Zero-Emission Bus Fleet Transition Study Update 2025

June 2025

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Executive Summary

MTS engaged the Center for Transportation and the Environment (CTE) to perform a zero- emission bus (ZEB) transition study in March 2018. The study's goal was to create a plan for a 100% zero-emission fleet by 2040 to be in compliance with the Innovative Clean Transit (ICT) regulation enacted by the California Air Resources Board (CARB). The results of the study were used to inform MTS Board members and educate MTS staff of estimated costs, benefits, constraints, and risks to guide future planning and decision making. In addition to the ZEB transition study, MTS initiated a pilot program to test ZEB technology in their service to better understand the technology and inform decision making.

In support of the Pilot in 2019, MTS installed six (6) 62.5- kilowatt (kW) ChargePoint vehicle chargers at the Imperial Avenue Division (Imperial Ave) and deployed six (6) 40-foot New Flyer battery-electric buses (BEBs). In 2020, MTS installed an additional two (2) ChargePoint chargers each at South Bay Bus Maintenance Facility (South Bay), Kearny Mesa Division (Kearney Mesa), and the East County Bus Maintenance Facility (East County) to facilitate BEB pilot operations throughout the service area. Two (2) 40-foot Gillig BEBs were deployed in early 2021 and later December 2021, five (5) additional Gillig BEBs were deployed. The pilot program ended shortly after that. In September 2023, MTS finished constructing an overhead gantry that includes twenty-four (24) Schunk pantographs which is powered by eight (8) Heliox 180kw charging cabinets at the South Bay Division. Shortly after the overhead structure was completed, twelve (12) 60-foot New Flyer BEBs were deployed to serve a dedicated route. Thirteen (13) BEBs were purchased in 2024 and will be delivered in Q2 2025.

Zero-emission technologies considered in this study update include 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's 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 to extend the range. The electric drive components and energy source for a BEB and FCEB are illustrated in Figure 1.

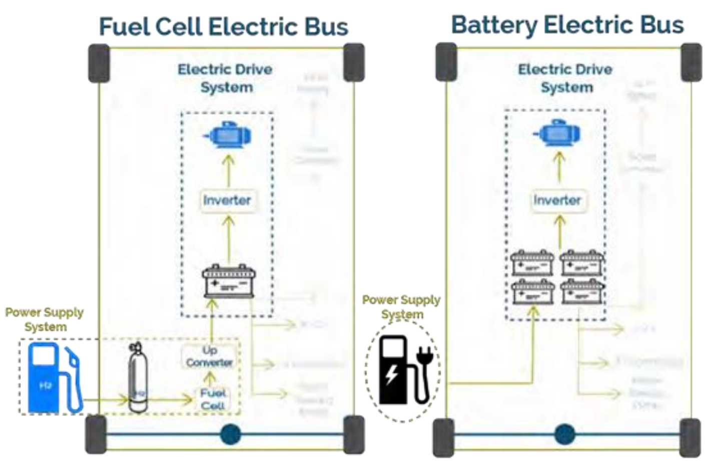

Figure ES-1 – Battery and Fuel Cell Bus Schematic

On December 14, 2018, CARB enacted the ICT regulation with a statewide goal, requiring all California public transit agencies to gradually transition to a 100 percent (%) zero-emission bus (ZEB) fleet. The ruling specifies the timeline for the required annual percentage of new bus procurements that must be zero-emission, starting with 25% of new bus purchases in 2023 and ramping up to 100% of new bus purchases in 2029. Following this schedule is intended to lead to a 100% zero-emission fleet in 2040. However, there are some waivers that allow for purchase deferrals in the event of economic hardships or if the technology has not matured to meet the service requirements of a given route. These concessions recognize that the technology may cost more than current technologies on a life cycle basis and the technology may not currently meet all service requirements.

CTE worked closely with MTS staff during the original transition study to develop the approach, define the assumptions, and confirm the results. The approach to the study was based on analysis of five (5) scenarios:

1. Baseline
2. BEB Depot-Only Charging
3. BEB Depot and On-Route Charging
4. FCEB Only
5. Mixed BEB and FCEB

A primary assumption for the transition analysis was that MTS is unable to increase fleet size as a strategy to overcome BEB range limitations to achieve a 100% ZEB transition due to space constraints present at the current MTS depots. The Baseline scenario assumed that there were no changes to the current technology for bus procurements (e.g. compressed natural gas [CNG], gasoline, diesel, propane) and is used for comparison to the other ZEB transition scenarios. The BEB Depot-Only Charging and FCEB Only scenarios were used as the 'bookends' to help identify potential constraints or risks in scaling to fleetwide adoption of ZEBs that may not be readily apparent from pilot-bus deployments.

Mixed BEB and FCEB scenario was developed with the underlying assumption that neither exclusively BEB and FCEB technology is suitable for 100% of the fleet replacement due to inherent constraints. Since the completion of the 2020 study, MTS has adopted the Mixed BEB and FCEB scenario to implement towards the transition. While manufacturers have produced BEBs for each of the vehicle lengths and types used at MTS, only 40' and 60' BEBs have completed Altoona testing and are applicable under the CARB ICT regulation. Currently, FCEBs have only been produced in 40' and 60' models. In addition, due to the limited deployment of FCEBs in service in the United States, FCEB and hydrogen fuel costs remain high. These costs were predicted to come down in the future as more vehicles are deployed and as hydrogen production ramped up; however, there is currently no basis for assuming future cost reductions. Significant investments in hydrogen production and distribution infrastructure are required and will take years to develop to gain a better understanding of the long-term costs for FCEB deployment.

Improvements in technology beyond the current state are expected, but there is no indication of when we may see the BEB technology improve to the point of one-for-one replacement of internal combustion engine vehicles or when the cost of FCEB or hydrogen fuel will decrease to competitive levels. As a result, when considering all the various scenarios, this study can be used to develop an understanding of the range of costs that may be expected for MTS' ZEB transition.

In the 2020 transition study, CTE completed the following assessment to develop cost estimates for each transition scenario. The Baseline and Mixed BEB & FCEB figures below have been updated and compared to reflect 2025 costs.

1. Fleet Assessment
2. Fuel Assessment
3. Infrastructure/Facilities Assessment
4. Maintenance Assessment
5. Total Cost of Ownership Assessment

These assessments result in a total cost of ownership, inclusive of capital investments (ZEBs and fueling infrastructure) and operating expenses (fuel and maintenance) over the transition period (2020 – 2040) for the Baseline and Mixed BEB & FCEB scenario. The table and figure below provide a side-by- side comparison of the cumulative transition costs for the Baseline and Mixed BEB & FCEB approach.

	Baseline	**Mixed BEB and FCEB**
Fleet	$1,263,176,640.87	$1,543,816,832.87
Fuel	$380,886,639.99	$441,231,673.26
Infrastructure/Facilities	$-	$487,263,937.50
Maintenance	$525,268,109.81	$530,393,271.58
Total	$2,169,331,390.67	$3,002,705,715.20
Incremental Cost Over Baseline		**$833,374,324.53**
% ZEB in 2040	**5%**	**99%**

Table ES-1 – Total Cost of Ownership, Baseline vs Mixed BEB & FCEB

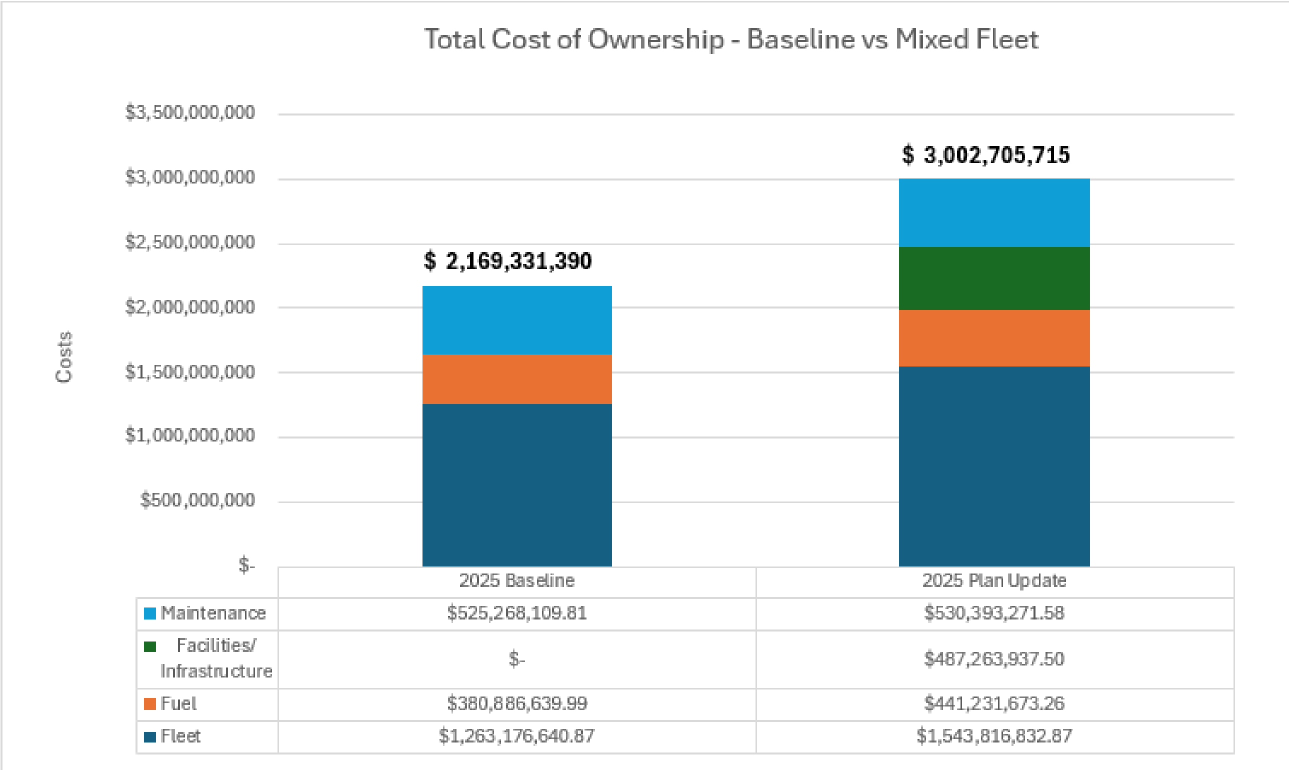

Figure ES 2 – Total Cost of Ownership, Baseline vs. Mixed BEB & FCEB

The Mixed BEB and FCEB approach is projected to transition approximately 99% of the fleet, with an incremental cost of approximately $833 million by 2040. There will be expected complexities with managing the fleet through the transition that would require maintaining existing internal combustion engine vehicle infrastructure (CNG, propane, and gasoline), installing new BEB infrastructure, and installing new FCEB fueling infrastructure. Space constraints at the depot will require careful planning if this path is continued.

MTS has accumulated ZEB credits from their procurement of ZEBs prior to 2023. These credits can be used in place of ZEB purchases to satisfy CARB's ZEB procurement requirements which started in 2023. With the purchase of thirteen (13) BEBs to support the ZEB pilot operations in 2019 and 2020, and the purchase of twelve (12) BEBs to support a new service in 2021, MTS recently had twenty-five (25) ZEB credits that can be applied to ZEB purchase requirements from 2023 and beyond. In February 2025, the MTS Board of Directors approved a request to CARB, utilizing seven (7) credits for FY25 bus purchases and thirteen (13) credits for FY26 bus purchases, both extinguishing the 25% ZEB requirement for those fiscal years. These developments have been incorporated into this analysis.

As a result, recommendations for MTS are as follows:

1. Remain proactive with ZEB deployments: MTS has been proactive in the purchase and deployment of BEBs throughout the ZEB Pilot Program and since it has ended. To incorporate FCEBs into the fleet, lower fuel costs and lower costs associated with the production hydrogen will be required. MTS should move forward carefully, taking

advantage of various grant and incentive programs to offset the incremental cost for ZEB deployment.Target specific routes and blocks for early ZEB deployments: MTS should consider the strengths of given ZEB technologies and focus those technologies on routes and blocks that take advantage of their efficiencies and minimize the impact of the constraints related to the respective technologies. Technologies cannot follow a "one-size-fits-all" approach from either a performance or cost perspective. Matching technology to the service will be a critical best practice.

2. Continue with BEBs and consider FCEBs: At this stage, it is too early to tell which technology will dominate the market 10 to 20 years from now. Having the capability to deploy both ZEB technologies creates an opportunity for MTS to fully assess BEBs and FCEBs to determine which technology can best meet the operational range requirements while being financially efficient and sustainable.
3. Do not over commit to one form or brand of technology over another. ZEB and charging technology is rapidly changing each day as battery chemistry develops to help improve bus efficiency/range and charging equipment becomes more sophisticated. Commitment to one form and brand of technology can have a detrimental impact to efficient operations and service as a whole, especially if significant advancements are assumed to be made.
4. Continue to maintain or increase the level of service throughout the ZEB transition. As outlined in the ICT regulation, CARB does not expect, recommend or require a transit agency to reduce service at the expense of completing the transition. If the transition costs or technology limitations result in service reductions, it would be counter-productive to greenhouse gas reduction by propelling transit riders to utilize personal vehicles and increase VMT's and overall emissions.

The transition to ZEB technologies represents a paradigm shift in bus procurement, operation, maintenance, and infrastructure. 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. MTS, with endorsement and approval from their Board of Directors, elected to pursue a mixed-use scenario that will allow them to initially deploy BEBs and explore possible opportunities and funding mechanisms to deploy FCEBs in service where BEBs are not able to meet range requirements. MTS will continue to monitor technology improvements and funding availability to accelerate the transition to a 100% zero-emission fleet. Evaluation will be completed in annual updates provided to the MTS Board of Directors and CARB.

Introduction

Founded in 1975, the San Diego Metropolitan Transit System (MTS) provides bus and light rail services to the urban areas of San Diego County and rural parts of East County, generating over 92 million passenger trips per year.

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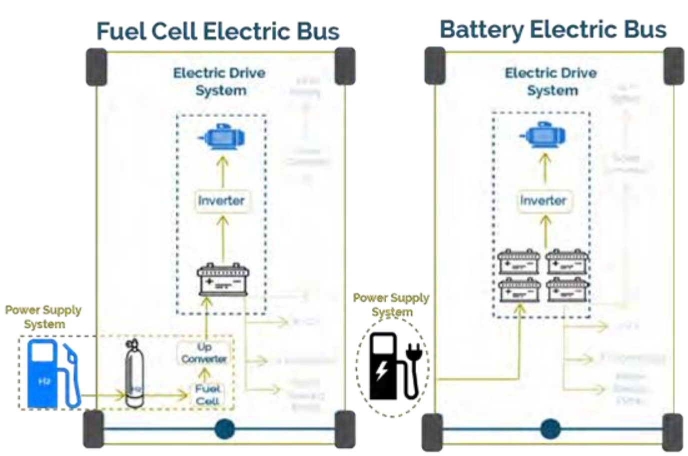


Figure 1 - Battery and Fuel Cell Electric Bus Schematic

CARB's Innovative Clean Transit Regulation

On December 14, 2018, CARB enacted the Innovative Clean Transit (ICT) regulation requiring all California public transit agencies with the statewide goal to gradually transition to a 100% ZEB fleet. The ruling specifies the timeline for the required annual percentage of new bus procurements that must be zero-emission, starting with 25% of new bus purchases in 2023 and ramping up to 100% of new bus purchases in 2029. This section summarizes key elements of the ICT.

