Zero-Emission Bus Transition Plan

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Executive Summary

The Spokane Transit Authority (STA) contracted the Center for Transportation and the Environment (CTE) to revise the previously prepared *Analysis of Alternatives for Fleet Conversion to Zero-Emission Technologies* to evaluate transitioning STA's fixed-route service to zero-emission technology. The original study was completed to understand the transition lifecycle costs required to achieve a zero-emission fleet, including evaluation of the total cost of ownership as well as help STA understand the challenge and manage the constraints associated with a full-fleet transition to zero-emission buses (ZEBs). The analysis considered both operational and financial impacts of ZEB technologies that were considered commercially available during the time period of the study (through 2040). In late 2022, STA contracted CTE to revise the ZEB study assumptions that may have changed over the last three years based on improvements in technology, changes to costs, changes to STA service, etc. and update the analysis. Results from this revised analysis are included in this *Zero Emission Bus Transition Plan*. In addition, the plan includes elements required by the FTA to be eligible to apply for federal funding.

Zero-emission technologies considered include both battery electric buses (BEBs) and hydrogen fuel cell-electric buses (FCEBs). BEBs and FCEBs have similar electric drive systems that feature a traction motor powered by a battery. The primary difference between BEBs and FCEBs, however, is the amount of battery storage and how the batteries are recharged. The energy supply in a BEB comes from electricity provided by an external source, typically the local utility grid, which is used to recharge the batteries. The energy supply for an FCEB is completely on-board, where hydrogen is converted to electricity using a fuel cell. The electricity from the fuel cell is used to recharge the batteries.

CTE worked closely with STA staff throughout the analyses to develop the approach, define the assumptions, and confirm the results. The approach for this plan is based on the creation and analysis of four transition scenarios. The baseline utilizes STA's updated procurement plan (May 2024) while the goal of the other fleet transition scenarios was to approach a 100% zero-emission bus fleet by 2045.

- Baseline: Current Technology – Utilizes existing planned procurements of ZEBs (40 by the end of 2023). All other replacements moving forward assumed to be diesel for comparison except for planned BEB Bus Rapid Transit (BRT) service (2030).
- Scenario 1: Depot Charged BEBs Only – Mixed fleet of BEBs and Internal Combustion Engine (ICE) based on block feasibility.
- Scenario 2: Depot Charged BEBs and FCEBs – Mixed fleet of BEBs and FCEBs based on block feasibility.
- Scenario 3: FCEBs Replacements Only (Original BEBs) – All BEBs in original Baseline will remain BEB; all others replaced with FCEBs.

The Baseline scenario assumes that no change is made from currently planned technologies and procurements. The Baseline scenario is used to compare the incremental costs of deploying ZEBs in the other scenarios. Each scenario uses a set of assumptions for improvements in battery storage capacity and efficiency, ultimately yielding improvements in bus range. In addition, the scenarios incorporate the current fleet procurement schedule as of May 2024, the planned phasing-out of diesel-hybrid vehicles, and BEB deployments for Central City Line (CCL) and Monroe Regal Line (MRL) regardless of other vehicle technologies employed.

The underlying basis for the assessment is CTE's ZEB Transition Planning Methodology, including route, charge and rate modeling. This methodology allows CTE to assess energy efficiency and energy consumption. This information can then be used to project the range of given vehicle technologies. CTE previously collected data from seventeen (17) STA routes, including the proposed CCL and MRL alignments and used bus specifications for vehicles that STA was considering purchasing to estimate range and energy consumption for all of STA's routes and blocks. Nominal and strenuous range at beginning-of-life and end-of-life batteries were developed. In 2023, CTE utilized the existing modeling results from 2020 and data collected during initial BEB deployments to update the analyses.

Once estimates for vehicle efficiency, range, and energy consumption were established, CTE completed the following assessments to develop cost estimates for each transition scenario.

1. Service Assessment
2. Fleet Assessment
3. Maintenance Assessment
4. Charging Analysis
5. Fuel Assessment
6. Facilities Assessment
7. Emissions Assessment

These assessment results yield a total cost of ownership for each transition scenario over the transition period (2024 – 2045). The total cost of ownership for all scenarios is summarized in the table and figure below.

Table E1: Total Cost of Ownership for ZEB Transition (2024-2045)

Category	Baseline	BEB Depot Only	Depot BEB and FCEB	FCEB Replacements Only
Fleet	$239.9M	$430.8M	$437.3M	$482.2M
Maintenance	$256.5M	$254.9M	$254.6M	$197.8M
Fuel	$100.9M	$74.9M	$75.1M	$162M
Infrastructure	$4.9M	$24.7M	$32.7M	$17.9M
Total	**$602.2M**	**$785.3M**	**$799.7M**	**$859.9M**
Compared to Baseline	-	$183.1M	$197.5M	$257.7M
% ZEB Fleet	33%	97%	100%	100%

Section 1 - Introduction

Founded in 1980, the Spokane Transit Authority (STA) provides transit services to the city of Spokane, Washington and surrounding urban areas, serving a population of approximately 499,000 across 248 square miles. The agency provides services across multiple transportation formats, including fixed-route bus service, paratransit, and vanpool. The fixed-route bus service currently consists of approximately 52 routes served by a fleet of 160 buses of various lengths and configurations (not including contingency vehicles).

In 2019, STA contracted the Center for Transportation and the Environment (CTE) to conduct a study to evaluate transitioning STA's fixed-route service to zero-emission technology. The study also included a detailed evaluation of two specific planned service expansions/modification, the Central City Line (CCL) and Monroe-Regal Line (MRL). The CCL was being developed as a 6-mile, all-electric, Bus Rapid Transit (BRT) service that will operate from Browne's Addition and Spokane Community College (SCC) through Downtown Spokane and the University District. The project was awarded $53.4 million in Small Starts Grant funding from the U.S. Department of Transportation Federal Transit Administration (FTA). The service was originally scheduled to begin in May 2022 but actually began service on July 15, 2023 under the name "City Line" due to construction delays. The detailed CCL analysis is included in the *Central City Line Zero-Emission Bus Deployment Implementation Plan* (CTE, May 2019) with updates to the charging analysis included in this report.

The MRL is an 11.4-mile service that operates from STA's Five Mile Park & Ride to the Moran Station, a new facility constructed as part of the project. Service started in late 2019 and is currently operating with up to four BEBs with plans to extend service to BEB only. Detailed MRL analysis is included in the *Monroe-Regal Line Zero-Emission Bus Deployment Implementation Plan* (CTE, July 2019) with updates to the charging analysis included in this report.

The initial transition study was completed to understand the transition lifecycle costs required to achieve a zero-emission fleet, including evaluation of the total cost of ownership as well as help STA understand the challenge and manage the constraints associated with a full-fleet transition to zero-emission buses (ZEBs). The analysis considered both operational and financial impacts of ZEB technologies that were considered commercially available during the time period of the study. In late 2022, STA contracted CTE to update the ZEB study assumptions that may have changed over the last three years based on improvements in technology, changes to costs, changes to STA service and plans, etc. and revise the analysis. In addition, STA requested that the revised analysis incorporate the 2024 vehicle replacement schedule. Results from this revised analysis are included in this *Zero Emission Bus Transition Plan*. In addition, the plan includes elements for a ZEB transition study required by the FTA to be eligible for federal funding programs.

Zero-emission technologies considered in this evaluation included both BEBs and hydrogen fuel cell-electric buses (FCEBs). BEBs and FCEBs have similar electric drive systems that feature a traction motor powered by a battery. The primary difference between BEBs and FCEBs, however, is the amount of battery storage and how the batteries are recharged. The energy supply in a BEB comes from electricity provided by an external source, typically the local utility grid, which is used to recharge the batteries. The energy supply for an FCEB is completely on-board, where hydrogen is converted to electricity using a fuel cell. The electricity from the fuel cell is used to recharge the batteries. Illustrated below is the electric drive components and energy source for a BEB and FCEB.

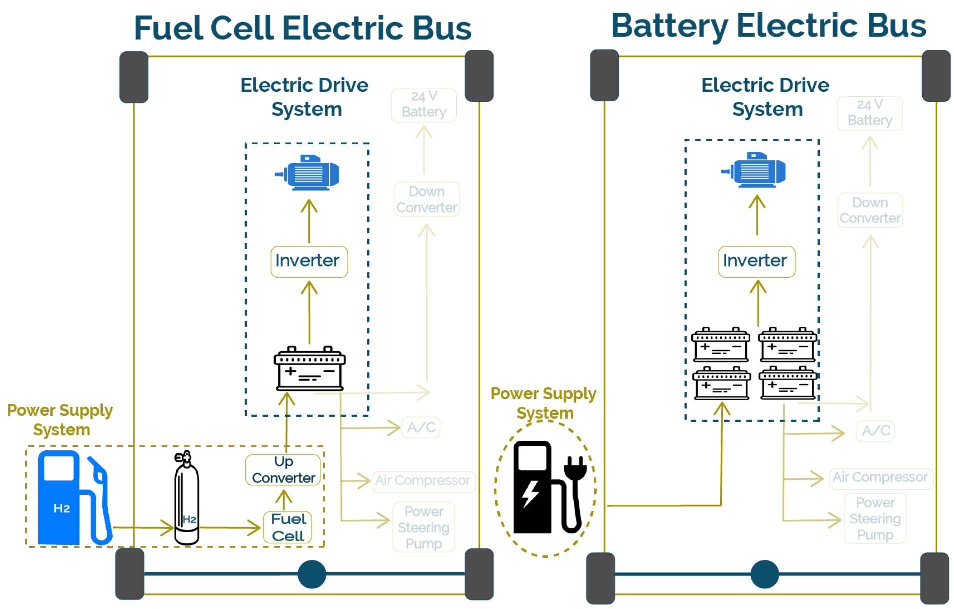


Figure 1: Schematic of ZEB Technologies

There are considerations and limitations associated with each technology. One of the primary limitations of BEBs is overall energy storage capacity. Although BEBs are approximately four times more efficient than diesel vehicles, the total amount of energy that can be stored on board without adding excessive weight is still considerably less than diesel. That means that using current technology, the overall BEB range on one charge is less than the range of a diesel vehicle on one tank of fuel. Range limitations can be mitigated by the use of the appropriate charging technologies and strategies, and this is a very important element in the planning for any BEB deployment, especially when considering a full fleet transition.

Furthermore, battery and charging technologies are changing at a rapid pace, hence the need to update the initial transition analysis. The trends toward higher battery energy densities and increasingly sophisticated software-based charge management methodologies are expected to improve the range of BEBs to levels more comparable with traditional diesel vehicles over time. New charging vendors continue to enter the marketplace, offering various charger configurations and charge rates that help agencies customize a charging strategy and reduce operational risk associated with BEB deployments. Regardless of which battery technology or chemistry is utilized, all high voltage vehicle batteries in the market today degrade over time. Therefore, the impact on performance over time and associated battery warranties should be reviewed to optimize operations and further reduce risk.

Finally, lifecycle costs of electricity and overall infrastructure represent significant investments. Charging an entire fleet of buses can require a substantial real estate footprint and associated upfront cost to purchase and install the required equipment, not to mention the appropriate training and ongoing operational requirements.

There are similar considerations in FCEB deployment in that the infrastructure footprint can be substantial and since battery technology is also utilized there are similar concerns with degradation and end-of-life performance. Current FCEBs do have a range that is longer than BEBs and more similar to traditional diesel or CNG buses, so theoretically there will be less operational risk due to fueling strategies when incorporating FCEBs into a fleet. However, both the upfront cost of FCEB vehicles and the cost of fuel are currently higher than with their BEB counterparts (hydrogen vs. electricity). Finally, there are still a limited number of demonstrations of FCEBs to learn from partly because BEB charging technology is easier to scale and deploy to small fleets (which has been a large part of BEB deployment activity to date).

The *Zero-Emission Bus Transition Plan* is arranged in the following sections:

- Section 1 – Introduction
- Section 2 – Policy Assessment
- Section 3 – Transition Planning Methodology
- Section 4 – Transition Scenarios and Assumptions
- Section 5 – Baseline Data
- Section 6 – Service Assessment
- Section 7 – Fleet Assessment
- Section 8 – Maintenance Assessment
- Section 9 – Charging Analysis
- Section 10 – Fuel Assessment
- Section 11 – Facilities Assessment
- Section 12 – Emissions Assessment
- Section 13 – Total Cost of Ownership
- Section 14 – Funding Needs Assessment
- Section 15 – Partnership Assessment
- Section 16 – Workforce Analysis
- Section 17 – Conclusions and Recommendations
- Section 18 – References

As discussed previously, the original ZEB analysis was initiated in 2019 and completed in 2020 and reflected the state of technology at the time that it was prepared. The analysis was updated to reflect the state of technology as of 2024 with the understanding that the transition to a full ZEB fleet is expected to take over 20 years to complete. As with the previous evaluation, CTE recommends that the plan be reviewed and updated periodically to reflect the latest state of technology development, costs, regulatory environment, service requirements, and supply chain to ensure that STA continues to meet their mission in the most effective and efficient way possible.

Section 2 - Policy Assessment

Policy Assessment Overview

Policies and regulations supporting the transition to zero-emission are proliferating as the efforts to decarbonize the transportation sector expand. STA is monitoring the implementation of relevant policies and legislation. While relevant funding programs are considered, policies and regulations that direct aspects of zero-emission transit deployments beyond funding are considered in this section. STA will thoroughly assess all relevant policies and legislation throughout the fleet transition.

Alignment with Federal Priorities and Policies

With the passage of the *Bipartisan Infrastructure Law* and *Executive Order 14008: Tackling the Climate Crisis at Home and Abroad*, the federal government has set a renewed focus on zero-emission transit. STA's goal to transition to 100% zero-emission supports the federal administration priorities of safety, modernization, climate, and equity for public transportation.

Washington Policies & Goals

In 2021, the Washington State legislature enacted two statutes intended to reduce greenhouse gas emissions by 95% by 2050. The Climate Commitment Act (CCA) caps and reduces greenhouse gas emissions from Washington's largest emitting sources and industries, allowing businesses to find the most efficient pat to lower carbon emissions. The CCA puts environmental justice and equity at the center of climate policy and will use funds from the auction of emission allowances for investment in climate-resilient infrastructure including clean transportation. The Clean Fuel Standards, approved by the legislature in 2021, and adopted in November 2022 (effective January 1, 2023) reduces annual transportation emissions statewide by 20% over the next 12 years. This equates to approximately 4.3 million metric tons of carbon dioxide removed, or permanently removing 900,000 cars from the road. The fate of the CCA is currently in question, as Initiative 2117 is an effort to repeal the CCA on the November 2024 ballot.

Finally, under the Zero-Emission Vehicle Standard (WAC 173-423-07, December 2022), the state of Washington adopted additional vehicle emission standards to increase the sale of new zero-emission vehicles including passenger cars, light-duty trucks, and medium-duty vehicles to 100% starting in 2035. This ruling requires the state of Washington to meet California vehicle emission standards for on-road vehicles over 8,500 GVWR.

Support for Local Policy Goals

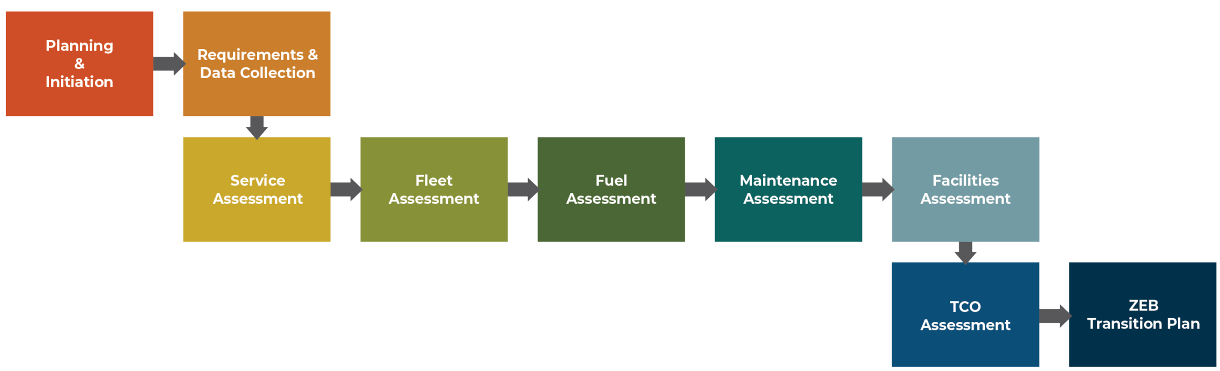
The City of Spokane approved a Sustainability Action Plan in October 2021. The Plan has three goals: 1) reduce GHG emissions by 95% (from 2016 levels) by 2050; build a community and economy that are resilient to climate change; and prioritize people who are most at risk of health and financial impacts. Previously in 2018, the City adopted a goal of 100% renewable electricity by 2030. This goal has been superseded by the State of Washington's passage of the Clean Energy Transformation Act in 2019 that now requires 100% clean energy by 2045.

Section 3 - Transition Planning Methodology

The initial evaluation completed in 2020 as well as these revision used CTE's Transition Planning Methodology, which is a complete set of analyses used to inform agencies in converting their fleets to zero-emission. The methodology consists of data collection, analysis and assessment stages; these stages are sequential and build upon findings in previous steps. Steps specific to this study are outlined below:

1. Planning and Initiation
2. Service Assessment
3. Fleet Assessment
4. Fuel Assessment
5. Maintenance Assessment
6. Facilities Assessment
7. Total Cost of Ownership Assessment

Figure 2: ZEB Transition Study Methodology



The **Planning and Initiation** phase builds the administrative framework for the transition study. During this phase, the project team drafted the scope, approach, tasks, assignments and timeline for the project. CTE worked with STA staff to plan the overall project scope and all deliverables throughout the full life of the study. During the kickoff meeting CTE met with stakeholders and collected updated route, block, fleet, operational, maintenance, and facilities information from STA staff to form the baseline scenario.

The **Service Assessment** phase initiated the data collection and technical analysis of the study. CTE met with STA to update the assumptions and requirements used throughout the study and to collect operational data (Requirements & Data Collection). CTE utilized results from the previously completed route modeling work as well as results from current BEB operations on STA blocks to update the service assessment. The results from the Service Assessment were used to guide ZEB procurements in the Fleet Assessment and determine energy requirements (Depot Charging, On-Route Charging and/or Hydrogen) in the Fuel Assessment. In the revised assessment, the outputs of the modeling were updated based on changes to battery capacity assumptions. A 5% improvement in battery capacity every two years, a usable capacity of 90% of the nameplate capacity, an End of Life (Warranty) capacity at 80% of usable capacity, and the 2020 route modeling efficiency results were used in the Service Assessment.

The **Fleet Assessment** analyzed the capabilities of the current ZEB technologies to meet STA's service requirements. The analysis projected the timeline for replacement of diesel and diesel-hybrid buses with BEBs and FCEBs consistent with STA's fleet replacement plan (updated as of May 2024). The Fleet Assessment also includes an assessment of projected fleet procurement costs over the transition lifetime. The assumed STA's fleet size would increase to a total of 170 vehicles (not including contingency vehicles) by 2030 and remain consistent at that level throughout the remainder of the transition period. The analysis assumed a 15 year vehicle life.

The **Fuel Assessment** analyzed annual fueling requirements and developed cost estimates based on the electrical rate structures (Schedule 23 EV Rate) provided by Avista, the local electrical utility, as well as estimates for hydrogen fuel costs. These costs were compared to the expected costs to refuel diesel (and diesel-hybrid) vehicles based on current and projected fuel costs.

