	Quantity	Vehicle Type
2021	12	cutaway
2022	2	cutaway
	5	van
2023	0	
2024	5	van
2025	12	cutaway
2026	12	cutaway
	5	van
2027	12	35-foot bus
2028	3	35-foot bus
	5	van
2029	0	
2030	5	van
	12	cutaway
2031	12	cutaway
	2	trolley
2032	5	van
	2	cutaway
	2	trolley
2033	0	
2034	0	
2035	12	cutaway

5 OPERATING AND MAINTENANCE FACILITIES

The BCRTA bus maintenance and administrative office facility at 3045 Moser Court in Hamilton was constructed in 2000. A bus parking garage building was constructed on the site in 2010. The facility was constructed for maintenance of diesel and gasoline vehicles. BCRTA is currently in advanced design of a new maintenance and operating facility in Oxford.

5.1 EXISTING CONDITIONS

BCRTA's Hamilton facility is shown in Figure 5-1.

The BCRTA fleet at Hamilton includes a mix of buses, paratransit, and other vehicles. The main bus storage building is capable of storing approximately 12 40-ft vehicles or 24 cutaways. There is a generous aisle space between each vehicle door and at each end, north and south. Buses enter and exit from vehicle doors on the west side of the storage facility (no through traffic) through six overhead doors, two bus aisles per door. The bus storage area is shown in Figure 5-2.

Figure 5-1. Hamilton Facility

There is one maintenance area where major and minor repair work is performed. The bays are conditioned with gas-fired infrared tube heaters. A roof-mounted exhaust fan provides ventilation. The fan will operate automatically in conjunction with a carbon monoxide (CO) detection system or manually. When the bay doors are closed, makeup air is provided via a roof-mounted air intake ducted to floor level. There is a separated welding room at the southeast corner of the bay area which has a dedicated exhaust fan drawing makeup air through door louvers. The roof structure within the maintenance area has open bar joists and the repair bays have fire protection sprinklers. A photo of the bus maintenance area is shown in Figure 5-3.

Figure 5-2. Vehicle Storage Area

Figure 5-3. Vehicle Maintenance Area

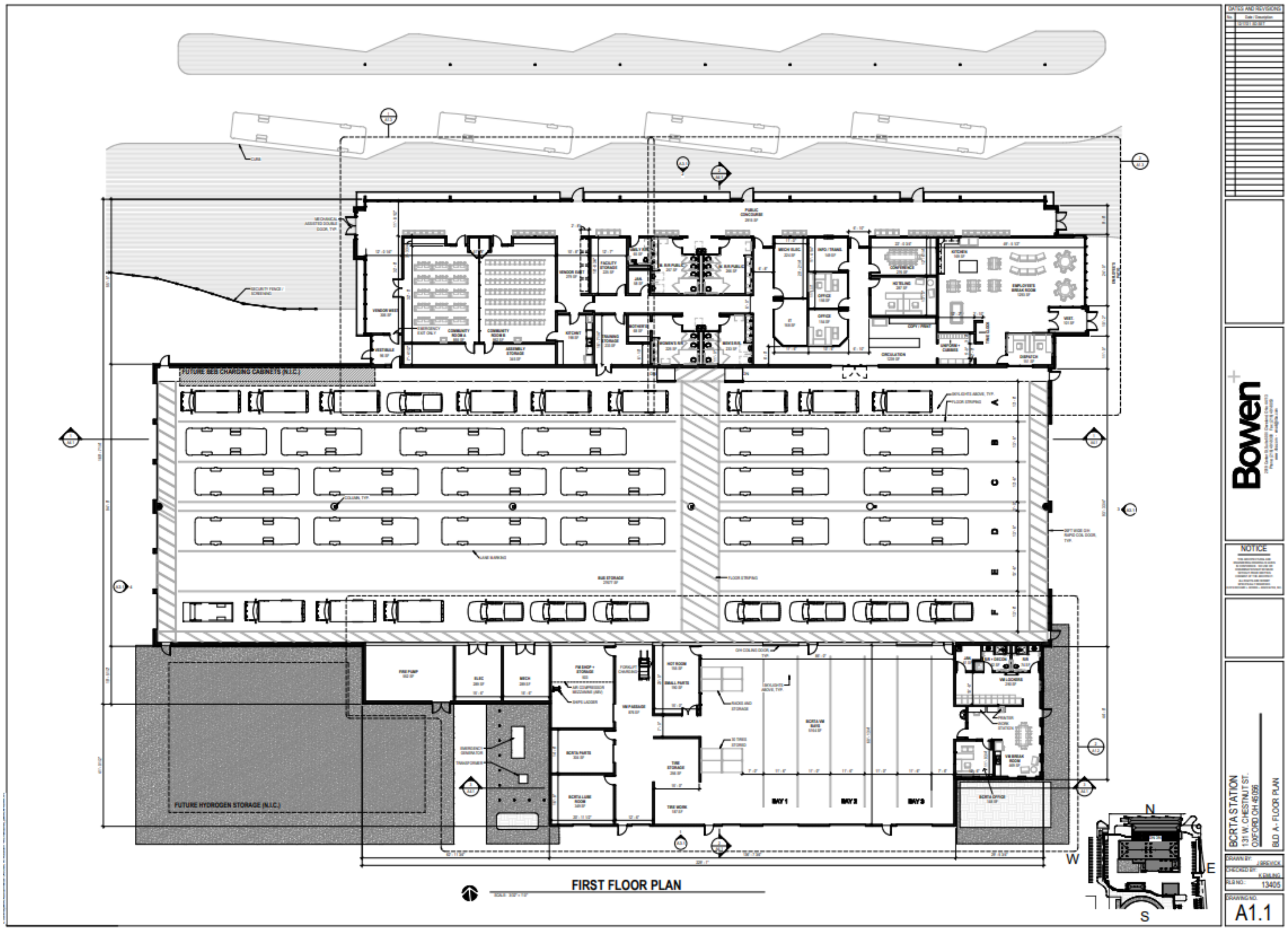
The facility reports a monthly fuel consumption of 10,856 gallons of gasoline and 1878 gallons of diesel fuel. It has a main 480-volt switchboard rated for 800 amps. Locally, it was observed that there are three available switches on the switchboard. Standby power is provided only for emergency loads with a 40 kW natural gas generator on the south side of the administration building and east side of the maintenance building.

According to record drawings, the garage location is served by a 500 kVA transformer by the City of Hamilton. The utility pad transformer is located at the entrance, near the street and is fed from an overhead 13.2 kV line on Moser Court. Actual transformer rating is 300 kVA; this, in effect, throttles the available current to the 800-amp switchboard to 361 amps.

Local personnel report that there is significant land around the facility that is available for future growth.

The new Oxford facility is being designed to accommodate either a 100% BEB fleet or a 100% FCEB fleet. The current layout design is shown in Figure 5-4. The facility will also include an indoor and outdoor passenger transfer facility that can be equipped with overhead BEB charging equipment.

Figure 5-4. Planned Oxford Facility Layout



Source: BCRTA

5.2 ACCOMMODATING BATTERY ELECTRIC BUSES

The Hamilton facility can accommodate a 100% BEB fleet with appropriate modifications. The new Oxford facility will be able to accommodate a 100% BEB fleet.

5.2.1 SWITCHBOARD

To accommodate a 100% BEB fleet at the Hamilton facility, new charging capacity would be supplied using a 2000-amp, 480/277-volt, three-phase, four-wire, switchboard that makes use of molded-case breaker technology.

It is expected that the incoming feeder will be separately metered and City of Hamilton will impose its secondary power tariff.

At the Hamilton facility, this analysis assumes that 1500 kVA is the maximum readily-available pad transformer that can be supplied by the City of Hamilton. A 1500 kVA transformer circuit is conservatively capable of serving eight Heliox 180 chargers. Higher-rated transformers are likely available but making use of inventory units that are readily available will permit the City of Hamilton to streamline installation schedule and also quickly address a damaged transformer should the need arise. The switchboard would be a single transformer served by a feeder from the nearby City of Hamilton 13.2 kV medium voltage feeders.

5.2.2 POWER NEEDS

Table 5-1 shows the existing monthly liquid fuel consumption for Hamilton if it were converted to the equivalent kWH:

Table 5-1. Fuel Conversion to Electric

	Gallons	GGE	DGE	kWH
Diesel	1,878	2,169	1,878	69,962
Gasoline	10,856	10,856	9,400	50,209
Total		13,025	11,277	120,171

5.2.3 EQUIPMENT QUANTITY REQUIREMENTS

The proposed charging capacity for 24 vehicles and the proposed charge level of each vehicle is 60 kW, with the capability to intermittently provide increased charging rates as need requires, is shown in Table 5-2.

- Power required to energize (24) 60kW dispensers
  24 x 60kW = 1,440 kW
- Quantity of Heliox 180 (180kW) chargers required to serve (24) 60kW dispensers
  1,440kW ÷ 180kW = 8 ≈ (8) Heliox 180 chargers
- Quantity of Heliox 180 chargers that can be served by a 2000 amp, 480/277 Volt switchboard (Heliox chargers are 95% efficient and have a 98% power factor)

180kW ÷ [(0.98)(0.95)] = 193.3kVA 193.3kVA ÷ 0.480kV ÷ √3 = 232.5 amps

2000 amp ÷ 232.5 = 8.6 ≈ (8) Heliox 180 chargers

- Quantity of 1500kVA transformers to serve a 2000A switchboard

  (8) Heliox 180 x 193.3kVA = 1546 ≈ 1500kVA

Table 5-2. Major Components for BEB Accommodation

Quantity	Components
24	60kW charger dispensers
8	180kW charger cabinets
1	2000 amp, 480/277 Volt switchboard
1	1500 kVA pad transformer
1	1.5 MVA utility feeders

5.2.4 POSSIBLE PHYSICAL ARRANGEMENT

One possible arrangement that would permit all equipment to be located would involve locating:

- (1) City of Hamilton 1500 kVA pad transformers on or near the south end of the bus storage garage.
- (1) 2000-amp switchboard in the bus storage building along the south wall.
- (4) 180kW Charger cabinets in the bus storage building along the south wall and (4) along the south side of the center wall.
- (2) floor-mounted dispensers in the bus storage building along the south wall and (2) along the north wall, plus (2) on the north side and (2) on the south side of the center wall, for a total of 8 dispensers.
- (4) floor-mounted dispensers in the bus storage building between lanes 2 & 3, 4 & 5, 8 & 9, and 10 & 11 for a total of 16 dispensers.

5.2.5 ELECTRICAL DEMAND MAMAGEMENT

A word of caution regarding utility demand: Ordinary power tariffs are heavily weighted so that instantaneous demand could asymmetrically affect monthly electrical charges. Despite the proposed system's capability, discretion should be exercised in order to limit instantaneous demand with a strategy of scheduling daily charging operation over a wider schedule window, so as to consume the same energy, with lower demand.

To illustrate the sensitivity of electrical demand in charge management policy, consider two theoretical cases. In each case, the operation proposes to daily charge 200 vehicles to 80% using 60 kW charging dispensers: 355 kilowatt-hours (kWHrs) x 24 buses x 30 days = 255,600 kWHrs per month.

A power tariff for Power Service (PS) that assesses an energy charge of $0.03 per kWHr for secondary service, could also assess, possibly, a demand charge of $20 per kilowatt (kW).