ZEB Purchase Requirements

MTS' fleet exceeds 100 buses and, as such, is considered a "large" agency by CARB. All new bus purchases must include a specified percentage of ZEBs in accordance with the following schedule:

Starting January 1	Percent of New Bus Purchases
2023	25%
2024	25%
2025	25%
2026	50%
2027	50%
2028	50%
2029	100%

Table 1 – CARB Innovative Clean Transit (ICT) ZEB Transition Timeline.

Purchase of cutaway/minibus, over-the-road, double-decker, or articulated buses may be deferred until the latter of either January 1, 2026, or until a model of a given type has passed the "Altoona" bus testing procedure and obtained a Bus Testing Report. As of the date of this report, mostly heavy- duty 30', 35', 40' and 60' ZEBs and a few medium-duty ZEBs have passed Altoona bus testing.

ZEB Bonus Credits

ZEB Bonus Credits were earned by agencies that acquired ZEBs early and could have been used against future compliance requirements. To have earned bonus credits, ZEBs would have had to be placed into service according to the following schedule. Bonus credits expire December 31, 2028.

Technology	Placed in Service	ZEB Bonus Credit
BEB	As of January 1, 2018	1
FCEB	As of January 1, 2018	2
FCEB	January 1, 2018 to December 31, 2022	1

Table 2 - ZEB Bonus Credits Applied to CARB ICT Transition Schedule

ZEB Credits

Although MTS did not generate ZEB Bonus Credits to utilize toward compliance, ZEBs purchased in advance of the new purchase requirements may be used as credits toward annual ZEB procurement compliance. As such, BEBs purchased in 2019 (6), 2020 (7), and 2021 (12) represent twenty-five (25) ZEB credits that may be applied toward purchase compliance with the ICT regulation in the early years of the transition. In February 2025, the MTS Board of Directors approved a request to CARB, utilizing seven (7) credits for FY25 bus purchases and thirteen (13) credits for FY26 bus purchases, both extinguishing the 25% ZEB requirement for those fiscal years. These developments have been incorporated into this analysis.

Exemptions

Agencies may request exemption from ZEB purchase requirements in a given year due to circumstances beyond the transit agency's control. Acceptable circumstances include:

- Delay in bus delivery is caused by the setback of construction schedule of infrastructure needed for the ZEB.
- Available depot-charged BEBs cannot meet a transit agency's daily mileage needs.
- Available ZEBs do not have adequate gradeability performance to meet the transit agency's daily needs
- When a required ZEB type for the applicable weight class based on gross vehicle weight rating (GVWR) is unavailable for purchase because the ZEB has not passed Altoona, cannot meet ADA requirements, or would violate any federal, state, or local regulations or ordinances.
- When a required ZEB type cannot be purchased by a transit agency due to financial hardship and the agency can demonstrate that they have applied for applicable ZEB funding mechanisms.

Reporting Requirements

Started on March 31, 2021, and continuing every year thereafter through March 31, 2050, each transit agency must submit an annual ICT ZEB compliance report by March 31 for the prior calendar year. The initial report was submitted on March 31, 2021, and included the number and information of active buses in the transit agency's fleet as of December 31, 2017.

ZEB Transition Planning

ZEB TRANSITION PLANNING METHODOLOGY

The 2020 study used CTE's ZEB Transition Planning Methodology, which was a complete set of analyses used to inform agencies in converting their fleets to zero-emission. The methodology consisted of data collection, analysis and assessment stages. The stages were sequential and were built upon findings in previous steps. The work steps specific to the 2020 study are outlined below:

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

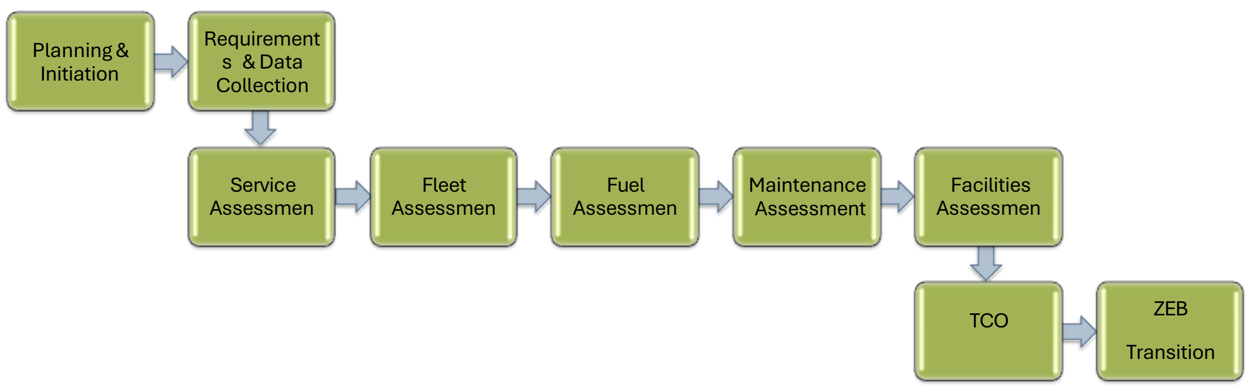


Figure 2 – CTE's ZEB Transition Study Methodology

The Planning and Initiation phase built 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 MTS staff to plan the overall project scope and all deliverables throughout the full life of the study. CTE conducted an "Assumptions Workshop" to start the Requirements & Data Collection phase. The assumptions collected during this phase provide key parameters used in each of the Assessment phases that follow. CTE collected fleet, operational, maintenance, and facilities information to define the "As Is" or baseline scenario. CTE also collected route and block mileage and duty cycle information as the basis for the Service Assessment.

During the Service Assessment, CTE worked with MTS staff to assess how MTS fleet vehicles are used and to identify service requirements. CTE leveraged several different tools and methods, including route modeling and simulation software, and empirically derived screening models based on real world operational data, to calculate expected energy efficiency, range, endurance, and energy consumption to identify any limitations or constraints to the application of electric vehicle technologies. Results from modeling were used to estimate the achievability of every block in MTS' network using BEBs and FCEBs. 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. The Fleet Assessment developed a projected timeline for replacement of current buses with ZEBs that is consistent with the agency's Fiscal Year 2025 fleet replacement plan. This assessment also included a projection of fleet capital cost over the transition lifetime, and it can be optimized with regard to any state mandates, like CARB's ICT regulation, or to meet agency goals such as minimizing cost or maximizing service levels.

The Fuel Assessment merges the results of the Service Assessment and Fleet Assessment to determine annual fuel requirements and associated costs. The Fuel Assessment calculated energy costs through the full life of the transition for each scenario, including the agency's current internal combustion engine vehicles. To more accurately estimate BEB charging costs, a focused Charging Analysis was performed to simulate daily system-wide charging use. As current technologies are phased out in later years of the transition, the Fuel Assessment calculated the increasing energy requirements for ZEBs. The Fuel Assessment also provided a total energy cost over the transition lifetime.

The Facilities Assessment determined the necessary infrastructure to support the projected zero-emission fleet based on results from the Fleet Assessment and Fuel Assessment. The result showed quantities of hydrogen and battery electric infrastructure and calculates associated costs.

The Maintenance Assessment calculated all projected fleet maintenance costs over the life of the project. This included costs related to existing internal combustion engine vehicles remaining in the fleet, as well as new BEBs and FCEBs, calculated for each scenario.

The Total Cost of Ownership Assessment compiled results from the previous assessment stages and provided a comprehensive view of all associated costs, over the transition lifetime.

Requirements Analysis

BASELINE DATA COLLECTION

It is essential to understand the key elements of MTS' service to evaluate the costs associated with a full-ZEB transition. Key data elements of the current MTS service were compiled and included the following:

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

At the time of this study update, the MTS bus fleet totaled 753 vehicles that provide service on nearly 100 fixed routes with additional, complementary, on-demand paratransit service. A breakdown of size and fuel type is shown in Table 3 and Table 4. Bus services operate out of five divisions, all of which include operations, maintenance and fueling functions: Imperial Avenue Division (Imperial Ave), Kearney Mesa Division (Kearney Mesa); South Bay Bus Maintenance Facility (South Bay); East County Bus Maintenance Facility (East County); and Copley Park Maintenance Facility (Copley). MTS' fixed route minibuses and on-demand paratransit buses operate from Copley.

Division	Bus Length [ft]				Totals
	22, 29, 32	40	45	60	
Copley	149	0	0	0	149
East County	3	69	24	0	96
Kearny Mesa	0	71	0	42	113
Imperial Ave	0	99	0	44	143
South Bay	0	213	0	39	252
Totals	**152**	**452**	**24**	**125**	**753**

Table 3 - Fleet Breakdown by Division and Length

Division	Fuel Type					Totals
	CNG	Diesel	Propane	Gasoline	Electric	
Copley	0	0	135	14	0	149
East County	91	0	0	3	2	96
Kearny Mesa	111	0	0	0	2	113
Imperial Ave	136	0	0	0	7	143
South Bay	238	0	0	0	14	252
Totals	**576**	**0**	**135**	**17**	**25**	**753**

Table 4 - Fleet Breakdown by Division and Fuel Type

2025 Transition Plan Blocks (WK, SAT, & SUN)					
Division	Bus Length [ft]				Totals
	22, 29, 32	40	45	60	
Copley	40	0	0	0	**40**
East County	6	86	16	0	**108**
Kearny Mesa	0	137	0	74	**211**
Imperial Ave	0	170	0	87	**257**
South Bay	0	344	0	102	**446**
Totals	**46**	**737**	**16**	**263**	**1062**

Table 5 - Count of Blocks by Division and Bus Length

2025 Transition Plan Annual Total Miles (WK, SAT, SUN)					
Division	Bus Length [ft]				Totals
	22, 29, 32	40	45	60	
Copley	4,586,497.78	-	-	-	**4,586,497.78**
East County	860,991.75	2,331,969.89	472,938.47	-	**3,665,900.10**
Kearny Mesa	-	2,610,694.25	-	2,490,574.70	**5,101,268.95**
Imperial Ave	-	3,718,765.04	-	1,463,881.90	**5,182,646.94**
South Bay	-	7,666,018.00	-	1,737,382.05	**9,403,400.05**
Totals	**5,447,489.53**	**16,327,447.17**	**472,938.47**	**5,691,838.65**	**27,939,713.81**

Table 6 – Annual Total Miles by Division and Bus Length

Division	Bus Length [ft]				Totals
	22, 29, 32	40	45	60	
Copley	-	-	-	-	**-**
East County	-	1,111,574	386,634	-	**1,498,208**
Kearny Mesa	-	1,143,793	-	676,610	**1,820,403**
Imperial Ave	-	1,594,866	-	708,830	**2,303,696**
South Bay	-	3,431,379	-	628,281	**4,059,660**
Totals	**-**	**7,281,612**	**386,634**	**2,013,720**	**9,681,967**

Table 7 - Annual CNG Fuel Consumption by Division and Bus Length (Therms)

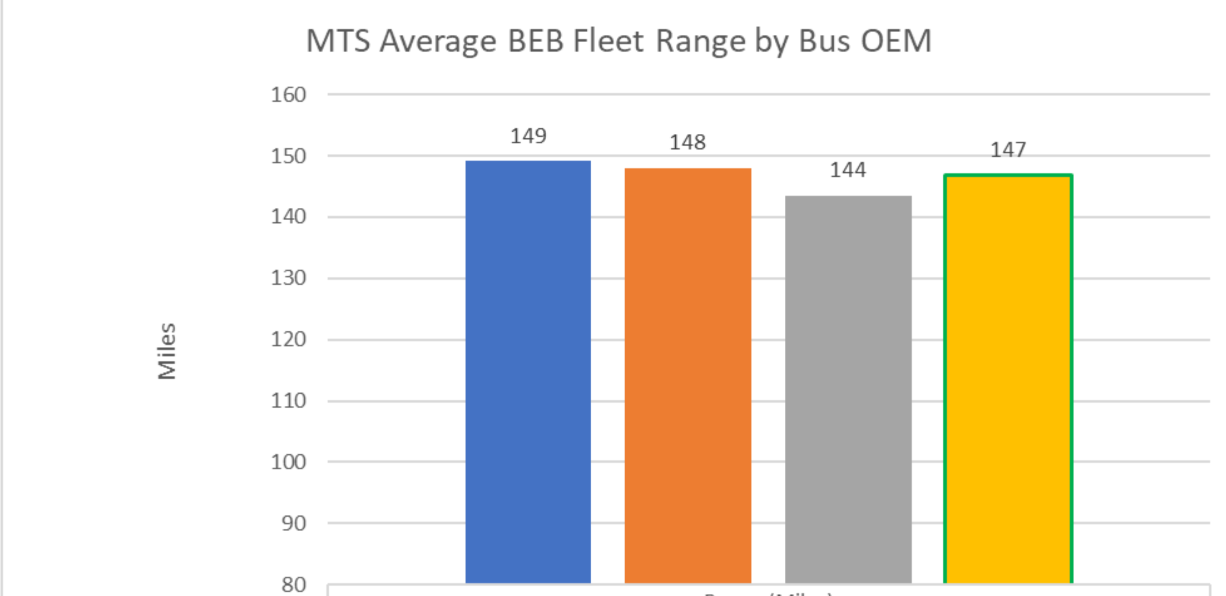
Division	**Bus Length [ft]**				**Totals**
	22, 29, 32	**40**	**45**	**60**	
Copley	535,643.31	-	-	-	**535,643.31**
East County	1,286.21	-	-	-	**1,286.21**
Kearny Mesa	-	-	-	-	**-**
Imperial Ave	-	-	-	-	**-**
South Bay	-	-	-	-	**-**
Totals	**536,929.52**	**-**	**-**	**-**	**536,929.52**

Table 8 - Annual Diesel, Gasoline, and Propane Fuel Consumption by Division and Bus Length (DGE)

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 MTS' system to complete the assessment.

At the time of this plan update, MTS's average BEB fleet efficiency is 2.8 kWh/mile which encompasses thirteen (13) 40' BEBs and twelve (12) 60' BEBs. Average efficiency for the 40' BEBs is approximately 2.4 kWh per mile with an estimated range of 148 miles for a single charge. The 60' BEB's average efficiency is approximately 3.4 kWh per mile with an estimated range of 144 miles. The estimated fleet range is 147 miles. It is important to note that the fleetwide efficiency fluctuates, which causes the range to fluctuate on a month-to-month basis. Figure 3 below shows the average range of the BEB Fleet by OEM.



	Range (Miles)
New Flyer 40ft BEB Range	149
Gillig 40ft BEB Range	148
New Flyer 60ft BEB Range	144
Average Range (All BEBs)	147

Figure 3 – Average BEB Fleet Range by Bus OEM

Despite the average fleet range of the BEBs being estimated 147 miles, MTS, assigns BEBs to blocks that are 130 miles and less, utilizing approximately 80% of the battery. As a result, 48% of MTS's total blocks are capable of being operated by a BEB. Figure 4 below shows a graph of block assignments with BEB Mileage Range.

