ZERO EMISSION BUS PROGRAM

# Capital and Operating Progress Report

Publication Date: June 28, 2023


*Leading the way to a*

**ZERO EMISSION FUTURE.**

# Abstract

This report is the second phase of reporting based off the 2-year Zero Emission Transit Bus Technology Analysis (ZETBTA) that was launched in 2020. The Capital and Operating Progress Report expands the evaluation of the Zero Emission Bus (ZEB) technologies beyond the initial 5X5 control fleet and includes the District's ZEB Program capital investment inception and the financial forecast needed to deliver the full fleet transition. Tracking of this transition progress is to ensure the District meets the FTA requirements and the California Air Resources Board's (CARB's) Innovative Clean Transit (ICT) regulation. ZEB deployments follow the District's Clean Corridors Plan to prioritize disadvantaged communities and improve air quality while promoting social equity.

This report contains an integrated master schedule that incorporates existing projects in the District's current Capital Improvement Program and the comprehensive analysis of the Transit Asset Management (TAM) to support prioritization and programming of future projects. The TAM analysis examines the assets age and condition that are used to determine the eligibility for replacement and are aligned with the District's Strategic Plan and its goals and objectives.

# Table of Contents

# Executive Summary

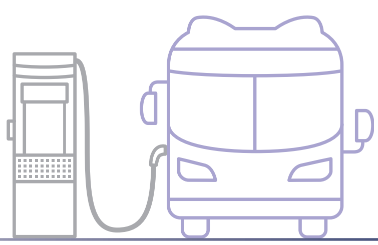
AC Transit has built the most comprehensive ZEB Program in the United States, spanning the past two decades. The program has generated over 5.6 million miles and produced over 26 thousand hours of workforce training to eliminate 14 thousand metric tons of CO2. The program's technology has expanded from a single hydrogen fuel-cell electric bus to a fleet of new generation hydrogen fuel cell and battery electric buses. Our ZEB infrastructure includes on-site hydrogen production and fueling, electric charging, on-site fleet Maintenance, and workforce training. The District's ZEB Transition Plan is to replace the fleet with 100% ZEB's by 2040 that will meet the ICT CARB regulation with an estimated mix fleet of 70% fuel cell buses (FCEB) and 30% battery electric buses (BEB) with a current funding need of $1.8 Billion.

## ZEB Program Risk Factors:

1) ZEB Transition funding need of $1.8 Billion
    - Fleet cost – $1.6 Billion
    - Infrastructure – $200 Million
2) BEB Service Range Limitation (60% of Block Assignments)
3) BEB Charging Infrastructure Delays (Switchgear Supply)
4) FCEB Hydrogen Cost Increase ($9.09 per kg)
5) FCEB Hydrogen Station O&M Cost Increase ($440K Annually)
6) ZEB Bus Procurement Cost Increase (30% per bus)
7) BEB Charging Infrastructure Reliability
8) Utility Grid Capacity to support BEB fleet charging needs
9) Resource constraints caused from fiscal cliff forecast
10) Cost escalations from inflation and supply chain issues

## ZEB Transition Progress

Currently the District has procured fifty-eight (58) ZEBs of which thirty-seven (37) are deployed for service. Twenty-one (21) BEB's are delayed for deployment as the charging infrastructure project was delayed due to the long lead time for the switchgear. The District is exploring on-site power generation (micro-grid) as an alternative energy solution to provide the energy required for the twenty-three charging stations and resiliency needs. Based on our Capital Improvement Program and the ability to secure funds, the District will have 287 ZEB's by 2028.



## ZEB Program Highlights:

**First ZEB Pilot:**
2002

**Life-to-Date Miles:**
5.6 Million

**ZEB Workforce Training:**
26,798
**Hours**

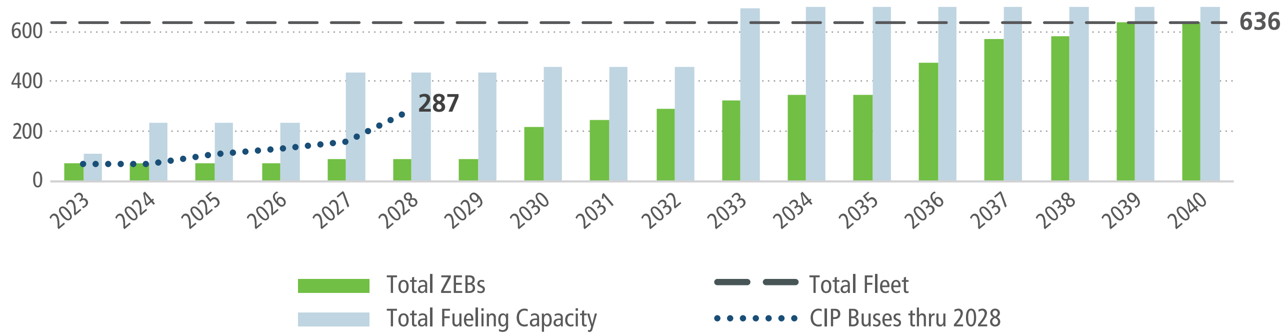
**CO2 Emissions Eliminated:**
13,943
**Metric Tons**