Case 1: All 24 vehicles are charged simultaneously. 24 buses charging simultaneously have a theoretical charging window of approximately 6 hours and resulting electrical demand is:

- 60kW x 24 buses = 1,440 kW demand.
- Monthly Energy Charge = 255,600 kWHrs x $0.03 = $7,668
- Monthly Demand Charge = 1,440 kW x $20 = $28,800

Case 2: Vehicle charging is staggered so that only 16 buses are charged simultaneously. 16 buses charging simultaneously have a theoretical charging window of approximately 10 hours and resulting electrical demand is

- 60kW x 16 buses = 960 kW demand.
- Monthly Energy Charge = 255,600 kWHrs x $0.03 = $7,668
- Monthly Demand Charge = 960 kW x $20 = $19,200

In both cases, the utility delivers 355 kWHrs to each vehicle daily, resulting in identical energy charges. However, limiting theoretical demand to 16 vehicles charging simultaneously saves a theoretical $9600 monthly. This does not suggest that training drivers to operate buses in skills and techniques that minimizes energy consumption; those activities are still useful. In this comparison, however, there is no policy or protocol that has the ability to reduce energy consumption enough to match the value of aggressive demand management.

5.3 ACCOMMODATING FUEL CELL ELECTRIC BUSES

The Hamilton facility can accommodate a 100% FCEB fleet with appropriate modifications. The new Oxford facility will be able to accommodate a 100% FCEB fleet.

5.3.1 HYDROGEN NEEDS

Table 5-3 shows the existing monthly liquid fuel consumption for Hamilton, measured in terms of gasoline gallon equivalent (GGE) and diesel gallon equivalent (DGE) if it were converted to the equivalent amount of hydrogen (H2).

Table 5-3. Hamilton Facility Fuel Conversion to Hydrogen

	Gallons	GGE	DGE	H_2 (kg)
Diesel	1,878	2,169	1,878	2,104
Gasoline	10,856	10,856	9,400	10,650
Total		13,025	11,278	12,754

5.3.2 FACILITY MODIFICATIONS

The location of a potential FCEB on-site fueling yard is accounted for in the future at the Oxford location. Given the property limits of the site at Hamilton, there is currently enough area to accommodate a minimum of two hydrogen fueling yards.

To perform any repairs on FCEBs at the existing Hamilton facility, facility modifications will be required since it was originally designed to service diesel and gasoline vehicles. It is worth mentioning that facility modifications at repair bays are not required for minor repair work if the FCEB is defueled; however, defueling a FCEB to do any minor repair or maintenance work is not practical from a time consumption and cost standpoint.

The design of facilities for hydrogen fueled vehicles is regulated and guided by codes and standards that include:

- NFPA 2, Hydrogen Technologies Code
- NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages
- NFPA 55: Compressed Gases and Cryogenic Fluids Code
- NFPA 70, National Electrical Code
- NFPA 88A, Standard for Parking Structures (NFPA 88A refers to NFPA 2)
- IM, International Mechanical Code
- IFC, International Fire Code
- OSHA Regulations 29 CFR 1910, Subpart H (https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.103)

Facility modifications for the maintenance repair bays include:

- Ventilation upgrades – Increased exhaust and makeup air ventilation with continuous operation. Ducted exhaust air grilles installed near the roof level.
- Hydrogen gas detection system.
- Removal of infrared tube heaters. Alternate means of heating will need to be provided.
- Standby power for any hydrogen safety systems such as mechanical ventilation and gas detection systems.

Other modification considerations include interior wall separations to reduce the amount of ventilation air increase. Since the repair bay area is currently sprinklered, no modifications are required to the fire protection system except for recommended gas detection alarm tie-in. Also, with the existing open bar joists roof structure, the potential for hydrogen gas to get trapped in pockets is alleviated, unlike a double-tee roof system.

Bus Parking: NFPA recommends that vehicles powered by gaseous hydrogen be subject to the same parking garage requirements applicable to vehicles powered by traditional fuels such as diesel. Facility modifications for the bus parking area includes parking garage ventilation.

A mobile fueler for FCEBs can also be accommodated at Hamilton or Oxford with similar required modifications, including setbacks, as needed for a permanent facility. Given that the footprint and setback requirements for a mobile facility are close to that of a permanent facility, a mobile fueler may be more practical for a pilot program of ten or less buses than for a large-scale conversion to FCEBs.

6 LIFECYCLE COST ANALYSIS: BASELINE AND ZEB SCENARIOS

The purpose of the lifecycle cost analysis is to provide in-depth analyses on the lifecycle costs for BCRTA's fleet transition effort. The lifecycle cost estimation includes cash and non-cash costs. Cash costs consist of vehicle and infrastructure capital costs, operating and maintenance costs, and disposal costs. Non-cash costs consist of environmental costs and benefits.

6.1 METHODOLOGY

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

WSP is actively engaged with fuel providers, agencies operating zero-emission buses (ZEB), and vehicle manufacturers to understand technology and cost trends in the industry. Underlying ZEB cost values used as the basis for the lifecycle model assumptions were primarily sourced and aggregated using actual data from King County Metro in Seattle; Alameda-Contra Costa Transit District (AC Transit) in Oakland, California; District Department of Transportation (DDOT) in Washington, DC for their Circulator bus service; Massachusetts Bay Transportation Authority (MBTA) in Boston; and SunLine Transit Agency in southern California. This information is utilized to inform assumptions on the availability and pricing of vehicles and supporting infrastructure. The values presented are subject to change and are based on the most current capital and operational information available at the time of this analysis in mid-2022.

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

While the lifecycle analysis assumes delivered hydrogen in the case of FCEBs, on-site production may also be considered, space permitting, with a range of costs from $30 million to $110 million based on recent design estimates for similarly sized fleets using electrolysis or steam methane reforming.

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

The structure of the lifecycle cost modeling includes the assessment of capital, operating, disposal, and monetized environmental costs associated with the transition of existing vehicles under a **Baseline Scenario** and **ZEB scenarios**, defined as:

- **Baseline Scenario** - Continued operation of the current diesel, clean diesel, and diesel-electric hybrid vehicles with replacement by similar models at the end of the assumed vehicle service life
- **BEB Scenario** - Replacement of current vehicles with BEBs at the end of the assumed vehicle service life
- **FCEB Scenario** - Replacement of vehicles with FCEBs at the end of the assumed vehicle service life

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

BEBs and FCEBs and facilities may offer the opportunity for the authorities to lower some operations and maintenance costs; however, other costs will increase. Similar to conventionally fueled vehicles, BEB and FCEB operations and maintenance costs are highly dependent on the size and complexity of the vehicle fleet. Additionally, an electrification strategy would shift the authorities' primary fuel source for core bus operations from diesel fuel to electric power, which would subject the agency to different energy pricing structures and market prices. Based on U.S. Energy Information Administratoin data, the average price for electricity as measured in cents per kw/hr have ranged from 7.18 cents to 10.71 cents over the past 20 years, a variance of 49 percent. In comparison, diesel prices have ranged from $1.40 per gallon to $4.99 per gallon over the same period- a variance of 256 percent.

Table 6-1 outlines the major cost categories evaluated as part of the lifecycle analysis.

Table 6-1. Primary Cost Categories

Cost Type	Cost Category	Cost Variable
Cash Costs	Capital	Vehicle
		Vehicle modifications and contingency
		Facility costs for charging or fueling Infrastructure
		Major component replacement
	O&M	Vehicle maintenance, tools, training, and equipment
		Tire replacement costs
		Vehicle fuel/energy costs
		Charging and fueling infrastructure maintenance costs
		Training costs
	Disposal	Bus disposal costs or salvage value
Non-Cash Costs (Benefits)	Environmental	Vehicle emissions (including tire and brake wear)
		Upstream emissions
		Noise impacts

Source: WSP

6.2 GENERAL DATA, ASSUMPTIONS, AND LIMITATIONS

This section details the data inputs and sources, and operational assumptions underlying the lifecycle cost analysis and modelling.

6.2.1 GENERAL DATA SOURCES

Lifecycle cost modeling utilizes various capital, operating, disposal and environmental assumptions. Wherever possible, agency-specific datapoints are used to inform the cost assumptions and when unavailable, peer agency data and WSP assumptions based on previous experience with other agencies are leveraged.

6.2.2 CAPITAL COSTS: VEHICLES

Capital costs of vehicles are sourced from the base vehicle prices provided through the California State Buyboard for BEBs, the American Public Transportation Association (APTA) 2020 vehicle inventory and recent BCRTA experience for internal combustion vehicles. The additional cost of battery extended warranties were applied to the capital cost of BEBs. Vehicle costs represent the cost of replacing the existing vehicle fleet and do not consider incremental vehicle requirements due to potential range reductions from the transition to BEBs. Because off og BCRTA's blocks are within the range of a BEB, a 1:1 replacement ratio is used. Capital costs of vehicles are incurred based on the fleet replacement plan developed by WSP. The fleet replacement plan is based on the current operations of BCRTA, with the assumption that BEB and FCEB-related infrastructure costs will be incurred during the applicable vehicle transition timeframe. Vehicle purchases for BEB and FCEB conversion may not fully align with the current vehicle fleet due to other operational considerations. Additionally, capital costs of vehicles are incurred one year prior to operational start date to account for delivery lag and acceptance testing.

6.2.3 CAPITAL COSTS: INFRASTRUCTURE

Capital costs for charging and fueling infrastructure are based on recent experiences of peer agencies to replace their existing fueling tanks for the Baseline scenario. For the BEB scenario, infrastructure cost estimates represent the cost to procure, design, and install BEB chargers. Cost assumptions were developed by a cost estimator with experience on ZEB transition studies, or in the case of comparable cost estimates, by a contractor. The facility cost estimates prepared by WSP are based on a combination of facility improvements, vehicle charger units, and supporting utility infrastructure upgrades. Current costs for BEB chargers were used and applied to each facility based on the number of anticipated BEBs in operation. Facility improvements and utility upgrades are based on unit estimates and corresponding unit costs values. The analysis does not amortize the capital costs and assume costs will be incurred during the specified fleet replacement years or assumed construction period.

6.2.4 OPERATING AND MAINTENANCE COSTS

Operating and maintenance costs are evaluated on a cost per mile basis and applied to the average vehicle mileage over the lifecycle of BEB, FCEB, diesel-electric hybrid, and ICEB (diesel) vehicles. The operating life of the buses is assumed to be 12 years. The average mileage of each vehicle type is determined based on the fleet odometer for each vehicle. Values on operating costs per mile are sourced from the operating experience of peer agencies. Fuel costs (electricity) are based on the local utility tariffs. Diesel fuel costs are based on 2022 monthly rack prices plus delivery fees. Disposal costs are based on the current FTA guidance pertaining to salvage value and offsets of future federal funding if the salvage values exceed $5,000. Lastly, the environmental assumptions for tailpipe and lifecycle GHG emissions are based on Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool, Fuel Pathways by the California Air Resources Board (CARB), and the EPA Moves 2014b model.

6.2.5 GENERAL INFLATION

The lifecycle cost model accounts for inflation using the historical Consumer Price Index for all Urban Consumers (CPI-U) applied primarily to labor-related cost escalation, Producer Price Index (PPI) applied to bus chassis manufacturing, and Construction Cost Index (CCI) applied to infrastructure capital costs. The model accounts for the historic differential in growth rates based on the regional CPI-U and national PPI and CCI. Table 6-2 is an overview of the assumed escalation values from 2022 through 2024, which is also the rate assumed through the remaining forecast horizon.

The historical values through June 2022 are provided by Bureau of Labor Statistics, and CCI is based on WSP's analysis and projections. After June 2022, annual growth rates are based on anticipated lower cost increases in 2023 and a return to historical averages starting with the 2025 values. For example, a 40-foot BEB purchased in 2022 for $991,000 is assumed to cost $1,051,000 in 2025 after three years of escalation at 6.06% based on assumed increases in PPI. The resulting value is the year of expenditure (YOE) dollar amount that is presented in the lifecycle cost model output tables. A discount rate is also considered, for purposes of economic analysis of various technological alternatives and application to various federal benefit-cost analysis requirements for discretionary grants.