The **Maintenance Assessment** analyzed labor and materials costs for maintenance over the transition period as well as major component replacements for each technology type.

The **Facilities Assessment** defined the requirements for charging and hydrogen fueling infrastructure including operational impact and utility service requirements. CTE developed estimates for equipment and infrastructure, design, construction, and installation costs, space and sitting requirements. CTE evaluated the requirements for upgrading STA's facilities to be compatible with hydrogen and determine the requirements for any hydrogen refueling stations needed to support the fleet. STA has reached maximum capacity of 40 BEBs at the Northwest Boone Garage based on electricity capacity constraints. As such, a new storage and maintenance facility for additional BEB charging or hydrogen fueling was assumed in the analysis (to be constructed by 2030).

The **Emissions Assessment** was prepared based on the transition analysis. The analysis was completed to estimate the emissions associated with the fleet assessment scenarios in terms of number of diesel gallons reduced, and carbon production, reduction, and net savings.

The **Total Cost of Ownership Assessment** summarizes the costs of annual bus procurements, operation and maintenance costs, and infrastructure and facility upgrades over the transition period.

Section 4 - Transition Scenarios and Assumptions

Transition Scenarios

The following scenarios were assumed for the updated transition assessment:

- Baseline: Current Technology – Utilizes existing planned procurements of ZEBs (40 by the end of 2023). All other replacements moving forward assumed to be diesel for comparison except for planned BEB BRT service (2030).
- Scenario 1: Depot Charged BEBs Only – Mixed fleet of BEBs and ICE based on block feasibility.
- Scenario 2: Depot Charged BEBs and FCEBs – Mixed fleet of BEBs and FCEBs based on block feasibility.
- Scenario 3: FCEBs Replacements Only (Original BEBs) – All BEBs in original Baseline will remain BEB; all others replaced with FCEBs.

Assumptions

Due to the inherent nature of varying conditions over the period of a long-term fleet transition, it is necessary to establish a number of simplifying assumptions in a study such as this. These assumptions were developed based on discussions between CTE and STA during the **Planning & Initiation** stage of this project and include the following:

- Transition to a 100% ZEB fleet by 2045, if possible
- STA will increase fleet size to 170 vehicles during the transition period; this is inclusive of new vehicles that will be purchased to support further service expansion but does not include contingency vehicles.
- Current fleet composition (as of the time of this study) used for the baseline scenario
- Currently planned procurement schedule (as of May 2024)
- 15-year bus lifespan assumed for future vehicles purchased
- Costs are expressed in terms of 2023 dollars with 3% escalation and ICE and ZEB bus costs are based on Washington State Procurement Contract (2023 updated costs)
- 5% improvement in battery technology every two years
- Usable capacity estimated at 90% of nameplate capacity. End of Life (warranty) estimated at 80% of usable capacity.
- Estimated maximum range of 350 miles for FCEBs

Other operational assumptions associated with the current fleet replacement schedule and vehicle technology include the following:

- STA will not purchase any additional diesel-hybrid vehicles
- Current battery sizes for BEBs and fuel tank sizes for FCEBs are based on existing specification for vehicles that have completed Altoona Testing
- A 5% improvement in battery (for BEB) and fuel tank (for FCEB) capacity every two years
- A battery replacement will occur at the mid-life (7.5 years) of each BEB

Current BEB technologies have range limitations relative to diesel vehicles, and as a result, it is not always possible to replace an agency's current fleet one to one using BEBs. Improvements are expected to be made over time, but there are significant challenges to overcome, and the timeline to achieve the goal is uncertain. In addition to the uncertainty of technology improvements, there are other risks to consider. Although current BEB range limitations may be remedied over time as a result of advancements in battery energy density and more efficient components, battery degradation may re-introduce range limitations as a risk to an all-BEB fleet over time. In emergency scenarios that require use of BEBs, agencies may face challenges supporting long-range evacuations and providing temporary shelters in support of fire and police operations. Furthermore, fleetwide energy service requirements and power redundancy and resiliency may be difficult to achieve at any given depot in an all-BEB scenario. Higher capital equipment costs and availability of hydrogen may constrain FCEB solutions.

Section 5 - Baseline Data

It is essential to understand the key elements of STA's service to evaluate the costs associated with a full-ZEB transition. Key data elements of the existing STA service was provided by STA staff and include the following:

- Fleet composition
- Routes and blocks
- Mileage and fuel consumption
- Maintenance costs

Fleet

At the time of the updated evaluation, STA's bus fleet consists of 160 vehicles of various lengths and fuel types that provide service for 40 fixed-routes, with tracked data for 25 additional trip destinations. The number of vehicles is based on the vehicles that will be in the fleet at the end of 2024. The following table provides a breakdown of the existing fleet vehicles by length and fuel type.

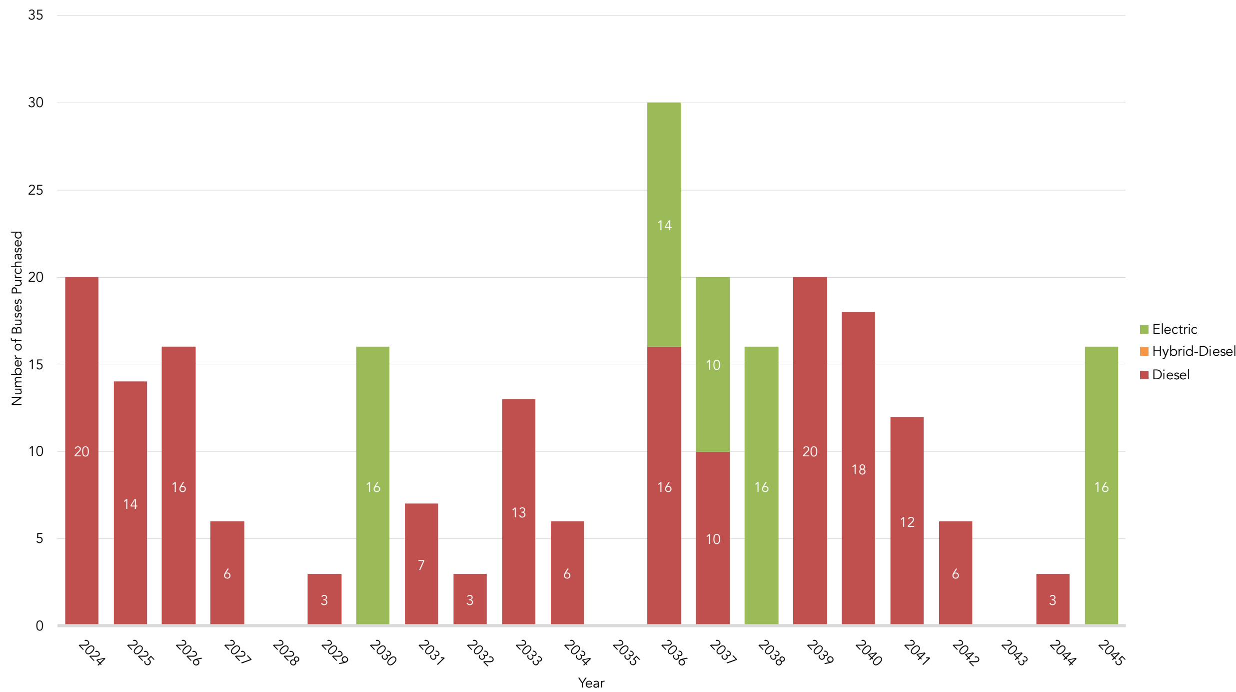
Table 1: Bus Quantity by Length and Fuel Type – 2024

Vehicle Length	Diesel	Diesel Hybrid	Battery Electric	Fleet Total
30'	—	3	—	3
35'	—	—	3	3
40'	82	21	23	126
60'	14	—	14	28
TOTAL	***96***	***24***	***40***	***160***

All service operates out of the Main Garage, located at 1229 West Boone Avenue, or the newly constructed Northwest Boone Garage, located immediately across West Boone Avenue from the Main Garage. Although they are separate buildings, due to their proximity they are considered the same destination for route modeling and energy evaluation purposes.

STA's goal is to maintain buses for 15 years before retirement. **Figure 3** depicts the annual bus replacement schedule (as of May 2024) throughout the transition period, regardless of scenario or technology type.

Figure 3*: *Bus Replacement Schedule



Routes and Blocks

STA's fixed-route bus service in the summer consists of approximately 52 routes run on 171 blocks served by a fleet of 160 buses of various lengths and configurations. During the school year there are additional blocks that operate service (school trippers); however, these additional blocks are typically short.

Fuel

STA's current fuel use was collected and used to estimate energy costs throughout the study life. Cost escalation was not assumed throughout the study. When vehicles are added to the fleet, all vehicles of the same length that are acquired in that year to replace retiring vehicles are assumed to operate the average annual mileage of that vehicle size and, for diesels, are assumed to consume the same amount of fuel as other vehicles of the same length and fuel type. According to STA, the average heavy-duty bus operates between 50,000 and 55,000 miles per year. Historical fuel economy information for the fleet are included in **Table 2**.

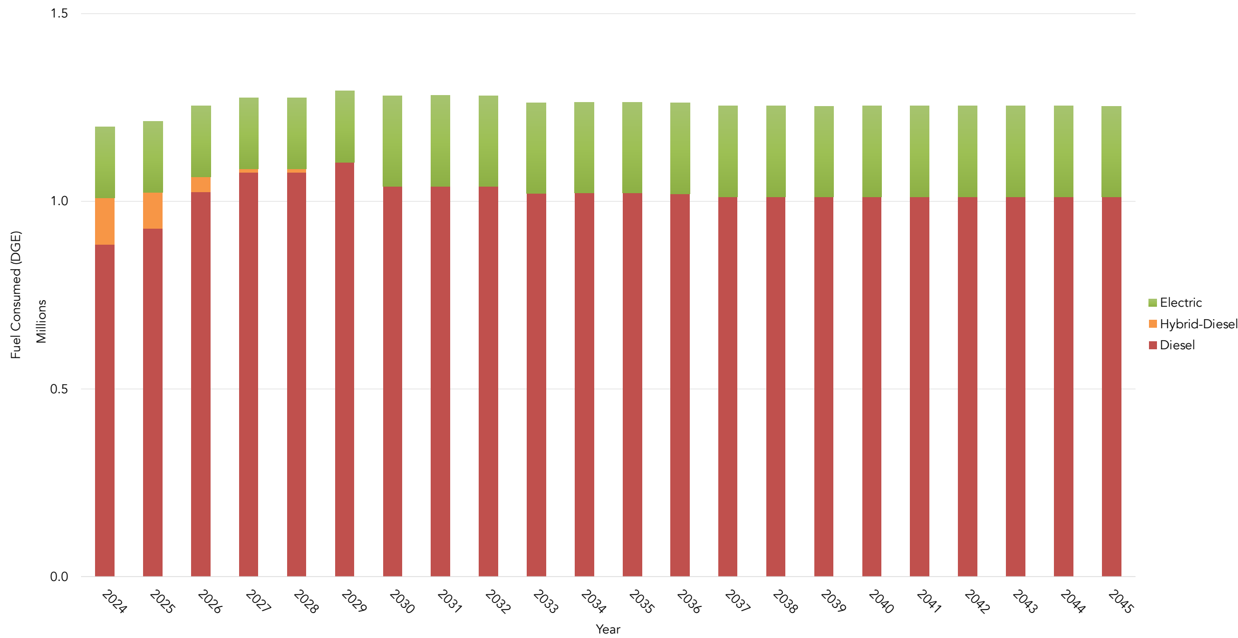
Table 2: Fuel Economy by Bus Length and Fuel Type

Vehicle Length	Diesel (mpg)	Diesel-Hybrid (mpg)	BEB (kwh/mi)
40'	5.7	6.3	—
60'	3.3	—	—

mpg = miles per gallon
mpgdge = miles per gallon diesel gallon
kWh/mi = kilowatt-hour per mile

Annual fuel use by fuel type was calculated to form the baseline scenario. **Figure 4** below shows the estimated annual fuel use by fuel type across the transition period, based on STA's currently planned procurement schedule.

Figure 4: Annual Fuel Use by Fuel Type (DGE)



Maintenance

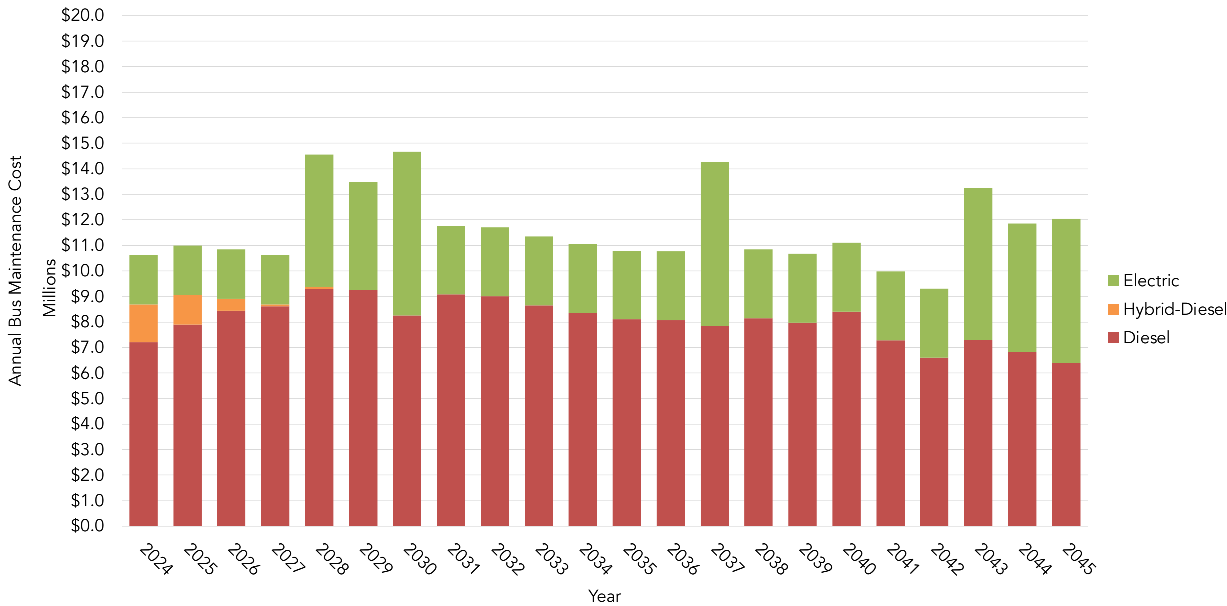
Historical maintenance costs are used to project future maintenance costs for all legacy fuel types. The average maintenance cost per mile for the fleet of $1.43/mile was provided by STA. It should be noted that the average maintenance costs per mile are affected by the age of the vehicle or fleet, as older fleets typically experience higher maintenance costs per mile. The average midlife overhaul cost for the current diesel vehicles was determined to be approximately $43,000 ($29,000 for an engine rebuild and $14,000 for a transmission rebuild).

Total fleet maintenance cost throughout the transition period were estimated at $257 million with an average annual cost of approximately $12 million. **Table 3** below shows the annual fleet maintenance cost by fuel type and **Figure 5** shows the baseline fleet maintenance cost across the transition period.

Table 3: Annual Fleet Maintenance Cost (Baseline)

Fuel Type	2024-2045 Total	Average Annual
Diesel	$177M	$8.4M
Hybrid-Diesel	$3M	$156K
Battery Electric	$76M	$3.6M

Figure 5: Baseline Fleet Maintenance Cost



Section 6 - Service Assessment

Bus efficiency and range are primarily driven by vehicle specifications; however, it can be impacted by a number of variables including the route profile (i.e., distance, dwell time, acceleration, sustained top speed over distance, average speed, traffic conditions, etc.), topography (i.e., grades), climate (i.e., temperature), driver behavior, and operational conditions such as passenger loads and auxiliary loads. As such, BEB efficiency and range can vary dramatically from one agency to another. Therefore, it is critical to determine efficiency and range estimates that are based on an accurate representation of the operating conditions associated with STA's system to complete the assessment.

The first task in the Service Assessment was to develop route and bus models to run operating simulations for representative STA routes. CTE uses Autonomie, a powertrain simulation software program developed by Argonne National Labs for the heavy-duty trucking and automotive industry. CTE has modified software parameters specifically for electric buses to assess energy efficiencies, energy consumption, and range projections. CTE collected GPS data from seventeen (17) STA routes, including the proposed CCL and MRL routes. GPS data includes time, distance, vehicle speed, vehicle acceleration, GPS coordinates, and roadway grade that is used to develop the route model. CTE used component level specifications and the collected route data to develop a baseline performance model by simulating the operation of an electric bus on each route. The route modeling included analysis of several scenarios, varying passenger load, accessory load, and battery degradation, to estimate real-world vehicle performance, fuel efficiency, and range.

Ideally it would be best to collect data and model every route in STA's network; however, this is impractical due to the amount of time and labor this approach would require. Instead, a sampling approach is used where sample routes are identified with respect to topography and operating profile (e.g. average speeds, etc.). The modeling results of the sample routes are then applied to the routes and blocks that share the same characteristics.

The data from the routes, as well as the specifications for each of the bus types selected, was used to simulate operation of each type of bus on each type of route. The models were run with varying loads to represent "nominal" and "strenuous" loading conditions. Nominal loading conditions assume average passenger loads and moderate temperature over the course of the day, which places marginal demands on the motor and heating, ventilation, and air conditions (HVAC) system. Strenuous loading conditions assume high or maximum passenger loading and either very low or very high temperature (based on agency's latitude) that requires near maximum output of the HVAC system. This Nominal/Strenuous approach offers a range of operating efficiencies to use in estimating average annual energy use (Nominal) or planning minimum service demands (Strenuous). Details for the modeled operating scenarios are included in **Table 4** below.

Table 4: Modeling Operating Scenarios

Vehicle Length	Condition	Occupants	Average HVAC Load	Average Other Accessory Load	Total Average Accessory Load
35'	Nominal	17 + Operator	3.8 kW	2 kW	5.8 kW
35'	Strenuous	28 + Operator	10.45 kW	2 kW	12.45 kW
35' Low Occupancy	Nominal	9 + Operator	3.8 kW	2 kW	5.8 kW
35' Low Occupancy	Strenuous	16 + Operator	10.45 kW	2 kW	12.45 kW
40'	Nominal	18 + Operator	4 kW	2 kW	6 kW
40'	Strenuous	30 + Operator	11 kW	2 kW	13 kW
40' Low Occupancy	Nominal	9 + Operator	4 kW	2 kW	6 kW
40' Low Occupancy	Strenuous	18 + Operator	11 kW	2 kW	13 kW
60'	Nominal	19 + Operator	7.2 kW	3 kW	10.2 kW
60'	Strenuous	34 + Operator	19.8 kW	3 kW	22.8 kW

Estimated efficiencies developed based on modeling are provided in **Table 5**, **6**, and **7**.