**Current Expenditures:**
$153M
**(2005-2022)**

**ZEB Fleet:**
58 → 69
**Actual** **Planned**

**Fueling Capacity**
84 → 134
**Actual** **Planned**

**ZEB Transition Schedule**




# Financial Outlook (Cost vs. Funding)

The ZEB Program funding needs are anticipated through 2036 to contract the last phase of bus purchases and infrastructure projects to reach compliance with ICT/CARB regulations by 2040. Reasonable estimates have been made for grants to cover ZEB transition forecast cost through 2034. As the transition plan progresses, updates to the funding forecast will be conducted. The Program Build Sheet table below contains an estimated cost of $1.9 Billion and a funding shortfall of $663 Million based on potential grants that the District could secure. Cost estimates include 30% bus price increases and annual escalations aligned with market conditions to support current program risks.

**Program Build Sheet Summary**

| Investment Type | Pre-2023 Expenditures | ZEB Transition Forecast (2022 Dollars) | Program Estimated Cost | Potential Grant Funding | Funding Gap (Shortfall) |
|---|---|---|---|---|---|
| **Revenue Bus** | $97,200,000 | $1,599,957,000 | $1,697,157,000 | $987,200,000 | ($612,757,000) |
| **Infrastructure** | $55,800,000 | $172,930,000 | $228,730,000 | $143,300,000 | ($29,630,000) |
| **Supporting Projects** | $253,708 | $20,796,292 | $21,050,000 | – | ($20,796,292) |
| **ZEB Program Total** | **$153,253,708** | **$1,793,683,292** | **$1,946,937,000** | **$1,130,500,000** | **($663,183,292)** |

# Workforce Development

AC Transit has successfully scheduled and produced over 26,798 hours of training with the use of content in eighteen (18) courses. In addition, the District is seeking 18 million dollars to modernize the Training and Education Center that is coined as AC Transit's Zero Emission Bus University or ZEBU. The ZEBU project will implement advanced technologies for synchronous learning that includes virtual and augmented reality systems. Modernizing the TEC will catapult workforce training on all aspects of zero emissions bus deployment.

# Bus Evaluation And Performance

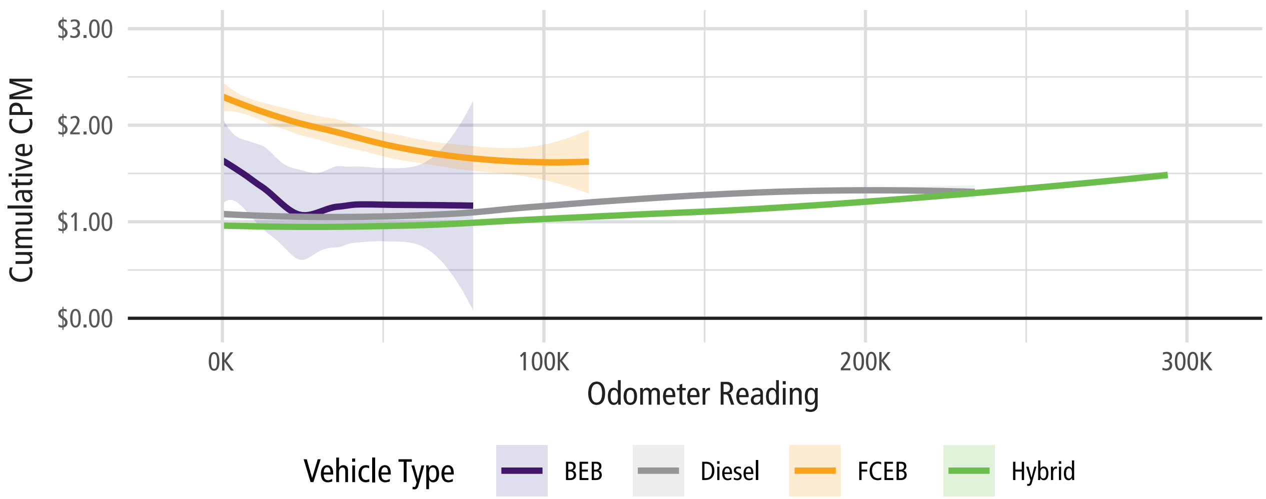
Buses that were selected for this report are all 40-foot buses spanning manufacturing years from 2016 through 2022. This includes a fleet mix of fuel cell, battery electric, diesel, and diesel-hybrid technologies. The performance evaluation table below provides an overview of the six (6) fleet groups with a summary of key statistics during the 2022 calendar year. Key performance takeaways show that the BEB fleet produced the lowest cost per mile, however the fleet was the least available and reliable.