Table 6-2. National Consumer Price Index for all Urban Consumers (CPI-U) and National Producer Price Index (PPI) for Bus Chassis Manufacturing Based on Historic Ratio

Factor	2022	2023	2024	2025	2026+
CPI-U	7.25%	5.29%	2.75%	2.24%	2.30%
PPI Bus Chassis Manufacturing	9.60%	6.33%	2.31%	1.45%	1.28%

Source: Bureau of Labor Statistics

6.2.6 DISCOUNT RATES

Total agency lifecycle cost analysis results are provided in YOE dollars and also provided in discounted 2022 dollars that align with anticipated U.S. Department of Transportation (USDOT) benefit-cost analysis requirements starting in 2023. The lifecycle cost model employs nominal discount rate of 4.5%. The rate accounts for historical average interest rates and an addition of average escalation of approximately 2.5% to offset escalation factors assumed in the lifecycle cost model. For purposes of federal discretionary grant applications, USDOT has historically required a 7% real discount rate, which can be evaluated separately in the supporting model as required. The application of discount rates reflects that benefits and costs incurred in the near term are more highly valued than benefits and costs incurred in a future year. The costs incurred are assumed to divert funds from alternative investments in economically beneficial activities in future years, which is quantified through discounting, and normalization of future benefits and costs in present values to provide a comparable basis in investment alternatives.

6.3 LIFECYCLE COST INPUTS

This section outlines the cost assumptions for the lifecycle cost analysis of continued operations of diesel buses (Baseline Scenario) and the cost to transition to BEBs and FCEBs. The four major categories for the cost assumptions are capital, operating, disposal and environmental.

6.3.1 SCHEDULED VEHICLE PROCUREMENT

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

The procurement timeline needs to align with facility enhancements and is subject to considerations such as the useful life of the vehicles and any established procurement goals. The lifecycle model assumes that buses will be retired 12 years after their acceptance date, vans will be retired four years after their acceptance date, and cutaway vehicles will be retired five years after their acceptance date.

The following vehicle procurement schedule (Table 6-3) was developed by WSP in alignment of BCRTA's replacement schedule.

Table 6-3. Baseline and ZEB Scenarios Vehicle Replacement Schedule

Vehicle Type	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
BASELINE SCENARIO															
35ft Diesel - Hamilton	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-
35ft Diesel - Oxford	-	-	-	-	-	12	-	-	-	2	2	-	-	-	-
Cutaway E10 - Hamilton	19	-	5	12	17	-	-	-	17	12	7	-	-	12	-
BEB SCENARIO															
35ft BEB – Hamilton	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-
35ft BEB – Oxford	-	-	-	-	-	12	-	-	-	2	2	-	-	-	-
Cutaway E10 - Hamilton	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cutaway BEB - Hamilton	-	-	5	12	17	-	5	-	17	12	7	-	-	12	-
FCEB SCENARIO															
35ft FCEB - Hamilton	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-
35ft FCEB - Oxford	-	-	-	-	-	12	-	-	-	2	2	-	-	-	-
Cutaway E10 - Hamilton	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cutaway BEB - Hamilton	-	-	5	12	17	-	5	-	17	12	7	-	-	12	-

Source: WSP

6.3.2 CAPITAL COST

Bus capital costs are based on standard vehicle purchase prices, after-market equipment, allowances for contingency, and charging infrastructure. Charging and fueling infrastructure requirements are a key consideration for BEBs and FCEBs. Costs are based on the number of operating vehicles per facility and their expected lifespan, to estimate the total infrastructure costs per bus.

VEHICLE PURCHASE COST

Vehicle purchase costs includes the standard purchase price and additional options and charges as shown in Table 6-4. The values provided exclude sales tax costs. For BEBs, an additional cost for battery extended warranty over the life of the vehicle is assumed. All values are rounded to the nearest thousands.

Table 6-4. Vehicle Purchase Price Assumptions (2022$)

Vehicle Type	Bus Cost Estimate	Additional Options and Charges	Total Vehicle Purchase Costs
35ft Diesel	$428,000[6]	$58,000	$586,000
35ft BEB	$783,000[7]	$99,000	$882,000
35ft FCEB	$849,000[8]	$212,00	$1,061,000
Cutaway E10	$102,000[9]	-	$102,000
Cutaway BEB	$220,000[10]	-	$220,000

Source: WSP

VEHICLE MODIFICATIONS AND CONTINGENCY

In addition to the vehicle purchase costs, considerations are made for service preparation and inspection (2 percent of base vehicle price), special tools and diagnostic equipment (0.3 percent of base vehicle price) and allowances for contingency based on the vehicle base price and existing experience of the bus manufacturer (5 percent for diesel-electric hybrids and diesels and 10 percent for BEB and FCEB models).

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[6] From BCRTA document and escalated from 2020 price

[7] BYD California Contract Pricing with 446 kWh battery and extended warranty

[8] Estimated Bbsed on 40-ft models, current market price as of March 2022

[9] From BCRTA document and escalated from 2020 price

[10] Direct quote - Green Power EV Star

SUPPORTING INFRASTRUCTURE COST

Charging and fueling infrastructure includes the supporting equipment and facility construction to support the operations and maintenance of buses. Charging infrastructure conceptual estimates are developed by a WSP cost estimator based on the equipment and construction needs to host BEBs. Hydrogen costs are based on infrastructure to support hydrogen delivery, as well as mitigation of lighter than air flammable gas risk. For the Baseline Scenario, the costs are based on assumed future replacements of underground storage tanks, pumps, and dispensers.

Table 6-5 shows the overall capital investment costs assumed for each scenario.

Table 6-5. Facility Improvement Costs by Scenario (2022$)

Scenario	Diesel Fueling Infrastructure	BEB Infrastructure	Hydrogen Infrastructure	Total
Baseline	$1,005,000	$-	$-	$1,005,000
BEB	$-	1,056,427	$-	$1,056,427
FCEB	$-	$901,070	$19,360,000	$20,261,070

Source: WSP

TOTAL CAPITAL COSTS

Combining the capital costs categories results in a Baseline Scenario cost of $16.9 million compared with $58.6 million for the BEB transition scenario and $80.7 million for the FCEB transition scenario. Table 6-6 shows the overall estimated capital costs by year in year of expenditure dollars.

Table 6-6. Estimated Overall Capital Costs by Scenario by Year (YOE$ Millions)

Scenario / Year	Baseline	BEB	FCEB
2022	$0.24	$0.00	$0.00
2023	$0.24	$0.00	$0.00
2024	$0.30	$1.31	$1.31
2025	$0.45	$2.40	$2.40
2026	$0.59	$4.44	$4.44
2027	$1.13	$4.58	$4.53
2028	$1.31	$4.81	$6.41
2029	$1.31	$3.24	$5.31
2030	$1.31	$6.05	$8.16
2031	$1.31	$4.89	$7.06
2032	$1.34	$5.64	$7.08
2033	$1.34	$3.56	$5.64
2034	$1.28	$3.14	$5.48
2035	$1.28	$4.89	$7.28
2036	$1.07	$2.24	$4.70
2037	$1.05	$3.04	$4.65
2038	$1.05	$2.36	$4.71
2039	$0.33	$2.05	$1.50
2040	$0.00	$0.27	$0.00
Total	$16.93	$58.63	$80.65

Source: WSP

6.3.3 OPERATING AND MAINTENANCE COSTS

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

AVERAGE MILEAGE PER VEHICLE AND USEFUL LIFE

Average miles per vehicle are estimated using the fleet odometer for each vehicle. Vehicle life was assumed based on the FTA's useful life benchmark. Average mileage and useful life for each fleet type is shown in Table 6-7.

Table 6-7. Average Mileage per Vehicle and Useful Life

Vehicle Type	Average Vehicle Mileage[11]	Useful Life[12]
35ft - Hamilton	32,039	12
35ft - Oxford	15,388	12
Cutaway - Hamilton	33,406	5

Source: BCRTA

MAINTENANCE AND TIRE COSTS

General vehicle maintenance costs, tire replacement costs, and fueling unit maintenance costs for the Baseline and ZEB scenarios are outlined in Table 6-8. The charging unit cost for BEBs assumes a five-year warranty on charging infrastructure, drastically lowering O&M cost in the first five years. After the five-year warranty period charging costs include preventative and failure maintenance costs. Hydrogen costs include the ongoing maintenance and operation of the hydrogen delivery, conversion, storage, and fueling systems.

Table 6-8. Operating and Maintenance Costs for Vehicle Types (2022$/Mile)

Year / Vehicle Type	Diesel 35'	BEB 35'	FCEB 35'	E10 Cutaway	BEB Cutaway
Year 1	0.74	1.09	0.99	0.78	0.69
Year 2	0.73	1.20	0.98	0.85	0.76
Year 3	0.71	1.51	0.95	0.92	0.82
Year 4	0.78	1.38	1.05	0.99	0.88
Year 5	0.72	1.62	0.97	1.07	0.95
Year 6	0.84	1.96	1.13	1.10	0.98
Year 7	0.79	1.65	1.07	1.14	1.02
Year 8	0.78	2.07	1.05	1.17	1.04
Year 9	0.76	2.15	1.03	1.20	1.07
Year 10	0.81	1.90	1.09	1.24	1.11
Year 11	0.77	1.99	1.03	1.38	1.23
Year 12	0.74	1.85	1.00	1.52	1.36
Tires ($/mi)	0.065	0.072	0.068	-	-

Source: BCRTA and Peer Agency

FUEL AND ENERGY COST

Fuel costs are based on average 2022 prices through June, escalated using the U.S. Department of Energy, Energy Information Administration (USEIA) 2022 Annual Energy Outlook Reference Case Scenario price forecast. The USEIA price

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[11] Estimated based on the fleet age and mileage outlined in the BRCTA revenue vehicles documentation

[12] BRCTA operational experience

forecast is referenced as annual percent increases which are applied to the 2022 price baseline. Prices for electric vehicles are based on City of Hamilton utility rates and USEIA's five-year historical utility rates. Table 6-9 summarizes the energy cost assumptions. Demand charges are rounded to the nearest thousand. Hydrogen prices of $8.00 per kg are based on delivered costs for other agencies currently using hydrogen vehicles.

Table 6-9. Fuel / Energy Cost per Bus (2022$ Values)

	BEB 35'	Diesel 35'	FCEB 35'	E10 Cutaway	BEB Cutaway	BEB 35'
Utilty	Oxford - Duke Energy	-	-	-	Hamilton - Hamilton Electric	
Fuel/Energy Cost	$0.12/kWh[13]	$3.05/gal[14]	$8.00/kg[15]	$3.63/gal[16]	$0.035/kWh[17]	
Demand Charges ($/kW)	$12.00	-	-	-	$26.60	
Vehicle Fuel Efficiency Diesel Equivalent (mpdge)	-	5.52	9.72	7.00	-	-
Vehicle Fuel Efficiency (kWh/mi)	1.88	-	-	-	2.70	1.88
Average Annual Miles	15,388			33,406		32,039
Total Fuel/Energy Costs per Year per Bus	**$3,471**	**$8,502**	**$12,665**	**$17,323**	**$3,156**	**$2,108**

Source: WSP and Peer Agency

6.3.4 DISPOSAL AND RESALE VALUE

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

6.3.5 ENVIRONMENTAL COST

Environmental costs consist of tailpipe emissions, upstream emissions, and noise. The analysis converts these non-monetized values to cash costs. The environmental costs are measured in dollars per mile and the total cost calculations are driven by vehicle annual mileage.

The analysis applies the average annual mileage and the tailpipe and greenhouse gas emissions of grams of CO2 equivalent per millijoule per mile to estimate the lifecycle emissions in the Baseline and ZEB scenarios.

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[13] Based on City of Hamilton electricity price rates.

[14] Based on EIA Table 12 petroleum and other liquids prices

[15] Based on estimate from peer agency

[16] Based on estimate from peer agency

[17] Based on City of Hamilton electricity price rates.

Table 6-10 outlines the vehicle tailpipe emissions in grams/mile provided by AFLEET Analysis, and EPA MOVES 2014b model. Table 6-11 provides the lifecycle GHG emissions based on current diesel production and energy sourced from the current City of Hamilton grid sources. Noise emission calculations are shown in Table 6-12.