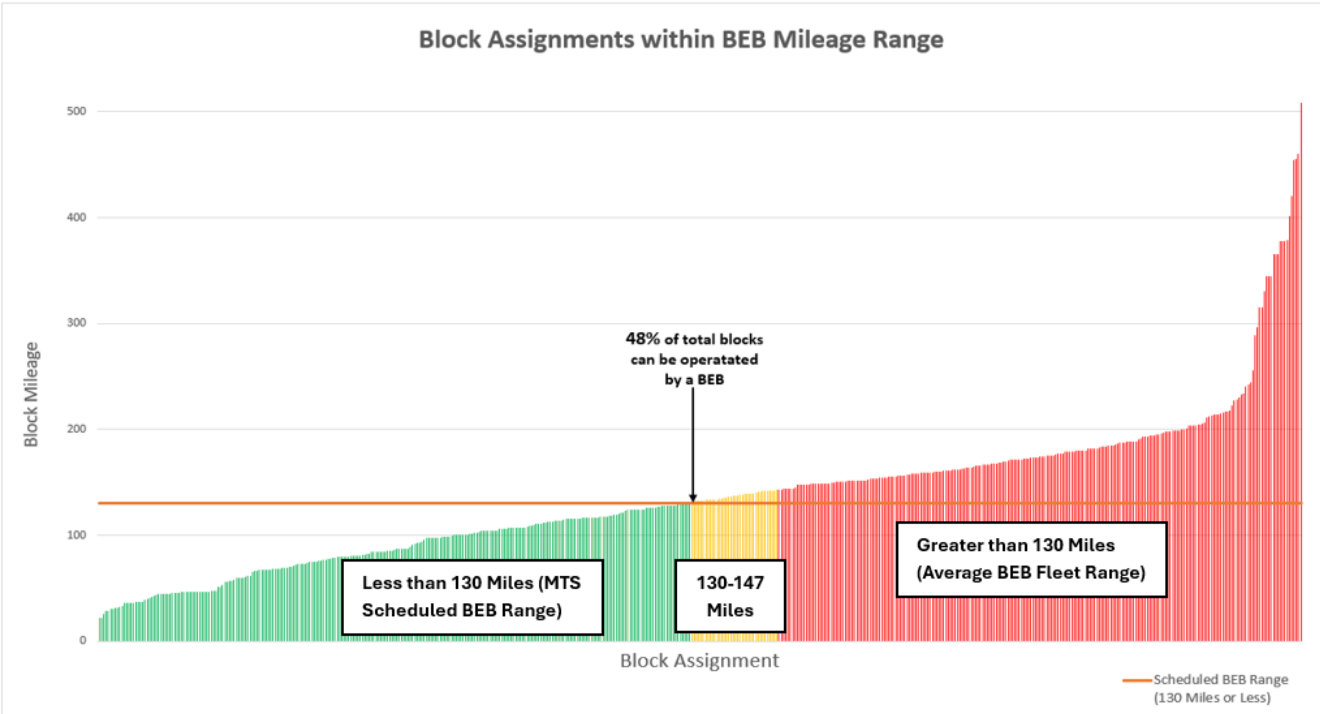


Figure 4 – Block Assignments within BEB Mileage Range

While routes and block schedules are unlikely to remain the same over the course of the transition period, these projections assume 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.

It should be noted that BEB range is negatively impacted by battery degradation over time. A BEB may be placed in service on a given block with beginning-of-life batteries; however, it may not be able to complete the entire block at some point in the future before the batteries at are end-of-life (typically considered 80% of available service energy). Conceptually, older buses can be moved to shorter, less demanding blocks and newer buses can be assigned to longer, more demanding blocks. MTS can rotate the fleet to meet the demand assuming there is a steady procurement of BEBs each year to match service requirements. This could also be said for FCEBs, although the impact of degradation is assumed to be less. MTS could also consider a midlife replacement of batteries that cannot meet the service needs due to degradation. Those costs are relatively unknown right now and are not included in the current cost per mile projections through the transition.

Battery density for electric vehicles has made significant improvements each year. For the purposes of this study, considering the extended period of a complete fleet transition (e.g. through 2040), it is assumed a 5% improvement will be made 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 internal combustion engine buses one-for-one. FCEBs do not have the same range constraints as BEBs. Typically, FCEBs can more readily serve an agency's current blocks on a one-to-one basis with internal combustion engine buses. An FCEB's range is estimated to be between 250 to 300 miles. Most MTS blocks could run on a FCEB, but not all as there are some blocks that are beyond its maximum range which do not make replacement of all internal combustion engine buses completely one-to-one. Additionally, the costs of hydrogen fuel and bus capital costs can create higher barriers to entry. There is also a significant amount of research going towards fuel cell technologies. We assume 5% bi-annual improvement in hydrogen tank size as a proxy for other component improvements such as battery capacity, motor efficiency, fuel cell efficiency, etc.

The block analysis, with the assumption of 5% improvement in battery capacity or improvement in hydrogen storage capacity every other year, is used to determine the timeline for when routes and blocks become achievable for BEBs and FCEBs, respectively, to replace internal combustion engine buses one-for-one. 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.

Results from the block analysis that indicate the yearly block achievability by bus length throughout the transition period for BEBs and FCEBs are included in Figure 5 and Figure 6 below, respectively.

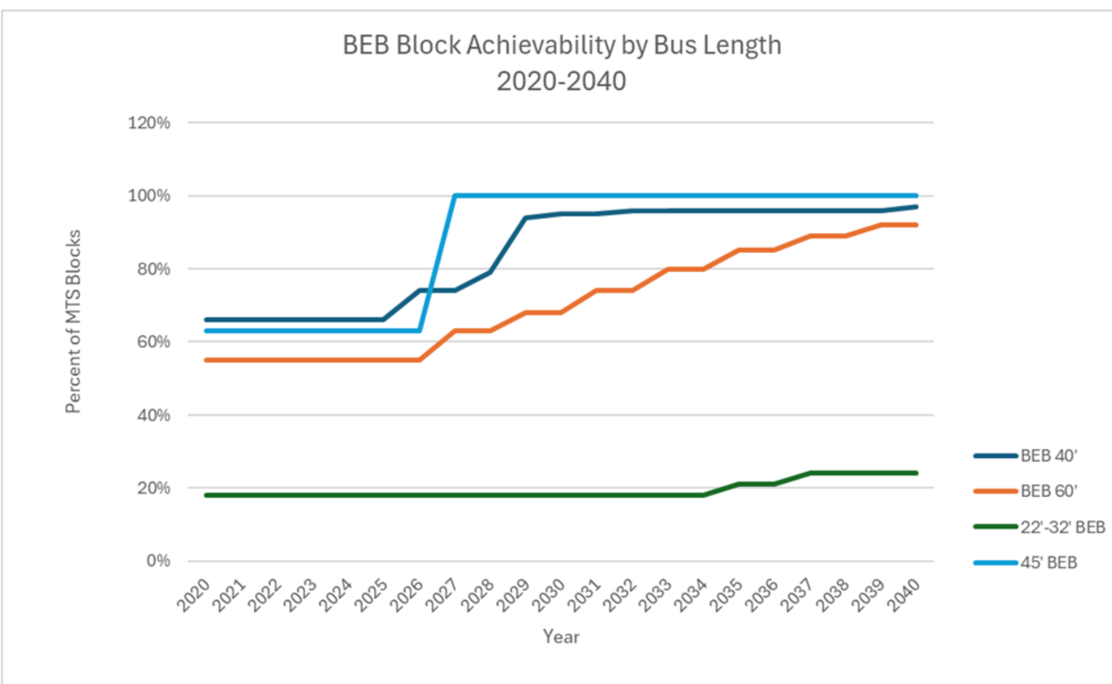


Figure 5 – BEB and MTS Block Achievability

The BEB achievability in Figure 5 shows that by 2040, it is expected that nearly all 40’, 45’, and 60’ MTS blocks can be completed by BEBs. However, in 2040, cutaway blocks (22’-32’) struggle, with only approximately 24% able to be completed by BEBs, respectively.

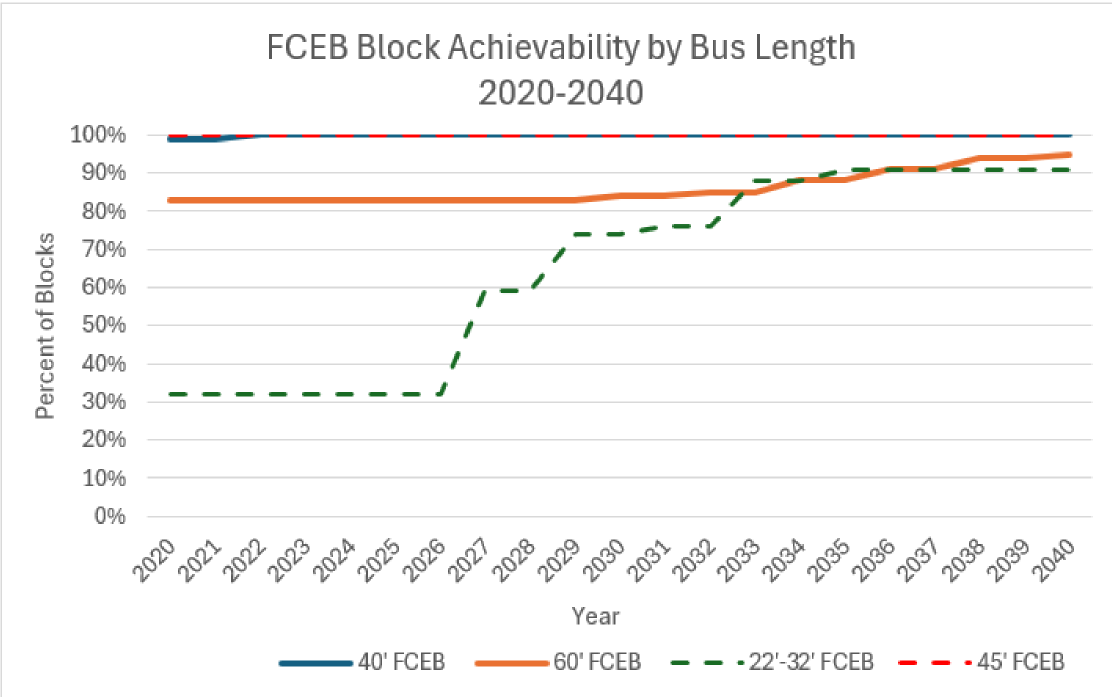


Figure 6 – FCEB and MTS Block Achievability

The FCEB achievability in Figure 6 shows that by 2040, it is expected that 98% of MTS blocks can be completed by FCEBs. It is predicted that with the exception of cutaway buses (22’-32’), all other FCEB sizes can complete 96% or greater of MTS blocks starting in 2025. Please note that the dashed lines indicate that, at the time of the study, there are no 45’or cutaway FCEBs available on the market that have completed Altoona testing and the timeline for these to be available is uncertain.

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 the fleet to zero-emissions. Results from the Service Assessment are integrated with MTS' current fleet replacement plan and purchase schedule to produce two main outputs: a projected bus replacement timeline through the end of the projection period, and the associated total capital costs. While the industry is rapidly changing, there are still tradeoffs for each zero-emission technology, primarily between range, operational impact, capital costs and operating costs.

COST ASSUMPTIONS

In the 2020 study, CTE and MTS developed cost assumptions for this analysis for each bus length and technology type (e.g. CNG, gasoline, propane, BEB, FCEB). Key assumptions for the updated 2025 bus costs for the MTS Transition Study Update are as follows:

- Bus costs are based on MTS procurements, industry quotes, and the State of California statewide procurement contract for BEBs and FCEBs executed in 2024.
- Bus costs are inclusive of configurable options and taxes.
- Bus costs are estimated where buses of a given configuration are not commercially available or where no quotes were available.
- Future bus costs incorporate inflation escalation.

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 have increased in recent years. However, it should be also noted that vendors have added more battery storage since the completion of the 2020 study. Table 9 provides estimated bus costs used in the analysis.

Length [ft]	CNG	Diesel	Gasoline	Propane	Electric	Hydrogen
22' Cutaway	-	-	$99,200	$136,400	$310,000	*$465,000*
29' Cutaway	-	-	$186,000	-	*$403,000*	*$603,880*
32' Cutaway	-	-	-	$219,480	*$403,000*	*$604,500*
40'	$681,953	-	-	-	$1,195,539	$1,422,919
45'	$992,000	$868,000	-	-	*$1,178,000*	*$1,736,000*
60'	$1,244,173	-	-	-	$1,704,173	$2,022,767

Note: Italic text indicates that the cost was an estimate based on similar vehicle costs

Table 9 – Fleet Assessment Cost Assumptions

BASELINE

The Baseline scenario was used for comparative purposes only. It assumed no changes to MTS' current fleet composition throughout the life of the 2025 study update. The Baseline scenario created context for incremental costs incurred or benefits accrued by transitioning the fleet to zero- emission.

Figure 7 presents the number of each bus type that is purchased each year to maintain MTS' current fleet composition through 2040. The number of buses purchased each year is based on the Fiscal Year 2025 MTS vehicle replacement schedule.

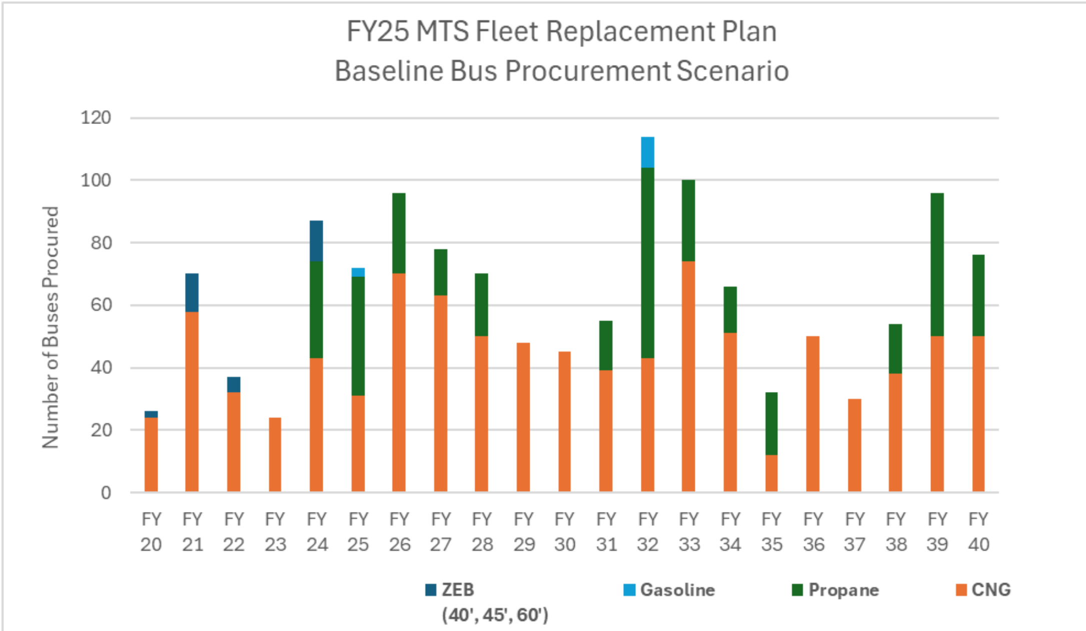


Figure 7 – Projected Vehicle Purchases, Baseline Scenario

Figure 8 shows the annual capital costs based on the purchase schedule and bus cost assumptions for the Baseline Scenario. Total bus purchases range from approximately $20 to $100 million each year.