### Zeb Performance Evaluation (2022)

| FLEET | DIESEL (BASELINE) | DIESEL HYBRID | FUEL CELL ELECTRIC (FCEB) | BATTERY ELECTRIC (BEB) |
|---|---|---|---|---|
| **Bus Quantity** | 35 | 25 | 30 | 7 |
| **Life-to-Date Mileage (Avg)** | 205,410 | 264,293 | 44,816 | 52,185 |
| **2022 Mileage** | 1,973,317 | 883,386 | 767,085 | 149,054 |
| **Cost/Mile (w/ credits)** | $1.81 | $2.22 | $2.50 | $1.36 |
| **Fleet Availability** | 90% | 83% | 80% | 74% |
| **Reliability (MBCRC)** | 15,179 | 12,421 | 8,494 | 7,237 |
| **MPG (DGE)** | 4.9 | 5.2 | 8.1 | 18.6 |

Additional analysis on the bus technology trends was performed using the cost per mile metric. The data trend figure below shows the normalization pattern by the various fuel sources where the lightly shaded area reflects the range of values for the bus within that fleet. Currently, the District is experiencing more variability and uncertainty in BEB and FCEB fleets than there are in Diesel and Hybrid which is primarily due to sample size issues (35 diesel, 25 hybrid, 30 FCEB and 7 BEB).

**Trend in Cumulative Operating Cost per Mile**
***by Mileage Grouping (2022$)***




Overall, Diesel and Hybrid buses are more consistent and cheaper to operate than ZEB. However, the trend in FCEB may approach that of Diesel and Hybrid as it operates more miles. BEB has significant variability in costs and requires further study with more buses to understand the true costs over time.

# AC Transit Overview

The Alameda-Contra Costa Transit District (AC Transit) is the largest public bus-only transit agency in California. Based in the San Francisco Bay Area's East Bay, and headquartered in Oakland, AC Transit formed in 1960, assuming the storied transit routes of the Key System and its predecessors, which over the previous 100 years, carried passengers via horse-drawn rail streetcars, electric streetcars, ferries, and buses. AC Transit has an established commitment to preserving and improving the quality and quantity of transit service for 1.5 million East Bay passengers that populate our 364 square mile service area, which includes Alameda and Contra Costa counties' 13 cities and adjacent unincorporated areas of the East Bay.

## ZEB Program

As a recognized leader in zero-emission buses (ZEB), both nationally and internationally, AC Transit has been aggressively pursuing opportunities and determining the feasibility of reduced emission and zero emission technologies for nearly 20 years. The ZEB Program aligns with the District's Strategic Plan and the environmental improvement goal that focuses on the reduction of carbon emissions from our buses and facilities, which will also directly benefit the neighborhoods we operate in.

AC Transit has improved the ZEB deployment process by enhancing project delivery methods and ongoing sustainable maintenance practices. Each phase of development offered our internal subject matter experts an opportunity for improved best practices on procurement, project delivery, operations, and ZEB technology performance.

The District's staff continues to partner with Stanford University's Precourt Institute for Energy to ensure the transparency and validation of the data, analysis methodology, and performance statistics. The Precourt is world renowned for its more than 200 faculty members and staff scientists working on energy-related challenges.

## Service Profile

AC Transit operates 101 fixed routes, with two primary forms of service: East Bay local service and Transbay express service. East Bay local service consists of regular routes, bus rapid transit routes, and supplemental school service. The service hours vary by line, with most of the local service operating every day from approximately 5:30 a.m. to midnight and All-Nighter lines operating from 1:00 a.m. to 5:00 a.m. Based on AC Transit's Clean Corridors Plan, the ZEB deployments are prioritized for disadvantage communities that stretch from the northern-most point of the District to nearly the southern-most part of Alameda County and touch all operating Divisions (Richmond, Emeryville, East Oakland, and Hayward).

**AC Transit Service Area**

# ZEB Program: Capital Investment

The District's ZEB Transition Plan is to replace the fleet with 100% ZEB's by 2040 that will meet the ICT CARB regulation with an estimated mix fleet of 70% fuel cell buses (FCEB) and 30% battery electric buses (BEB) with a current funding need of $1.8 Billion. Other ZEB Program costs include $18 Million to modernize the Training and Education Center, $2.2 Million to replace the non-revenue fleet, and $800 Thousand to enhance the data integration, management, and analytics platforms. The figure below provides the historical breakdown of the $153 Million in ZEB technology investments for bus and infrastructure.