Table 6-10. Vehicle Tailpipe/Pollutants Emissions (g/VMT)[18]

Emission / Vehicle Type	Diesel 35'	BEB 35'	FCEB 35'	E10 Cutaway	BEB Cutaway
CO2	2,547	-	-	1,343	-
NOX	1.13	-	-	0.02	-
SOX	0.01	-	-	0.01	-
PM10	0.13	0.11	0.10	0.03	0.03
VOC	0.08	-	-	0.17	-
PM2.5	0.03	0.01	0.01	0.01	0.01

Source: AFLEET Analysis and EPA Moves 2014 Model

Table 6-11. Lifecycle Greenhouse Gas Emissions (g/VMT)[19]

Emission / Vehicle Type	Diesel 35'	BEB 35'	FCEB 35'	E10 Cutaway	BEB Cutaway
CO2	361	433	1,648	190	11.0

Source: Diesel Based on EPA Factors and BEB based on Regional Power Generation Profile

Table 6-12. Lifecycle Noise Emissions Cost ($/VMT)[20]

Emission / Vehicle Type	Diesel 35'	BEB 35'	FCEB 35'	E10 Cutaway	BEB Cutaway
Noise	0.067	0.05	0.07	0.07	0.07

Source: Altoona Testing

6.4 LIFECYCLE COST ANALYSIS RESULTS

The lifecycle cost analysis compares the lifecycle costs and benefits for each scenario in three primary cash cost categories: capital costs, operating costs, and disposal/salvage costs. Additionally, a non-cash cost of environmental benefits and costs, which the lifecycle model monetizes to account for a holistic comparative cost and benefit, is assessed. Results are presented in both 2022 dollars and YOE dollars in Table 6-13 and Table 6-14, respectively.

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[18] Values based on AFLEET analysis
[19] Values based on CARB for CNG, diesel, and unleaded vehicles
[20] Values based on Altoona testing and peer agencies

Table 6-13. Lifecycle Cost Analysis Results (2022$ Millions)

Scenario		BASELINE	BEB	FCEB
Capital	VEHICLE PURCHASE PRICE	$13	$27	$27
	MODIFICATIONS & CONTINGENCY	$2	$3	$3
	CHARGING/FUELING INFRASTRUCTURE	$0	$13	$9
	COMPONENT REPLACEMENT	$1	$0	$1
	TOTAL CAPITAL COSTS	**$16**	**$43**	**$39**
Operating	VEHICLE MAINTENANCE	$16	$23	$15
	VEHICLE TIRES	$0	$0	$0
	VEHICLE FUEL COSTS	$9	$15	$12
	CHARGING/FUELING INFRASTRUCTURE	$1	$2	$2
	TRAINING COSTS	$0	$0	$1
	TOTAL OPERATING COSTS	**$25**	**$40**	**$31**
Disposal	BATTERY DISPOSAL	$0	$0	$0
	BUS DISPOSAL	$0	-$1	$0
	TOTAL DISPOSAL COSTS	$0	-$1	$0
Total Cash Costs		**$40**	**$83**	**$69**
Comparison to Base	*DOLLARS*	*$0*	*$42*	*$29*
	PERCENT	-	*105%*	*71%*
Total Cash Cost per Mile		**$1.99**	**$3.33**	**$3.39**
Environmental	$2	$1	$0	$1
	$1	$0	$0	$1
	$1	$1	$1	$3
	$4	$2	$2	**$5**
Total Cash and Non-Cash Costs		**$45**	**$85**	**$71**
Comparison to Base	*DOLLARS*	*$0*	*$40*	*$26*
	PERCENT	-	*90%*	*59%*
Total Cash and Non-Cash Costs per Mile		**$2.20**	**$3.42**	**$3.48**
Total Mileage (million miles)		*20*	*25*	*20*

Source: WSP

Table 6-14. Lifecycle Cost Analysis Results (YOE$ Millions)

Scenario		**BASELINE**	**BEB**	**FCEB**
Capital	VEHICLE PURCHASE PRICE	$20	$41	$41
	MODIFICATIONS & CONTINGENCY	$2	$5	$4
	CHARGING/FUELING INFRASTRUCTURE	$0	$19	$12
	COMPONENT REPLACEMENT	$1	$0	$1
	TOTAL CAPITAL COSTS	**$24**	**$65**	**$58**
Operating	VEHICLE MAINTENANCE	$23	$35	$22
	VEHICLE TIRES	$0	$1	$0
	VEHICLE FUEL COSTS	$13	$22	$18
	CHARGING/FUELING INFRASTRUCTURE	$1	$3	$3
	TRAINING COSTS	$0	$0	$1
	TOTAL OPERATING COSTS	**$37**	**$61**	**$44**
Disposal	BATTERY DISPOSAL	$0	$0	$0
	BUS DISPOSAL	-$1	-$1	-$1
	TOTAL DISPOSAL COSTS	**-$1**	**-$1**	**-$1**
Total Cash Costs		**$60**	**$126**	**$102**
Comparison to Base	*DOLLARS*	$0	$66	$42
	PERCENT	-	111%	70%
Total Cash Cost per Mile		**$1.95**	**$2.94**	**$5.07**
Environmental	EMISSIONS - TAILPIPE	$3	$1	$1
	EMISSIONS - REFINING/UTILITY	$1	$0	$0
	NOISE	$2	$2	$2
	TOTAL ENVIRONMENTAL COSTS	$6	$3	$3
Total Cash and Non-Cash Costs		**$66**	**$129**	**$104**
Comparison to Base	*DOLLARS*	$0	$63	$38
	PERCENT	-	95%	58%
Total Cash and Non-Cash Costs per Mile		**$3.25**	**$5.19**	**$5.11**
Total Mileage (million miles)		**20**	**25**	***20***

Source: WSP

The full lifecycle cash cost of a transition to BEBs and FCEBs is higher than the continued reliance on ICEBs (diesel). While the initial capital and operating costs are higher for ZEBs, there are opportunities for some savings in fuel costs. Additionally, operating cost benefits are highly dependent on factors that are continually evolving as BEBs and FCEBs are deployed in greater numbers across the U.S. The analysis also shows that the Baseline Scenario would result in a large emission generation over the lifecycle of diesel operations in comparison to the ZEB scenarios. The large vehicle emission difference between the two replacement scenarios was expected, as the technology in the BEBs are aimed to reduce GHG emissions, particularly for carbon emissions. The comparison of BEBs and FCEBs indicate that BCRTA may benefit from pursuing hydrogen over electricity. BCRTA’s relatively small size, the flexibility of the Hamilton facility and planned Oxford facility, are among the factors that lean in that direction.

7 POTENTIAL RISKS

7.1 BACKGROUND

A transition to alternative fuels and ZEBs, as with the introduction of and major change to capital infrastructure and operating procedures, entails some level of risk. The Lifecycle Cost Analysis identifies the cost implications of a transition to alternative fuels. The identification of potential risks – for both a transition to BEBs and FCEBs – along with an identification of potential risks if a transit agency does not elect to transition to alternative fuel/ZEBs is designed to further help BCRTA in determining a path forward.

The identification of risks is not considered a benefit-cost analysis. Risks are identified to help inform decision-makers with the various issues that are associated with the various technologies, primarily from the standpoints of technology, reliability, cost, and safety, but also in terms of the political and public considerations that come with a major change in infrastructure, agency policy, and carbon mitigation along with major expenditure of public dollars. Risks involve buses, charging and fueling infrastructure, facilities and maintenance, fuel and power supply, and funding.

7.2 RISK MATRIX

Table 7-1 presents a list of potential risks for BEBs, FCEBs, and diesel and diesel-electric hybrid buses, respectively. Accompanying each risk is a brief identification of potential mitigation measures and approaches. A detailed risk register is included in the Appendix of this report.

Table 7-1: Summary of Potential Risks

BEBs	FCEBs	Diesel / Diesel Electric Hybrids
Although new federal programs are designed to expand BEB technology, and availability, high demand for BEBs has the potential to slow production and delivery of BEBs and associated parts and infrastructure.	Relative newness of FCEB technology, limited industry experience to date and ongoing improvements may result in unachieved performance levels and render components or buses obsolete.	Contribution to climate change.
Battery fire may occur and spread to surrounding materials and adjacent buses at Bus Operating Facility.	High demand may significantly slow production and delivery of FCEBs and associated parts and infrastructure.	Nationwide shift to cleaner and renewable energy may result in fewer refineries and capacity.
Relative newness of BEB technology and ongoing improvements may render components or buses obsolete.	Equipment may fail and result in hydrogen leaks creating a potential fire hazard.	Nationwide shift to cleaner and renewable energy along with increased environmental regulations and government policy may reduce capacity.
A loss of cooling liquid causes arcing, heating the cells and causing thermal runaway.	Hydrogen is highly flammable; static electricity can cause sparks.	Price swings due to infrastructure issues, weather, international conditions, etc.
Crashes put mechanical strain on the batteries; cells can come lose from the vehicle and spread around the crash site.	Limitation on adequate and safe location of fueling facilities may restrict the ability to convert 100% of the fleet to FCEB, resulting in a mixed fleet.	Erosion of public and government support for the agency. Public relations issues.

BEBs	FCEBs	Diesel / Diesel Electric Hybrids
Potentially subject to cyberattacks.	The increasing frequency of severe weather, such as flooding, high winds, and severe lightning, poses a threat to maintaining power supply.	Reduced funding for diesel buses.
Monitoring system transmitting telemetry data can fail on a mechanical or software platform.	Equipment malfunction or force majeure at production facility interrupts hydrogen deliveries. Limited number of suppliers in area.	Shift by manufacturers to ZEB production may reduce ability to replace buses or expand fleet.
First responders to a battery-related combustion incident may be at the risk of harm when subject to a volatile and dangerous environment	Pipeline availability may be limited and subject to strict regulation, delaying or precluding direct service to a Bus Operating Facility.	
Use of lithium batteries propagates the unregulated mining of materials in developing countries.	Insurers may increase rates due to the publicity on the volatility of hydrogen.	
Unregulated manufacturing plants often release harmful organic electrolytes and requires high energy consumption	Fueling, maintaining, and operating FCEBs requires significant and on-going training, resulting in increased costs; agency reliance on manufacturer for training may cause delays and erosion of quality of training; employee turnover can also impact training costs and effectiveness.	
Insurers may increase rates due to the publicity on the volatility of batteries.	Local fire and emergency personnel may not be familiar with and/or adequately training in safety and hazard mitigation procedures.	
The increasing frequency of severe weather, such as flooding, high winds, and severe lightning, poses a threat to maintaining power supply.	Manufacturer assistance or warranty services may be delayed.	
Charging, maintaining, and operating BEBs requires significant and on-going training, resulting in increased costs; agency reliance on manufacturer for training may cause delays and erosion of quality of training; employee turnover can also impact training costs and effectiveness.	On-site production of hydrogen is relatively expensive and requires additional outdoor space.	
Local fire and emergency personnel may not be familiar with and/or adequately training in safety and hazard mitigation procedures.	Limited number of hydrogen suppliers may impact supply reliability	
Manufacturer assistance or warranty services may be delayed.		
Preferred site may have inadequate power access or neighborhood opposition.		

8 IMPLEMENTATION

The Lifecycle Cost Analysis and Risk identification, detailed in the previous two sections, provide data, information, and assessment by which BCRTA can determine which direction it will head toward achieving a ZE fleet.

The previous section of this report identifies an array of risks of both ZEB technologies as well as for the Baseline Scenario, which does not transition to ZEBs and retains a fleet of diesel/diesel-electric hybrid buses. Between BEBs and FCEBs, perhaps the most significant risk factors and considerations focus on the relatively minimal industry experience with FCEB versus BEBs. There is still, at this point, no indication that FCEBs will eventually comprise a major market share that will eventually result in the moderating trend of capital costs – or downward pressure on price - thay typically arises from a new technology that becomes standard technology. Grant availability is another factor. While hydrogen technology is eligible under various funding programs, the current federal emphasis is on BEBs.