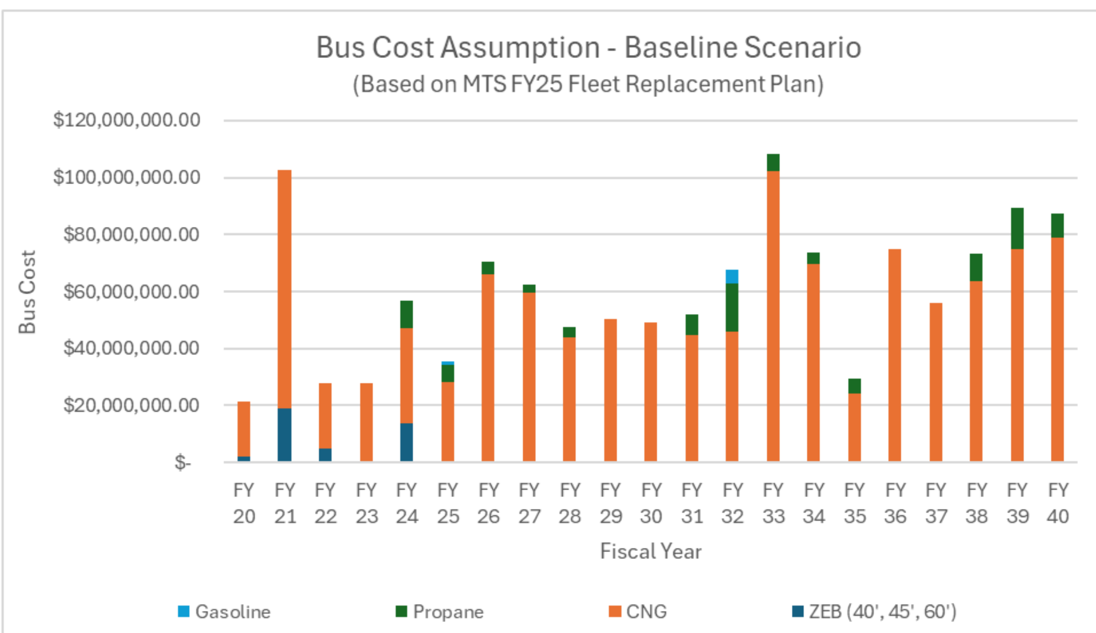


Figure 8 – Annual Bus Costs, Baseline

MIXED BEB AND FCEB

In the Mixed BEB and FCEB approach, depot-charged BEBs are utilized where they can replace internal combustion engine buses on a one-for-one basis. Since FCEBs have a greater range, they would be used on the longer blocks and in Paratransit service where BEBs are not feasible. By the end of the transition period, any instance where block coverage is insufficient, a FCEB is used to replace MTS' original vehicle type. The figures below show projected purchases, annual fleet composition, and annual total capital costs for the Mixed BEB and FCEB fleet. By 2040, MTS will be able to replace approximately 99% of its fleet with BEB and FCEBs. The remaining 1% of vehicles will be replaced with FCEBs when they reach their useful life after 2040. There is a lag between when ZEB technology can meet block energy requirements and when a vehicle is replaced due to the vehicle replacement schedule.

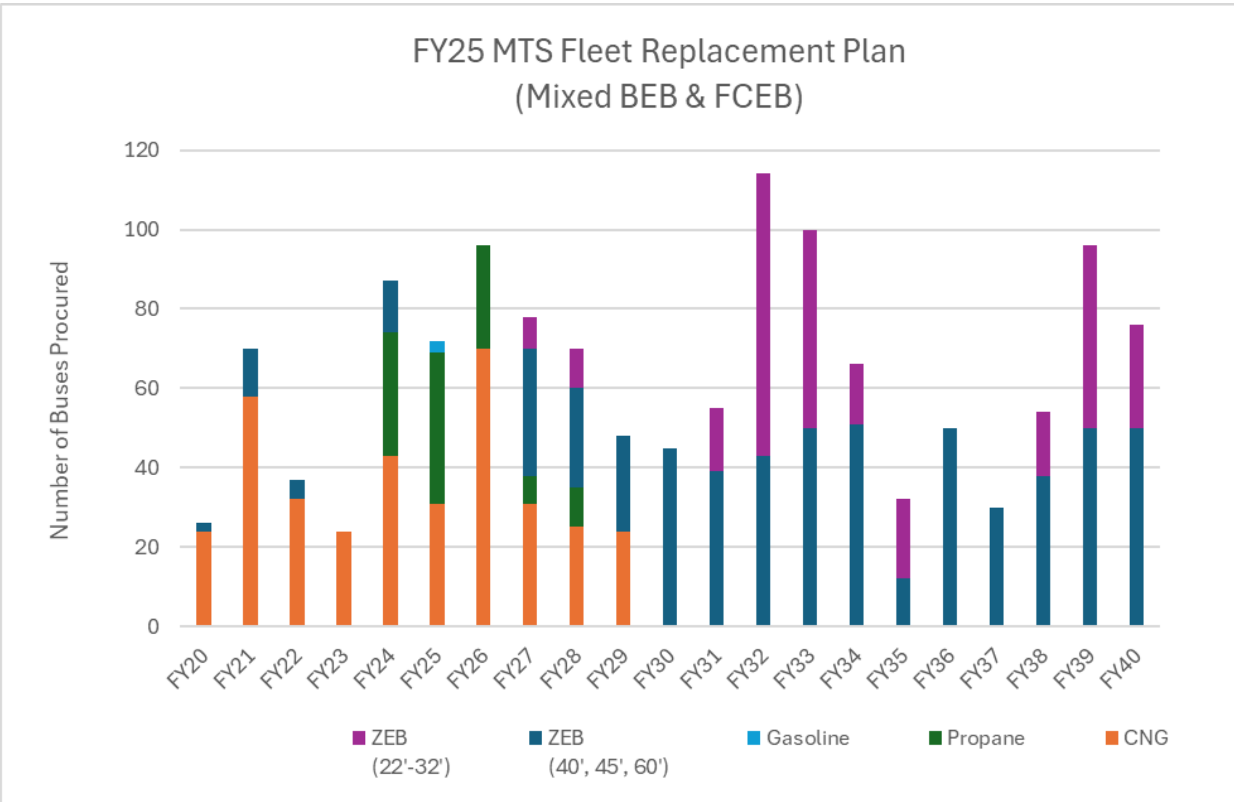


Figure 9 – Projected Vehicle Purchases, Mixed BEB & FCEB

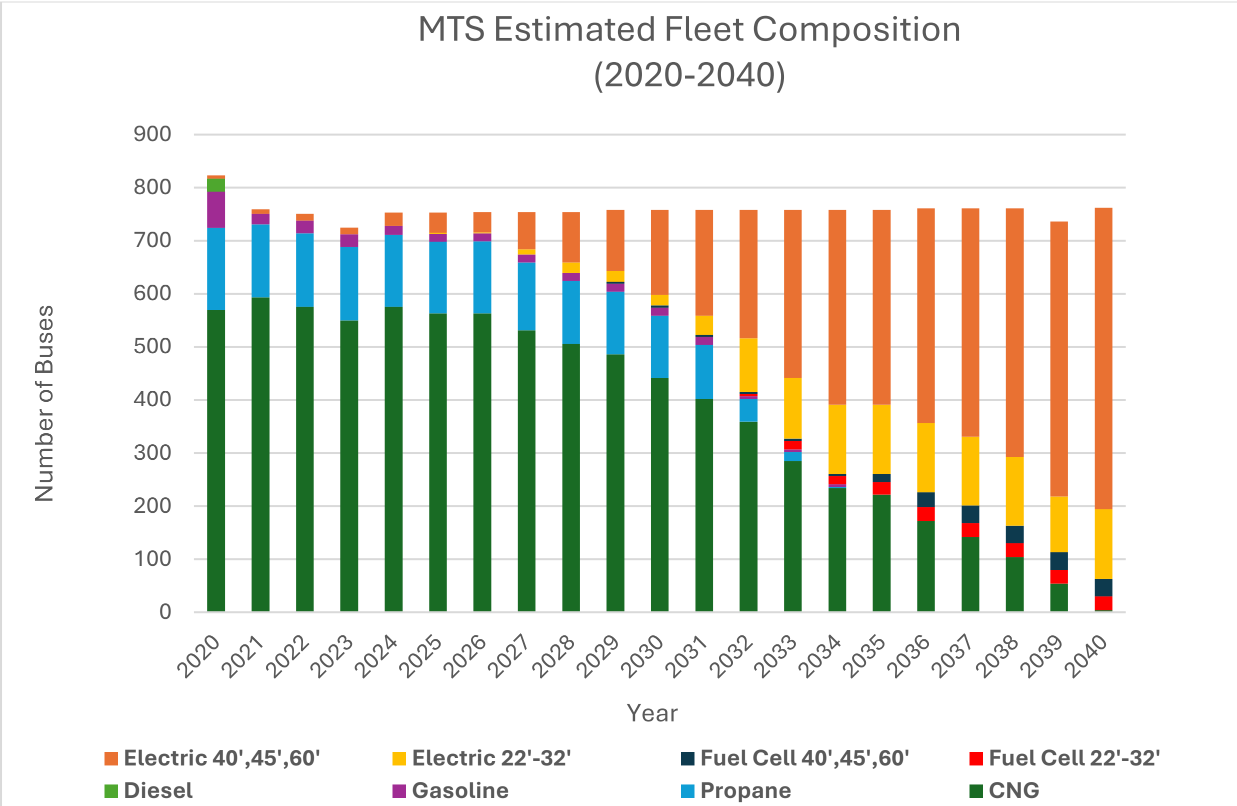


Figure 10 – Annual Fleet Composition, Mixed BEB & FCEB

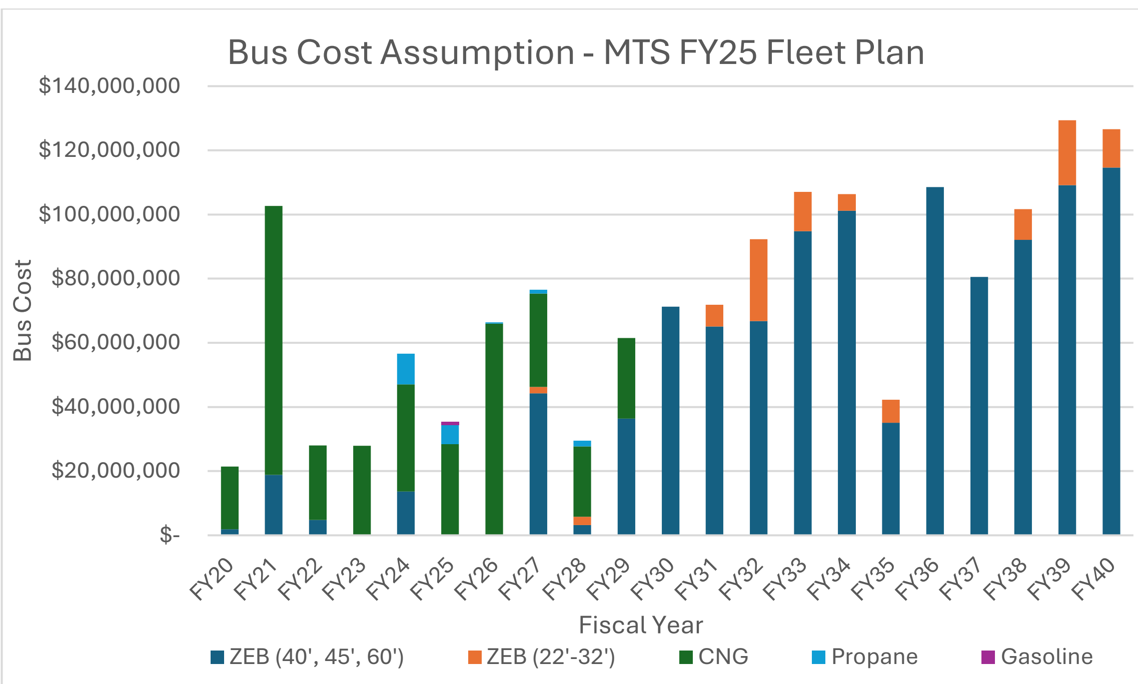


Figure 11 - Annual Bus Costs, Mixed BEB & FCEB

FLEET ASSESSMENT COST COMPARISON

The transition and fleet composition schedules were used to develop the total capital cost for vehicle purchases through the transition period. Figure 12 shows the cumulative fleet purchase costs for both scenarios.

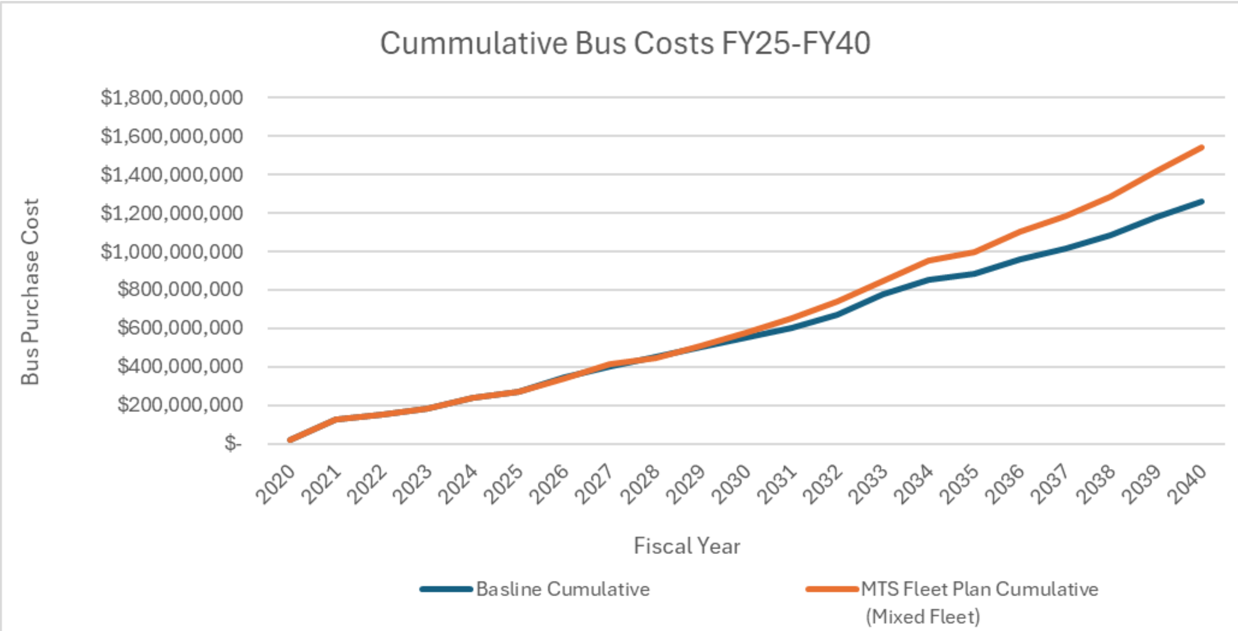


Figure 12 – Cumulative Fleet Purchase Costs

Table 10 provides the combined total costs for each transition scenario

Scenario	Cost
Baseline	$ 1,263,176,641
Mixed BEB & FCEB	$ 1,543,816,833

Table 10 – Total Costs, Fleet Assessment

Fuel Assessment

The Fuel Assessment estimates quantities and costs for MTS' current and future internal combustion engine vehicles as well as electrical energy and hydrogen fuel quantities and costs for the future BEB and FCEBs. The terms "fuel" and "energy" are used interchangeably in this assessment, 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. FCEBs are more similar to internal combustion engine vehicles as they are fueled by 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. Fuel cost estimates are based on the assumptions shown in Table 11 below.