**Zero Emission Technology Investment (Millions)**

| Project Type | Scope | Time Period | | | | Total |
|---|---|---|---|---|---|---|
| | | 2002 - 2015 | 2016 - 2019 | 2017 - 2022 | 2018 - 2022 | |
| Bus | FCEB | $31 | $12.9 | | $23 | $66.9 |
| | BEB | | $5.3 | $3 | $22 | $30.3 |
| Infrastructure | FCEB | $30 | $3.2 | | $18 | $51.9 |
| | BEB | | $1.6 | $.3 | $2 | $3.9 |
| | | **$61.7** | **$23** | **$3.3** | **$65** | **$153** |

Currently there are thirty-seven (37) active ZEBs used in service, which include seven (7) 40-foot battery electric buses and thirty (30) 40-foot fuel-cell electric buses. As we grow our ZEB fleet, we will also need to build the infrastructure required to re-energize each bus.

AC Transit is deploying both ZEB technologies side-by-side at our Oakland (Division 4) facility. Built in 2014, the Oakland division's hydrogen station has the capability to fuel thirteen (13) buses in a 24-hour period. The six (6) depot DC-fast charging stations, installed in 2020, provide a maximum output of 125kW when two charging stations are configured in a daisy chain. Our transit district's future design plans include the installation of charging infrastructure for up to fifty (50) buses. At the Emeryville (Division 2) facility, AC Transit recently expanded our hydrogen fueling capacity to sixty-five (65) buses consecutively, with design plans to install up to twenty-six (26) depot DC fast-charging stations.

AC Transit also participates in the California Low Carbon Fuel Standard (LCFS) market as a generator of credits based on green hydrogen production for bus use and through the deployment of ZEBs. As the District's ZEB fleet expands, our transit district will continue to capitalize on through the sale of LCFS credits that can be used to offset the fuel costs of the fleet.

The Agency continues to explore funding opportunities that will expand the zero-emission program. Our transit district has secured purchasing support for an additional fifty-one (51) ZEBs that includes the combination of seventeen (17) 40-foot battery electric buses, twenty-five (25) 40-foot and nine (9) 60-foot fuel-cell electric buses that will have the latest advancements in zero-emission technology.

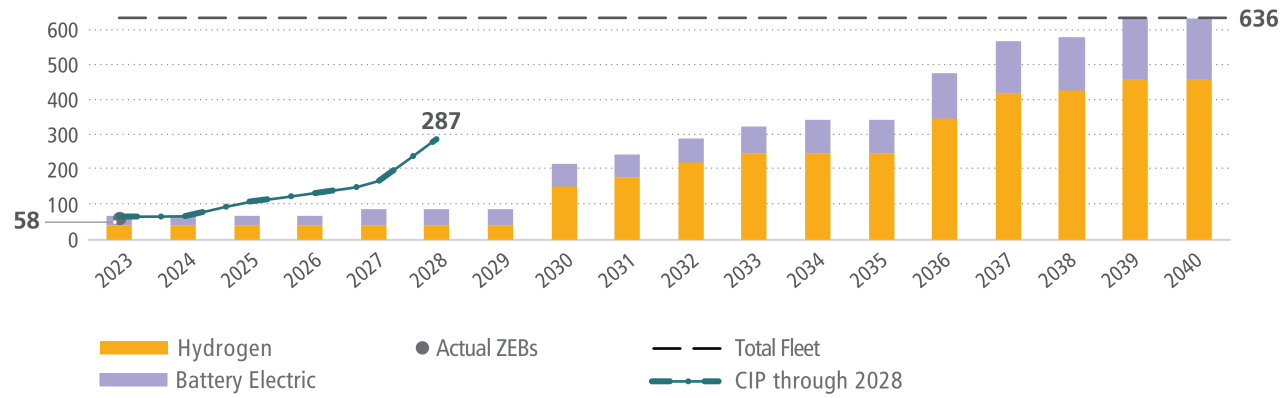
# Zero Emission Transition

The scope of the ZEB Transition plan includes replacement of all diesel buses with 70% FCEB and 30% BEB buses along with infrastructure upgrades at all district division properties to support fueling and maintenance. Also included in the transition are the projects to modernize the Training and Education Center, replace the non-revenue fleet, and enhance the data integration, management, and analytics platforms. The ZEB Program Investment Integrated Master Schedule in Appendix A displays the activities for the bus procurements and infrastructure projects.