BCRTA is fortunate in that its existing Hamilton facility and planned Oxford facility provide maximum flexibility to convert to either technology with minimal retrofitting on its infrastructure. Given the indicated lifecycle cost favorability of FCEB technology, the decision of which direction BCRTA will pursue may focus on whether to take the more conservative path (BEB). In terms of operating range, BCRTA's service can be operated by either technology with no need to modify blocks, which can incur additional operating costs.

8.1 REGIONAL NETWORK BENEFITS

Benefits of all three authorities pursuing the same ZEB technology are speculative at this time. Potential network benefits of BEBs appear minimal primarily because each authority has its own contract and arrangements with the local utility. Shared opportunity charger locations are also limited. Interface locations with SORTA are highly limited and not a significant potential network benefit factor.

FCEB technology may offer potential network benefits involving the production and procurement of hydrogen. A regional commitment of the authorities to hydrogen may encourage the development of providers, which are currently very limited.

It is theoretically possible for one authority to arrange with another to fuel at their facility. In terms of infrastructure, this is dependent on the ability of a hydrogen facility to store enough H2 for a large number of buses. Even if this should occur, the practicality of one authority sending its buses every day or night to a fueling facility several miles away would create major logistical issues and operating cost increases.

Network benefits can extend beyond the transit authorities. For example, other major public entities that desire to convert large fleets to ZE may team with one of more of the authorities to help encourage available supply of hydrogen. At this time, however, the region's largest public entity, the City of Cincinnati, has expressed minimal interest in hydrogen and intends to pursue electric.

8.2 TRANSITION TIMELINE AND CONSIDERATIONS

WSP has developed a sample schedule for the transition to ZEBs based on assumptions listed in Table 8-1. This schedule was developed to support the vehicle replacement/procurement schedules included in Section 6 of this report.

The transition timeline is divided up into three components: Utilities, Facilities, and Vehicles.

Utility and facility development would prepare the authorities to accept BEBs or FCEBs and infrastructure through their transition periods. Utilities application, design, and construction can take up to 36 months, although this timeline is shorter or longer depending on the utility and power required. It is paramount that the authorities complete infrastructure to support vehicles before vehicles arrive onsite.

The facilities timeline is based upon a design-bid-build strategy. While the lengths of time required for each stage of this process depends heavily on internal procurement and design procedures of each authority, the assumptions shown below provide a rough estimate based on experience with other agencies. The facility build itself is divided into three "phases" to allow partial fleet relocation during construction.

These assumptions take into account a preliminary procurement schedule, and two rounds of bus production extending into 2025. It is assumed that the authorities will not go out for bid in successive years for vehicles, but instead exercise options off existing procurement contracts for several years before going out for bid. It is also assumed that chargers will be purchased with BEBs, and/or hydrogen fueling stations purchased with FCEBs.

Table 8-1. Sample Transition Timeline Activities and Assumptions (Based on Modification of Existing Facility)

Activity	Start Date	Duration (Days)
Utilities Application	6/1/2023	180
Utility Design	12/30/2023	270
Utility Construction	9/26/2024	180
Facility Design	6/1/2023	180
Facility Bid	12/30/2023	90
Facility Build Phase 1	3/28/2024	180
Facility Build Phase 2	9/26/2024	90
Facility Build Phase 3	12/30/2024	90
Vehicle RFP Development	10/1/2023	180
Vehicle RFP Bid	3/28/2024	90
Vehicle Pre-Production & Inspection	6/27/2024	270
Charging Installation	3/22/2025	60
Vehicle Production	5/21/2025	21

Source: WSP

8.3 TRAINING

Transitioning to ZEBs requires training employees to keep pace with changing technologies. BCRTA provides operational training for its bus operators, mechanics, and other support employees. The emphasis for ZEBs is primarily on mechanic training. The shift from ICEBs and propulsion technologies to ZEB systems is more complicated for mechanics than it is for bus operators.

Training will be required prior to deployment of ZEBs into revenue service. It should be provided by bus OEMs and coincide with pre-production activities. Training should be coordinated with OEMs and internal stakeholders for authority employees to attend OEM familiarization and safety orientation sessions. Of utmost importance in training awareness of high voltage conditions including "lock out/tag out" procedures and other safety considerations.

Training must also be refreshed on a regular basis, for new employees and refresher training for existing employees on a quarterly basis. While new technology requires strong partnerships with OEMs and sub-component suppliers, the ultimate goal of the authorities is to reduce reliance on OEMs in the long term and bring ZEB training in-house. Classes can be taught by staff on the array of essential topics including safety awareness for high voltage and high-pressure hydrogen, operational start-up/shut-down and emergency procedures, familiarization with the location and function of fuel cell and battery electric components, fueling, and charging.

All training, for operators, mechanics, supervisors, and others, would typically be scheduled through an agency-based leaning management system. This can take the form of an intranet site that serves as the primary portal for the authorities' transportation and maintenance departments to access course and course schedules. It also allows the authorities to track training compliance for each employees and is essential to tracking training progress and results.

8.3.1 OPERATOR TRAINING

Operator training should include both academic (classroom) and behind-the-wheel experience. Training topics include dash controls, indicator lights, specific start-up and shut-down procedures, and defensive driving safety.

8.3.2 MAINTENANCE/MECHANIC TRAINING

For mechanics and others, familiarization and safety orientation is an OEM-led class. Content includes high voltage safety awareness, personal protective equipment (PPE), safety measures, and preventive maintenance. Training sessions would be conducted for each shift upon ZEB delivery. In addition to mechanics and service employees, maintenance supervisory staff and maintenance trainers would require the same training.

Additional topics that OEMs would provide training for include air systems, brakes, steering/suspension, electrical systems, computer diagnostic systems, energy storage systems, fuel cell systems, and troubleshooting. Table 8-2 identifies the potential number of hours of training for mechanics in both BEB and FCEB scenarios.

Table 8-2. Potential Mechanic Training Scenario

BEB-FCEB Coursework	Hours
Orientation and PPE/High Voltage	8
Energy Storage System	40
Power Train Technology	40
Fuel Cell	30
Five Week Technical Training Program	200

Source: WSP, AC Transit

Work with transitioning agencies around the country has resulted in a variety of lessons learned for both Procurement and incorporation of ZEB technology into a fleet. The following considerations should be made in developing a full fleet transition:

- Facility construction and infrastructure installation should complete before buses arrive onsite. This will ensure that vehicles can be used when they arrive and prevent warranty delays.
- The authorities may consider "evergreen battery warranties" to ensure performance for the lifetime of a vehicle. Adding warranty language to bus contracts will allow authorities to maintain their fleet performance as batteries age, for example.

- The authorities should engage a facility designer to perform 100% designs. Regardless of technology choice, a facility designer will enable each authorities to best optimize its facility(ies) to fit new technology with minimal impact to ongoing operations.

8.4 EQUITY CONSIDERATIONS

Equity is an important consideration in an Alternative Fuel strategy in terms of facilities and deployment of vehicles.

In terms of bus operating facilities, equity considerations should be minimal. When an authority's first ZEBs are deployed, equity considerations are a greater factor. ZEBs will be considered an improvement; as such, it will be essential that ZEBs be deployed equitably throughout its service area to ensure that equity-focused communities receive the same benefit than non-equity-focused communities may receive. For BCRTA, a somewhat robust equity analysis may be required prior to implementation given the contrasts between areas that require equity consideration, such as portions of Hamilton and Middletown, and those that do not.

9 FINANCE PROGRAMS

9.1 BACKGROUND

The federal government, which is a primary funding source for bus procurements, is heavily promoting the transition from carbon-emitting vehicles, such as diesel buses, to alternative fuels and clean technologies such as BEBs and FCEBs. It is also incentivizing transit agencies to make this transition by providing substantial funding.

On November 15, 2021, the Infrastructure Investment and Jobs Act (IIJA or "Act") was signed into law. Now formally known as the Bipartisan Infrastructure Law (BIL), the Act reauthorized surface transportation programs for five years and provides new investments in transportation, energy, water, buildings, and other programs to improve the nation's infrastructure.

The BIL contains $550 billion in new spending over five years. It provides new federal funding to support roads and bridges, public transit, freight and passenger rail, ports, and airports; investment in broadband infrastructure; water systems; modernizing the power sector; and improving climate resilience. Nearly half of the BIL's funding - $284 billion – is allocated to transportation. In addition to authorizing these programs, the BIL also provides $113.3 billion in advance general fund appropriations to allow agencies to begin funding infrastructure improvements before the fiscal year (FY) 2022 appropriations process is completed.

The BIL emphasizes investments in equity and measures to mitigate climate change, while safety remains a top priority for the US Department of Transportation (US DOT). The BIL includes separate sections for equity, climate and safety programs that impact the provision of funding for transportation, energy, water, and other programs in the act. The federal agencies overseeing these programs will be updating their policies to include these cross-cutting requirements in their regulations, guidance, future Notices of Funding Opportunities (NOFOs) and project rating criteria in the months ahead. For funding levels, this white paper generally reports the amounts included in the authorizing language. For some programs, the amounts made available by the advanced appropriations are included.

The purpose of this section is to identify the universe of funding sources that may potentially be available to support BCRTA as part of the evaluation and transition to an alternative fuel bus fleet. Funding sources are applicable for funding ZEB purchases and/or associated facility enhancements and charging infrastructure to accommodate ZEBs. Options considered include federal formula and discretionary grant funding options, including programs that were created or expanded via the BIL.

This white paper is arranged by the federal agency in charge of administering funds:

- Federal Transit Administration (FTA)
- Federal Highway Administration (FHWA)
- U.S. Department of Transportation (US DOT)
- Other non-transportation departments including U.S. Department of Energy (US DOE) and U.S. Department of the Treasury (USDT).

9.2 FEDERAL TRANSIT ADMINISTRATION (FTA) PROGRAMS

This section outlines relevant FTA funding programs that could potentially be used to support an alternative fuel fleet transition at BCRTA.

FTA has instituted various new requirements pertaining to some of the most promising ZEB-focused programs. On December 1, 2021, FTA released a letter amending statutory provisions for the 5339 (b) Grants for Buses and Bus Facilities Competitive Program and 5339 (c) Low or No Emissions Program. The amendment includes a requirement that applicants requesting funding for zero-emissions vehicle related projects include a single Zero-Emission Transition plan document containing the following information, at a minimum:

- Demonstrate a long-term fleet management plan with a strategy for how the applicant intends to use the current request for resources and future acquisitions.
- Address the availability of current and future resources to meet costs for the transition and implementation.
- Consider policy and legislation impacting relevant technologies.
- Include an evaluation of existing and future facilities and their relationship to the technology transition.
- Describe the partnership of the applicant with the utility or alternative fuel provider.
- Examine the impact of the transition on the applicant's current workforce by identifying skill gaps, training needs, and retraining needs of the existing workers of the applicant to operate and maintain zero-emission vehicles and related infrastructure and avoid displacement of the existing workforce.

Furthermore, the following two provisions are also stated:

- FTA's guidance permits agencies to include vehicles that have met their minimum useful life in their contingency fleet if an agency is introducing ZEBs into its fleet, and those vehicles are not included in the calculation of spare ratio.
- The federal share of the cost of leasing or purchasing a ZEB is not to exceed 85% of the total transit bus costs, and the federal share of the cost of leasing or acquiring low-or no-emission bus-related equipment and facilities is 90% of the net project cost.

9.2.1 FTA SECTION 5339 (A) & (B): BUS AND BUS FACILITIES PROGRAM, BOTH FORMULA AND COMPETITIVE

Section 5339 (A) and (B) focuses on assisting bus operators, states, or local governmental authorities that operate fixed route in the financing of buses and bus facilities. The program goal is to replace, rehabilitate and purchase buses, vans, and related equipment, and to construct bus-related facilities, including technological changes or innovations to modify low or no emission vehicles or facilities.