Table 5**: **Modeling Results Summary for 35-foot BEBs

Route	Profile	Length (mi)	Duration (h:mm)	Efficiency (kWh/mi)	
				Nominal	Strenuous
21	Flat, Slow	5.8	0:36	1.7	2.5
24	Hills, Slow	9.5	0:58	2.4	3.2
39	Flat, Slow	10.5	0:57	2.0	2.7
64	Hills, Fast	39.4	1:56	2.0	2.4
90	Flat, Slow	15.5	1:16	1.8	2.4
97	Hills, Slow	19.2	2:01	1.8	2.2
98	Flat, Slow	19.3	1:14	1.8	2.3
			Average	***1.9***	***2.5***

Table 6*: *Modeling Results Summary for 40-foot BEBs

Route	Profile	Length (mi)	Duration (h:mm)	Efficiency (kWh/mi)	
				Nominal	Strenuous
20	Hills, Slow	8.0	0:24	1.6	2.1
21	Flat, Slow	5.8	0:36	1.7	2.5
24	Hills, Slow	9.5	0:58	2.3	3.2
25	Hills, Slow	17.9	1:31	2.2	2.9
33	Hills, Slow	16.9	0:54	1.8	2.6
34	Hills, Slow	11.9	0:57	2.0	2.7
39	Flat, Slow	10.5	0:57	2.0	2.8
44	Hills, Slow	8.3	0:37	1.9	2.6
45	Hills, Slow	13.9	1:11	2.1	2.8
64	Hills, Fast	39.4	1:56	2.1	2.5
66	Hills, Fast	33.0	1:04	2.1	2.4
74	Flat, Fast	35.4	1:19	2.2	2.6
90	Flat, Slow	15.5	1:16	1.8	2.5
97	Hills, Slow	19.2	2:01	1.8	2.2
98	Flat, Slow	19.3	1:14	1.8	2.3
			Average	***2.0***	***2.6***

Table 7: Modeling Results Summary for 60-foot BEBs

Route	Profile	Length (mi)	Duration (h:mm)	Efficiency (kWh/mi)	
				Nominal	Strenuous
25	Hills, Slow	17.9	1:31	3.4	4.6
64	Hills, Fast	39.4	1:56	3.1	3.8
66	Hills, Fast	33.0	1:04	3.0	3.5
74	Flat, Fast	35.4	1:19	3.1	3.6
			Average	***3.1***	***3.9***

Using vehicle performance predicted from route modeling and simulation completed in 2020 as well as recent data collected during BEB operations in STA service, CTE analyzed the expected performance and range needed on every block in STA's network (Summer 2023). The block analysis was completed based on the weekday blocks. The analysis focuses on bus endurance and range limitations to determine if the ZEBs could meet the service requirements of the blocks throughout the transition period. The energy needed to complete a block is compared to the available energy for the respective bus type that is planned for the block to determine if a BEB or FCEB can successfully operate on that block. Data from the limited current BEB operations was also compared to the results to validate these route modeling projections.

Research suggests that battery density for electric vehicles has improved by an average of 5% each year.[1] For the purposes of this study, considering the extended period of a complete fleet transition (e.g., through 2045), CTE assumes a more conservative 5% improvement every two years. If the trend continues, it is expected that buses may continue to improve their ability to carry more energy without a weight penalty or reduction in passenger capacity. Over time, BEBs are expected to approach the capability to replace all of an agency's fossil-fuel buses one-for-one. For FCEBs, improvements in hydrogen compression and storage technologies are expected to occur over the course of the transition period; however, based on recent advancements an achievable distance of 350 miles was used for feasibility evaluation.

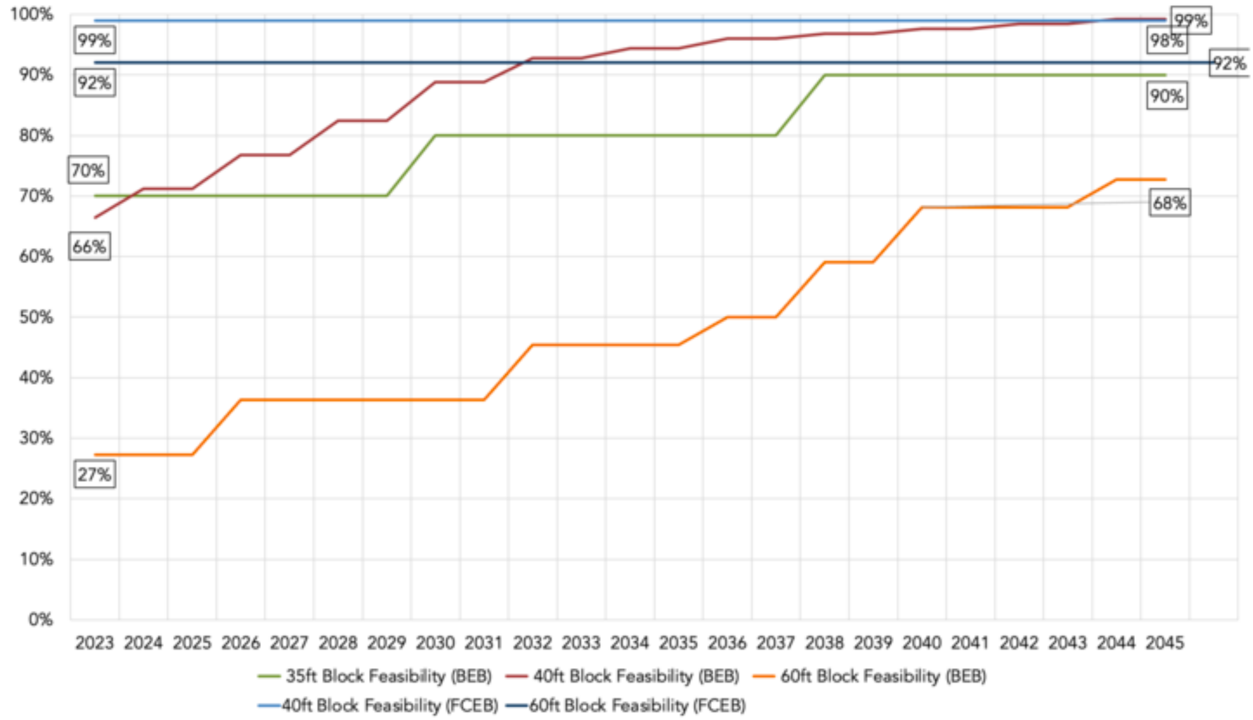
The block analysis, with the assumption of 5% improvement in battery capacity every other year, is used to determine the timeline for when routes and blocks become achievable for BEBs to replace diesel buses 1:1. For FCEBs, block feasibility is compared to the current estimated range. This information is used to then inform ZEB procurements in the Fleet Assessment.

The results from the block analysis are used to determine when/if a full transition to BEBs or FCEBs may be feasible. Results from this analysis are also used to determine the specific energy requirements and develop the estimated costs to operate the ZEBs in the Fuel Assessment.

[1] U.S. Department of Energy; LONG-RANGE, LOW-COST ELECTRIC VEHICLES ENABLED BY ROBUST ENERGY STORAGE, MRS Energy & Sustainability, Volume 2, Wednesday, September 9, 2015; https://arpa-e.energy.gov/?q=publications/long-range-low-cost-electric-vehicles-enabled-robust-energy-storage

Results from the updated block analysis that indicate the yearly block achievability by bus length throughout the transition period for BEBs and FCEBs are included on **Figure 6**.

Figure 6*: *Overall BEB and FCEB Block Achievability by Bus Length



As detailed in **Figure 6**, the block evaluation indicates estimated feasibility as follows:

Table 8: Estimated Block Feasibility for BEBs

Vehicle Length	2023	2045
35’	70%	90%
40’	66%	98%
60’	27%	68%

The vast majority of blocks operated by 35’ and 40’ buses are expected to be feasible to operate with a BEB under all conditions by 2045; however, approximately 32% of the 60’ blocks still remain infeasible. Note that as these are projections, there may be limitations to the actual battery capacity available on BEBs in the future due to weight restrictions, particularly on the 60’ BEBs. The block achievability evaluation includes CCL and MRL blocks that include on-route charging and are determined to be feasible. These CCL and MRL routes are achievable upon deployment based on the modeling completed as part of the detailed evaluations of each route and included in the previously mentioned Implementation Plans.

While routes and block schedules are unlikely to remain the same over the course of the transition period, this projection assumes the blocks will retain a similar structure to what is in place today. Despite changes over time, this analysis assumes blocks will maintain a similar distribution of distance, relative speeds, and elevation changes by covering similar locations within the city and using similar roads to get to these destinations. This core assumption affects energy use estimates as well as block achievability in each year.

As part of the updated Service Assessment, CTE reviewed the battery capacity of the BEBs that STA already has in their fleet or has contracted to have in their fleet by the end of 2023 to assess feasibility for the service as it exists today. **Table 9** below shows the results based on the characteristics (battery capacity and bus size) of the current STA fleet (2024).

Table 9: Block Feasibility for Current STA Fleet Vehicles

Bus Size (ft)	Number of Vehicles	Nameplate Battery Capacity (kWh)	Usable Battery Capacity (kWh)	Strenuous Blocks Achievable BOL Battery (%)	Strenuous Blocks Achievable EOL Battery (%)
35	3	440	396	70%	60%
40	2	320	288	On-Route Charge	On-Route Charge
40	8	440	396	54%	37%
40	3	520	468	66%	38%
40	10	675	608	87%	62%
60	10	320	288	On-Route Charge	On-Route Charge
60	4	520	468	27%	0%

Please note that 29-foot and 35-foot buses are not included in the block achievability chart for FCEBs because there are currently no commercially available FCEBs of that size vehicle on the market today and it is unclear if one will ever be built. A review of the data indicates that 99% of the blocks operated by 40’ buses and 92% of the blocks operated by 60’ buses are feasible with a FCEB today and in the future.

Section 7 - Fleet Assessment

The goal of the Fleet Assessment is to determine the type and quantity of ZEBs, as well as the schedule and cost to transition a transit fleet to zero emission. Results from the Service Assessment are integrated with the STA's current fleet replacement plan and purchase schedule (May 2024) to produce the projected bus replacement timeline and the associated total capital cost.

Cost Assumptions

CTE and STA created cost assumptions for this analysis for each bus length and technology type (e.g., diesel, BEB, FCEB). Key assumptions for the bus cost estimate are as follows:

- All procurements based on 15-year service life
- Total fleet size is based on STA's May 2024 procurement schedule
- 5% improvement in battery technology every two years
- Usable capacity estimated at 90% of nameplate capacity. End of Life (warranty) estimated at 80% of usable capacity
- ICE and ZEB bus costs are based on Washington State Procurement Contract (2023 updated costs)
- 3% annual inflation

Conventional wisdom dictates that the costs of BEBs will decrease over time due to higher production volume and competition from new vendors entering the market. While initially this was true, costs appear to have leveled out in recent years. However, it should be also noted that vendors have added more battery storage over the same time period without increasing base costs. FCEB prices are expected to decrease over time as vehicle orders increase; however, CTE does not currently have an adequate basis to reduce the costs over time for the purchase of FCEBs.

Table 10 provides cost estimates for new vehicle purchases used in the analysis. All bus purchase prices are inclusive of tax and configurable options and are based on the current Washington State Purchasing Contract. The configurable options cost added to all base bus is $60,000.

Table 10*: *Cost Estimates Used in Fleet Assessment (2023)

Length	BEB Base Price Average	FCEB Base Price Average	Diesel Base Price Average	Hybrid Base Price Average
35'	$1,064,072	-	$540,000	-
40'	$1,074,432	$1,306,165	$546,000	-
60'	$1,574,688	$1,928,192	$861,000	$682,000
Double Decker	$1,484,097	-	$1,043,097	-

ZEB Fleet Transition Schedule and Composition

Given the block analysis and STA's fleet replacement schedule and currently planned procurements, a transition timeline depicts the annual baseline fleet composition through the transition period. The baseline scenario utilizes existing planned procurements of ZEBs (40 ZEBs by the end of 2023). All other replacements moving forward assumed to be diesel for comparison except for planned BEB BRT service in 2030. According to STA's current procurement plan, STA's fleet is expected to grow to 170 vehicles. The baseline scenario is used for comparison to the other scenarios in the evaluation. The annual fleet composition is depicted in **Figure 7**.

Figure 7: Baseline - Annual Fleet Composition

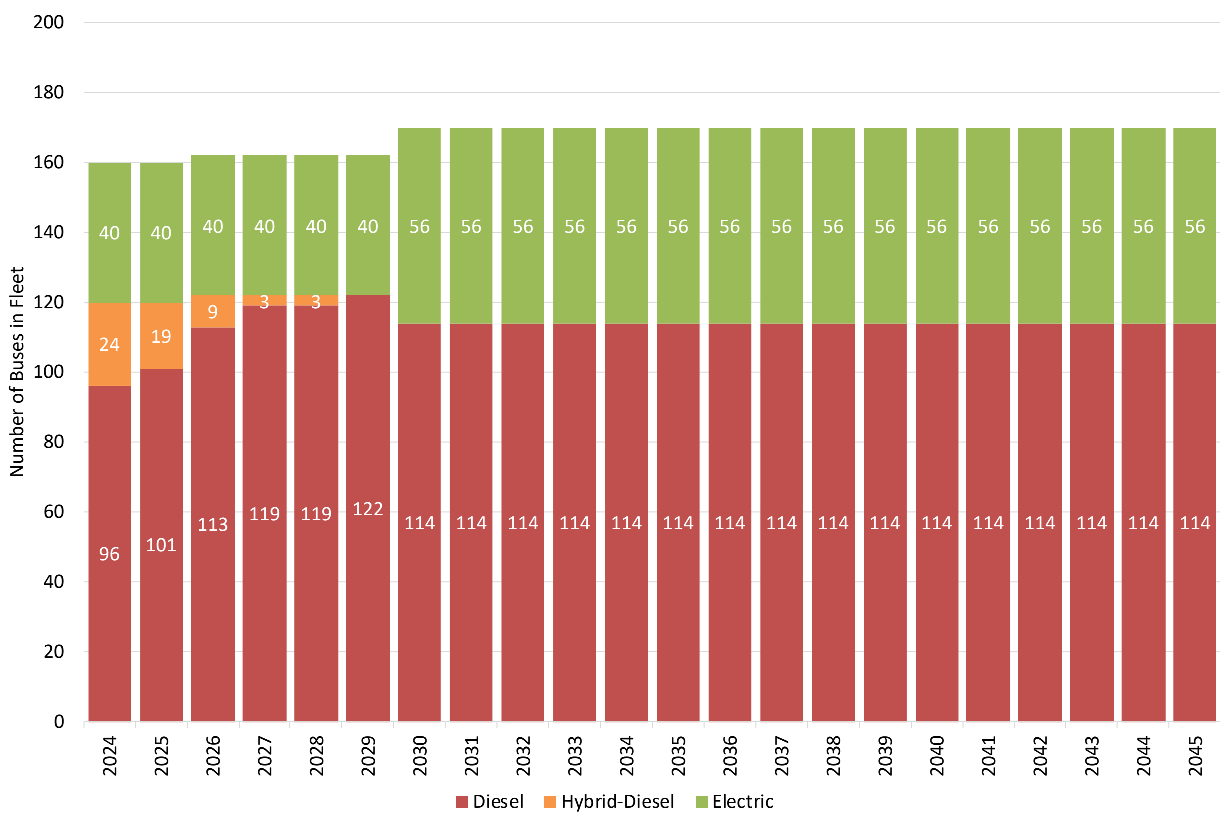
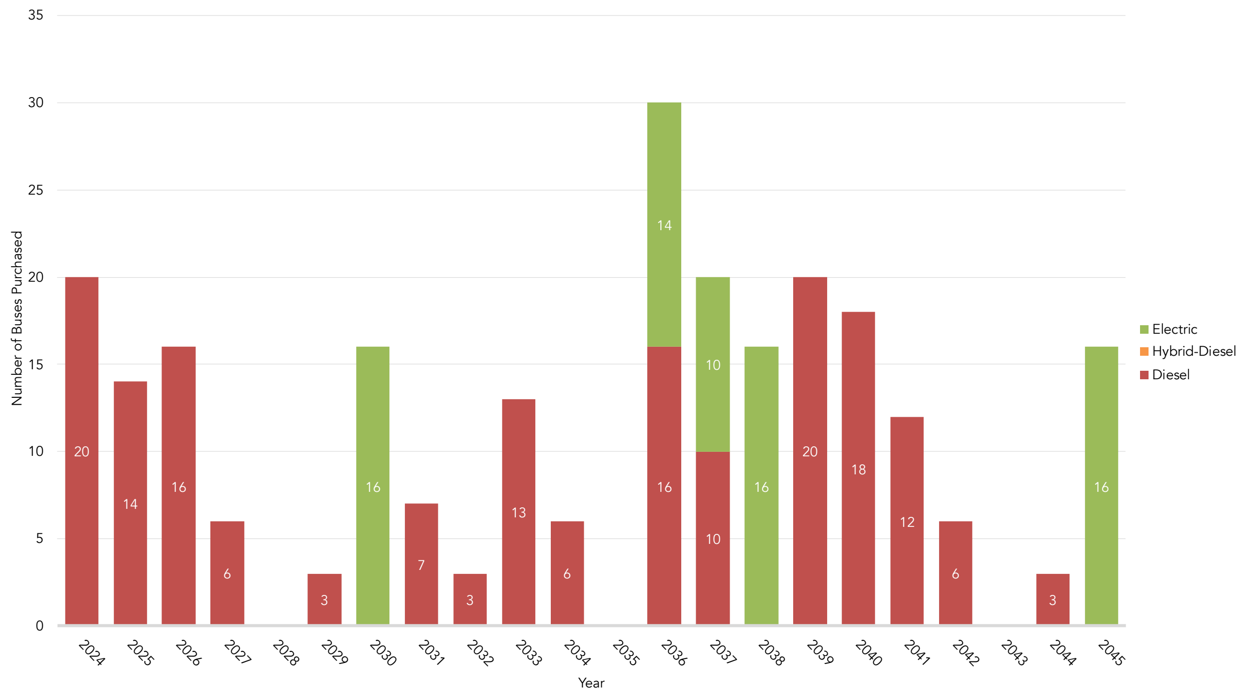


Figure 8 depicts annual fleet purchases by fuel type. The current plan provides for a conversion to 33% ZEB by the end of the transition period. This plan is estimated to cost $240 million in expenditures between 2024 and 2045 with an average annual expense of $11 million.

Figure 8: Baseline - Annual Fleet Purchases



Despite recent increases in energy storage, BEBs are still subject to range limitations and cannot be placed into service on every block on a 1:1 replacement basis for diesel. As discussed in the Service Assessment section, BEBs can currently be operated on between 27% and 70% of STA's blocks depending on vehicle size, improving to between 68% and 98% by the end of the transition period. It should be noted that this analysis includes use of on-route charging for the planned CCL, MRL, and future BRT blocks. If STA desires to place BEBs on routes where the estimated vehicle range is less than the block distance, they must (1) modify the block distance and duration; (2) use multiple BEBs to replace a single diesel vehicle; or (3) utilize on-route charging. As there is no regulatory driver for full-scale BEB replacement, CTE assumes that STA would replace the vehicles that could be replaced with BEBs on a 1:1 basis, including those supporting the CCL and MRL where on-route charging is anticipated.

A mixed fleet scenario of both BEBs and ICE vehicles (based on block feasibility) is depicted in **Figure 9**. In this scenario, BEBs are charged at the depot only without use of on-route charging (except for the current on-route service as well as the 2030 planned BRT). Of the 170 vehicles, 165 would be BEB and five remaining diesel by the end of the transition period in 2045 (a 97% ZEB fleet).