# Bus Procurement Schedule

The schedule for bus replacement is planned to be completed by 2039 and aligns with the District's Transit Asset Management (TAM) Plans useful life benchmarks for fleet replacement. ZEB Infrastructure projects are scheduled to be completed prior to new technology bus acceptance to support fueling/ charging and maintenance for service operation deployments.

**Planned Zero Emission Buses Accepted by Year**




# Bus Procurement Progress

ZEB transition bus purchase project phases begin with authorization from the Board of Directors to secure funding. Once funding has been secured the project moves into procurement including technical specification, bid, award, production, delivery, and lastly inspection and acceptance from manufacturer. Accepted buses are made ready for service by AC Transit staff then deployed in service directly or used for training purposes, if required, then deployed into service.

Each bus procurement project is tracked in three different categories; completed, current (in progress and upcoming) and future planned purchases needed to comply with regulations. The district has a total of 58 ZEB buses because of its completed bus projects with technology type shown in the figure at right.

Fourteen bus purchase projects are in the approval process and the first projects within this set are anticipated to start in 2024. These projects replace 229 diesel buses with ZEBs by

**Completed Bus Projects by Technology**

| Project Description | FCEB Qty | BEB Qty |
|---|---|---|
| Bus Procurement Project (10 ZEBs) | 10 | |
| Bus Procurement Project (5 ZEBs) | | 5 |
| Bus Procurement Project (40 ZEBs) | 20 | 20 |
| Bus Procurement Project (3 ZEBs) | | 3 |
| **Total** | **30** | **28** |

the anticipated completion of the last project in the set by 2030 putting the district ahead of its transition schedule. Additionally, these bus purchases allow the district to maintain compliance with its Transit Asset Management performance targets. This early progress is feasible given completed infrastructure projects allowing capacity for fueling/charging and maintaining the ZEB buses.

The bus procurement costs are summarized by phase in the figure below to comply with the 2040 ICT CARB regulations. Appendix B provides additional detailed information for the current and future bus projects.

**Current and Future Bus Projects by Phase (Millions)**

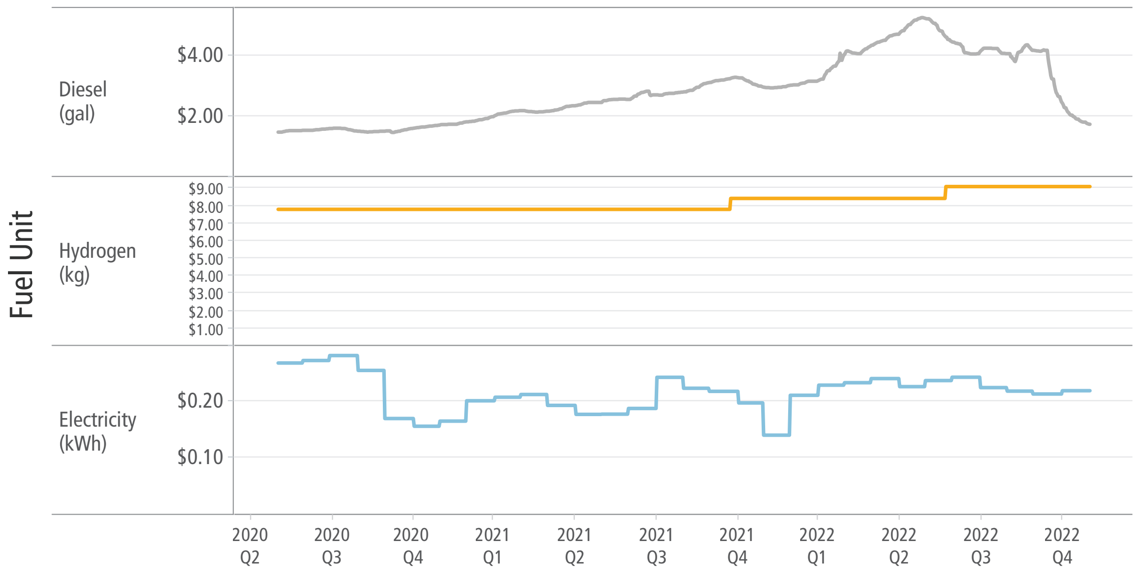
| Phase | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2032 | 2033 | 2034 | 2035 | 2036 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Board Approval Process | | $19 | $26 | $217 | $66 | $77 | | | | | | | | $406 |
| Future | | | | $32 | | $8 | $69 | $34 | $309 | $204 | $34 | $264 | $119 | $1089 |
| Production & Delivery | $104 | | | | | | | | | | | | | $104 |
| **Total** | **$104** | **$19** | **$26** | **$249** | **$66** | **$86** | **$69** | **$34** | **$309** | **$204** | **$34** | **$264** | **$119** | **$1599** |