Applications for the competitive discretionary program, Section 5339 (b) are evaluated based on demonstration of need, or the quality and extent to which they demonstrate how the proposed project will address the need for capital investment in bus vehicles and/or supporting facilities. Applications are also assessed based on demonstration of benefits, or how well they describe how the proposed project will improve the condition of the transit system, improve the reliability of transit service for its riders, and enhance access and mobility within the service area.

The program includes $3.16 billion in authorizations for 5339 (a) and $1.97 billion for 5339 (b) over the next five years. A maximum federal share of 80% is in place for this program; 25% of funds from this program will be reserved for low emission bus projects. The rural area set aside increased to 15%.

The BIL authorizes major increases in 5339 formula and discretionary funding over the next several years. BCRTA could consider allocating a portion of 5339 funds above those amounts needed for operations to capital projects such as ZEB purchases and charging infrastructure.

9.2.2 FTA SECTION 5539 (C): LOW OR NO EMISSION VEHICLE PROGRAM

The BIL includes massive increases in funding for the 5339(c) discretionary funding over the next several years. FY 2022 funding exceeds the FY 2021 amount by sixfold, increasing from $182 million to $1,122 million.

The Low or No Emission Vehicle Competitive (LoNo) program provides funding to state and local governmental authorities for the purchase or lease of zero-emission and low-emission transit buses as well as acquisition, construction, and leasing of required supporting facilities.

Eligible projects include:

- Purchasing or leasing low- or no-emission buses
- Acquiring low- or no-emission buses with a leased power source
- Constructing or leasing facilities and related equipment (including intelligent technology and software) for low- or no-emission buses
- Constructing new public transportation facilities to accommodate low- or no-emission buses
- Rehabilitating or improving existing public transportation facilities to accommodate low- or no-emission buses

9.2.3 FTA SECTION 5307 URBANIZED AREA FORMULA GRANTS

Section 5307 makes federal resources available for transit capital and operating assistance in urbanized areas and for transportation-related planning.

Eligible activities include:

- Planning, engineering, design and evaluation of transit projects and other technical transportation-related studies
- Capital investments in bus and bus-related activities such as replacement, overhaul and rebuilding of buses, crime prevention and security equipment and construction of maintenance and passenger facilities
- Capital investments in new and existing fixed guideway systems including rolling stock, overhaul and rebuilding of vehicles, track, signals, communications, and computer hardware and software
- Transit improvements associated with capital investments and certain expenses associated with mobility management programs.
- The program focuses on preventive maintenance and some Americans with Disabilities Act (ADA) complementary paratransit service costs, which are considered capital costs under this program.
- The BIL authorizes major increases in 5307 formula funding over the next several years -- 28% increase in overall FY 2021 levels in FY 2022, steadily increasing to 41% increase above FY 2021 funding levels by FY 2026. SORTA, TANK, and BCRTA could consider allocating a portion of 5307 funds above those amounts needed for operations for capital projects such as ZEB purchases and charging infrastructure.

9.2.4 FTA CAPITAL INVESTMENT GRANTS (CIG) – SMALL STARTS

The total maximum allowable cost of Small Starts Projects is raised from $300 million to $400 million, with the CIG share capped at $150 million. BCRTA is not planning fixed guideway projects and would not be eligible for CIG funding that could cover ZEBs.

9.2.5 FTA SECTION 5310 ENHANCED MOBILITY OF SENIORS & INDIVIDUALS WITH DISABILITIES

Section 5310 comprises formula funding allocated based on the population of older adults and people with disabilities established by FTA. A three-tiered formula with 60% of the funds going directly to urbanized areas over 200,000, 20% allocated to states for urbanized areas under 200,000 and 20% to states for non-urbanized areas.

The BIL authorizes major increases in 5310 formula funding over the next several years -- 44% increase in overall FY 2021 levels in FY 2022, steadily increasing to 56% increase above FY 2021 funding levels by FY 2026. BCRTA could consider allocating a portion of 5310 funds above those amounts needed for operations to capital projects such as ZEB purchases that support the goals of the 5310 program.

9.2.6 FTA FUNDING SOURCES SUMMARY

Table 9-1 provides a high-level summary of the key characteristics and considerations of each funding sources evaluated in this section.

Table 9-1. Potential FTA Funding Sources Summary

FTA Funding Program	Program Type	Eligibility			Funding Amount (FY 22 – FY 26)
		Alt Fuel Vehicle/ZEB Purchase	Vehicle Charging Infrastructure	Facility Capital Investments	
Bus and Bus Facilities Program, both formula and discretionary	Formula and Discretionary	✓	✓	✓	$ 5.1 B
Low or No Emission Vehicle Program	Discretionary	✓	✓	✓	$ 5.6 B
Urbanized Area Formula Grants	Formula	✓	✓	✓	$ 33.5 B
Capital Investment Grants (CIG) – Small Starts	Discretionary	✓	✓	✓	$ 23 B
FTA Section 5310: Enhanced Mobility of Seniors & Individuals with Disabilities	Formula	✓	✓		$ 2.2 B

9.3 FEDERAL HIGHWAY ADMINISTRATION (FHWA) PROGRAMS

This section outlines relevant Federal Highway Administration (FHWA) funding programs that could perhaps be used to support alternative fuel vehicle and ZEB fleet transition.

9.3.1 CARBON REDUCTION PROGRAM

This program authorizes the distribution of funds to metropolitan planning organizations (MPOs), including the Ohio Kentucky Indiana Regional Council of Governments (OKI, the MPO for the region served by TANK,SORTA, and BCRTA), 65% of which will be sub-allocated by population. MPOs can award these funds to eligible projects that support the reduction of transportation emissions.

Program funds can be used to aid public mass transportation systems that operate buses transporting passengers on federal-aid highways via construction of bus and passenger infrastructure along federal-aid highways. Eligible projects include electric vehicle charging stations and/or natural gas vehicle refueling stations.

9.3.2 SURFACE TRANSPORTATION BLOCK GRANT (STBG)

STBG provides flexible funding that may be used by states and localities for projects to preserve and improve the conditions and performance on any federal-aid highway, bridge and tunnel projects on any public road, pedestrian and bicycle infrastructure, and transit capital projects, including intercity bus terminals. The BIL expanded STBG funding eligible uses expanded to include installation of electric vehicle (EV) charging infrastructure.

9.3.3 CONGESTION MITIGATION AND AIR QUALITY (CMAQ)

A significant amount of flexible funding is available, and changes have been made to the program with the BIL. Most changes to the CMAQ section relate to eligible projects and the addition of the following project types:

- Bike-sharing and shared scooter systems
- Diesel retrofit replacements
- Purchase of medium- or heavy-duty zero emissions vehicles and related charging equipment
- Purchase of construction vehicles to support alternative fuel projects, including port-related freight operations

9.3.4 CHARGING AND REFUELING INFRASTRUCTURE GRANTS PROGRAM

This program focuses on deploying publicly accessible vehicle charging and fueling infrastructure for low or no-emission vehicles along key corridors throughout the US. It supports alternative fuel vehicle and ZEB charging/fueling projects that could exclusively be utilized by a transit agency that may otherwise not be considered eligible in other programs.

9.3.5 FHWA STRENGTHENING MOBILITY AND REVOLUTIONIZING TRANSPORTATION (SMART)

The SMART program supports projects that incorporate innovative transportation technologies or uses of data, including coordinated automation, connected vehicles, and intelligent sensor-based infrastructure. Proposed projects will be evaluated against the sponsor's ability to successfully undertake the project and is serving a population with a demonstrated need; ability to advance data, technology and applications that provide significant benefits to the area served.

9.3.6 FHWA FUNDING SOURCES SUMMARY

Table 9-2 provides a high-level summary of the key characteristics and considerations of each funding sources evaluated in this section.

Table 9-2. Potential FHWA Funding Sources Summary

FHWA Funding Program	Program Type	Eligibility			Funding Amount (FY 22 – FY 26)
		Alt Fuel Vehicle/ZEB Purchase	Vehicle Charging Infrastructure	Facility Capital Investments	
Carbon Reduction Program	Formula		✓		$ 6.4 B
Surface Transportation Block Grant (STBG)	Formula	✓	✓	✓	$72 B
Congestion Mitigation and Air Quality (CMAQ)	Formula	✓	✓		$13.2 B
Charging and Refueling Infrastructure Grants Program	Discretionary		✓		$ 2.5 B
Strengthening Mobility and Revolutionizing Transportation (SMART)	Discretionary		✓		$ 500 M

9.4 OTHER U.S. DEPARTMENT OF TRANSPORTATION (US DOT) PROGRAMS

This section outlines relevant US DOT funding programs that could perhaps be used to support the transition of BCRTA's fleet to alternative fuel vehicles and ZEBs.

9.4.1 REBUILDING AMERICAN INFRASTRUCTURE WITH SUSTAINABILITY AND EQUITY (RAISE) PROGRAM

The FY 22 RAISE Program consisted of $1.5 billion in federal funds, excluding an additional $1.5 billion in advanced appropriations that could still be made available in FY 2022, intended to leverage money from private sector partners, states, local governments, metropolitan planning organizations and transit agencies. Individual grants are limited to $25 million and provide and equal split between rural and urban areas. Eligibility requirements include:

- Applicants must match funds with a minimum of 20% non-federal funds (no local match required in Areas of Persistent Poverty).
- Applications require a benefit-cost analysis and projects compete best if their benefit-cost ratio is above 1.0.
- Additional merit criteria related to climate change, racial equity, barriers to opportunity, and to enhance community connectivity and mobility.

9.4.2 US DOT RECONNECTING COMMUNITIES PILOT PROGRAM

Eligible entities may apply for planning funds to study the feasibility and impacts of removing, retrofitting, or mitigating existing transportation facilities that create barriers to mobility, access, or economic development. The program includes construction funds to carry out projects to remove, retrofit or mitigate an eligible facility and, if appropriate, to replace it with a new facility.

9.4.3 US DOT/U.S. DEPARTMENT OF ENERGY (US DOE) DOE NATIONAL ELECTRIC VEHICLE (EV) FORMULA FUNDING PROGRAM

This joint program between the two federal departments focuses on further deployment of an interconnected network of EV charging stations along critical corridors and will focus on public accessibility. The program prioritizes data collection, access, and reliability of charging infrastructure with primary criteria established including:

- The acquisition and installation of EV charging infrastructure to serve as a catalyst for the deployment of such infrastructure and to connect it to a network to facilitate data collection, access, and reliability.
- Proper operation and maintenance of EV charging infrastructure.
- Data sharing about EV charging infrastructure to ensure the long-term success of investments made under the program.
- The federal share maximum for projects funded under the program is 80%.

9.4.4 US DOT/US DOE NATIONAL ELECTRIC VEHICLE CHARGING AND FUELING INFRASTRUCTURE DISCRETIONARY GRANT PROGRAM

This program provides funding to strategically deploy EV charging infrastructure and to establish an interconnected network to facilitate data collection, access, and reliability. Funding can only be used to support electric vehicle charging infrastructure projects that are open to the general public (or commercial motor vehicle operators from more than one company) and located along a designated alternative fuel corridor. Funds must be used for the Federal share payable for projects funded under the EV Charging Program is 80%.

9.4.5 OTHER US DOT FUNDING SOURCES SUMMARY

Table 9-3 provides a high-level summary of the key characteristics and considerations of each funding sources evaluated in this section.

Table 9-3. Other Potential US DOT Funding Sources Summary

USDOT Funding Program	Program Type	Eligibility			Funding Amount (FY 22 – FY 26)
		Alt Fuel Vehicle/ZEB Purchase	Vehicle Charging Infrastructure	Facility Capital Investments	
RAISE	Discretionary	✓	✓	✓	$15 B
Reconnecting Communities Pilot	Discretionary		✓	✓	$1 B
National EV Formula Fund*	Formula		✓		$ 2.5 B
National EV Charging and Infrastructure*	Discretionary		✓		$ 2.5 B

* National EV Formula Funds and EV Charging and Infrastructure Grants can only be used on charging infrastructure available for public use.