Figure 9*: *BEB Depot Only - Fleet Composition Projection (Scenario 1)

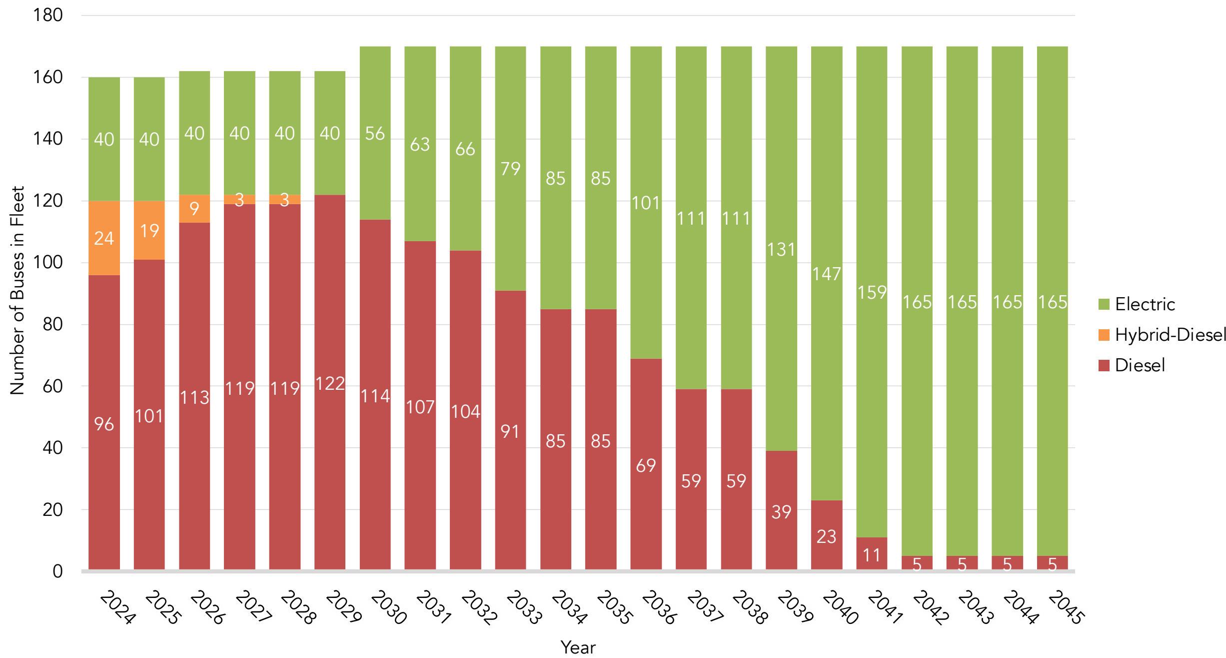
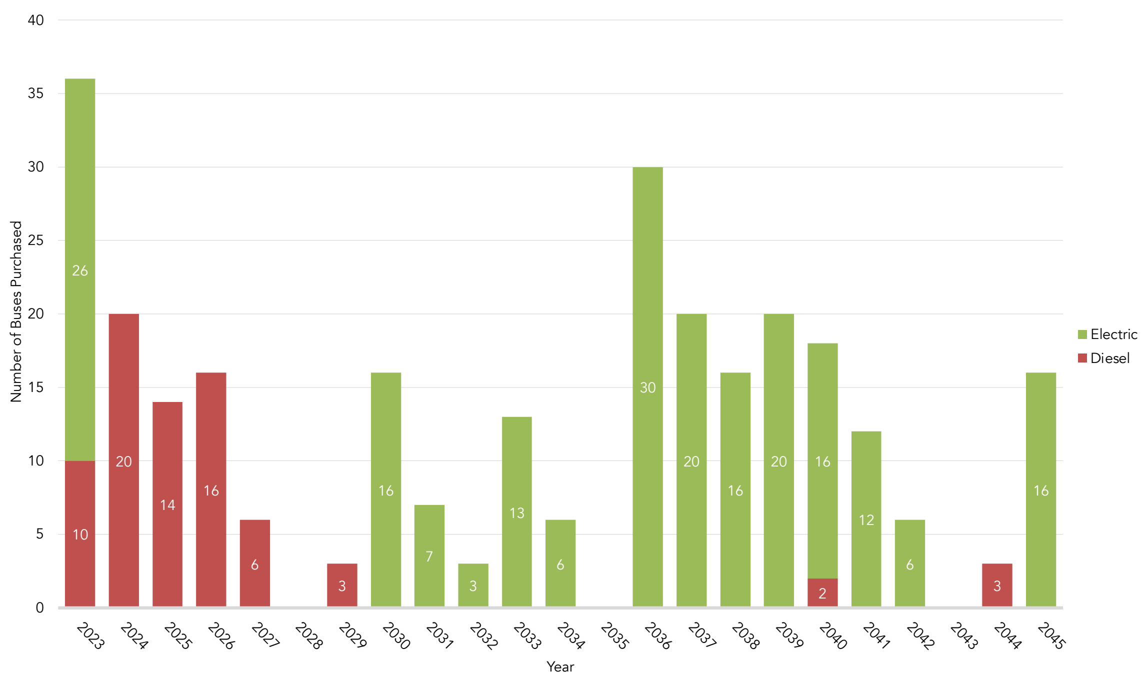


Figure 10 shows the annual fleet purchases by fuel type under Scenario 1. Under this scenario costs are expected to reach $431 million total with an average annual expense of $20 million.

Figure 10: BEB Depot Only – Annual Fleet Purchases (Scenario 1)



The second fleet transition scenario, depicted below in **Figure 11**, is a mixed fleet of BEBs and FCEBs where BEBs are charged at the depot. In this scenario, STA's fleet is composed of 165 BEBs and 5 FCEBs (97% FCEB), reaching 100% ZEB fleet by 2044.

Figure 11: BEB Depot and FCEB – Fleet Composition Projection (Scenario 2)

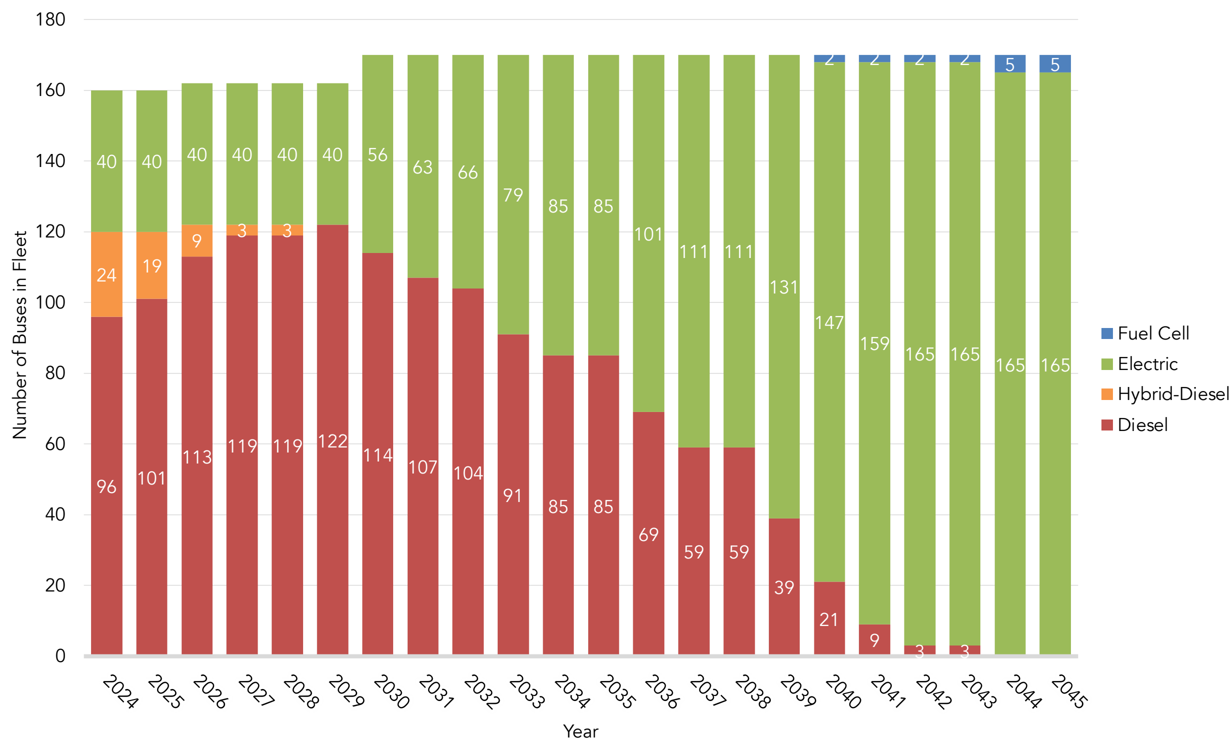
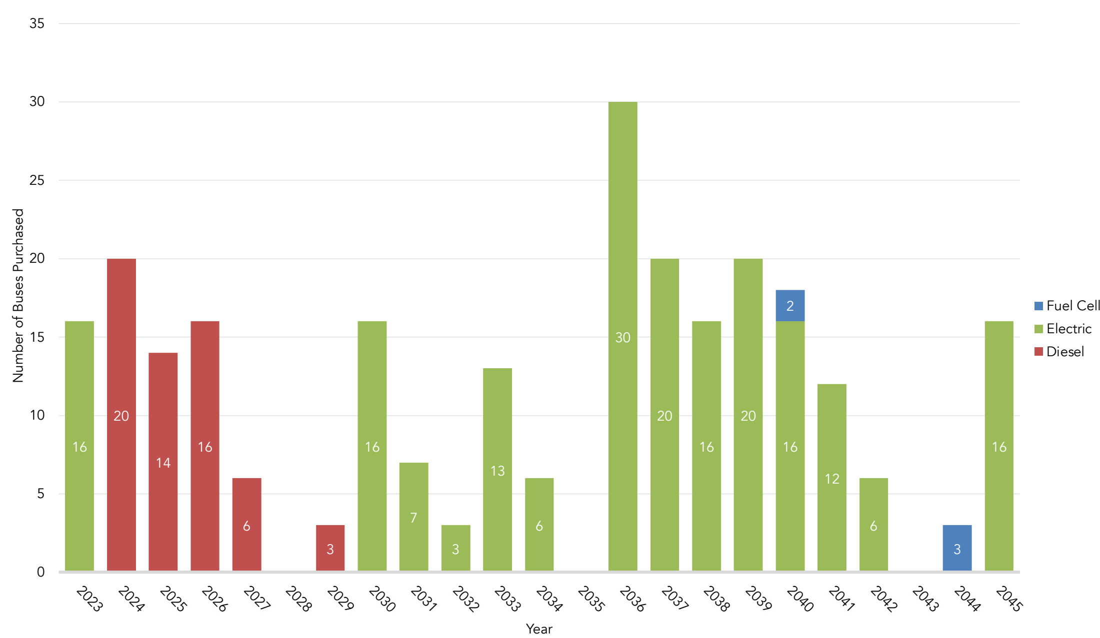


Figure 12 depicts the annual fleet purchases by fuel type in this scenario. Expenditures for this scenario were estimated to be $437 million with an average annual expense of $21 million.

Figure 12: BEB Depot and FCEB – Annual Fleet Purchases (Scenario 2)



The third fleet transition scenario, depicted in **Figure 13**, is one in which all BEBs in the original Baseline scenario will remain BEB with all others replaced with FCEBs. In this scenario, STA reaches 100% ZEB by 2044 with 114 FCEBs and 56 BEBs (67% FCEB/33% BEB).

Figure 13: FCEB Replacements Only – Fleet Composition Projection (Scenario 3)

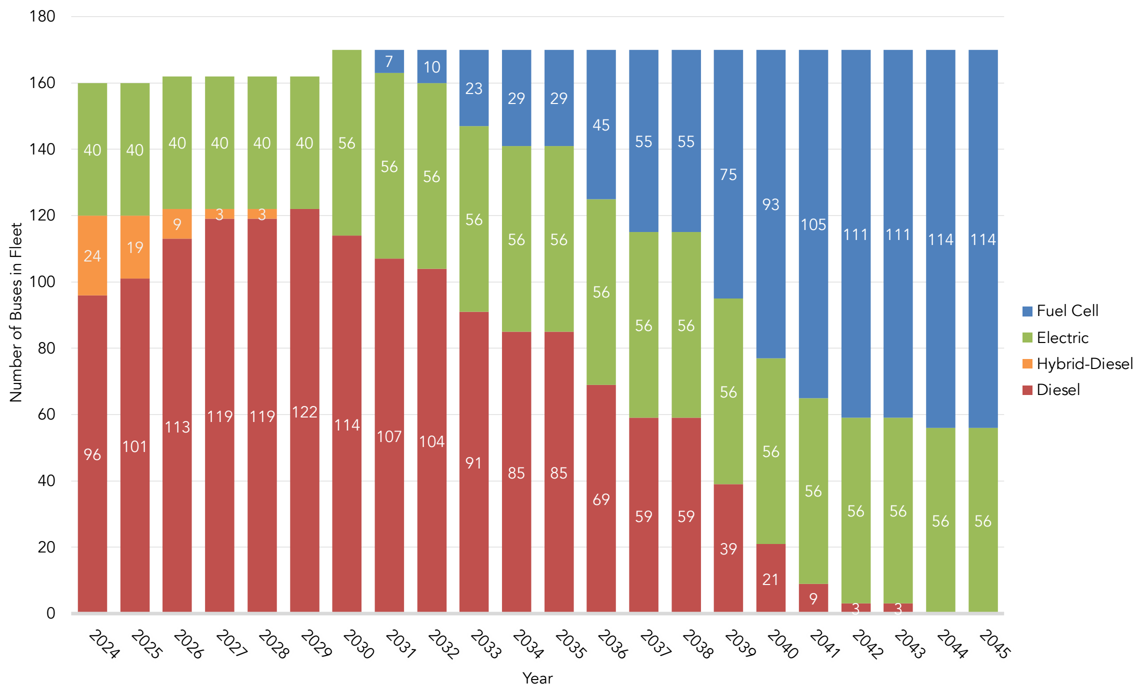
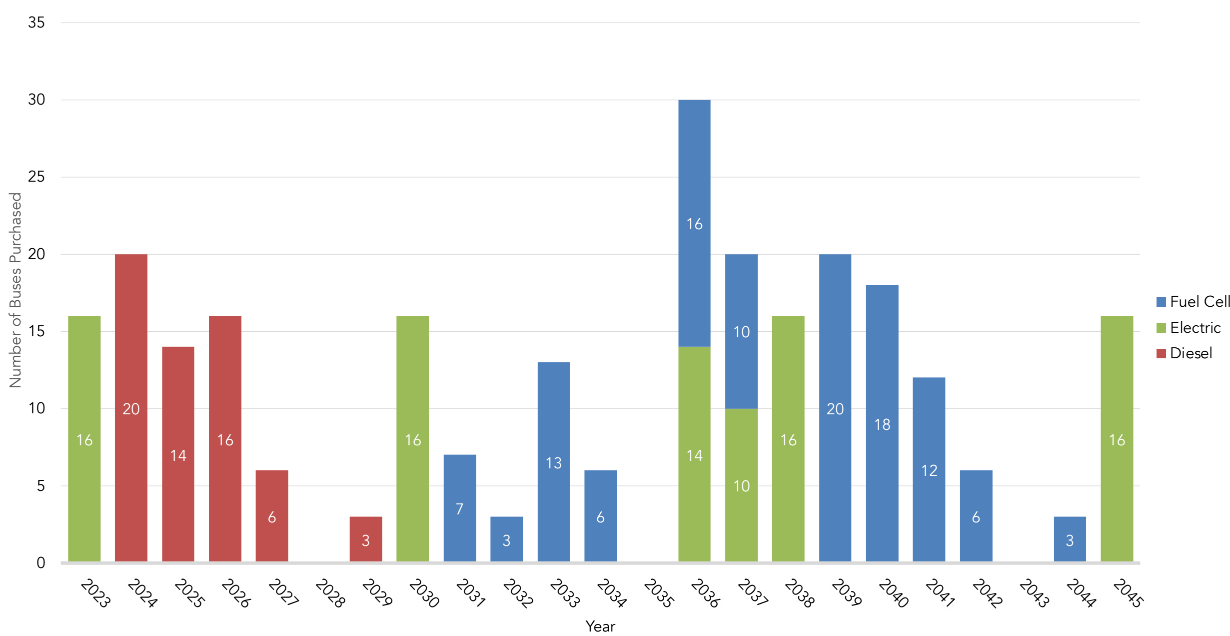


Figure 14 shows the annual fleet purchases by fuel type under Scenario 3. Total expenditures under this scenario are expected to be approximately $482 million with an average annual expense of approximately $23 million.

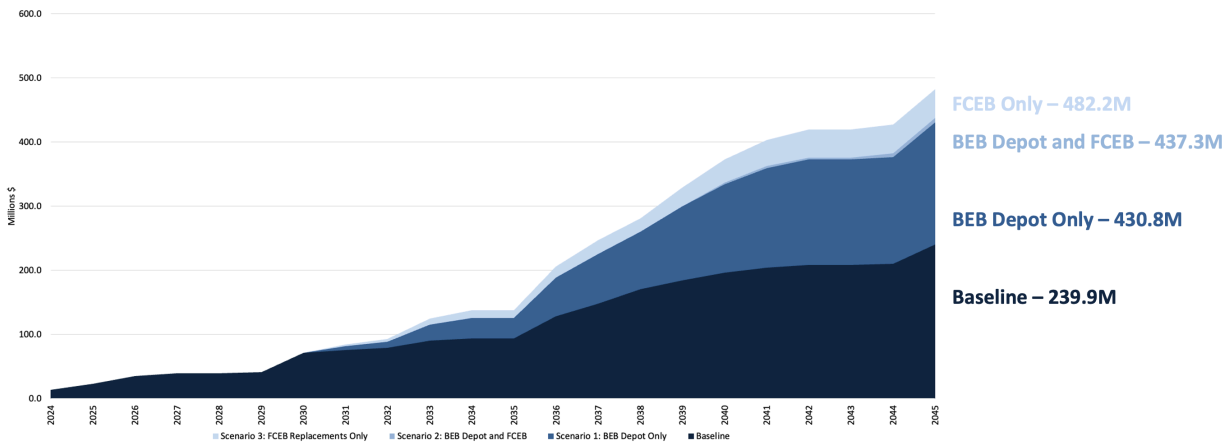
Figure 14: FCEB Replacements Only – Annual Fleet Purchases (Scenario 3)



BEB Fleet Transition Costs

The transition and fleet composition schedules were used to develop the total capital cost for vehicle purchases throughout the transition period. Results are provided in **Figure 15** below. Note that the costs are provided in 2023 dollars, assuming 3% annual inflation of the cost of vehicles during the transition period. The cumulative costs depicted in the figure include all buses that are projected to be purchased during the scenario timeline (2024-2045).

Figure 15: Cumulative Vehicle Purchase Costs



By the end of the transition period, the cumulative vehicle costs vary substantially according to the technology selected, as does the percentage of the fleet that can be transitioned to zero emission by 2045. Due to ICE-vehicle purchases in STA's purchase plan from 2026 through 2029, none of the scenarios can achieve 100% ZEB by 2040. However, Scenarios 2 and 3 can be expected to achieve 100% ZEB by 2045, while Scenario 1 achieves 97% ZEB by 2045.