# Bus Procurement Risk Factors

Risks and mitigations associated with the bus transition include the following:

- Delays with charging infrastructure due to the change from the utility provider (PG&E) to provide the necessary electrical capacity to serve the battery electric equipment. The District is in the process of implementing a microgrid project as a mitigation solution to meet the energy requirements.
- Dramatic rise of bus prices due to inflation that has an increase over an 20% cost increase for FCEB and BEB bus.
- Hydrogen fueling price has increased to over $9/kg that will impact operating expenditures (Figure below provides the trend with the energy sources)

**Energy Price Trend (3 Year)**



# Infrastructure Project Delivery

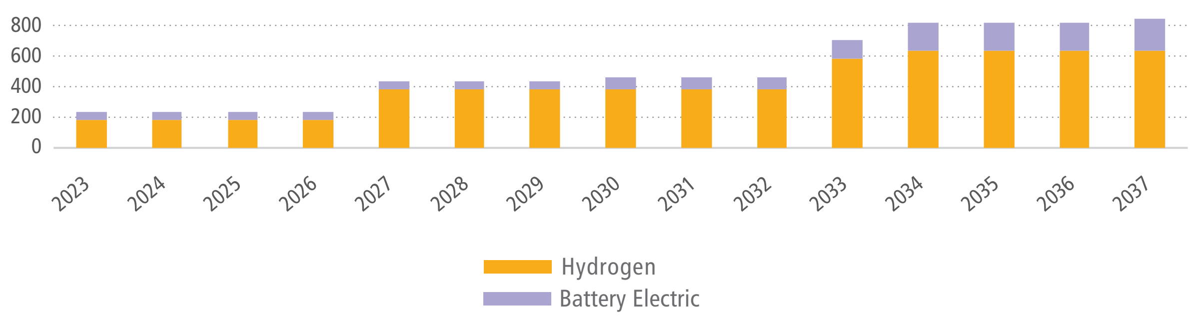
AC Transit operates zero-emission technology buses from both its Oakland (Division 4) and Emeryville (Division 2) facilities. The Oakland Division has six stationary battery chargers for Battery Electric Buses (BEB) and a vapor compression hydrogen station for Fuel Cell Electric Buses (FCEB). Meanwhile, the Emeryville Division has a liquid compression hydrogen station.

### Existing Facilities Technology

| | BATTERY ELECTRIC BUS | FUEL CELL ELECTRIC BUS | |
|---|---|---|---|
| **Facility** | **Oakland Facility** | **Oakland Facility** | **Emeryville Facility** |
| **Bus Energy Capacity** | 6 | 13 | 65 |
| **In Service Date** | 2020 | 2014 | Rehab 2020 |
| **Type of Fuel** | Electric | Hydrogen | Hydrogen |
| **Technology** | Stand-Alone Chargers | Vapor Compression | Liquid Compression |
| **Capital Cost (Build)** | $896,937 | $6,300,308 | $4,424,644 |
| **Core Hardware** | (6) ChargePoint CPE250s | IC-50 Ionic Compressor | Dual ADC MP-100 Cryo Pumps |
| **Related Hardware** | (6) 100A/480V Circuits | Ambient Vaporizer | High Pressure Vaporizers |
| **Dispenser Location** | West Wall of Facility | Fuel Island | Fuel Island |
| **Funding Source** | Federal, Regional | Federal, State, Regional | State, Regional |
| **Operating Statistics: January – December 2022** | | | |
| **Total O&M Cost** | $0 | $222,596 | $220,812 |
| **Availability** | 61.1% | 99.6% | 99.6% |

The transition schedule is currently showing all buses being replaced by 2039, whereas the supporting infrastructure upgrades are planned to be completed in 2035 to ensure fueling capacities are established. The schedule for both bus and infrastructure are consistently monitored, and adjustments are made to consider TAM priorities, inflation, and technology advancements. Below is the schedule for planned transition to 100% zero emissions fueling charging capacity based on planned infrastructure projects.

### Planned Zero Emission Buses Fueling Charging Capacity by Year



# Infrastructure Project Progress

The FCEB infrastructure design plans include a change in core hardware from a traditional compression system to cryogenic pumps with multiple dispensers. To resolve the pressure settling issue, the dispensers communicate with the bus in real time through an RFID ring to monitor flow rate, temperature, and pressure. The fueling island has a 25,000 liquid hydrogen storage tank that can support 150 buses within an 8-minute fueling window.

The BEB infrastructure design plans include charging specifications for dual port dispensers along the perimeter wall or bus yard overhead trellis locations. The charger power blocks require 200 kW per pair of charging positions and a charge management system to ensure buses are ready for daily operations. Due to power unavailability from the utility provider, the District includes microgrid solution to meet the facility energy need for charging.