Fuel	Cost	Source
Gasoline	$3.85/gal	MTS contracted rate
Propane	1.94/gal	MTS contracted rate
CNG	$1.00/DGE	MTS contracted rate
Hydrogen (trucked)	$25.00/kg	Average of contracted rates for multiple CA transit agencies/recent baseline quotes from area suppliers
Electricity	Varies	SDG&E AL-TOU and EV-HP Tariff Schedules

Table 11 - Fuel Cost Assumptions

The primary source of energy for a BEB comes from the local electrical grid. Utility companies typically 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 the system, both the energy used and the demand increase. Rates also vary throughout the year and throughout the day; this makes costs highly variable. Costs not only depend on seasonal differences like temperature, but also the time-of-day buses are charged. Table 12 shows the current San Diego Gas & Electric (SDG&E) rate schedule used in the Fleet Assessment to estimate electrical costs for BEBs.

SDG&E Energy Rates		
Time-of-Use (TOU)	**Rate/kWh**	**Hours**
Off-Peak	$0.12	6:00am - 4:00pm
On-Peak	$0.29	4:00pm - 9:00pm
Off-Peak	$0.12	9:00pm - 12:00am
Super Off-Peak	$0.10	12:00am - 6:00am

Table 12 – Time-of-Use Energy Rates

CHARGING ANALYSIS

To accurately estimate energy use and electrical demand, and subsequent costs, due to BEB charging, charging was simulated at each depot, for each year of the transition. Electrical energy and demand were estimated based on current block schedules and BEB purchase projections and apply SDG&E tariff schedules to calculate an annual cost of charging. This annual cost is evaluated for each year of the study and at each depot to obtain a total BEB depot charging cost for the transition. This estimate is used as the total “fuel” cost for BEB depot charging in the subsequent Mixed BEB & FCEB approach assessment and it is incremental hydrogen fuel costs and internal combustion engine costs.

Figure 13 shows the estimated annual BEB depot charging costs. These costs are inclusive of all divisions. The following assumptions were considered while determining the annual costs:

- 80% percent of BEB batteries are charged daily.
- 180 kW chargers and dispensers utilized
- As BEBs continue to be delivered to divisions, BEBs are deployed, they are prioritized/assigned to blocks that pull-in outside of the on-peak charging window.
- Increased bi-annual on-board battery capacity on newly delivered BEBs.
- All blocks that pull-in during the on-peak begin charging during the on-peak window instead of after 9pm.

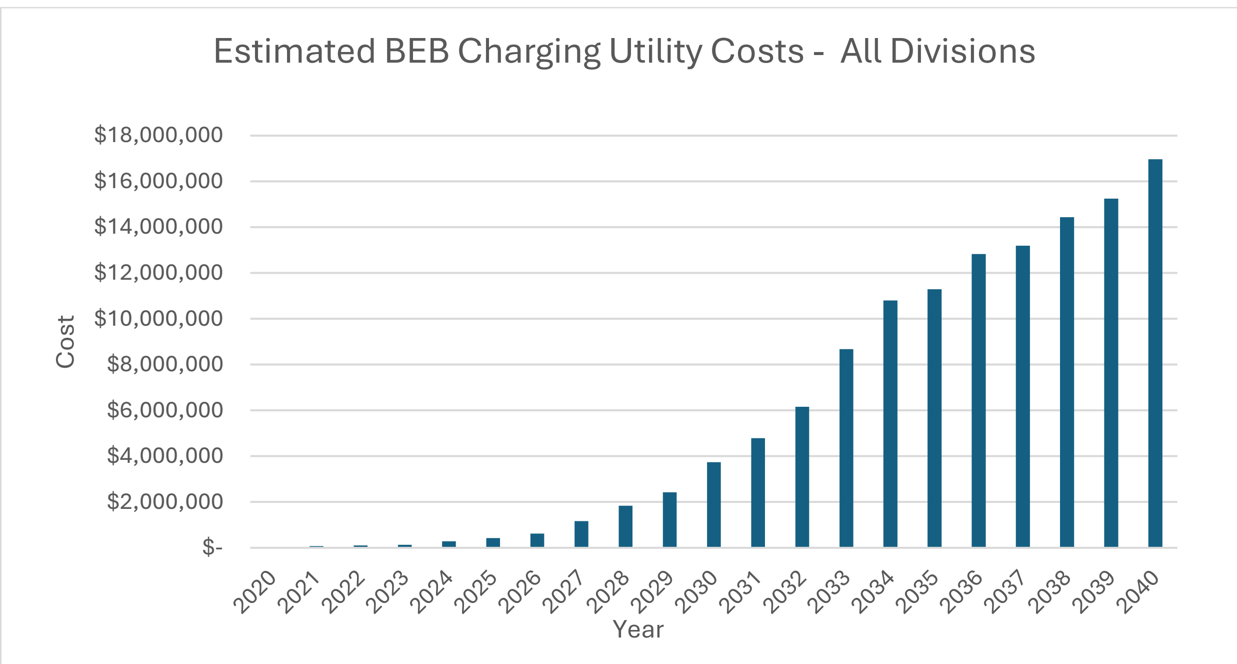


Figure 13 – Estimated Annual BEB Depot Charging Costs

BASELINE

The Baseline scenario is comparative purposes only and assumes that there is no change in the current MTS fleet configuration throughout the life of the study. The Baseline scenario helps create context for incremental costs incurred or benefits accrued by transitioning the fleet to zero-emission.

Figure 14, below, depicts energy consumption for each fuel type over the transition period for the Baseline scenario. Fuel use is shown in diesel gallon equivalent (DGE) for all fuel types. It is assumed that the fuel economy for MTS' internal combustion engine vehicles remain constant over the study life.

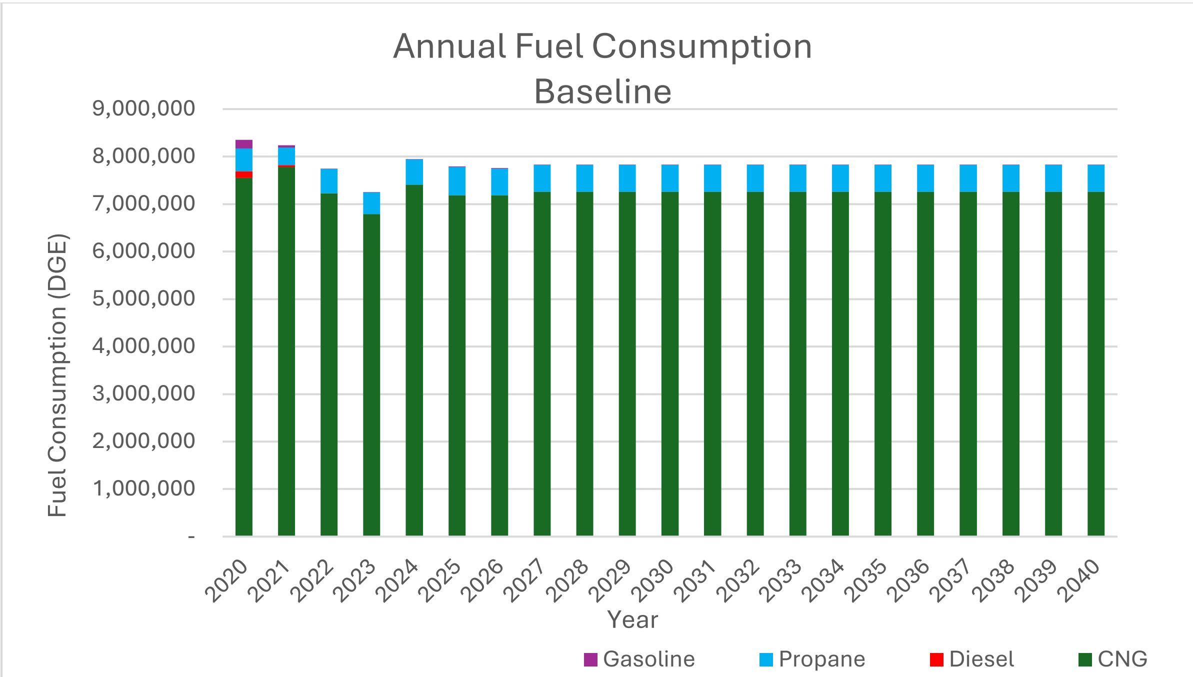


Figure 14 – Annual Fuel Consumption, Baseline

Figure 15 shows the calculated annual costs for each fuel type based on the quantities for the Baseline scenario.

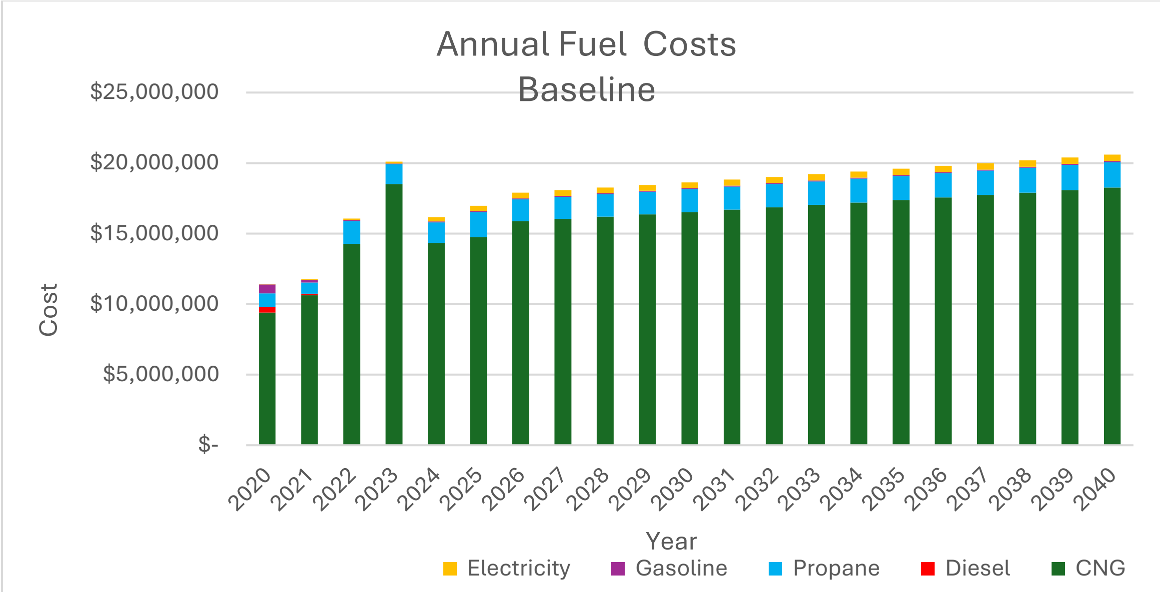


Figure 15 – Annual Fuel Costs, Baseline

Mixed BEB and FCEB

In the Mixed BEB and FCEB approach, BEBs are utilized where they can replace internal combustion engine vehicles on a one-for-one basis. Since FCEBs have a greater range, they are used on the longer blocks where BEBs are not feasible. Figure 16 depicts the reduction of energy consumption for legacy fuels over the transition period for the Mixed BEB and FCEB approach. Legacy fuels are phased out as electricity and hydrogen consumption increases, reflecting an increasing number of BEBs and FCEBs in the fleet.

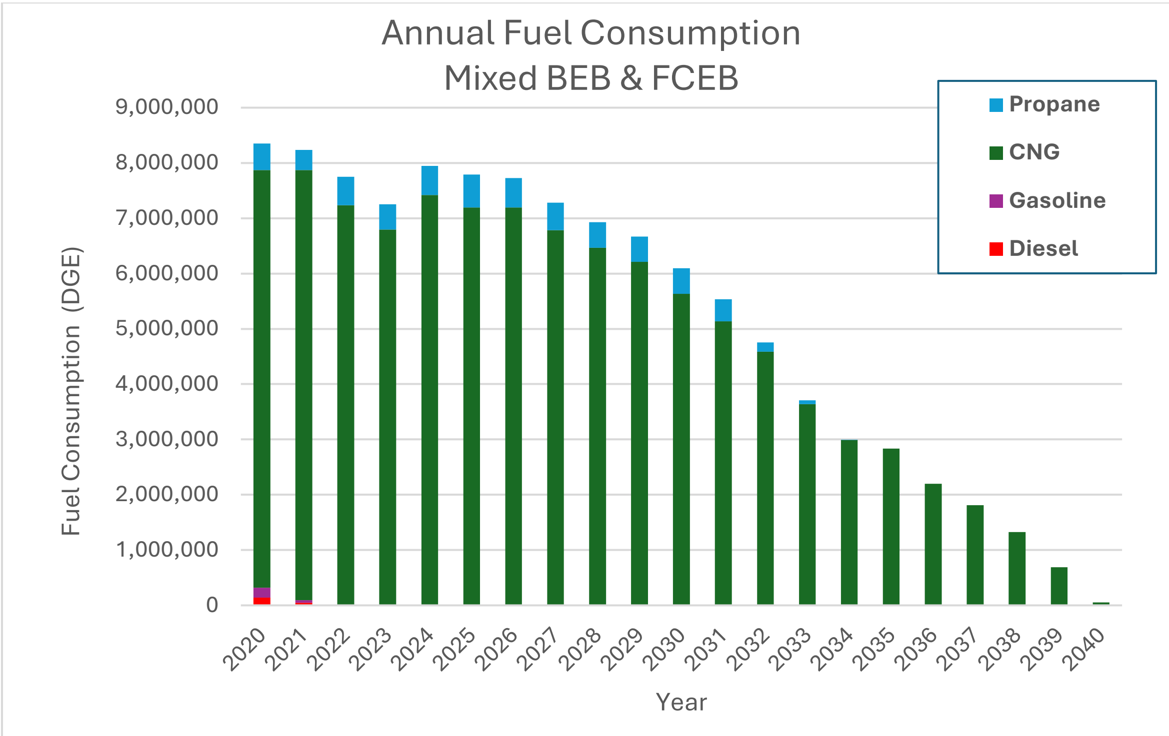


Figure 16 – Annual Fuel Consumption, Mixed BEB & FCEB

Figure 17 shows the estimated annual costs for each fuel type. Total estimated fuel costs in 2040 are approximately $30 million, which consists of electricity use for BEBs and hydrogen fuel.