Table 11: Capital Cost Summary for Vehicle Purchases (2024 – 2045)

	Baseline	BEB Depot Only (Scenario 1)	Mixed Fleet BEB & FCEB (Scenario 2)	FCEB Replacements Only (Scenario 3)
Cost	$239.9 M	$430.8 M	$437.3 M	$482.2 M
Incremental Cost Over Baseline	-	$190.9 M	$197.4 M	$242.3 M
Incremental Cost (%)	-	79%	82%	101%
% ZEB by 2045	33%	97%	100%	100%

Section 8 - Maintenance Assessment

The objective of the updated Maintenance Assessment is to estimate maintenance costs associated with each fleet transition scenario.

One of the expected benefits of moving to a BEB or FCEB fleet is a reduction in maintenance costs. Conventional wisdom estimates that a transit agency may attain maintenance savings up to 30% by operating BEBs. This is due to the fact that there are fewer fluids to replace (no engine oil or transmission fluid), fewer brake changes due to regenerative braking, and far fewer moving parts than on a diesel bus. However, the savings in traditional maintenance costs may be offset by the cost of battery or fuel-cell replacements over the life of the vehicle. For this analysis, a battery warranty included with the vehicle purchase cost was assumed to mitigate the mid-life battery replacement.

There is limited data available on early deployments and many early deployments are from new manufacturers where production quality issues manifest as maintenance issues. Thus, assumptions used for calculating cost for labor and materials is based on current STA maintenance costs. BEB and FCEB labor and material costs are based on a percentage of costs associated with maintaining diesel buses or comparative analysis to maintenance of compressed natural gas (CNG) buses.

Percentages were derived from an analysis performed by the U.S. Department of Energy National Renewable Energy Laboratory (U.S. DOE NREL). There is limited information available regarding maintenance costs for FCEBs due to the limited number of vehicles in operation in the United States. Comparative data for FCEB operations was obtained from recent operations of 40’ FCEBs at Orange County Transit Authority (OCTA). In addition to labor and materials, the cost impact of mid-life overhauls for major components for each type of bus is also estimated. Maintenance cost assumptions are provided in **Tables 12** and **13**. Note that the cost per mile basis for the 2023 analysis is substantially higher than the cost per mile used for diesel and diesel hybrid operations in the 2020 analysis as a result of better visibility for STA on the operational costs.

Table 12: Maintenance Cost Assumptions

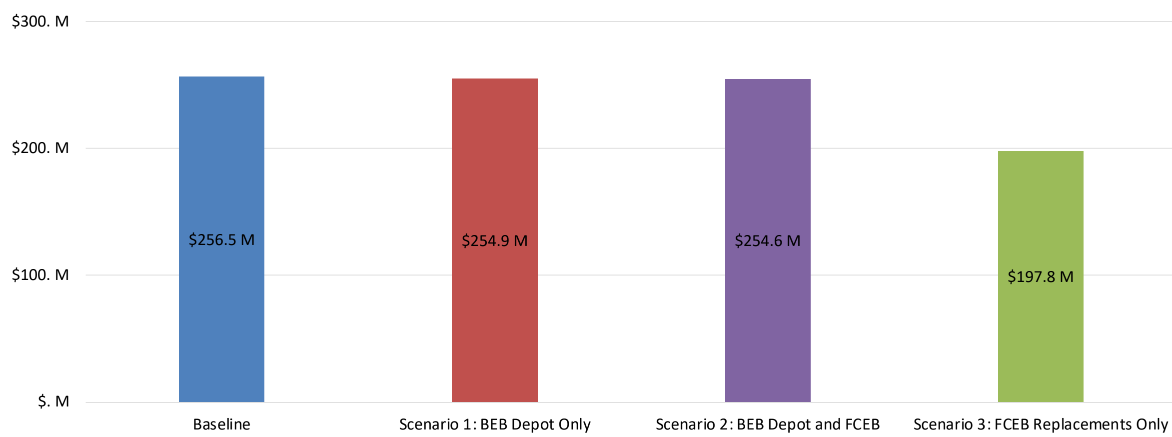
Type	Labor & Materials Estimate	Source
Diesel	$1.43/mile (35’, 40’, 60’)	STA Data
Diesel Hybrid	$1.43/mile (35’, 40’)	STA Data
BEB	$1.00/mile (30’, 35’, 40’, 60’)	Based on 30% reduction of diesel maintenance cost
FCEB	$1.07/mile (30’, 35’, 40’ , 60’)	Based on 25% reduction of diesel maintenance cost based on OCTA data

Table 13: Mid Life Overhaul Cost Estimates

Type	Overhaul Scope	Estimate	Source
Diesel	Engine & transmission overhaul	$29,0000 Engine, $14,000 Transmission = $43,000	STA Estimate
Diesel Hybrid	Hybrid system rebuild	$70,000 hybrid system rebuild	STA Estimate
BEB	Battery replacement [Can be mitigated with purchase of battery warranty during procurement for ~$35 – 100K]	$232,500 Battery Replacement	OEM Estimate
FCEB	Fuel cell overhaul	$40k per bus	OEM Estimate

The cumulative estimated costs of maintenance for each scenario over the transition period are provided in **Figure 16.**

Figure 16: Maintenance Evaluation Cost Summary



Section 9 – Charging Analysis

A charging analysis was completed to determine the feasibility of charging all of the BEBs that STA has planned for deployment by the end of 2023 at the Boone Northwest Garage with the available charging infrastructure. The charging evaluation was also used to support the development of the costs for the Fuel Assessment in the following section.

The Northwest Boone Garage is currently has five (5) 150 kW ABB chargers, each equipped with two plug-in dispensers for sequential charging, as well as two (2) 450 kW ABB high capacity overhead chargers with drop down pantographs. STA currently has plans to install five (5) additional 150 kW ABB plug in chargers equipped with two (2) dispensers each in the garage as well. The Spokane Community College (SCC) Transit Center (City Line) and Moran Station Park and Ride (Monroe-Regal) are each equipped with two (2) 450 kW ABB high capacity overhead chargers with drop down pantographs for on-route charging of BEBs.

City Line Service

The City Line BRT began service in July 2023 utilizing ten (10) 60' New Flyer BEBs equipped with fast charge 320 kWh batteries and one (1) 60' New Flyer BEB equipped with a 520 kWh long-range battery. Vehicles are stored at the Northwest Boone Garage and charge on-route at the SCC Transit Center. Overnight or top off charging may occur at the Northwest Boone Garage either before deployment or after the vehicle returns from performing service. For this analysis, it was assumed at the charging at the depot only utilizes the high capacity charger. The service will follow the requirements established in **Table 14** in 2024 following a ramp up period in 2023.

Table 14: City Line Service Requirements

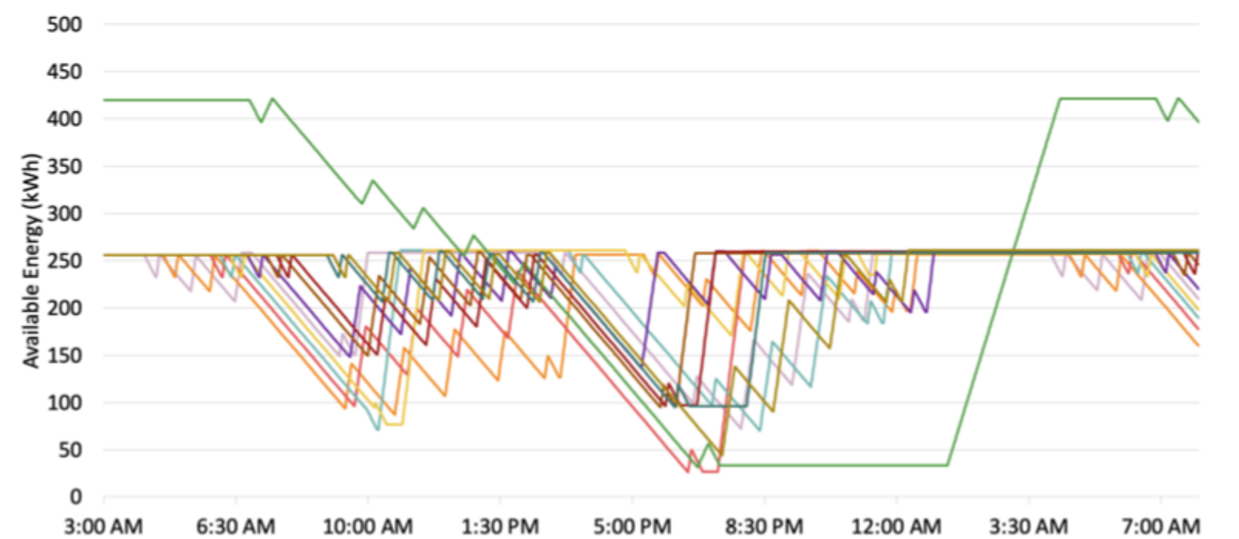
	Early Morning 4:30A-6:00A	Morning 6:00A-7:00A	AM Peak 7:00A-9:00A	Midday 9:00A-3:00P	PM Peak 3:00P-6:00P	Evening 6:00P-11:00P	Late Night 11:00P-Close
Cycle Time	60	90	67.5	80	67.5	90	60
Headway	30	15	7.5	10	7.5	15	30
Bus Requirement	2	6	9	8	9	6	2

Example blocks were developed to fit the schedule requirements for analysis. Multiple scenarios were evaluated to determine feasibility of completing the service under strenuous conditions. In the first scenario, shown in **Figure 17**, BEBs initially leave the garage with a full battery and charge each time through the SCC Transit Center for the maximum available layover (minus docking time) up to a total of 25 minutes.

Figure 17: City Line Charging – Scenario 1

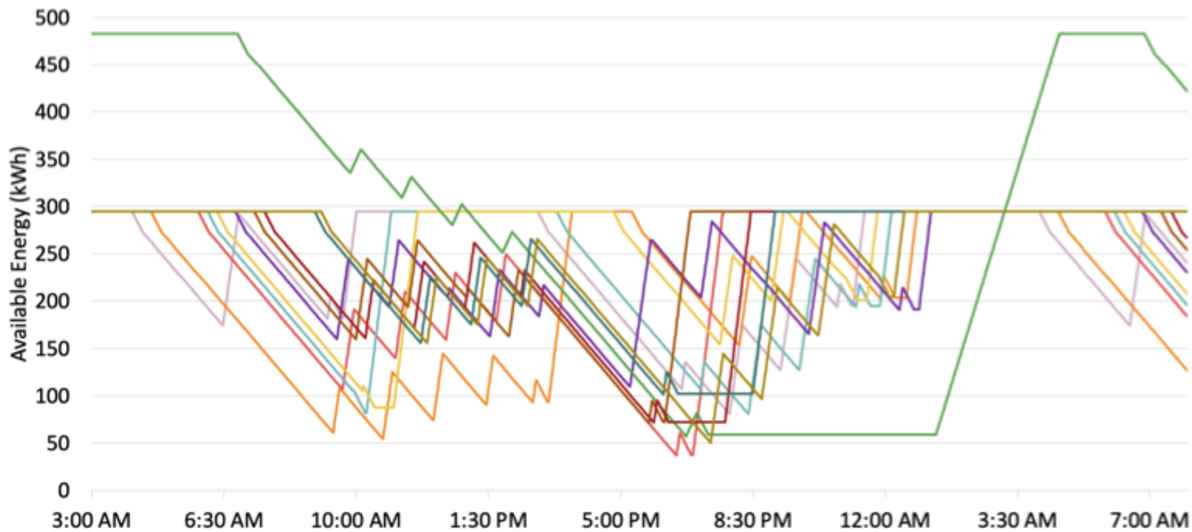
In the second scenario, shown in **Figure 18**, BEBs initially leave the garage at 80% state of charge (SOC) and charge each time through the SCC Transit Center for the maximum available layover (minus docking time) up to a total of 25 minutes.

Figure 18: **City Line Charging – Scenario 2**



In the final scenario, shown in **Figure 19**, BEBs initially leave the garage with a full charge but only charge at the SCC Transit Center when they are below a 70% SOC for the maximum available layover (minus docking time) up to a total of 25 minutes.

***Figure 19:* City Line Charging – Scenario 3**



Results from each of the scenarios indicates that it is feasible to operate the City Line service as detailed in **Table 14** with the eleven (11) vehicles under strenuous conditions by charging at the Northwest Boone Garage using the high capacity charger and on-route at the SCC Transit Center although several buses drop below 50 kWh of remaining energy.

Further block analysis was completed to evaluate extreme weather conditions (e.g. sustained cold temperatures from -10 degrees F to 1 degree F) and service changes, indicated energy use up to 6.5 kWh/mi. Under these challenging conditions, 6 of 9 blocks are unable to complete the daily service with on-route charging. As a result, STA is evaluating service changes during these very infrequent challenging conditions.

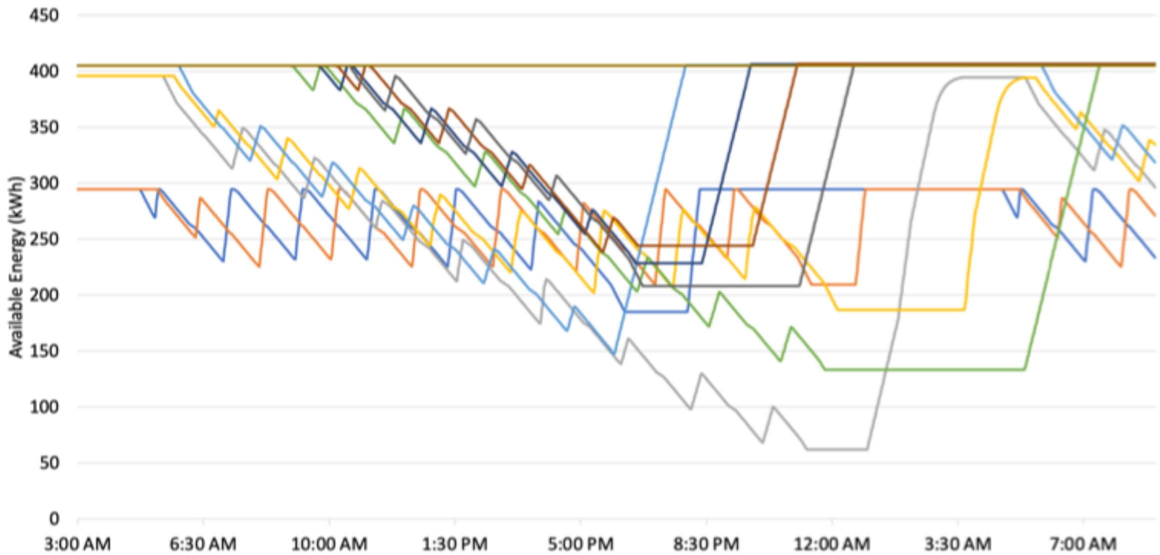
Monroe-Regal Line

The Monroe-Regal Line is proposed to operate fully electric using ten (10) BEBs that include:

- Two (2) 40' Proterra – 440 kWh long-range battery
- Two (2) 40' New Flyer – 320 kWh high-power battery
- Six (6) 40' New Flyer – 440 kWh long-range battery

Results from the evaluation are included in **Figure 20** below.

Figure 20: **Monroe-Regal Line Charging**



As with the City Line, BEBs may charge at the Northwest Boone Garage either using plug-in or high capacity chargers and charge on-route at the Moran Station Park and Ride using two (2) 450 kW high capacity chargers. For this analysis, it was assumed that the depot charging is only completed using a high capacity charger. Results indicate that the BEBs are able to complete all of the blocks using the available chargers under strenuous conditions; however, results indicate that the New Flyer fast charging buses should be scheduled to operate the most challenging blocks (45, 47, and 48).

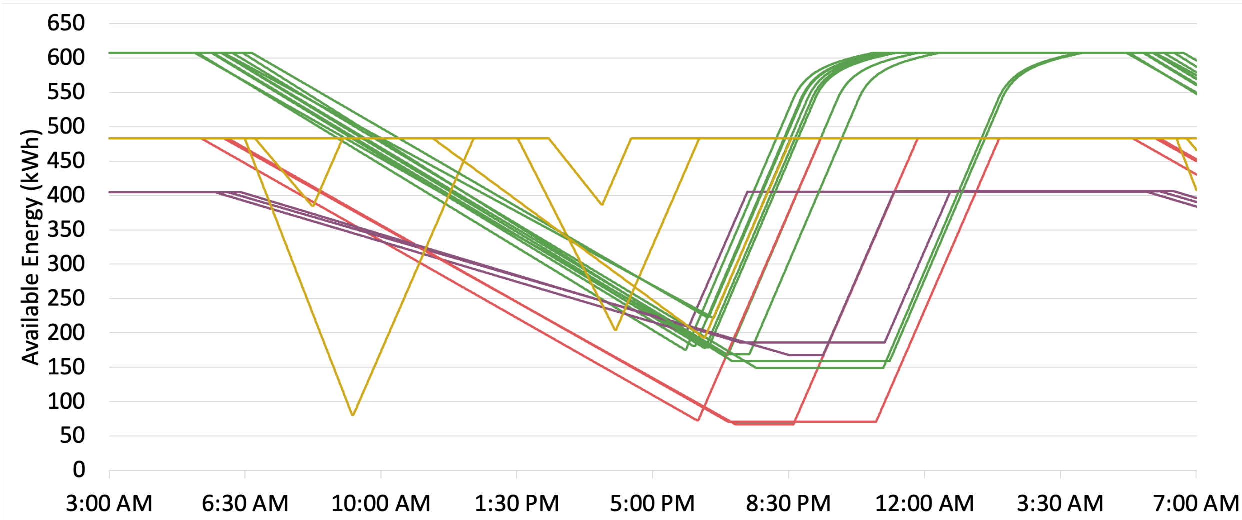
Northwest Boone Garage Plug-In Charging

Analysis of the planned BEBs that are not scheduled to be charged on-route was completed to determine if the remaining 19 buses could effectively be charged with the ten (10) planned plug-in chargers. Details of the BEBs that are not planned for on-route charging are as follows:

- Three (3) 35’ New Flyer – 440 kWh long-range battery
- Three (3) 40’ New Flyer – 520 kWh long-range battery
- Ten (10) 40’ Proterra – 675 kWh long-range battery
- Three (3) 60’ New Flyer – 520 kWh long-range battery

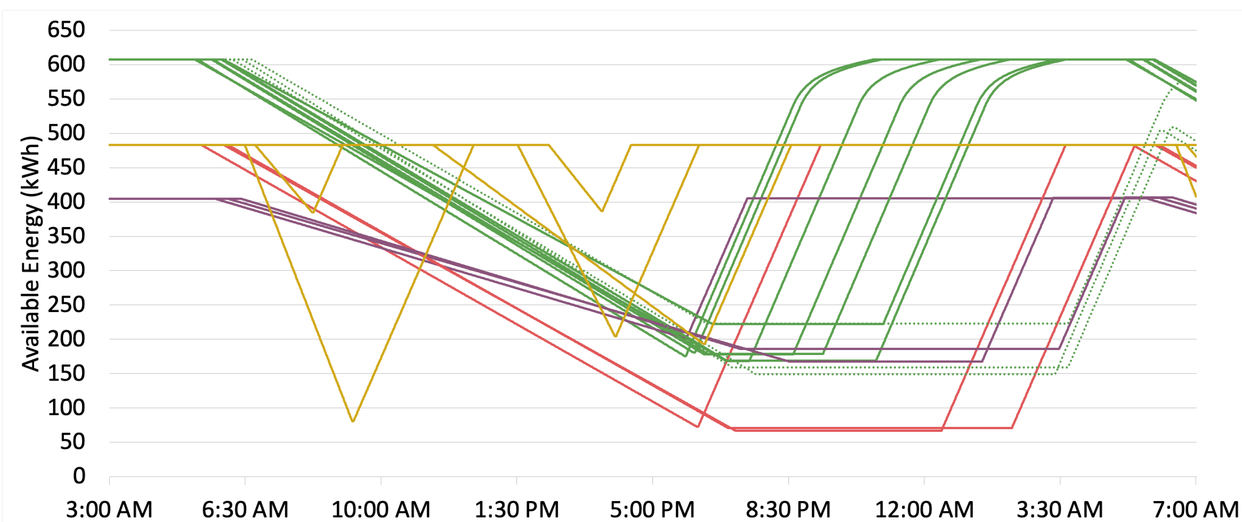
Results from the analysis are included in **Figure 21** below. Results indicate that all BEBs can be charged in the allotted time at the Northwest Boone Garage using the ten (10) available chargers.