The district has planned infrastructure projects to increase its capacity fueling hydrogen fuel cell bus and charging battery electric buses at each of its four divisions, Emeryville (D2), Richmond (D3), Oakland (D4) and Hayward (D6). Additionally, upgrades are planned for maintenance bays at each of these divisions as well as the Central Maintenance Facility (CMF). The infrastructure project phases begin with Board of Directors approval of the projects in Capital Improvement Plan and then move through design and construction with procurement for each phase.

Infrastructure projects are being tracked in three different categories; completed, current (in progress and upcoming) and future planned purchases needed to comply with regulations. The district currently has capacity to fuel/charge 84 ZEB buses because of its completed infrastructure projects with technology type shown in the figure below.

**Completed Infrastructure by Technology**

| Project Description | Hydrogen Fueling Capacity (Buses) | Electric Charging Capacity (Buses) |
|---|---|---|
| D4 Hydrogen Infrastructure | 13 | |
| D2 Hydrogen Infrastructure | 65 | |
| D4 Battery Electric Infrastructure | | 6 |
| **Total** | **78** | **6** |

The infrastructure costs are summarized by phase for the current and future projects that will support the bus procurements to comply with the 2040 ICT CARB regulations. Appendix C provides additional detailed information for the current and future infrastructure projects.

**Current Infrastructure Projects by Phase (Thousands)**

| Project Phase | 2021 | 2022 | 2023 | 2024 | 2027 | 2030 | 2031 | 2034 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Board Approval Process | | | | $18,630 | | | | | $18,630 |
| Construction | $6,145 | $13,575 | $9,100 | | | | | | $28,820 |
| Future | | | | $35,100 | $16,500 | $31,200 | $29,520 | $13,160 | $125,480 |
| **Total** | **$6,145** | **$13,575** | **$9,100** | **$53,730** | **$16,500** | **$31,200** | **$29,520** | **$13,160** | **$172,930** |

# Other Supporting Projects

Other supporting projects for the ZEB Program include the modernization of the Training and Education Center (TEC), ZEB Data Integration, Management and Analytics Platform enhancements, and non-revenue vehicle replacements. Additional information of the TEC modernization can be found in the workforce development section of the report. The data integration and analytics platform projects are underway, and the replacement of the non-revenue bus is currently seeking funding for the next fiscal cycle. Progress details of the supporting projects will be made available for the next reporting period.

**Supporting Projects Cost**

| Project Title | Total Project Cost |
|---|---|
| Non-Revenue Fleet Replacement | $2,250,000 |
| TEC Modernization | $18,000,000 |
| Zeb Data Integrations, Management, Analytics Platform | $800,000 |

# Infrastructure Risk Factors

Risks and mitigations associated with ZEB infrastructure include the following:

- Delays with charging infrastructure due to the change from the utility provider (PG&E) to provide the necessary electrical capacity to serve the battery electric equipment. The District is in the process of implementing a microgrid project as a mitigation solution to meet the energy requirements. Board-approved solicitation for on-site power generation facilities.
- Electrification projects deferred due to supply chain delays (12 months) procuring the distribution transformers and switchgears needed to support BEB charging infrastructure.
- Hydrogen fueling station O&M agreement has an increased cost over $400K annually
- Challenges securing Contractors with infrastructure projects

# Financial Plan

## PROGRAM ESTIMATED COST

Funding needs are anticipated through 2036 to contract the last phase of bus purchases and infrastructure projects to reach compliance with ICT/CARB regulations by 2040. Reasonable estimates have been made for grants to cover ZEB transition forecast cost through 2034. As the transition plan progresses, updates to the funding forecast will be conducted. The Program Build Sheet in Appendix D provides a breakdown of the $1.9 Billion estimated cost with a funding shortfall of $663 Million based on the potential funding available to secure.

**Program Build Sheet Summary**

| Investment Type | Pre-2023 Expenditures | ZEB Transition Forecast (2022 Dollars) | Program Estimated Cost | Potential Grant Funding | Funding Gap (Shortfall) |
|---|---|---|---|---|---|
| **Revenue Bus** | $97,200,000 | $1,599,957,000 | $1,697,157,000 | $987,200,000 | ($612,757,000) |
| **Infrastructure** | $55,800,000 | $172,930,000 | $228,730,000 | $143,300,000 | ($29,630,000) |
| **Supporting Projects** | $253,708 | $20,796,292 | $21,050,000 | — | ($20,796,292) |
| **ZEB Program Total** | **$153,253,708** | **$1,793,683,292** | **$1,946,937,000** | **$1,130,500,000** | **($663,183,292)** |

Cost estimates for the ZEB Transition Plan are rough order of magnitude based on existing zero emissions bus purchases with applied escalation as outlined in the MTC Regional Bus/Van Pricelists. Where technology is still in development for certain vehicle types, rough order magnitude cost is developed based on percentage of cost difference of same diesel vehicle type. Bus procurements use a 3.5% cost escalation factor that aligns with the producer price index. Infrastructure projects contain an 8% cost escalation factor.