9.5 OTHER FEDERAL PROGRAMS

This section outlines relevant U.S. Department of Energy (US DOE) and U.S. Department of the Treasury (USDT) programs that could perhaps be used to support a fleet transition to alternative fuels and ZEBs at BCRTA.

9.5.1 US DOE STATE ENERGY PROGRAM

The State Energy Program supports grants for vehicle-to-grid storage and to support the reliability of electric grids to meet the increased demand from EV charging and electrification of appliances. It focuses on projects to increase transportation energy efficiency, including programs to help reduce carbon emissions in the transportation sector by 2050 and accelerate the use of alternative transportation fuels for, and the electrification of, state government vehicles, fleet vehicles, taxis and ridesharing services, mass transit, school buses, ferries, and privately owned passenger and medium- and heavy-duty vehicles.

9.5.2 US DOE HYDROGEN RESEARCH AND DEVELOPMENT

The U.S. DOE is tasked with developing:

- Four regional clean hydrogen hubs ($8 billion)
- A clean hydrogen manufacturing and recycling program ($500 million)
- A program to reduce costs of clean hydrogen production from electrolyzers ($1 billion)

This program is not transit agency-specific but may have the potential to benefit transit agencies.

9.5.3 US DOE ADVANCED ENERGY MANUFACTURING AND RECYCLING GRANT PROGRAM

This program targets small businesses investing in certain advanced energy technologies that will reduce greenhouse gas emissions in communities that have been impacted by closures of coal mines or coal-fired power plants. Qualifying projects must (1) re-equip, expand, or establish a manufacturing or recycling facility to produce certain types of advanced energy property; or (2) re-equip a facility with equipment designed to substantially reduce greenhouse gas emissions. This program is not transit agency-specific but may have the potential to benefit transit agencies.

9.5.4 US DOE DEMONSTRATION OF ELECTRIC VEHICLE BATTERY SECOND-LIFE APPLICATIONS FOR GRID SERVICES

This program supports projects that demonstrate second-life applications of electric vehicle batteries as aggregated energy storage installations to provide services to the electric grid.

9.5.5 US DOE ALTERNATIVE FUEL TAX CREDIT

Credit is available for alternative fuel that is sold for use or used as a fuel to operate a motor vehicle. $0.50 per gallon is available for the following alternative fuels: natural gas, liquefied hydrogen, propane, P-Series fuel, liquid fuel derived from coal through the Fischer-Tropsch process and compressed or liquefied gas derived from biomass.

9.5.6 US DOE ENERGY EFFICIENCY AND CONSERVATION BLOCK GRANT PROGRAM

This block grant program supports state and local public agencies in projects that reduce fossil fuel emissions and total energy use, improve energy efficiency, and create and retain jobs.

Prior program funding has been focused on projects that are shovel ready or could break ground in less than two years. Transportation projects accounted for 4.3% of prior funding and building and facilities accounted for 9.7%. BCRTA's new Oxford facility is already funded; no short term projects other than alternative fuel vehicle/ZEB purchases, are underway at BCRTA.

Program formula funds are allocated to units of government including 68% to cities and counties and 28% to states.

9.5.7 US DOE UPGRADING OUR ELECTRIC GRID AND ENSURING RELIABILITY AND RESILIENCY PROGRAM

This program supports projects that demonstrate new and innovative approaches to enhance resilience and reliability of the electric grid. It offers $5 billion in competitive grants for states, Indian tribes, local governments, and public utilities. An additional $1 billion is available in this program for rural or remote areas.

9.5.8 US DOE SMART GRID INVESTMENT MATCHING GRANT PROGRAM

This matching grant program focuses on expanding eligible activities under the existing Smart Grid Investment Matching Grant Program to include activities that allow increased integration of renewable energy, storage, and mitigation of natural disasters to the electric grid. It allows grants for vehicle-to-grid storage and to support the reliability of electric grids to meet the increased demand from EV charging and electrification of appliances.

9.5.9 US DEPARTMENT OF THE TREASURY (USDT) NEW MARKETS TAX CREDIT (NMTC) PROGRAM

The NMTC program focuses on stimulating investment in low-income areas. Commercial real estate developers secure advantageous debt and equity terms for developments. It awards a 39% tax credit on invested capital to investors on qualified projects. Assuming a site is selected that meets the program criteria, BCRTA would likely need to partner with an eligible community development entity that could apply to the program.

9.5.10 USDT OPPORTUNITY ZONES

The Opportunity Zones Program is an economic development tool that allows people to invest in distressed areas. The program goal is to spur economic growth and job creation in low-income communities while providing tax benefits to investors.

BCRTA would not receive any direct benefit through opportunity zone tax incentives; however, this program could be used as a lever to attract a private entity to invest equity in the project since this entity would benefit from the tax incentives. The tax incentives apply to the private entity's capital gains on the investment, meaning the investment must be revenue-generating in order to receive the benefit. It may be difficult for BCRTA to identify a private entity interested in investing in a stand-alone maintenance facility. However, if the project were to incorporate a public-private partnership to construct, operate, and maintain solar panels on the bus canopies, that would be a qualified, revenue-generating investment (e.g., the revenue stream would come from selling the energy back to the grid).

9.5.11 OTHER FEDERAL FUNDING SOURCES SUMMARY

Table 9-3 summarizes the key characteristics and considerations of each funding sources evaluated in this section.

Table 9-4. Other Potential Federal Funding Sources Summary

USDOE or USDT Funding Program	Program Type	Eligibility			Funding Amount (FY 22 – FY 26)
		Alt Fuel Vehicle/ZEB Purchase	Vehicle Charging Infrastructure	Facility Capital Investments	
State Energy Program	Formula		✓		$1.0 B
Hydrogen Research and Development	Discretionary			✓	$ 19 B
Advanced Energy Manufacturing and Recycling Grant Program	Discretionary		✓		$ 1.5 B
Demonstration of Electric Vehicle Battery Second-Life Applications for Grid Services	Cooperative Agreement		✓		$ 400 M
Alternative Fuel Tax Credit	Discretionary				n/a
Energy Efficiency and Conservation Block Grant	Formula		✓		$ 550 M
Upgrading Our Electric Grid and Ensuring Reliability and Resiliency Program	Discretionary		✓		$ 11 B
Smart Grid Investment Matching Grant Program	Discretionary	✓	✓		$ 6 B
New Markets Tax Credit (NMTC)	Discretionary		✓	✓	$ 5 B
Opportunity Zones	Discretionary		✓	✓	n/a

9.6 STATE AND LOCAL PROGRAMS

The State of Ohio has a limited number of funding programs that are designed to facilitate transit agency transition to lower emission vehicles, alternative fuel vehicles, or ZEBs or have the potential to fund major infrastructure associated with clean technology vehicles.

9.6.1 DIESEL EMISSIONS REDUCTION GRANTS (DERG)

The Ohio Department of Transportation (ODOT) has enacted a Diesel Emission Reduction Grants (DERG) program to provide support with CMAQ funds to public transit systems serving Ohio counties. Grants are awarded by FHWA to ODOT for the early retirement and replacement of older diesel transit buses. Between $8 and 10 million is planned to be awarded annually from FY17 through FY23 for engine repowers and vehicle replacements.

To date, BCRTA or the City of Middletown have not been recipients of DERG funds.

9.6.2 MEDIUM- AND HEAVY-DUTY EMISSIONS REDUCTION GRANT

The Ohio Environmental Protection Agency (Ohio EPA) allocated $15 million in grants for the replacement or repower of eligible transit vehicles and equipment with Ohio's portion of the Volkswagen Environmental Mitigation Trust. Eligible buses include public transit buses with a Gross Vehicle Weight Rating (GVWR) greater than 14,001 pounds.

According to the Ohio EPA, nearly $8.6 million has been awarded to transit agencies as 2021, including $424,000 to BCRTA to replace four diesel buses with clean diesel buses. The program has funded replacement of diesel buses with ZEB as well, specifically in Akron, Columbus, Lake County, and Toledo.

9.6.3 TRANSPORTATION REVIEW ADVISORY COUNCIL (TRAC)

The Transportation Review Advisory Council (TRAC) was created in 1997 and approves funding for the development and construction of "Major New Capacity" projects across Ohio. These projects have greater than $12 million in costs and increase the capacity of a transportation facility or reduce congestion. While transit infrastructure and facilities are eligible for TRAC funding, recent awards have been concentrated in significant interchange modifications, bypasses, and general-purpose lane additions. A revamped or new bus garage equipped to handle ZEBs is technically eligible for consideration. Most program construction commitments from 2022 through 2025 range from approximately $10 million to $75 million.

9.6.4 LOCAL PROGRAMS

BCRTA is generally reliant on local funding sources to fund operations and maintenance and to provide match for federal programs that require a local share- and in some cases require substantial local share where competitive grant programs are involved.

APPENDIX: DETAILED RISK REGISTER

A detailed register of risks is listed by category, followed by a more specific description of the risk and identification of potential impact to the authorities and riders.

The rating of the risks is generally subjective but based on industry ZEB experience. The risks are first scored for impact, using a scale of 1-5, with 1 being least impactful and 5 the most impactful. Similarly, the risks are also scored on probability, using the same 1-5 scale.

The impact and probability scores are multiplied, resulting in an overall risk assessment. The total assessment ratings are categorized as follows:

Low	0-4
Moderate-Low	5-8
Moderate	9-12
Moderate-High	13-16
High	16-20

Table A-1. Battery Electric Bus (BEB) Risks and Potential Mitigation

Risk	Risk Description	Impact	Impact Level	Probability Level	Priority Level	Mitigation
Risk Category	What is the Risk?	Impact Description	Rate 1 (Low) to 5 (High)	Rate 1 (Low) to 5 (High)	Impact x Probability	Actions to Lower or Eliminate Impact or Probability
Vehicle Production and Supply Chain	High demand for BEBs may significantly slow production and delivery of BEBs and associated parts and infrastructure.	There are currently only four large BEB manufacturers approved to sell BEBs in the U.S.	4	4	16	Develop relatively standard specifications and minimize customization. Begin procurement process early. Include options for future bus purchases in contract.
Fire	Battery fire may occur and spread to surrounding materials and adjacent buses at Bus Operating Facility.	Loss of infrastructure; high replacement cost; long lead time to replace buses; additional high cost.	5	2	10	Prepare fire safety plan. Install fire detection thermal cameras. Provide large volume of water flow for fire extinguishing. Allow for additional space between parked buses. Consider firewalls.
Industry Experience / Standardization	Relative newness of BEB technology and ongoing improvements may render components or buses obsolete.	Parts may no longer be produced and available, resulting in unused assets, service issues, and higher agency capital costs for fleet and parts replacement.	4	4	16	Coordinate with transit industry organizations and other agencies on encouraging standard specifications. Include contractual provisions to ensure manufacturer liability for outdated technology and lack of replacement parts and servicing.
Electronic Abuse	Battery failure and fire.	Formation of lithium at the anode and delithiation of the cathode causes structural collapse and causes growth of dendrites which penetrate the separator short circuiting and causing thermal runaway and ignition.	5	1	5	Use battery chargers with fail-proof systems to avoid overcharge and provide a margin for error within that system. Incorporate a software management system for the battery to avoid over-discharge.
Coolant Leak	A loss of cooling liquid causes arcing, heating the cells and causing thermal runaway.	Battery pack can ignite and cause surrounding packs in a storage system to catch fire.	4	1	4	Incorporate multiple alarm systems to identify and notify of a coolant leak. Create more rigorous installation procedures with more detailed