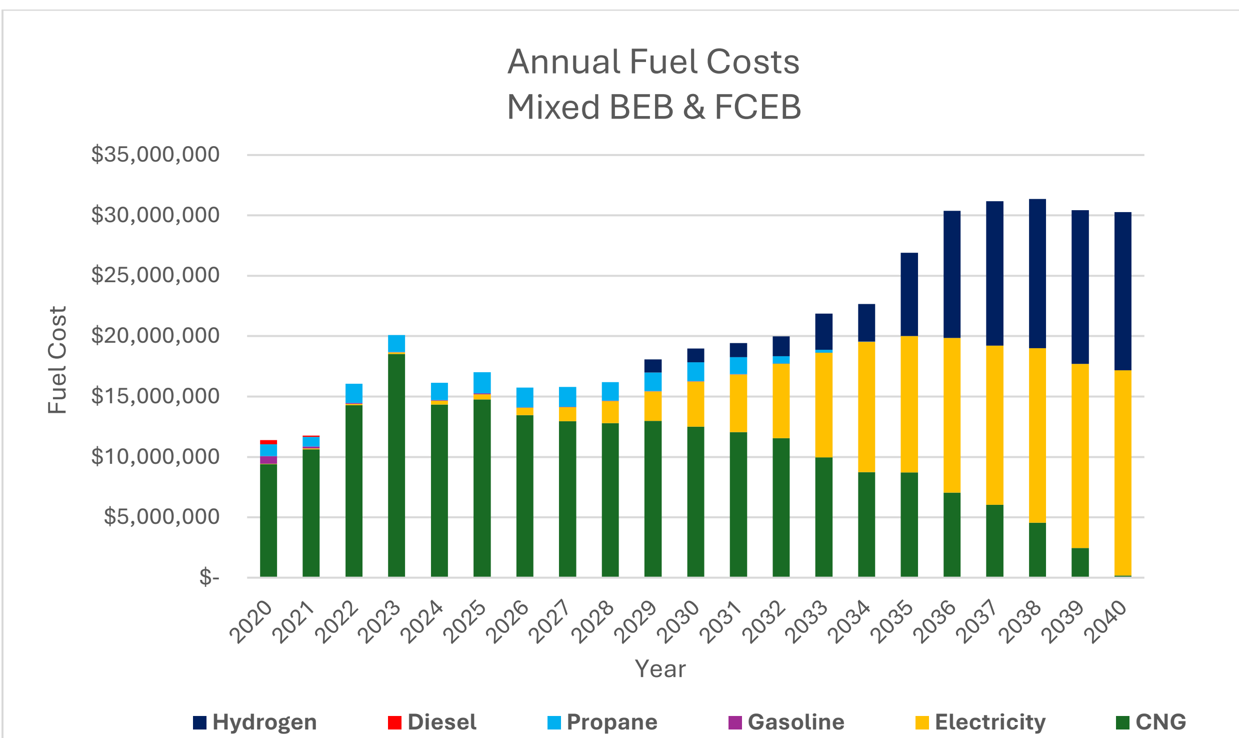


Figure 17 – Annual Fuel Costs, Mixed BEB & FCEB

Fuel Assessment Cost Comparison

The Fuel Assessment includes all electrical and fuel costs over the transition for each scenario. Figure 18 shows the cumulative fuel costs for the Baseline and Mixed BEB & FCEB approach. Table 13 shows the combined total costs, the incremental cost over the Baseline.

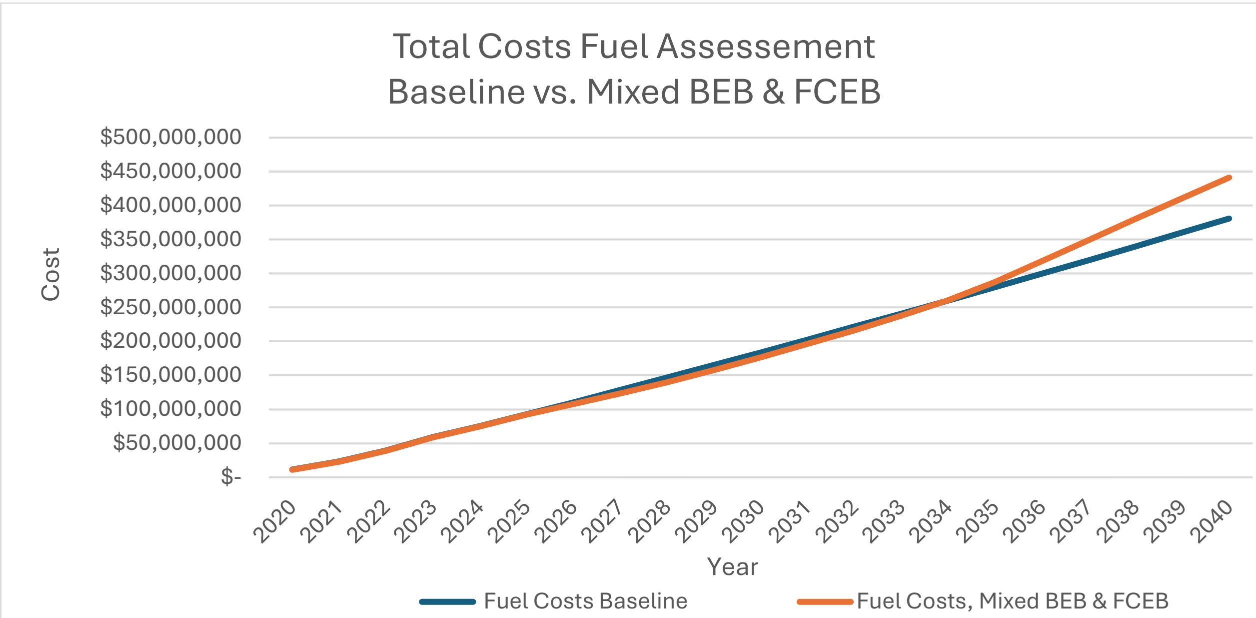


Figure 18 – Total Costs Fuel Assessment

Scenario	Cost
Baseline	$ 380,886,640
Mixed BEB & FCEB	$ 441,231,673

Table 13 – Total Costs, Fuel Assessment

Facilities Assessment

The Facilities Assessment determines the scale of charging and/or hydrogen infrastructure necessary to meet the demands of the projected fleets' energy use estimated in the Fleet and Fuel Assessments, as well as all associated costs with installation of this infrastructure.

Baseline

For the Baseline scenario, there are no additional costs associated with ZEB infrastructure because no ZEBs are added to the fleet. Although a total of thirteen (13) BEBs are scheduled to be added to the fleet in Q3 2025, these buses were already considered part of the baseline analysis as the infrastructure costs have already been programmed. No additional fueling infrastructure upgrades are required to support the Baseline scenario.

Battery-Electric Charging Infrastructure

During the BEB Pilot Program, it was realized that scaling a fleetwide BEB deployment required a different approach rather than utilizing plug-in charging. Plug-in charging was no longer practical as charger dispenser cables can create hazards in the bus yard. Instead, the preferred approach was determined to use overhead pantograph dispensers attached to gantries installed above bus parking lanes. Overhead plug-in reels could be utilized at East County for the 45' commuter bus fleet primarily because of these bus types with pantograph compatibility does not exist yet at the time of this plan update.

In addition to the installation of the charging stations, improvements to existing electrical infrastructure including switchgear, service connections, etc. are required to support deployment of BEBs. Design work will be required to support BEB deployment including development of detailed electrical and construction drawings required for permitting once specific charging equipment has been selected. Rather than building out the infrastructure all at once, projects are sized and scheduled to meet the near-term charging requirements. Charging infrastructure to support 699 depot-charged BEBs in 2040 is required, as calculated in the Fleet Assessment. Key assumptions include:

- Gantry structures are used at each division except for Copley Division as depot plug-in charging will be utilized with cutaway vehicles.
- One (1) overhead pantograph per bus for 40' and 60' BEBs.
- Overhead reel plug-ins for 45' BEB at East County Division
- Three (3) buses per 180 kW charger except at Copley Division.

Depot Planning Projects

The build-out of charging and hydrogen infrastructure will require planning at each division. Planning is assumed to cost approximately $150,000 for each division. At the time of this plan update, division master plans have been completed for South Bay, Imperial Avenue, and Kearny Mesa. East County is currently in development and Copley will be planned in future years. The table below shows past and upcoming planning projects at each division. At the time of this plan update, there is no FCEB infrastructure in place.

ZEB Planning Projects						
Year	**Copely**	**EC**	**SB**	**IAD**	**KMD**	**All Divisions**
2020			1			**1**
2021						**0**
2022				1		**1**
2023						**0**
2024					1	**1**
2025		1				**1**
2026						**0**
2027						**0**
2028	1					**1**
2029						**0**
2030						**0**
2031						**0**
2032						**0**
2033						**0**
2034						**0**
2035						**0**
2036						**0**
2037						**0**
2038						**0**
2039						**0**
2040						**0**
Total	**1**	**1**	**1**	**1**	**1**	**5**

Table 14 – ZEB Planning Projects

Depot Installation Projects

Charging projects include purchase and installation of at least 180kW chargers and dispensers. Each bus will require one dispenser. Every three (3) buses (40' and larger) will require one (1) charger, while buses at Copley (all smaller, cutaway-style buses) which are assigned two (2) buses to one charger. Please note that six (6) 62.5 kW plug-in chargers with one dispenser each at Imperial Avenue and two (2) 62.5 kW plug-in chargers with one dispenser each at East County, Kearney Mesa, and South Bay have already been installed to support the pilot program. Additionally at South Bay, there are currently eight (8) 180 kW charging cabinets and 24 overhead charging positions with dispensers. Future dispenser installations are expected to be primarily pantograph style except for Copley where plug-in chargers are assumed.

Based on anticipated size of the future charging infrastructure at each division, the existing infrastructure does not have enough capacity to support the full buildout of BEB charging and the equipment that will be required. The total estimated power requirement for all division combined is assumed to be approximately 43 MW. Power upgrade costs are included and incorporated within the annual ZEB Annual Infrastructure Costs by Division graph (Figure 19) and table (Table 17) on the following page. Estimated total power required for each division is shown on Table 15.

Estimated Power Required	
Division	**Megawatts**
Copley	3
East County	6
Kearny Mesa	7
Imperial Avenue	10
South Bay	17
Total	**43**

Table 15 – Estimated Power Required by Division

In regard to hydrogen, cost assumptions for FCEB infrastructure are summarized in the table below.

Project	Cost Estimate
Infrastructure Planning	$150,000 per division
Incremental Addition of 15,000 Gallon Liquid Hydrogen Tank	$4,000,000 tank which includes installation (Supports approximately 50 Buses)
Maintenance Upgrades	Electrical, Lighting, Ventilation, and Gas Detection
	$125,000 per bay for depots that do not service CNG
	$50,000 per bay for depots that currently service CNG

Table 16 – FCEB Infrastructure Planning Assumptions

Costs for the Clean Transit Advancement Campus (CTAC), which will be a new facility to accommodate overflow due to reduced bus capacity at existing facilities due to infrastructure space requirements have not been incorporated in this analysis. However, there will be a need to construct a new facility as the build-out progresses. Initial concept planning for CTAC has already begun as design workshops have been held which include BEB and FCEB infrastructure. Additionally, three of the five land parcels have been acquired at the time of this plan update. Estimated costs of $350 million for CTAC are not included in this analysis.

Mixed BEB & FCEB

Annual costs for the FCEB infrastructure portion of the mixed fleet are provided in Figure 19. Table 17 summarizes all costs for charging infrastructure by division for Mixed BEB & FCEBs. Figure 20 provides the cumulative total cost breakdown by division. The estimated total infrastructure costs are approximately $488 million; this includes all divisions:

- All gantry structural projects
- All power upgrade projects
- All charger and dispenser installations
- All planning projects
- Design engineering costs

- 20% contingency on all costs.
- Microgrid solutions (BESS, solar panels, and generator)
- Hydrogen tank (Division TBD)

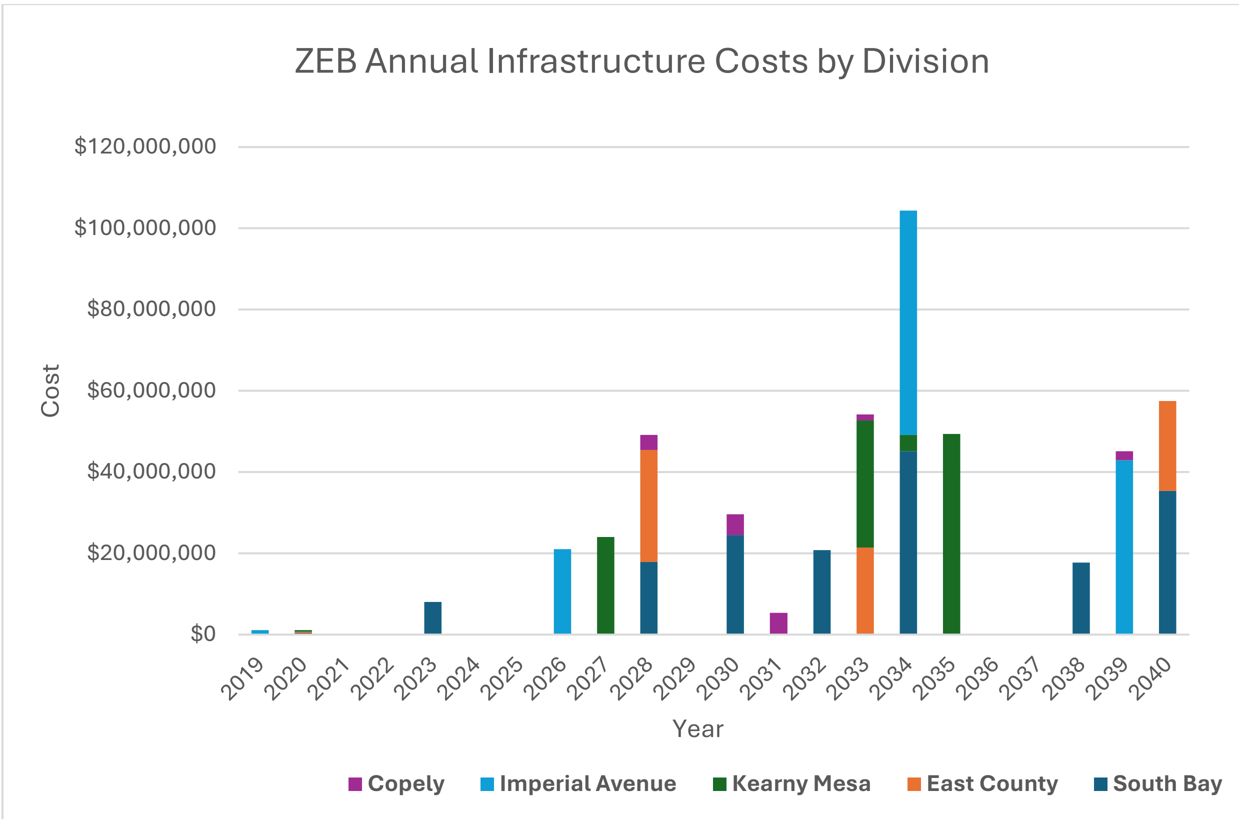


Figure 19 – Annual Infrastructure Costs, Mixed BEB & FCEB

Division	Cost	
South Bay	$	169,644,977.09
East County	$	71,525,350.51
Kearny Mesa	$	108,991,671.37
Imperial Avenue	$	120,247,419.03
Copely	$	17,965,803.51
Total	**$**	**488,375,221.50**

Table 17 – Total Infrastructure, Mixed BEB & FCEB

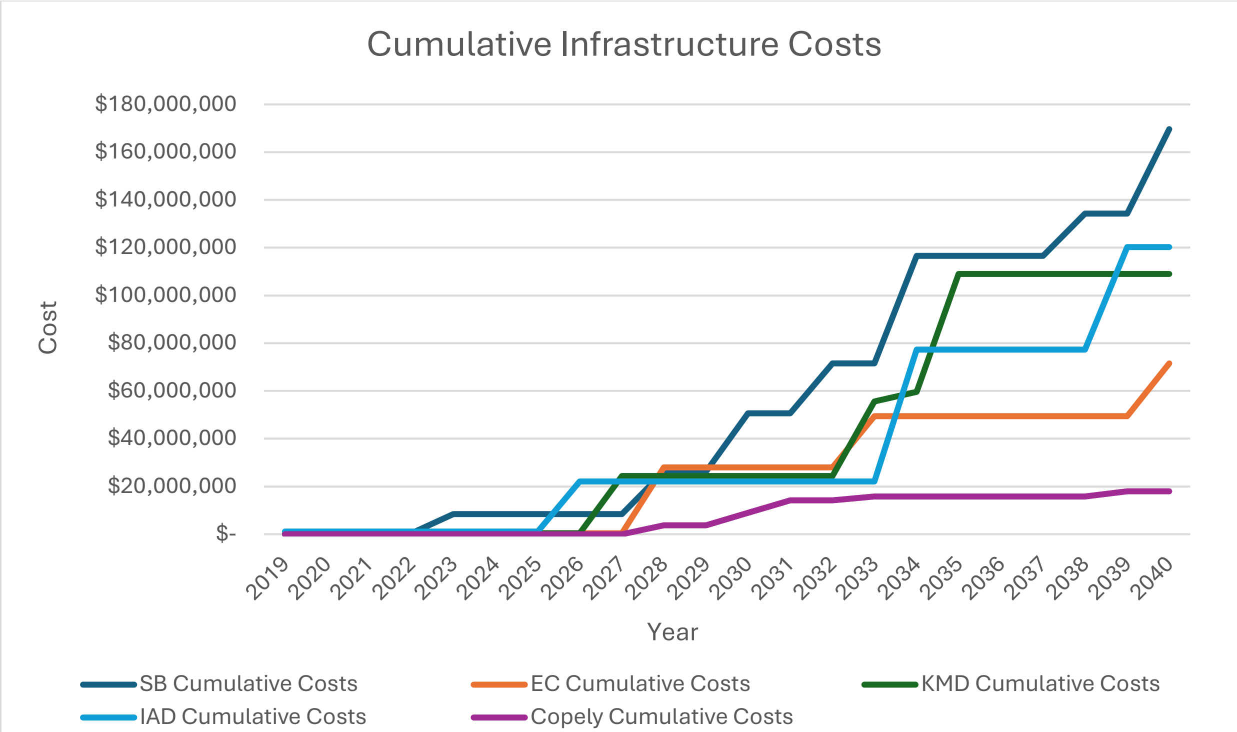


Figure 20 – Cumulative Infrastructure Costs, Mixed BEB & FCEB

Maintenance Assessment

One of the anticipated benefits of moving to a BEB or FCEB fleet is maintenance costs. Conventional wisdom indicates that a transit agency may attain 30% to 50% in maintenance cost savings for a BEB. This is because 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 an internal combustion engine 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 vehicles. Table 18 shows the assumed costs of scheduled and unscheduled labor and maintenance used in this analysis.