Figure 21: **Northwest Boone Garage Charging (10 Chargers)**



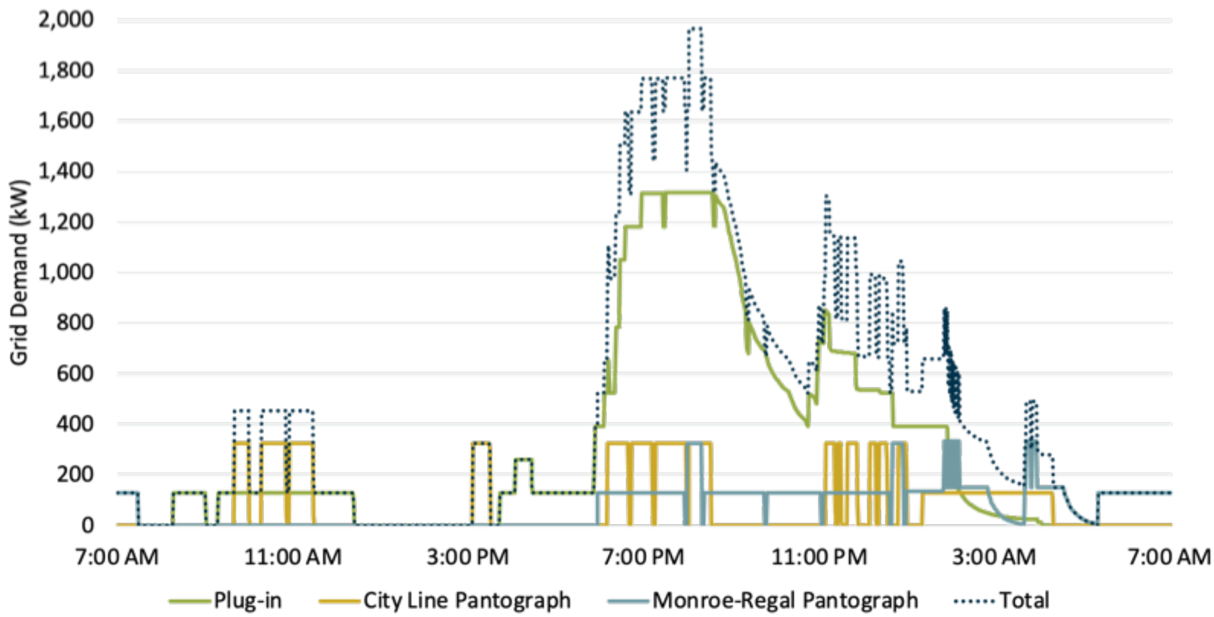
Further evaluation was complete to determine if all of the buses could be charged with only the five (5) existing chargers; however, results provided in **Figure 22** indicate that some buses do not fully charge prior to going back into service the following day.

Figure 22: **Northwest Boone Garage Charging (5 Chargers)**



Grid demand was estimated for the Northwest Boone Garage assuming all forty (40) of the BEBs are in operation. Results are depicted in **Figure 23**.

***Figure 23:* Grid Demand at Northwest Boone Garage**



Demand analysis indicates that an estimated grid demand of 2 MW is expected at the Northwest Boone Garage with all chargers and BEBs in operation. It should be noted that this is the expected demand, not the total connected load of all of the chargers (estimated at 2.4 MW).

Section 10 – Fuel Assessment

The objective of the updated Fuel Assessment is to estimate fuel use and costs associated with each of the transition scenarios. CTE updated assumptions used to complete this assessment and performed a sensitivity analysis associated with the cost of hydrogen.

The terms "fuel" and "energy" are used interchangeably in this analysis, as ZEB technologies do not always require traditional liquid fuel. For clarity, in the case of BEBs, "fuel" is electricity, and costs include energy, demand and other utility charges. The primary source of energy for a BEB comes from the local electrical grid. Utility companies charge separate rates for total electrical energy used and the maximum electrical demand on a monthly basis. As more buses, and chargers, are added to a system, both the energy used and the demand increase. Rates also vary throughout the year and throughout the day (also called time of day rates); this makes costs highly variable. Costs not only depend on seasonal differences like temperature or local school schedules, but also the time of day that buses are charged.

FCEBs are more similar to diesel vehicles as they are fueled by a gaseous or liquid hydrogen fuel. In addition to the cost of the fuel itself, however, there are additional operational costs associated with the hydrogen fueling station that must be considered. Operation and maintenance costs to maintain fueling infrastructure are built into the Fuel Assessment.

Fuel Assessment Assumptions

The primary source of energy for a BEB comes from the local electrical grid (Avista). Utility companies charge separate rates for total electrical energy used and the maximum electrical demand on a monthly basis.

Fuel cost estimates are based on the assumptions listed in **Table 15**. **Table 16** is a summary of the current Schedule 23 EV Rate Structure from the utility provider Avista.

Table 15: Fuel Assessment Assumptions

Fuel	Cost	Reference
Diesel	$3.99/gallon	STA 2023 costs
Hydrogen (delivered liquid)	$9.00/kilogram (kg)	Current CA costs

Table 16: Avista Schedule 23 EV Rate Structure

Charge Type	Amount
Basic Charge	$600/meter
On-Peak Energy Charge	$0.16531/kWh
Off-Peak Energy Charge	$0.0675/kWh
Demand Charge	None

Hydrogen Fuel Cost Projections

There are several recent developments that may significantly impact hydrogen fuel costs including the Department of Energy's Regional Hydrogen Hub Program, which involves a substantial investment of $8 billion. Potential projects in the region associated with this program include the Pacific Northwest Regional Hydrogen Hub (PNWH2 Hub)[2], Obsidian Renewables[3], Douglas County PUD's Renewable Hydrogen Production Facility[4], and the establishment of a Hydrogen Valley[5].

To assess the sensitivity of these costs, an evaluation was conducted considering an annual per kilogram hydrogen cost reduction of 3% annually starting in 2025. This analysis aims to capture the potential impact of future advancements and efficiencies in hydrogen production and distribution technologies as well as growth in hydrogen production and distribution in the region. By incorporating this sensitivity evaluation, this Fuel Assessment can account for potential fluctuations in hydrogen fuel costs.

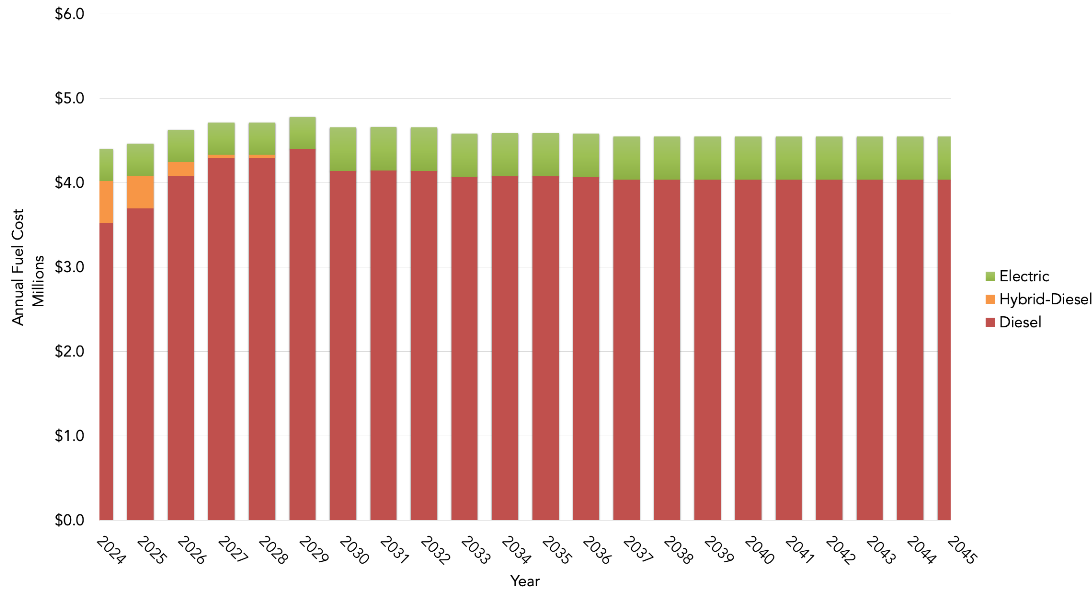
Cumulative Fuel Costs

Inputs from the fleet transition schedule/composition, fuel cost assumptions, and energy rate plans available from Avista were used to calculate the costs for each fuel type (diesel, electricity, and hydrogen) throughout the transition period.

As depicted in **Figure 24**, The baseline scenario results in a total fuel cost of approximately $100.9 million, or an average of $4.8 million annually.

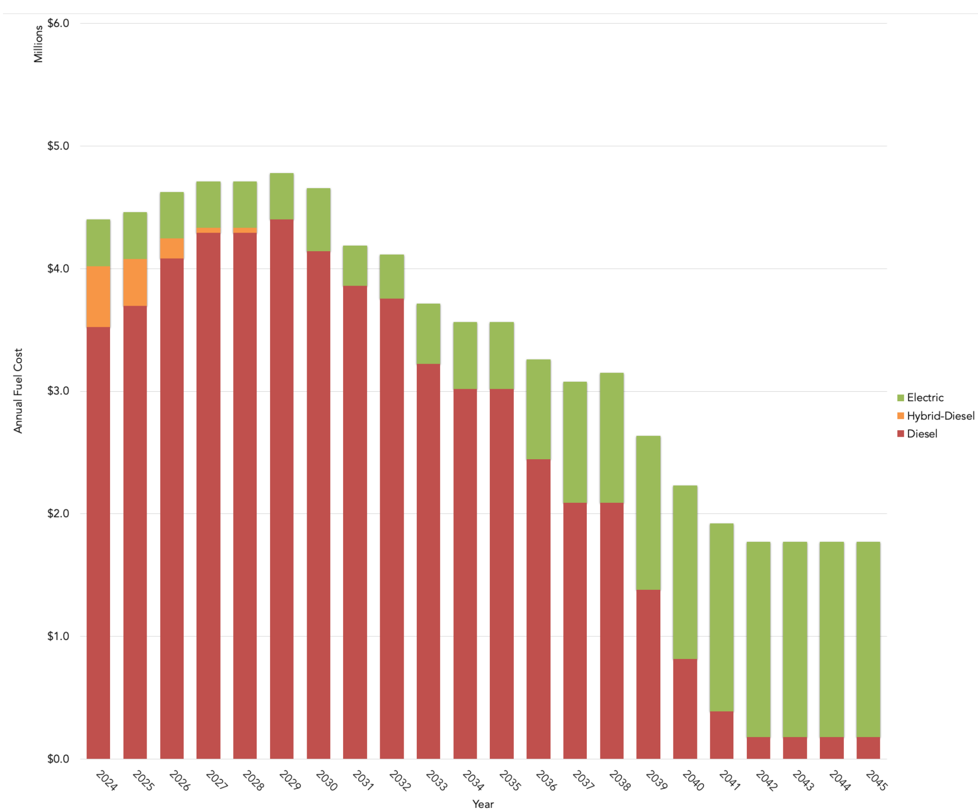
[2] https://pnwh2.com
[3] https://www.obsidianrenewables.com/projects.html
[4] https://douglaspud.org/about-us/hydrogen-facility/
[5] *https://www.opb.org/article/2022/05/14/hydrogen-valley-vision-for-southwest-washington-gets-boost-from-aussies-proposed-plant/*

Figure 24: Baseline Fuel Costs



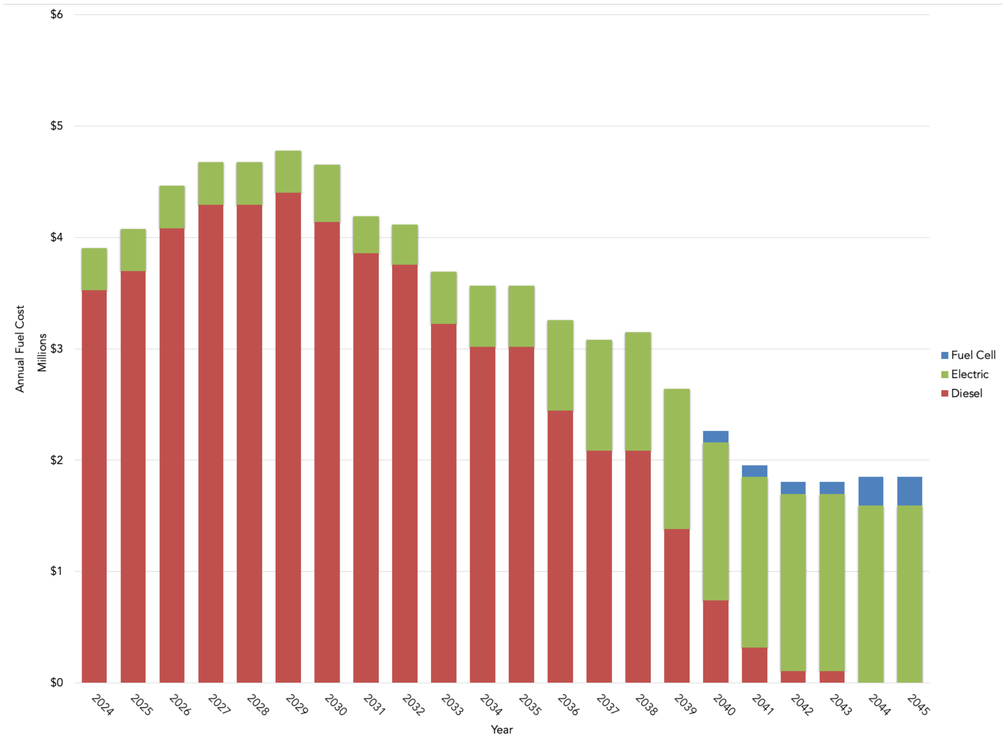
The BEB Depot Only scenario (Scenario 1), depicted in **Figure 25**, yields the lowest anticipated total fuel costs of approximately $74.9 million, or $3.6 million annually.

Figure 25: BEB Depot Only (Scenario 1) Fuel Costs



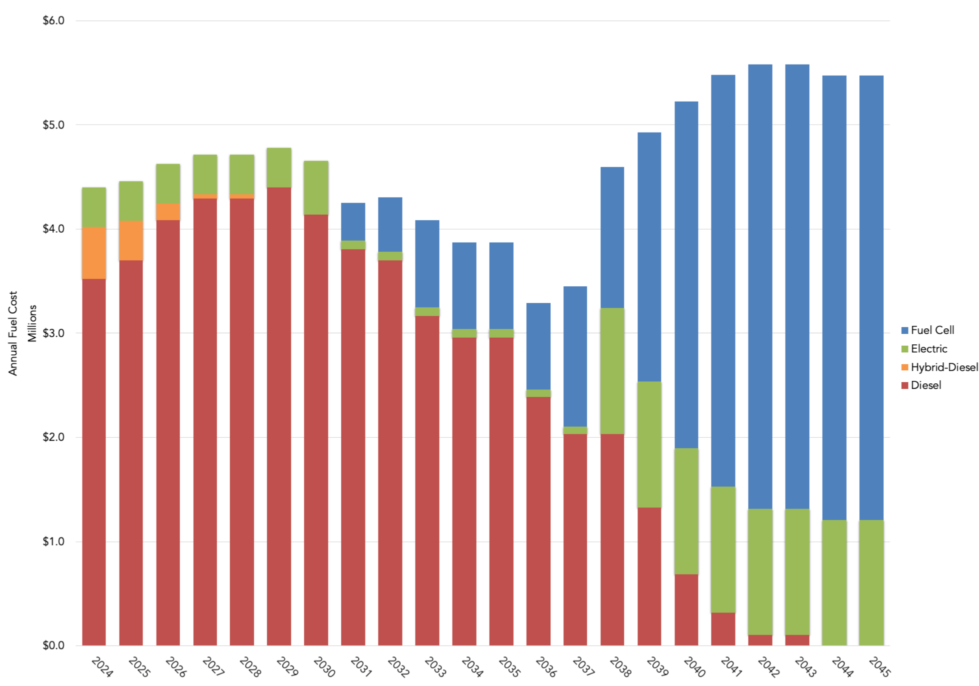
The total fuel costs projected for the BEB Depot and FCEB (Scenario 2) is estimated at approximately $75.1 million, or $3.6 million annually, as depicted in **Figure 26**.

Figure 26: BEB Depot and FCEB (Scenario 2) Fuel Costs



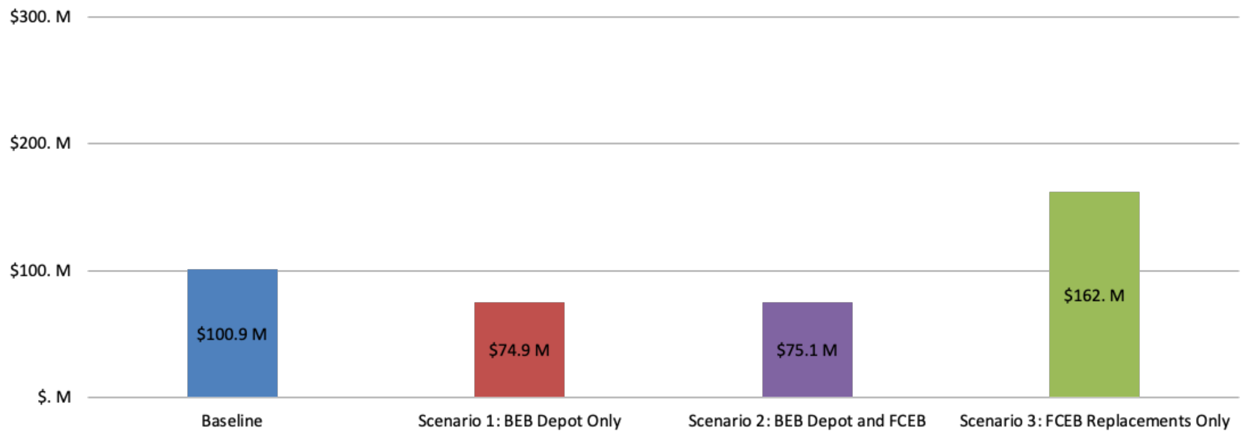
The FCEB Replacements Only scenario (Scenario 3) represents the highest total fuel cost, reaching approximately $162 million by the end of the transition period, or an average annual cost of approximately $7.7 million as depicted in **Figure 27**.

Figure 27: FCEB Replacements Only (Scenario 3) Fuel Costs



Results for all of the scenarios are included in **Figure 28**.