Risk	Risk Description	Impact	Impact Level	Probability Level	Priority Level	Mitigation
Risk Category	What is the Risk?	Impact Description	Rate 1 (Low) to 5 (High)	Rate 1 (Low) to 5 (High)	Impact x Probability	Actions to Lower or Eliminate Impact or Probability
						verification checks for correct installation.
Crash	Crashes put mechanical strain on the batteries; cells can come lose from the vehicle and spread around the crash site.	The battery can combust and leak; cells can come lose and spray across the roadway; it may be difficult for responders to handle, risking harm.	4	3	12	Seek to include auto crash avoidance systems in vehicle specifications. Use fireproof materials to reduce potential of the entire vehicle igniting.
Cyber Security	Subject to cyber attacks.	When attacked, monitors can be manipulated and can ultimately cause a thermal runaway event and potentially lose power to essential systems.	5	2	10	Use state of the art software to ensure security and cyber protection from potential hacks. Minimize all external connections to minimize pathways for cyber attacks.
Monitoring System Failure	Monitoring system transmitting telemetry data can fail on a mechanical or software platform.	Fail safes can fail and because the battery is unable to be monitored; issues can arise such as thermal runaway.	4	2	8	Have multiple monitoring systems that cannot be switched off so that if one fails, the other should still be running. Incorporate an alarm system to notify that a monitoring system has failed.
First Responder Harm	First responders to a battery-related combustion incident may be at the risk of harm when subject to a volatile and dangerous environment.	First responders can be harmed from unexpected combustions and irregular fire trends when a lithium-ion cell fails.	5	3	15	Create a training protocol on how to responders should handle failed, combusted, or compromised batteries. Use containment units to contain compromised batteries to be transported.
Harmful Mining Labor Impacts	Use of lithium batteries propagates the unregulated mining of materials in developing countries.	Causes mines to put workers into inhumane working conditions and use child labor.	4	5	20	Support regulations on manufacturing companies, restricting them to involvement with certified mines only. Support mining certification initiatives to regulate mines and improve worker environments.

Risk	Risk Description	Impact	Impact Level	Probability Level	Priority Level	Mitigation
Risk Category	**What is the Risk?**	**Impact Description**	**Rate 1 (Low) to 5 (High)**	**Rate 1 (Low) to 5 (High)**	**Impact x Probability**	**Actions to Lower or Eliminate Impact or Probability**
Harmful Mining Environmental Impacts	Use of lithium-ion batteries propagates the unregulated mining of materials in developing countries	Causes mines to pollute local water sources through poor mining and washing techniques.	4	5	20	Support regulations on manufacturing companies to restrict them to engage with certified mines only. Support mining certification initiatives to regulate mines in their processing of materials to reduce impact on surrounding environment.
Manufacturing Pollutants	Unregulated manufacturing plants often release harmful organic electrolytes and requires high energy consumption	Pollutants enter the air and harm surrounding wildlife, contaminates water sources, and harms human health.	4	5	20	Support strict regulations for manufacturing, strongly limiting emissions, energy sources for production lines, and capturing pollutants before they can enter the surrounding environment and be safely disposed of. Purchase from manufacturers that adhere to these regulations.
Increase in Insurance Rates	Insurers may increase rates due to the publicity on the volatility of batteries.	Could increase operating costs through higher premiums.	2	1	2	Help educate insurers prior to BEB acquisition. Support regulations on insurers to cap battery-related premiums.
Power Outage	The increasing frequency of severe weather, such as flooding, high winds, and severe lightning, poses a threat to maintaining power supply.	Facilities could lose power, disrupting the ability to charge buses and deploy service.	4	5	20	Consider having backup power sources such as a generators, solar and storage, and a battery electric storage system (BESS) to prepare for potential power failure. Work with other local entities with BEB fleets to allow use as a secondary charging site.

Risk	Risk Description	Impact	Impact Level	Probability Level	Priority Level	Mitigation
Risk Category	**What is the Risk?**	**Impact Description**	**Rate 1 (Low) to 5 (High)**	**Rate 1 (Low) to 5 (High)**	**Impact x Probability**	**Actions to Lower or Eliminate Impact or Probability**
Agency Staff Training	Charging, maintaining, and operating BEBs requires significant and on-going training , resulting in increased costs; agency reliance on manufacturer for training may cause delays and erosion of quality of training; employee turnover can also impact training costs and effectiveness.	Training fatigue or insufficient training may cause accidents cause personal and property damage and agency liability.	4	2	8	Include initial staff training and regularly scheduled follow-up training in contract with manufacturers. Obtain in-house training and develop expertise to conduct in-house training.
Local Emergency Response	Local fire and emergency personnel may not be familiar with and/or adequately training in safety and hazard mitigation procedures.	Unnecessary damage may occur.	4	3	12	Work with local fire and other emergency services on Bus Operating Facility layout and equipment, BEB composition (including battery location within bus), training requirements and response protocols.
Manufacturer Warranties / Responsiveness	Manufacturer assistance or warranty services may be delayed.	Vehicle or charging infrastructure performs below contract requirements, causing equipment and service unreliability.	5	4	20	Include strong warranty language and non-performance penalties in contracts.
Opportunity Chargers	Preferred site may have inadequate power access or neighborhood opposition.	Property must be obtained to accommodate charger, transformers, and pullout.	3	3	9	Locate opportunity chargers only at high transit volume, end-of-line locations. Works with local utility to determine additional power/transformer needs. Located sites away from residential areas.

Table A-2. Fuel Cell Electric Bus FCEB Risks and Potential Mitigation

Risk	Risk Description	Impact	Impact Level	Probability Level	Priority Level	Mitigation
Risk Category	**What is the Risk?**	**Impact Description**	**Rate 1 (Low) to 5 (High)**	**Rate 1 (Low) to 5 (High)**	**Impact x Probability**	**Actions to Lower or Eliminate Impact or Probability**
Industry Experience / Standardization	Relative newness of FCEB technology, limited industry experience to date, and ongoing improvements may result in unachieved performance levels and render components or buses obsolete.	Parts may no longer be produced and available, resulting in unused assets, service issues, and higher agency capital costs for fleet and parts replacement.	4	5	20	Allow other agencies to produce greater industry experience on which to weigh possibility of FCEB utilization.
Vehicle Production and Supply Chain	High demand may significantly slow production and delivery of FCEBs and associated parts and infrastructure.	There is currently a limited number of large FCEB manufacturers approved to sell FCEBs in the U.S.	4	4	16	Develop relatively standard specifications and minimize customization. Begin procurement process early. Include options for future bus purchases in contract.
Leakage	Equipment may fail and result in hydrogen leaks creating a potential fire hazard.	Loss of infrastructure; high replacement cost; long lead time to replace buses; additional high cost.	5	1	5	Install leak sensors/detectors. Include emergency stop features in fueling equipment. Provide adequate ventilation in storage and maintenance areas.
Explosion and Fire	Hydrogen is highly flammable; static electricity can cause sparks.	Loss of infrastructure; high replacement cost; long lead time to replace buses; additional high cost.	5	1	5	Include earthing cable to prevent sparks.
Fueling Infrastructure	Limitation on adequate and safe location of fueling facilities may restrict the ability to convert 100% of the fleet to FCEB, resulting in a mixed fleet.	May preclude 100% conversion to FCEB; mixed fleet requires additional fueling, charging facilities, a mixed bus fleet, larger parts inventory, and increased staff training.	4	4	16	Conduct a more in-depth analysis of the advantages and disadvantages of mixed ZEB fleets. Consider space and design requirements for FCEB fueling in siting and design of renovated or new Bus Operating Facilities.

Risk	Risk Description	Impact	Impact Level	Probability Level	Priority Level	Mitigation
Risk Category	**What is the Risk?**	**Impact Description**	**Rate 1 (Low) to 5 (High)**	**Rate 1 (Low) to 5 (High)**	**Impact x Probability**	**Actions to Lower or Eliminate Impact or Probability**
Power Outage	The increasing frequency of severe weather, such as flooding, high winds, and severe lightning, poses a threat to maintaining power supply.	Facilities could lose power, disrupting the ability to fuel buses and deploy service.	4	5	20	Consider having backup power sources such as a generators, solar and storage, and a battery electric storage system (BESS) to prepare for potential power failure.
Hydrogen Delivery	Equipment malfunction or force majeure at production facility interrupts hydrogen deliveries. Limited number of suppliers in area.	Disruption of service.	4	1	4	Provide for 7 days of hydrogen storage on-site (compared with industry standard of 3 days). Work with other users/potential users of hydrogen to help encourage supplier expansion.
Pipelines	Pipeline availability may be limited and subject to strict regulation, delaying or precluding direct service to a Bus Operating Facility.	Requires trucking in hydrogen, dependency on limited suppliers, and potential price volatility.	4	2	8	Use delivered hydrogen. Work with industry and supplier organizations to facilitate pipeline capacity.
Increase in Insurance Rates	Insurers may increase rates due to the publicity on the volatility of hydrogens.	Could increase operating costs through higher premiums.	2	1	2	Help educate insurers prior to FCEB acquisition. Support regulations on insurers to cap hydrogen-related premiums.
Agency Staff Training	Charging, maintaining, and operating FCEBs requires significant and on-going training , resulting in increased costs; agency reliance on manufacturer for training may cause delays and erosion of quality of training; employee turnover can also impact training costs and effectiveness.	Training fatigue or insufficient training may cause accidents cause personal and property damage and agency liability.	4	3	12	Include initial staff training and regularly scheduled follow-up training in contract with manufacturers. Obtain in-house training and develop expertise to conduct in-house training.
Local Emergency Response	Local fire and emergency personnel may not be familiar with and/or adequately	Avoidable damage may occur.	4	3	12	Work with local fire and other emergency services to on training requirements and response protocols.

Risk	Risk Description	Impact	Impact Level	Probability Level	Priority Level	Mitigation
Risk Category	What is the Risk?	Impact Description	Rate 1 (Low) to 5 (High)	Rate 1 (Low) to 5 (High)	Impact x Probability	Actions to Lower or Eliminate Impact or Probability
	training in safety and hazard mitigation procedures.					
Manufacturer Warranties / Responsiveness	Manufacturer assistance or warranty services may be delayed.	Vehicle or charging infrastructure performs below contract requirements, causing equipment and service unreliability.	5	4	20	Include strong warranty language and non-performance penalties in contracts.

Table A-3: Diesel/Diesel-Electric Hybrid Bus Risks and Potential Mitigation

Risk	Risk Description	Impact	Impact Level	Probability Level	Priority Level	Mitigation
Risk Category	**What is the Risk?**	**Impact Description**	**Rate 1 (Low) to 5 (High)**	**Rate 1 (Low) to 5 (High)**	**Impact x Probability**	**Actions to Lower or Eliminate Impact or Probability**
Carbon Emissions	Contribution to climate change.	Minimal impact on operations and costs.	1	5	5	Replace diesel buses with diesel-electric hybrids.
Refinery Capacity	Nationwide shift to cleaner and renewable energy may result in fewer refineries and capacity.	Limitations on fuel supply and ability to operate scheduled service. May require additional storage capacity on site	5	2	10	Stockpile fuel.
Pipeline Capacity	Nationwide shift to cleaner and renewable energy along with increased environmental regulations and government policy may reduce capacity.	Limitations on fuel supply and ability to operate scheduled service. May require additional storage capacity on site	5	2	10	Stockpile fuel.
Price Volatility	Price swings due to infrastructure issues, weather, international conditions, etc.	Increased operating costs and potential fuel scarcity. Inability to budget for subsequent years.	4	5	20	Lock in future year price in fuel purchase contracts.
Carbon Reduction Targets	Erosion of public and government support for the agency. Public relations issues.	Loss of local, regional, or state funding for bus purchase and operations.	5	3	15	None.
Government Policy and Incentives	Reduced funding for diesel buses.	Long term reduction of service.	5	4	20	None.
Vehicle Availability	Shift by manufacturers to ZEB production may reduce ability to replace buses or expand fleet.	Long term reduction of service.	5	4	20	Maintain reserve fleet in good operating condition.