Type	Estimate
Internal combustion engine	$0.89/mi
BEB	$0.79/mi
FCEB	$1.05/mi including tires

Table 18 – Average Labor and Materials Cost Per Mile

In addition to Labor and Maintenance, the cost impact of mid-life overhauls of major components for each type of bus are estimated. Assumptions used in this analysis are given in Table 19.

Type	Overhaul Scope	Estimate
Internal combustion engine	Engine/Transmission Overhaul	$50k per bus
BEB	Battery Replacement	$125 per kWh
FCEB	Battery Replacement	$125 per kWh
	Fuel Cell Overhaul	$40k per bus

Table 19 – Mid-Life Overhaul Cost Assumptions

Baseline

The baseline assumes no changes to MTS' current fleet configuration throughout the life of the study, i.e. no ZEB purchases other than those already planned, and is used for comparative analysis. Figure 21 shows the combined labor, materials and mid-life overhaul costs for the Baseline scenario fleet projection for each year of the study, in 2025 dollars. Annual fleet maintenance costs an average of approximately $25 million per year.

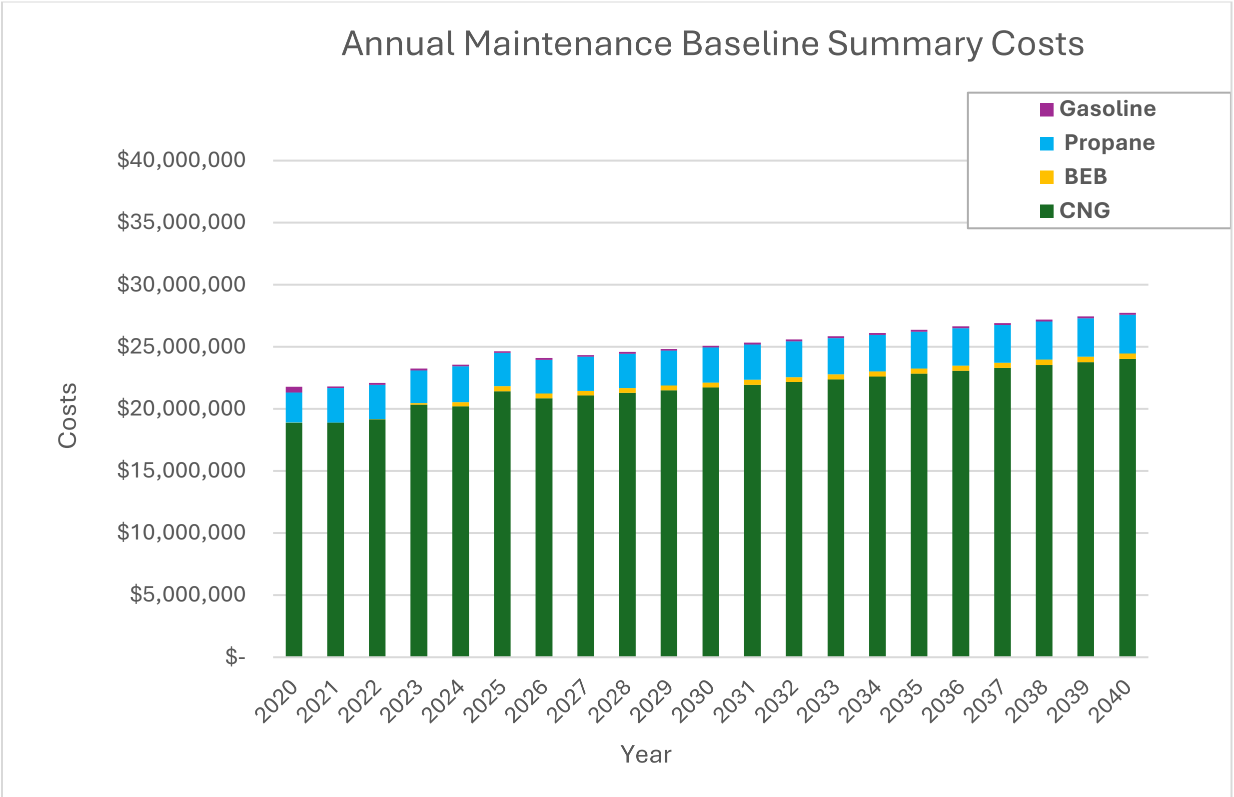


Figure 21 – Annual Fleet Maintenance Costs, Baseline

Mixed BEB and FCEB

Figure 22 shows the combined labor, materials and mid-life overhaul costs for the Mixed BEB and FCEB scenario for each year of the transition, in 2025 dollars.

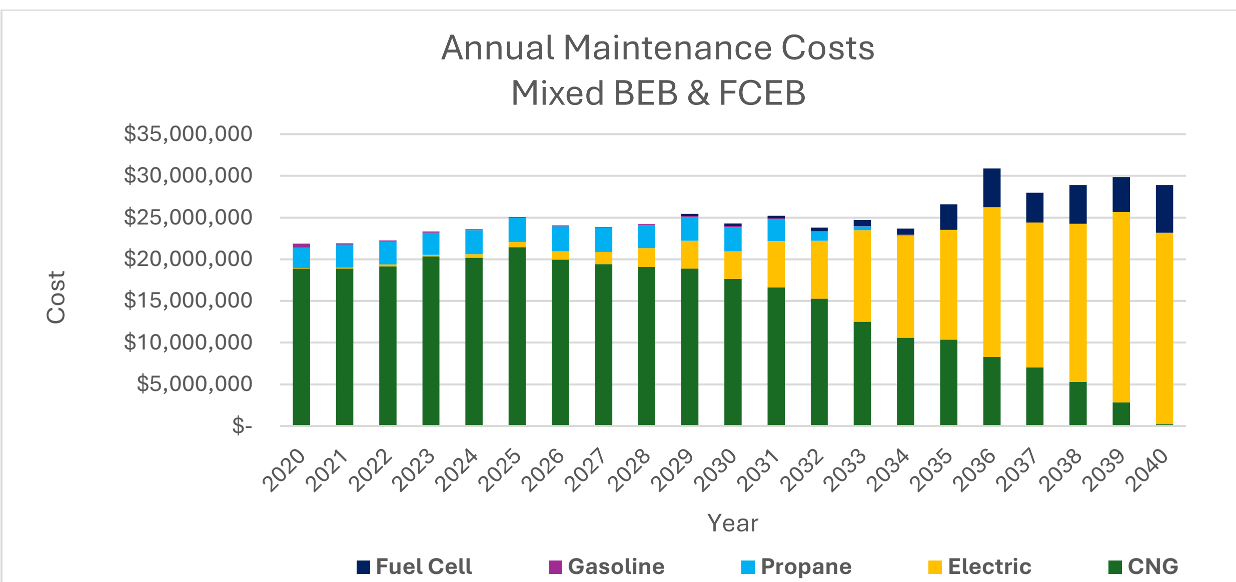


Figure 22 – Annual Maintenance Costs, Mixed BEB & FCEB

Maintenance Assessment Cost Comparison

The Maintenance Assessment includes all labor, materials and overhaul costs over the ZEB transition. Figure 23 shows the cumulative maintenance costs for the Mixed BEB & FCEB compared to the Baseline. Table 20 shows the combined total costs and the incremental cost over the Baseline.

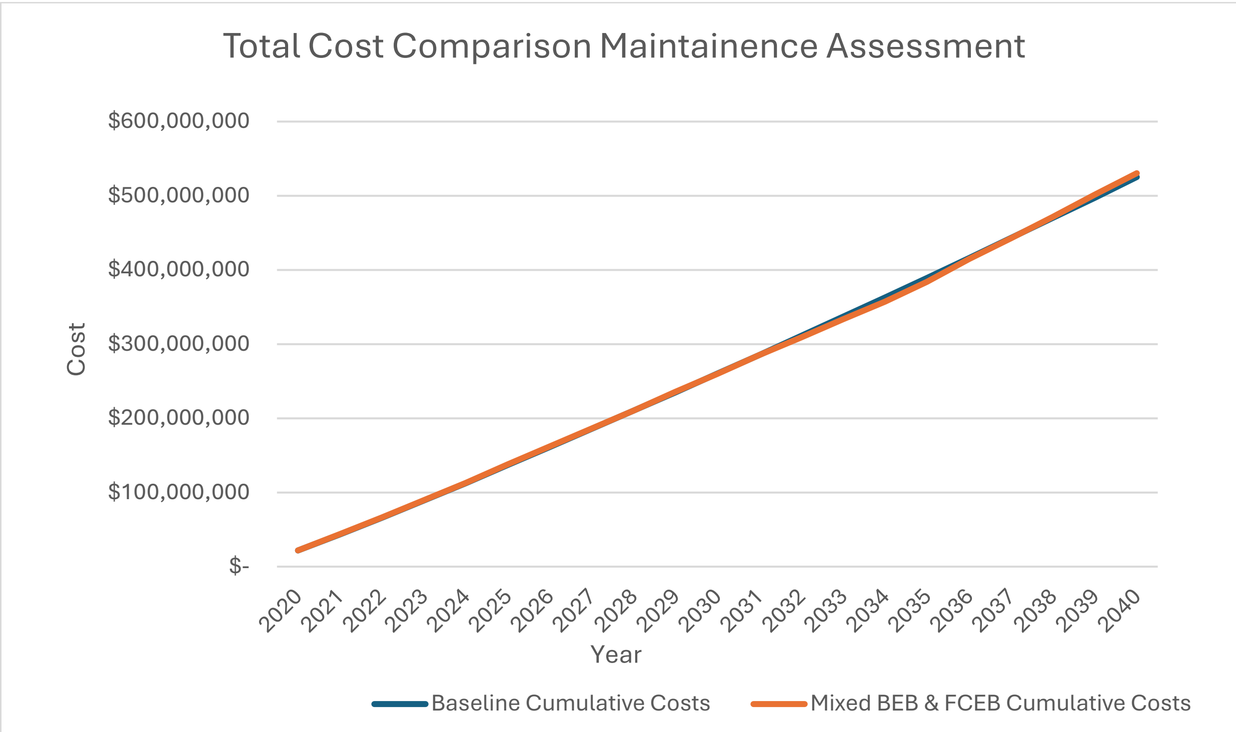


Figure 23 – Total Cost, Maintenance Assessment

Scenario	Cost
Baseline	$762,263,000
Mixed BEB and FCEB	$804,691,000

Table 20 – Total Cost, Maintenance Assessment

Total Cost of Ownership Assessment

The Total Cost of Ownership Assessment compiles and organizes the results from the Fleet, Fuel, Facilities and Maintenance assessments to show total and annual costs throughout the transition. It includes selected capital and operating costs for the Mixed BEB & FCEB over the transition timeline.

It's important to note the following:

- Costs associated with CTAC are not included within this analysis.
- Other costs such as battery recycling, operator/maintenance training costs, etc. were also not included within the analysis
- Cost reductions due to economies of scale for ZEB technologies were not assumed, since there is no historical basis or trend for this assumption.

Future changes to MTS' service level, depot locations, route alignments, block scheduling, etc. are unforeseen. The sections below provide best estimates using the information currently available, and using the culmination of assumptions explained throughout this study.

BASELINE

The Baseline scenario is used for comparative purposes only. It assumes no changes to the agency's current fleet configuration throughout the life of the study, i.e. no ZEB-related purchases. Table 21 shows the fleet, fuel, facilities and maintenance costs for the Baseline scenario in 2025 dollars.

Baseline Total Cost of Ownership					
Year	**Fleet**	**Fuel**	**Facilities/ Infrastructure**	**Maintenance**	**Total**
2020	$ 21,461,515.82	$ 11,403,552.61	$ -	$ 21,782,205.34	$ 54,647,273.77
2021	$ 102,625,211.05	$ 11,773,596.04	$ -	$ 21,800,462.40	$ 136,199,269.49
2022	$ 27,989,907.00	$ 16,059,592.99	$ -	$ 22,085,301.60	$ 66,134,801.59
2023	$ 27,947,832.00	$ 20,091,929.06	$ -	$ 23,249,409.30	$ 71,289,170.36
2024	$ 56,634,777.00	$ 16,151,761.26	$ -	$ 23,549,528.68	$ 96,336,066.94
2025	$ 35,382,467.00	$ 16,985,531.39	$ -	$ 24,648,303.32	$ 77,016,301.71
2026	$ 70,315,530.00	$ 17,904,909.90	$ -	$ 24,096,201.31	$ 112,316,641.21
2027	$ 62,280,233.00	$ 18,085,767.58	$ -	$ 24,339,597.29	$ 104,705,597.86
2028	$ 47,525,100.00	$ 18,268,452.10	$ -	$ 24,585,451.80	$ 90,379,003.90
2029	$ 50,175,288.00	$ 18,452,981.92	$ -	$ 24,833,789.70	$ 93,462,059.62
2030	$ 49,156,605.00	$ 18,639,375.67	$ -	$ 25,084,636.06	$ 92,880,616.73
2031	$ 51,843,144.00	$ 18,827,652.19	$ -	$ 25,338,016.22	$ 96,008,812.42
2032	$ 67,538,799.00	$ 19,017,830.50	$ -	$ 25,593,955.78	$ 112,150,585.28
2033	$ 108,451,021.00	$ 19,209,929.80	$ -	$ 25,852,480.59	$ 153,513,431.39
2034	$ 73,527,042.00	$ 19,403,969.49	$ -	$ 26,113,616.76	$ 119,044,628.25
2035	$ 29,550,620.00	$ 19,599,969.18	$ -	$ 26,377,390.66	$ 75,527,979.85
2036	$ 74,871,418.00	$ 19,797,948.67	$ -	$ 26,643,828.95	$ 121,313,195.62
2037	$ 55,799,619.00	$ 19,997,927.95	$ -	$ 26,912,958.54	$ 102,710,505.49
2038	$ 73,368,956.00	$ 20,199,927.22	$ -	$ 27,184,806.60	$ 120,753,689.83
2039	$ 89,425,216.00	$ 20,403,966.89	$ -	$ 27,459,400.61	$ 137,288,583.50
2040	$ 87,306,340.00	$ 20,610,067.57	$ -	$ 27,736,768.29	$ 135,653,175.86
Total	**$ 1,263,176,640.87**	**$ 380,886,639.99**	**$ -**	**$ 525,268,109.81**	**$ 2,169,331,390.67**

Table 21 – Total Costs, Baseline

MTS's total operating and capital costs are estimated at nearly $2.2 billion from 2020 to 2040. There are no facilities costs for this scenario. Since it is assumed that MTS will not be adding any additional buses (ZEB or internal combustion engine), other than those that are already included in the baseline scenario, no additional facilities are required.