Figure 28: Cumulative Fuel Cost Summary



A sensitivity analysis was completed for the cost of hydrogen that include both the BEB Depot and FCEB and the FCEB Replacements Only scenarios. **Figure 29** below shows the anticipated cost of hydrogen across the transition period, as more hydrogen fuel cell vehicles are added to STA's fleet for the BEB Depot and FCEB scenario. The green line represents the cost of hydrogen across the transition period assuming an anticipated 3% annual decrease. The blue line assumes a constant cost of $9.00 per kilogram throughout the transition period. The sensitivity analysis results in estimated cost difference of approximately $100,000 throughout the period. The total cost is minimal as only 5 FCEBs are operating; however, this equates to an approximately $20,000 cost reduction per vehicle.

Figure 29: BEB Depot and FCEB – Hydrogen Cost Sensitivity Evaluation (Scenario 2)

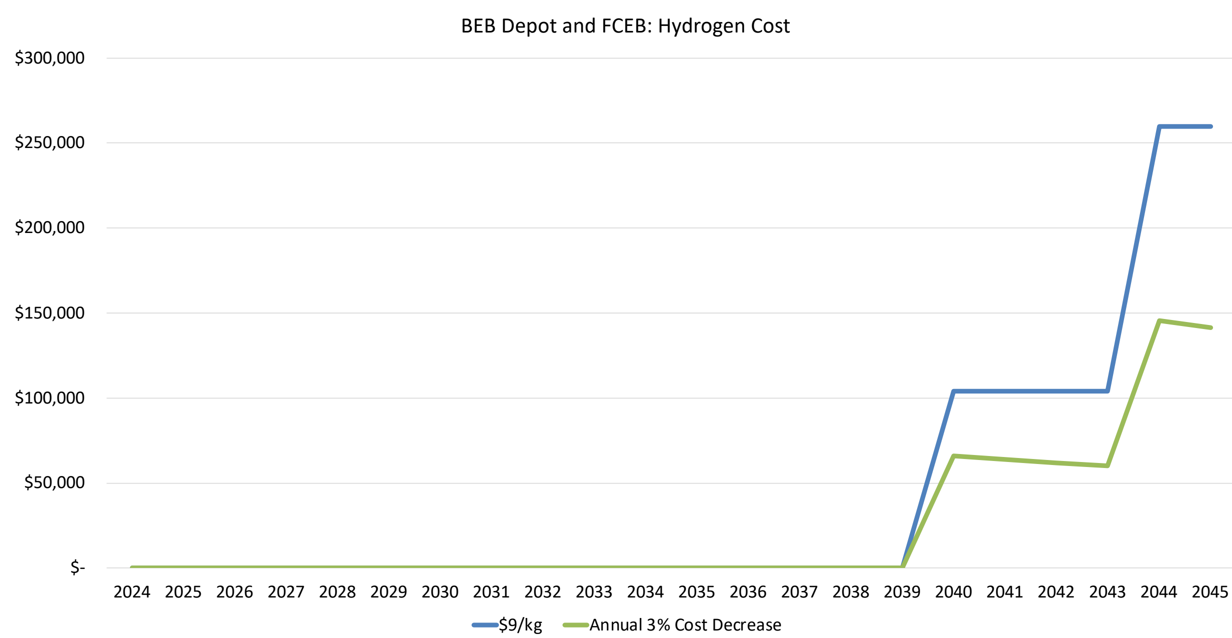
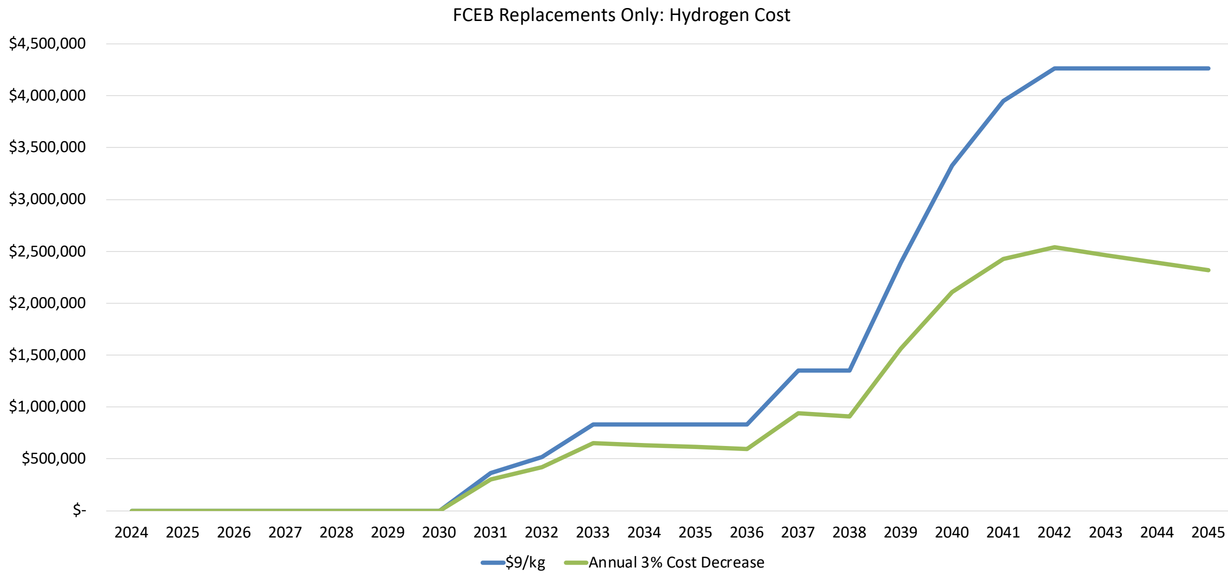


Figure 30 shows the anticipated cost of hydrogen across the transition period as more FCEBs are added to STA's fleet for the FCEB Replacements Only scenario. By the end of the transition period, the sensitivity analysis results in an almost $2M per year hydrogen fuel cost reduction.

Figure 30: FCEB Replacements Only Sensitivity Evaluation (Scenario 3)



The results of this sensitivity evaluation demonstrate the impact of the price per kilogram of hydrogen throughout the transition period on the total fuel cost. These projections are more conservative than those associated with the Regional Hydrogen Hub Program of less than $1 per kilogram production cost (not retail) in the next decade.

Section 11 - Facilities Assessment

Once bus and fueling requirements are understood for the ZEB transition, the requirements for supporting infrastructure were determined including the charging equipment for BEBs and/or hydrogen fueling equipment for FCEBs. The Facilities Assessment determines the scale of charging and/or hydrogen infrastructure necessary to meet the demands of the projected fleet and energy use estimated in the Fleet and Fuel Assessments, as well as all associated costs with installation of this infrastructure.

Current BEB Charging Infrastructure

With pilot BEB deployments, charging requirements are met relatively easily with a handful of plug-in pedestal chargers and minimal infrastructure investment. Scaling to a fleetwide BEB deployment requires a substantially different approach to charging and infrastructure upgrades. Plug-in charging may no longer be practical as charger dispensers installed in the parking area may create a hazard. Instead, an alternative approach is to use overhead pantograph or reel dispensers attached to gantries or to existing overhead roof structures like at the Northwest Boone Garage. As discussed in the Charging Analysis section, the Northwest Boone Garage currently has five (5) 150 kW ABB chargers, each equipped with two plug-in dispensers for sequential charging, as well as two (2) 450 kW ABB high capacity overhead chargers with drop down pantographs. STA currently has plans to install five (5) additional 150 kW ABB plug in chargers equipped with two (2) dispensers each in the garage as well. The SCC Transit Center (City Line) and Moran Station Park and Ride (Monroe-Regal) are each equipped with two (2) 450 kW ABB high capacity overhead chargers with drop down pantographs for on-route charging of BEBs. Based on discussions with STA, with the addition of the five (5) additional 150 kW plug-in chargers, electrical capacity provided by Avista has been reached with no ability to install additional chargers at the facility.

BEB Charging Infrastructure Assumptions

The BEB infrastructure cost estimates were developed assuming that all new charging will occur at a new facility location that is expected to be constructed by 2030. Cost estimates assume that charging will be installed at the time of construction of the new facility. Chargers are assumed to be 150 kW with two (2) dispensers each mounted with drop down pull cables or reals similar to the current infrastructure at the Northwest Boone Garage. Two (2) additional high capacity chargers (450 kW with drop down pantograph) are assumed to support the proposed future BRT service at a future transit center. The cost estimates include the costs for switchgear, charging infrastructure, and construction and commissioning, but do not include the costs for service expansion that could be required from Avista (or other utility supplier depending on the location of the facility). As the location of the future transit center is still being evaluated, the available electrical capacity is unknown at this time.

Rough-order-magnitude (ROM) cost estimates developed to build out charging options were based on work completed previously for the Northwest Boone Garage as well as recent costs developed for build outs at other locations across the country (San Diego Metropolitan Transit System, Broward County Transit, ABQ RIDE). All cost estimates for BEB infrastructure should be considered a Class IV estimated with an accuracy range of -30% to +50%.

A ROM estimate was developed for the Baseline to build out charging capacity at a future depot for overnight charging of BRT buses that are planned in the Baseline. In addition to the estimated $3.4M for depot buildout as shown in **Table 17**, approximately $1.5M is estimated for installation of two (2) on route chargers at a future transit center to support on-route charging of the BRT. As a result, the total ROM estimate for the Baseline is approximately $4.9M. The costs for the Baseline charging infrastructure are the same as those for the FCEB Replacements Only scenario, as both scenarios are only addressing BEB charging that is already planned.

Table 17: ROM Estimate for Depot Charger Construction - Baseline

Item	Units (EA)	Unit Cost ($)	Total Cost ($)	Source
Depot Charger Purchase – includes charger and 2 dispenser boxes	10	150,000	1,500,000	ABB
Electrical and Charger Install- includes switchgear, 3-phase feeders and breakers, low voltage conduit, communications	10	85,000	850,000	Unit Cost based on similar project
Indirect Costs (General Contractor) – mobilization/demob, overhead, profit, bonding, insurance	1	289,000	289,000	34% of installation
Service Feed Installation	1	100,000	100,000	Engineer's Estimate
Design	1	136,950	136,950	5% of project total not including contingency
Contingency	1	547,800	547,800	20% of construction costs
TOTAL			**3,423,750**	

The ROM estimate developed for the BEB Depot Only scenario assumed a total of 70 x 150 kW plug-in chargers each equipped with two (2) dispensers to support charging of up to 140 vehicles, including overnight charging of the future planned BRT vehicles. In addition to the estimated $23.2M for depot buildout of charging infrastructure, approximately $1.5M is estimated for installation of two (2) on route chargers at a future transit center to support on-route charging of the BRT. As a result, the total ROM estimate for the charging infrastructure for the BEB Depot Only scenario is approximately $24.7M. Details for the cost estimate for the depot installation are included in **Table 18**. As noted previously, these costs do not include potential costs associated with development of additional capacity that the utility may charge.

Table 18: ROM Estimate for Depot Charger Construction – BEB Depot Only

Item	Units (EA)	Unit Cost ($)	Total Cost ($)	Source
Depot Charger Purchase – includes charger and 2 dispenser boxes	70	150,000	10,500,000	ABB
Electrical and Charger Install- includes switchgear, 3-phase feeders and breakers, low voltage conduit, communications	70	85,000	5,950,000	Unit Cost based on similar project

Indirect Costs (General Contractor) – mobilization/demob, overhead, profit, bonding, insurance	1	2,023,000	2,023,000	34% of installation
Service Feed Installation	1	100,000	100,000	Engineer's Estimate
Design	1	928,650	928,650	5% of project total not including contingency
Contingency	1	3,714,600	3,714,600	20% of construction costs
TOTAL			**23,216,250**	

The ROM estimate developed for the BEB Depot and FCEB scenario assumes a similar costs to the BEB Depot Only scenario due similar number of BEBs to be charged. In addition, an estimated $4M is required for the purchase of a mobile hydrogen fueling system (see details later in this section) and the associated construction to complete the installation. As a result, the total ROM estimate for charger buildout for the BEB Depot and FCEB scenario is approximately $28.7M. As noted previously, these costs do not include potential costs associated with development of additional capacity that the utility may charge.

FCEB Infrastructure

A primary advantage of FCEBs is that fueling operations with hydrogen are similar to diesel or CNG fueling operations. As with electric, rather than building out the infrastructure all at once, projects are sized and scheduled to meet the near-term fueling requirements. There are three primary ways that hydrogen can be delivered as depicted in **Figure 31**.

Figure 31: Hydrogen Delivery

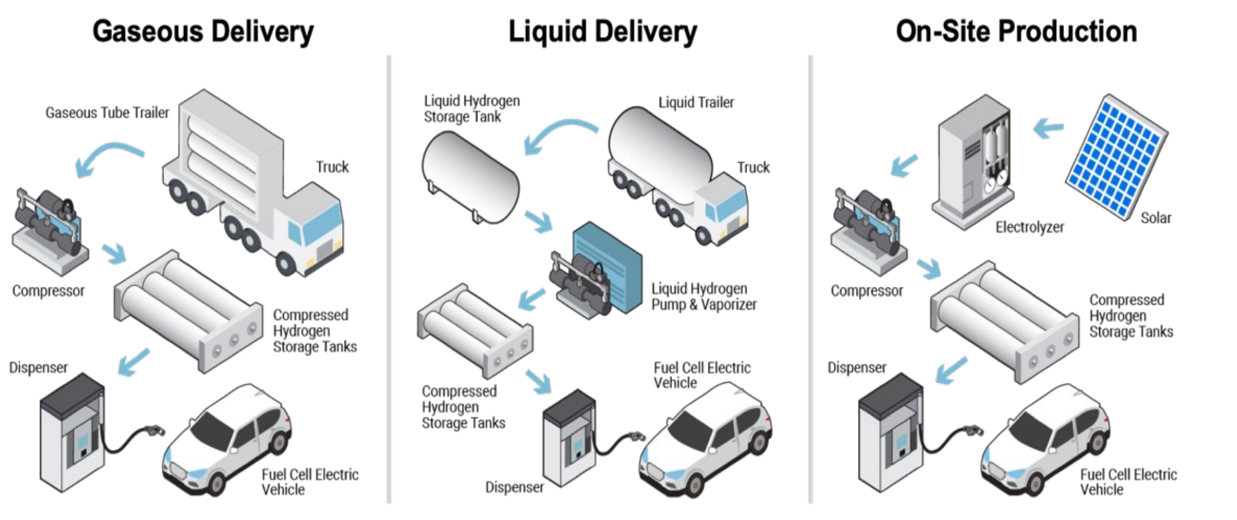


Figure 5. Summary of hydrogen fueling station delivery options (Image source: California Fuel Cell Partnership)

Hydrogen can be delivered either as a gas or as a liquid. Although gaseous hydrogen is more readily available today, it is not generally available in quantities that would support a large scale deployment of buses. In addition, liquid hydrogen is much more energy dense, therefore more energy can be stored on-site to support operations. Photos provided in **Figure 32** depict liquid hydrogen storage and fueling infrastructure at the Orange County Transportation Authority (top) and AC Transit (bottom).

Figure 32: Hydrogen Storage and Dispensing Examples

A third option is the on-site production of hydrogen through steam methane reformation (SMR) or electrolysis. SMR, utilizing methane, water, and heat, is the cheapest and most common method for hydrogen production in the United States today; however, significant quantities of carbon dioxide are produced as a bioproduct. Electrolysis utilizes water and energy to produce hydrogen with the only biproduct being oxygen. This is the preferred alternative for hydrogen production, particularly if it is produced using renewable energy sources. This is often referred to as green hydrogen and is 100% zero-emission. The United States government has made significant investment in building out hydrogen production infrastructure with $8 billion in funding for the Regional Hydrogen Hub program as well as providing tax incentives for producers/suppliers of green hydrogen.

Hydrogen fueling operations for STA assume trucking of liquid hydrogen to the depot, on-site storage at the depot, and the associated fueling equipment. Infrastructure costs were based on similar projects either completed to date or currently scoped. Upgrades to maintenance facilities including ventilation, electrical, lighting, and hydrogen detection equipment were not included in these estimates as it is assumed that the new facility would be designed to accommodate these safety design needs.

A mobile fueler, provided by a third-party hydrogen supplier, could be used to support the deployment of the first approximately ten (10) FCEBs. A mobile fueler consists of the equipment to store, compress, chill, and dispense hydrogen fuel to the buses. The fuelers are typically zero emission and do not require utility hook ups. Liquid hydrogen can be delivered by truck to the fueler. A pilot project utilizing a mobile fueler may be considered as it would give STA insight into long-term operations of hydrogen fueling in STA service. A photo of mobile fueling equipment provided by Air Products is included in **Figure 33**. Under the next phase of work, a scope and estimated costs for a mobile fueling project will be developed for STA consideration.

Figure 33: Mobile Hydrogen Fueling Trailer

In order to support a growing FCEB fleet beyond ten (10) vehicles, Phase I of permanent hydrogen fueling infrastructure would include installing a 25,000-gallon liquid hydrogen tank, two vaporizers, two pumps, and one assembly of high-pressure gaseous hydrogen storage vessels. These assumptions were based on an assumed fueling time of 12 to 18 minutes per bus, depending on the hydrogen storage capacity of the bus, and approximately two to three days of hydrogen storage. The footprint for this equipment is estimated to be approximately 30' x 90'. Two (2) dispensers would initially be installed with the ability to add additional dispensers as the fleet grows. To improve resilience, the hydrogen design would include a backup generator to operate the fueling equipment. Phase II of the installation of the hydrogen fueling infrastructure would involve adding additional liquid hydrogen storage, as necessary, and accompanying vaporization, pumping, and dispensing equipment. The equipment compound size would approximately double. A maximum of six (6) dispensers are expected to be required to support a full fleet of 114 FCEBs (and 56 BEBs). Detailed performance evaluation and design would be required to support the build out of hydrogen fueling infrastructure at a new facility. ROM costs for Phase I installation, which supports the BEB Depot and FCEB scenario is estimated at approximately $7M. Phase II of the installation, that would support the FCEB Replacements Only scenario is estimated at $13M.

Total infrastructure upgrade costs including both BEB charging and hydrogen fueling needs for the Baseline, BEB Depot Only, BEB Depot and FCEB, and FCEB Replacements Only scenarios are provided in **Table 19**. Please note that the charging infrastructure costs include redundant chargers but do not include backup generation in the event of power loss. Further evaluation and discussion will be required with Avista to determine options for resilience for a full build out. The hydrogen fueling options include backup power to allow hydrogen dispensing during power loss.

Table 19: Estimated Infrastructure Costs (ROM Estimates, -30% to +50% Range)

Scenario	Electrical Infrastructure ($)	Hydrogen Infrastructure ($)	Total Infrastructure ($)	% ZEB Fleet
Baseline	$4.9M	-	$4.9M	33%
BEB Depot Only	$24.7M	-	$24.7M	97%
BEB Depot and FCEB	$28.7M	$4M	$32.7M	100%
FCEB Replacement Only	$4.9M	$13M	$17.9M	100%

Section 12 – Emissions Assessment

The goal of the Emissions Assessment is to estimate the emissions associated with each of the scenarios by quantifying the diesel gallons reduced and the carbon dioxide production, reductions, and net savings.

A primary benefit of transitioning an entire fleet from fossil-fuel vehicles to zero-emission is the reduction of greenhouse gas (GHG) emissions. GHG emissions consist primarily of carbon dioxide (CO_2) but also include small amounts of methane (CH_4) and Nitrous Oxide (N_2O). In the transportation sector the vast majority of GHG emissions is from CO_2. For completeness, total GHG emissions are also calculated but the primary focus is on reduction of CO_2.