Mixed BEB and FCEB

Table 22 shows the combined fleet, fuel, facilities and maintenance costs related to the Mixed BEB and FCEB scenario in 2025 dollars. The total estimated combined cost is slightly over $2.9 billion over the length of the transition, from 2020 to 2040. This scenario estimates a total of 699 BEBs and 59 FCEBs (762 total ZEBs) in service by 2040.

Mixed BEB & FCEB Total Cost of Ownership					
Year	**Fleet**	**Fuel**	**Facilities/ Infrastructure**	**Maintenance**	**Total**
2020	$ 21,461,515.82	$ 11,036,063.07	$ 1,111,284.00	$ 21,866,107.62	$ 55,474,970.51
2021	$ 102,625,211.05	$ 11,668,986.87	$ -	$ 21,903,687.22	$ 136,197,885.14
2022	$ 27,989,907.00	$ 16,059,592.99	$ -	$ 22,256,869.03	$ 66,306,369.02
2023	$ 27,947,832.00	$ 20,091,929.06	$ 8,000,000.00	$ 23,318,462.83	$ 79,358,223.89
2024	$ 56,634,777.00	$ 16,151,761.26	$ -	$ 23,594,223.78	$ 96,380,762.04
2025	$ 35,382,467.00	$ 17,013,650.69	$ 6,580.00	$ 25,049,643.50	$ 77,452,341.19
2026	$ 66,429,830.00	$ 15,730,102.38	$ 21,000,000.00	$ 24,067,320.90	$ 127,227,253.27
2027	$ 76,565,869.00	$ 15,787,606.41	$ 24,000,000.00	$ 23,879,390.66	$ 140,232,866.07
2028	$ 29,494,350.00	$ 16,189,698.08	$ 49,170,728.55	$ 24,210,685.12	$ 119,065,461.75
2029	$ 61,465,207.00	$ 18,086,600.70	$ -	$ 25,453,375.31	$ 105,005,183.00
2030	$ 71,287,290.00	$ 18,969,332.67	$ 29,640,595.37	$ 24,272,451.80	$ 144,169,669.84
2031	$ 71,889,651.00	$ 19,426,123.98	$ 5,346,383.51	$ 25,195,835.33	$ 121,857,993.82
2032	$ 92,272,582.00	$ 19,973,036.07	$ 20,792,520.67	$ 23,782,066.41	$ 156,820,205.15
2033	$ 107,028,594.00	$ 21,869,331.30	$ 54,195,821.28	$ 24,729,409.65	$ 207,823,156.23
2034	$ 106,359,893.00	$ 22,652,866.07	$ 104,364,223.65	$ 23,684,063.14	$ 257,061,045.86
2035	$ 42,290,464.00	$ 26,911,929.47	$ 49,361,010.40	$ 26,593,902.13	$ 145,157,306.01
2036	$ 108,512,354.00	$ 30,377,252.66	$ -	$ 30,906,734.12	$ 169,796,340.78
2037	$ 80,535,253.00	$ 31,185,263.03	$ -	$ 27,974,777.55	$ 139,695,293.58
2038	$ 101,684,650.00	$ 31,347,679.94	$ 17,681,309.08	$ 28,882,997.29	$ 179,596,636.31
2039	$ 129,348,724.00	$ 30,425,638.71	$ 45,112,341.39	$ 29,864,308.06	$ 234,751,012.17
2040	$ 126,610,412.00	$ 30,277,227.85	$ 57,481,139.59	$ 28,906,960.12	$ 243,275,739.57
Total	**$ 1,543,816,832.87**	**$ 441,231,673.26**	**$ 487,263,937.50**	**$ 530,393,271.58**	**$ 3,002,705,715.20**

Table 22 – Total Costs, Mixed BEB & FCEB

Total Estimated Costs

Figure 24 and Figure 25 show the combined total costs comparing Baseline with the Mixed BEB & FCEB

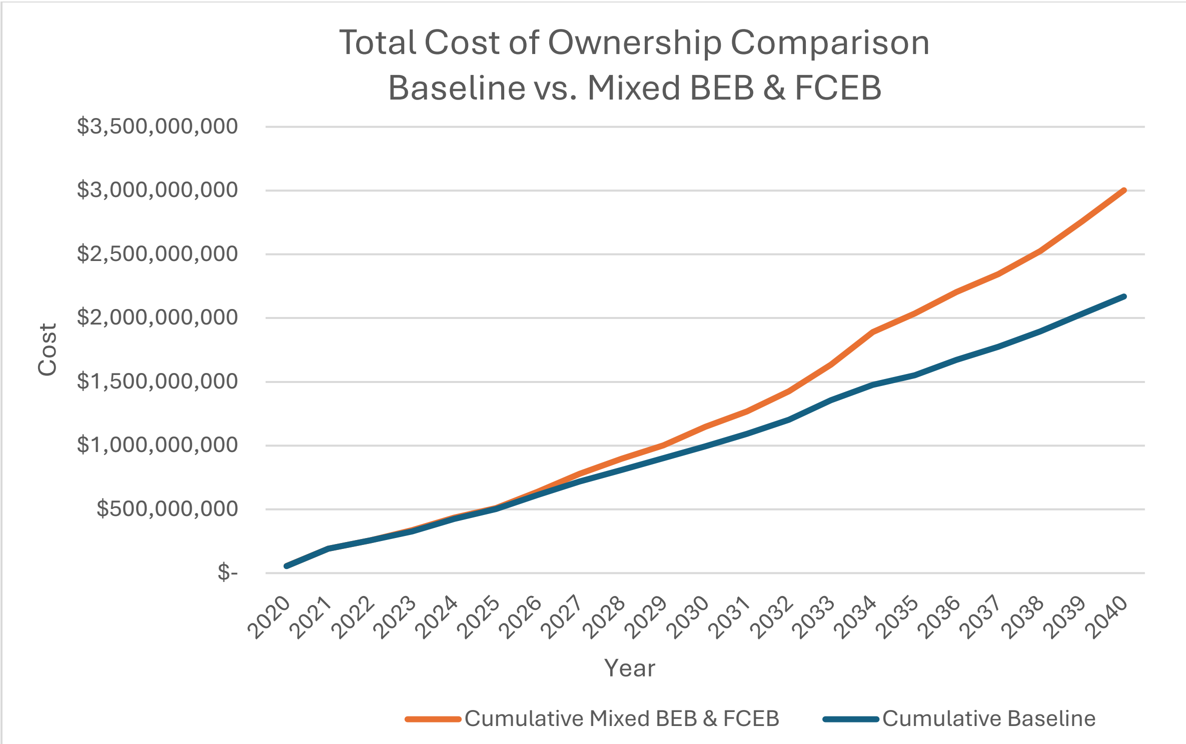
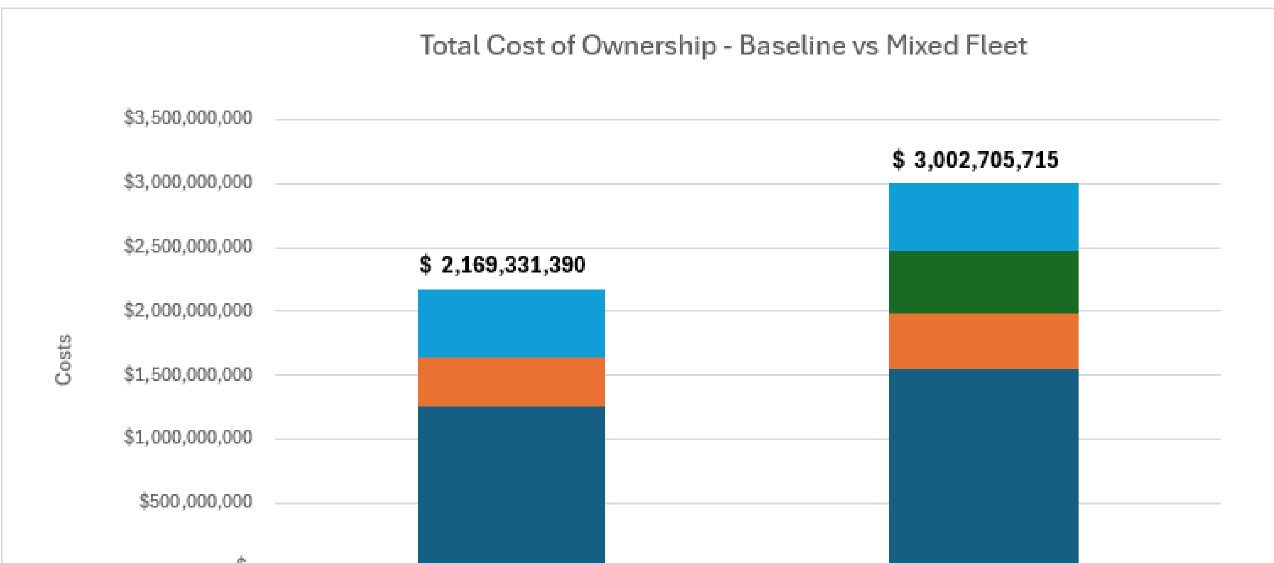


Figure 24 – Total Cost of Ownership, 2020-2040 Baseline vs. Mixed BEB & FCEB



	2025 Baseline	2025 Plan Update
Maintenance	$525,268,109.81	$530,393,271.58
Facilities/ Infrastructure	$-	$487,263,937.50
Fuel	$380,886,639.99	$441,231,673.26
Fleet	$1,263,176,640.87	$1,543,816,832.87

Figure 25 – Total Cost of Ownership, Baseline vs. Mixed BEB & FCEB

Conclusions and Recommendations

ZEB technologies are in a period of rapid development and change. While the technology is proven in many pilot deployments, it is not yet matured to the point where it can easily replace current internal combustion engine technologies on a large scale. 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 a closer operational equivalent to CNG, however, the incremental cost of buses, fueling infrastructure, and fuel places this technology at a serious disadvantage.

CARB's ICT regulation is an achievement toward addressing the challenges of climate change with a goal of 100% zero-emission transit fleets by 2040. However, as demonstrated in this analysis, there will be a substantial cost as well as technical challenges. Transit agencies may be challenged to meet this goal and provide the same level of passenger service. Fortunately, CARB's ruling provides waivers for economic hardship and in the event the current state of depot-charged bus technology does not meet service requirements.

A primary assumption for this analysis is that MTS is unable to increase fleet size due to significant space constraints at their depots and, as a result, vehicles must be replaced on a one-for-one basis. Analysis of additional land purchase and construction of the Clean Transit Advancement Campus (CTAC) was not part of this analysis, though it is expected to cost approximately $350 million to complete if required.

with an incremental cost of approximately $833 million, the Mixed BEB and FCEB approach that transitions approximately 99% of MTS' fleet to ZEB by 2040. There are expected complexities with managing the fleet through the transition that would require maintain existing internal combustion engine vehicle infrastructure (CNG, propane, and gasoline), installing new BEB infrastructure, and installing new FCEB fueling infrastructure. Space constraints at the depot will require careful planning if this path is continued. MTS may also experience additional benefits as a result of the transition to ZEBs.

MTS has accumulated ZEB credits from their procurement of ZEBs prior to 2023. These credits can be used in place of ZEB purchases to satisfy CARB's ZEB procurement requirements which started in 2023. With the purchase of thirteen (13) BEBs to support the ZEB pilot operations in 2019 and 2020, and the purchase of twelve (12) BEBs to support a new service in 2021, MTS recently had twenty-five (25) ZEB credits that can be applied to ZEB purchase requirements from 2023 and beyond. In February 2025, the MTS Board of Directors approved a request to CARB, utilizing seven (7) credits for FY25 bus purchases and thirteen (13) credits for FY26 bus purchases, both extinguishing the 25% ZEB requirement for those fiscal years. These developments have been incorporated into this analysis.

As a result, recommendations for MTS are as follows:

1. Remain proactive with ZEB deployments: MTS has been proactive in the purchase and deployment of BEBs throughout the ZEB Pilot Program and since it has ended. To incorporate FCEBs into the fleet, lower fuel costs and lower costs associated with the production hydrogen will be required. MTS should move forward carefully, taking

advantage of various grant and incentive programs to offset the incremental cost for ZEB deployment.

2. Target specific routes and blocks for early ZEB deployments: MTS should consider the strengths of given ZEB technologies and focus those technologies on routes and blocks that take advantage of their efficiencies and minimize the impact of the constraints related to the respective technologies. Technologies cannot follow a “one-size-fits-all” approach from either a performance or cost perspective. Matching technology to the service will be a critical best practice.
3. Continue with BEBs and consider FCEBs: At this stage, it is too early to tell which technology will dominate the market 10 to 20 years from now. Having the capability to deploy both ZEB technologies creates an opportunity for MTS to fully assess BEBs and FCEBs to determine which technology can best meet the operational range requirements while being financially efficient and sustainable.
4. Do not over commit to one form or brand of technology over another. ZEB and charging technology is rapidly changing each day as battery chemistry develops to help improve bus efficiency/range and charging equipment becomes more sophisticated. Commitment to one form and brand of technology can have a detrimental impact to efficient operations and service as a whole, especially if significant advancements are assumed to be made.

Continue to maintain or increase the level of service throughout the ZEB transition. As outlined in the ICT regulation, CARB does not expect, recommend or require a transit agency to reduce service at the expense of completing the transition. If the transition costs or technology limitations result in service reductions, it would be counter-productive to greenhouse gas reduction by propelling transit riders to utilize personal vehicles and increase VMT’s and overall emissions.

The transition to ZEB technologies represents a paradigm shift in bus procurement, operation, maintenance, and infrastructure. 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. MTS, with endorsement and approval from their Board of Directors, elected to pursue a mixed-use scenario that will allow them to initially deploy BEBs and explore possible opportunities and funding mechanisms to deploy FCEBs in service where BEBs are not able to meet range requirements. MTS will continue to monitor technology improvements and funding availability to accelerate the transition to a 100% zero-emission fleet. Evaluation will be completed in annual updates provided to the MTS Board of Directors and CARB.