The primary sources of data to support this analysis are listed below:

- Calculation data from Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool
- Hydrogen emissions from natural gas SMR and electrolysis
- Avista Grid Mix – power sources utilized to generate electricity

Net Carbon Emissions Reductions

There are three types of emissions generally referred to in the context of zero emission vehicle transportation: well-to-wheel emissions, tailpipe emissions and upstream emissions.

Well-to-wheel emissions (WTW) include all emissions generated by the vehicle during operation *and* emissions generated by the powerplant or refinery to produce the energy used by the vehicle. WTW emissions are present for the generation of nearly all different fuels, be it diesel, gasoline, CNG or electricity, as these fuels require a combination of petroleum, natural gas and coal for their production (except in the case of electricity produced by 100% renewable energy).

Tailpipe emissions include all emissions generated by the vehicle during operation. It is assumed that ZEBs do not produce any tailpipe emissions.

Upstream emissions are generated by the fuel refinery or powerplant during extraction, processing and transportation of the fuel. In this analysis, upstream emissions are calculated by the difference between WTW and tailpipe emissions.

These emissions are calculated using Argonne National Labs' AFLEET tool. Emissions for electricity production uses specific inputs from Avista Utilities (STA's local utility) and estimated local upstream and vehicle emissions from the EPA to better estimate STA's impact. Avista Utilities' energy mix is as follows: Hydroelectric (48%), Natural Gas (33%), Coal (8%), Wind (9%), Biomass (2%).

Emissions Assessment Results

The figure below shows the annual CO_2 emissions for the baseline scenario and each of the three fleet transition scenarios discussed in this report. These results reflect delivered hydrogen produced using electrolysis as is projected for future production in the state of Washington.

Figure 34: Annual CO_2 Emissions by Scenario

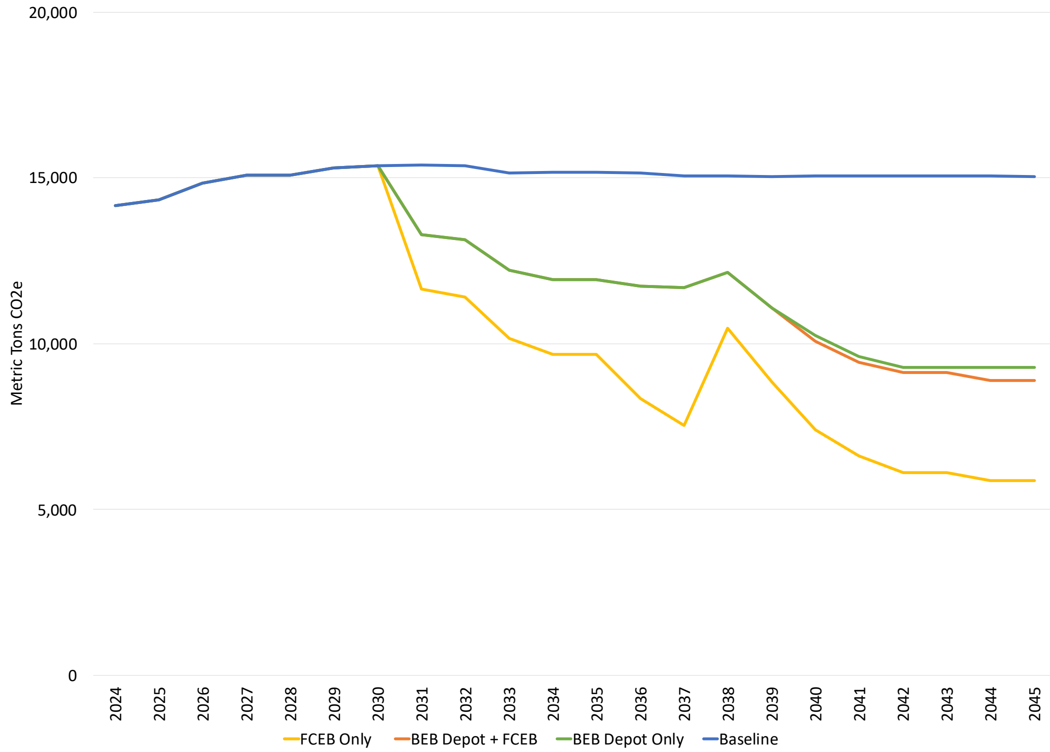


Table 20: Annual CO_2 Emissions Reductions by Scenario

Scenario	Estimated Total (tons CO2)	Reduction from Baseline (tons CO2)	% Reduction
Baseline	331,053	-	-
BEB Depot Only (Scenario 1)	270,386	60,667	18%
BEB Depot and FCEB (Scenario 2)	268,938	62,114	19%
FCEB Replacements Only (Scenario 3)	230,019	101,034	31%

Social Cost of Carbon

Externality costs of emissions can be quantified by their effect on agriculture, human health, property damage and other related factors. This estimate is widely known as the Social Cost of Carbon, or SCC. Using guidance developed by the Washington State Department of Commerce in *The Social Cost of Carbon: Washington State Energy Office Recommendation for Standardizing the Social Cost of Carbon When Used for Public Decision-Making Processes* prepared in 2014, the SCC for each scenario was calculated and provided in **Table 21** below. The costs shown are calculated using the projected emissions savings, based on a 2.5% discount rate as recommended in the guidance and converted to 2023 dollars based on inflation. This equates to a cost per metric ton of $97.42 in 2023 dollars.

Table 21: Estimated Social Cost of Carbon Savings

Scenario	Estimated Emissions (tons CO_2)	Net Emissions Reduction (tons CO_2)	SCC Savings Estimate (2023$)
Baseline	331,053	-	-
BEB Depot Only	270,386	60,667	$5.9M
BEB Depot and FCEB	268,938	62,114	$6.0M
FCEB Replacements Only	230,019	101,034	$9.8M

Section 13 - Total Cost of Ownership

The Total Cost of Ownership compiles the results from the Service, Fleet, Fuel, Maintenance, and Facilities assessments to provide estimated costs throughout the transition period. It includes selected capital and operating costs of each transition scenario over the transition timeline. There may be other costs incurred (i.e., incremental operator and maintenance training); however, these four assessment categories are the key cost drivers in ZEB transition decision-making.

It is important to note that cost escalation is only assumed for the capital vehicle purchase costs as STA has included a 3% inflation rate in their internal fleet procurement schedule and plan. All other cost categories do not include inflation in the analysis. In addition, cost reductions are not considered for economies of scale related to ZEB technology growth because there is no historical context with which to estimate. Future changes to STA's service level, depot locations, route alignments, block scheduling, etc. are unknown. The provided costs are an estimate, informed by detailed analysis using assumptions explained throughout this study. Also, this Total Cost of Ownership does not consider hydrogen fuel cost sensitivity scenario (3% reduction year over year beginning in 2025). The estimated Total Cost of Ownership for STA's ZEB transition as detailed in this analysis are provided in **Table 22** and **Figure 40**.

Table 22: Total Cost of Ownership for ZEB Transition (2024-2045)

Category	Baseline	BEB Depot Only	Depot BEB and FCEB	FCEB Replacements Only
Fleet	$239.9M	$430.8M	$437.3M	$482.2M
Maintenance	$256.5M	$254.9M	$254.6M	$197.8M
Fuel	$100.9M	$74.9M	$75.1M	$162M
Infrastructure	$4.9M	$24.7M	$32.7M	$17.9M
Total	**$602.2M**	**$785.3M**	**$799.7M**	**$859.9M**
Compared to Baseline	-	$183.1M	$197.5M	$257.7M
% ZEB Fleet	33%	97%	100%	100%

Results from the total cost of ownership analysis indicates that additional costs, expected to be between $183M to $257M more than Baseline, will be required to support a transition to ZEBs, whether BEBs, FCEBs, or a combination of technologies are selected.

Section 14 - Funding Needs Assessment

Funding Assessment Overview

STA allocates funds based on an established procurement timeline determined by the useful life of its buses. Transitioning to a zero-emission bus fleet increases overall fleet costs because of the incremental cost of ZEBs, the installation of new infrastructure, and required modifications to maintenance facilities. The current base market cost of 40' zero-emission transit buses is between $750,000 and $1,200,000, which is approximately $250,000 to $700,000 more expensive than diesel buses. Additionally, the necessary infrastructure to support these ZEBs adds to the financial burden of transitioning to a zero-emission fleet.

STA Funding Needs

Over the course of the transition period, STA plans to install charging infrastructure at a new maintenance facility and at an on-route transit center to support BRT service. STA may also consider deployment of hydrogen FCEBs and hydrogen fueling infrastructure in the future depending on availability of low-cost green hydrogen. To achieve these goals and move towards a successful deployment of zero-emission buses, STA projects will require between $456M and $500M in capital funding to cover the procurement of vehicles and infrastructure during the transition time period. This cost estimate includes the necessary costs for the transition, as determined via the cost analyses completed for the Fleet and Facilities Assessments.

Available Funding Resources & Resulting Funding Shortfalls

Based on the funding needs identified above and an assessment of STA's current projections, STA must identify resources that can cover this funding gap. Traditional formula funding will provide support for the transition to a zero-emission fleet (e.g., using formula funds to cover the base price of a zero-emission bus and applying for Low-No funds for the incremental cost difference), but it is likely STA will require additional funding to offset the higher costs associated with zero-emission technology.

STA is prepared to pursue funding opportunities at the federal, state, and local level, as necessary and as available.

Federal Funding sources STA is considering include:

- United States Department of Transportation (USDOT)
    - Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Grants
- Federal Transportation Administration (FTA)
    - Bus and Bus Facilities Discretionary Grant
    - Low-or No-Emission Vehicle Grant
    - Metropolitan & Statewide Planning and Non-Metropolitan Transportation Planning

  - Urbanized Area Formula Grants
  - State of Good Repair Grants
  - Flexible Funding Program – Surface Transportation Block Grant Program
- Federal Highway Administration (FHWA)
  - Congestion Mitigation and Air Quality Improvement Program
- Environmental Protection Agency (EPA)
  - Environmental Justice Collaborative Program-Solving Cooperative Agreement Program
- Volkswagen Environmental Mitigation Trust Funds
- Washington DOT Public Transportation Grants
- Washington State Climate Commitment Act Funding

Other potential future options include:

- Revenue bonds
- Tax increases
- Public-Private Partnerships

Section 15 - Partnership Assessment

Establishing and maintaining a partnership with the local electric utility is critical to successfully deploying zero-emission vehicles and maintaining operations. With the addition of BEBs to a fleet, a transit agency may become a utility's largest customer with added implications for grid-side infrastructure and agency operational costs. Early coordination and discussions can avoid costly delays and misaligned operational strategies while also revealing opportunities for lower operational costs and smart investments. Fortunately, electric utilities are beginning to develop electric vehicle rates and streamlined processes for charging infrastructure interconnections that can support successful zero-emission fleet deployments.

STA has a working relationship with the Avista's Manager of Electric Transportation, Rendall Farley. Avista has provided the necessary utility service for the Northwest Boone Garage and is currently working with STA to evaluate potential future locations for a new storage and maintenance depot. Avista has also established an electrical vehicle charging utility rate that STA is currently utilizing at the Northwest Boone Garage, SCC Transit Center, and Moran Station Park and Ride, for BEB charging. STA recognizes Avista as a critical partner in electrification and will continue to partner with Avista after the planning stages to coordinate fleet expansion efforts effectively.

In addition, STA partnered with New Flyer and Proterra for the deployment of their first BEBs. In addition, Proterra provided the charging infrastructure and design and installation services for the charging equipment at Northwest Boone Garage, SCC Transit Center, and Moran Station Park and Ride as part of a competitive procurement through the Small Starts Grant that supported the City Line BRT service project. STA may continue to partner with qualified OEMs and providers in the future if FCEBs and hydrogen fueling infrastructure is pursued or as part of a hydrogen fueling initial or pilot deployment.

Section 16 - Workforce Analysis

STA is committed to transition to a 100% zero-emission fleet. In order to support ZEB operations at this scale, STA has identified opportunities to ensure the current and future workforce is prepared to manage its full fleet of ZEBs. This Workforce Development Analysis focuses on ZEB operations and maintenance.

In alignment with FTA's requirements under the Workforce Development for the Low No and Buses and Bus Facilities Programs, STA is currently working to build a ZEB workforce program in consultation with labor representatives, and may look to build out an internship and apprenticeship program to address STA's future operational and maintenance needs.

Workforce Analysis Overview

Developing and training the workforce required to operate and maintain ZEBs requires significant investment and planning. STA is experienced in recruiting, hiring, training, and integrating new staff to ensure that employees are qualified to provide quality services. STA recognizes that a trained ZEB workforce is not readily available and the transit industry must address the shortage of technicians and mechanics together.

STA plans to develop and maintain a qualified ZEB staff by hiring qualified new staff and retraining existing staff who have previously worked with ICE systems. Meaningful investment is required to upskill maintenance staff and bus operators that were originally trained in diesel vehicle maintenance and fossil fuel fueling infrastructure. Transitioning to zero-emission vehicles is a paradigm shift for all aspects of transit operations including but not limited to scheduling, maintenance, and yard operations. STA's workforce development activities will address the identified skills and tools needed for each relevant team.

STA is collaborating with labor representatives in developing training needs and a training program for the transition to zero-emission buses.

Completed Trainings

STA's drivers and maintenance technicians have received training through Proterra, New Flyer, and ABB as part of the initial ZEB deployments from 2020 through 2023.

Identified Training Needs

Several training needs have been identified by STA staff in order to support the transition to a 100% ZEB fleet. STA is committed to ensuring new training and technologies do not displace current workers and has placed a priority on training existing staff as well as developing an apprenticeship program. The identified training needs are anticipated to evolve as STA's fleet expands. As such, the following training plans are intended to provide a framework.

1) *Internship and Apprenticeship Programs*
   STA has begun conversation with our human resources department and training department in order to begin preparing a workforce transition plan. We are currently evaluating internships and training programs related to individuals currently in school and at apprenticeship programs for graduates.

2) *Expand the Train-the-trainer approach*
Many procurement contracts include train-the-trainer courses through which small numbers of agency staff are trained and subsequently train agency colleagues. This method provides a cost-efficient opportunity to minimize the need for external training while maintaining institutional knowledge and providing widespread agency training on new equipment and technologies. STA currently utilizes a Train-the-Trainer approach and will expand the system to support ZEB training. Third party resources will continue to be used as needed.

3) *Vendor training from New Flyer, Proterra, and Charger Suppliers*
STA plans to take advantage of trainings from the bus manufacturers and infrastructure suppliers, including maintenance and operations training, maintenance and safety, first responder training, and other trainings that may be offered by the providers. OEM trainings provide critical information on operations and maintenance aspects specific to the equipment model procured. STA training staff will work closely with the OEMs providing vehicles to ensure all mechanics, service employees, and bus operators complete necessary training prior to deploying ZEB technology. STA staff will also be able to bring up any issues or questions they may have about their training with their trainers. Additionally, trainers will observe classes periodically to determine if any staff would benefit from further training.

4) *ZEB tools*
The following tools have been identified as top needs to bring in-house as more of the maintenance and management falls to internal staff with an expanded ZEB fleet.
    - Battery lift table
    - Bus Simulator (under consideration)

5) *ZEB Training from other transit agencies*
STA will consider zero-emission training offered by other transit agencies. One such agency is SunLine Transit Agency, which provides service to the Coachella Valley and hosts the West Coast Center of Excellence in Zero Emission Technology (CoEZET). The Center of Excellence supports transit agency adoption, zero-emission commercialization, and investment in workforce training. Similarly, AC Transit offers training courses covering hybrid and zero-emission technologies through their ZEB University program. STA is considering taking advantage of these trainings offered by experienced agencies.

6) *National Transit Institute training*
STA will consider NTI course training if zero-emission specific training courses are offered.

7) *Local Partnerships and Collaborations*

Resources and Strategies to Meet Identified Needs

STA envisions needing resources to address the above identified training programs. As STA continues to develop the Workforce Development Plan, these resources and funding needs will be identified.

Workforce Development Timeline

Demand for skilled and experienced workers will increase rapidly as new clean transportation policies and programs take effect and as numerous agencies begin fleet transitions. Aligning workforce development activities with the fleet transition timeline ensures that a qualified workforce is ready and available to support a successful deployment.

Workforce development is an ongoing process that must continue as fleets scale up and deploy additional zero-emission vehicles. To ensure that the workforce scales efficiently and cost-effectively, STA will employ training strategies that support additional zero-emission vehicle deployments in the future.

Section 17 - Conclusions and Recommendations

ZEB technologies are in a period of rapid development and change. BEBs will require significant investment in facilities and infrastructure and may require changes to service and operations to manage their inherent constraints. On the other hand, FCEBs are believed to provide an approximate operational equivalent to diesel or CNG, however, the current incremental cost of buses, fueling infrastructure, and fuel places this technology at a disadvantage.

STA has committed to a minimum fleet of 40 BEBs by the end of 2023. Charging requirements for these BEBs will utilize all of the existing electrical capacity at the Northwest Boone Garage. As a result, other alternatives including building out a new storage and maintenance facility to allow for further BEB charging or hydrogen fueling were considered as part of this evaluation, though the cost of the land and construction of the facility were not considered in the evaluation. Based on this evaluation, STA may be able to reach a 97% BEB fleet by 2045; however; to reach a 100% ZEB fleet, other alternatives such as on-route charging or the purchase of FCEBs would need to be implemented. In a mixed fleet scenario of depot charged BEBs and FCEBs, FCEB costs are adversely impacted by the currently high FCEB capital costs. The cost of an FCEB is approximately two times that of a comparable diesel vehicle and hydrogen costs are currently estimated at $9/kg. Hydrogen costs would need to be reduced to less than approximately $5/kg to be comparable to current diesel costs. The availability of green hydrogen is expected to increase significantly in the future as a result of federal, state, and private investment in production. As a result, the cost per kilogram may be significantly reduced in the future. These developments would positively impact the viability of incorporating FCEBs into the fleet.

Recommendations for STA are as follows:

1. **Complete evaluation of FCEB Pilot or Initial Deployment:** Evaluate the availability and cost of completing an initial deployment or pilot of FCEBs utilizing mobile hydrogen fueling. The plan, if endorsed by STA, could be used to request federal funding through a competitive grant program (Low No or Buses and Bus Facilities) to fund the deployment.
2. **Complete Facility Master Plan:** STA is currently preparing a facility master plan to determine future facility needs, including evaluation of locations for a second storage and maintenance facility that could be used to support expansion of the ZEB fleet.
3. **Consider design/build/operate agreements with hydrogen suppliers for build out of hydrogen fueling.** If utilization of hydrogen FCEBs is selected in the future, then consider agreements with a qualified firm to design, build, and operate (DBO) the hydrogen supply and fueling infrastructure. This typically requires an agreement to purchase fuel from the supplier at a set rate per kilogram of fuel delivered or dispensed. These agreements ensure consistent operation of the fueling equipment and supply.

The transition to ZEB technologies represents a paradigm shift in bus procurement, operation, maintenance, and infrastructure. The technology requires significant development before it is ready to support fleetwide transitions. However, it is only through a continual process of deployment with specific goals for advancement that the industry can achieve the goal of economically sustainable, zero-emission public transit. Ultimately, the ZEB technology that is most efficient and sustainable to operate will evolve into either the majority ZEB solution or the only ZEB solution.

Section 18 – References

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