**Program Funding Shortfall (Millions)**

| Year | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bus | (105) | (19) | 50 | (41) | (11) | (14) | (13) | (5) | | (42) | (26) | (4) | (264) | (119) |
| Infrastructure | (29) | (32) | 10 | (6) | (27) | | 8 | (52) | 33 | | | 47 | | |

# ZEB Program: Workforce Development

Moving to a ZEB fleet required changes to the District's multiple operating functions. Transitioning requires training employees to keep pace with changing technologies. AC Transit provides operational training for its bus operators, mechanics, and other support employees. The following describes the process for the planning and scheduling of training and the inter-agency cooperation with Original Equipment Manufacturers (OEMs). Emphasis herein is primarily focused on mechanic training. The shift from internal combustion engines and propulsion technologies to zero emission systems is more complicated for mechanics than it is for bus operators.

It is important to note however that every bus operator at a District ZEB bus location is trained prior to the fleet being deployed into revenue service. Training provides each employee with both academic and behind-the-wheel drive time experiences. Topics covered include awareness of high-voltage systems, dash controls and indicator lights, specific start-up and shut-down procedures, and defensive driving safety. Training meets regulatory requirements per California Highway Patrol, Motor Carrier Specialist inspections as is also defined in the California Code of Regulations (Title 13 CCR, § 1229, Driver Proficiency).

In alignment with its strategic goals, AC Transit is seeking state and federal advocacy programs to secure funding to support the planning, design, construction, and operation of a training center that will provide zero emission technological skills for operations and maintenance transit workers to serve as a career gateway and support a workforce development center for disadvantaged communities.

**Maintenance Mechanic Development**

| FCEB-BEB Courseware | Hours |
|---|---|
| Orientation and PPE/High Voltage | 8 |
| Energy Storage System | 40 |
| Power Train Technology | 40 |
| Fuel Cell | 30 |
| 2-Week Technical Training Program | 80 |

## Training and Education Center (TEC) Modernization

AC Transit is seeking 18 million dollars to modernize the Training and Education Center to complete implementation of advanced technologies as described herein. Modernizing the TEC will catapult workforce training on all aspects of zero emissions bus deployment. Coined as AC Transit's Zero Emission Bus University (ZEBU), once completed, AC Transit will achieve three pivotal goals with the creation of ZEBU:

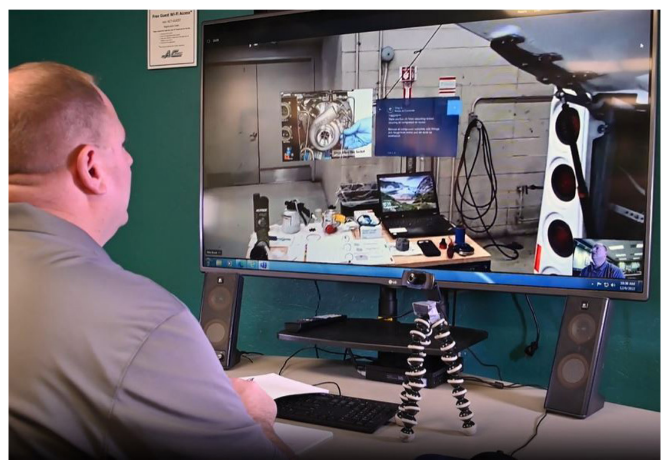
1. Provide proficiency and advanced technological skills training for AC Transit frontline essential workers in mechanics, service employees, and bus operators.
2. Be the leading clean transit training center in the United States that can provide zero emission bus (ZEB) training to any transit agency interested in implementing, maintaining, and sustaining zero emission buses.
3. Seek partnerships with community-based organizations (CBO), including secondary and post-secondary or collegiate institutions to help them develop zero-emission bus (ZEV) programs. The purpose is to support the development of new career pathways by working collaboratively with CBOs who engage with disadvantage communities (DACs), including low-income and low-income households, interested in promoting sustainable, life-changing career opportunities in public transit.

# Mixed Reality Systems

Moving ahead, AC Transit will introduce a new, innovative learning methodology in implementing virtual and augmented reality systems (also known herein as mixed reality systems). Mixed reality systems will re-invent and re-invigorate workforce training by engaging staff in the learning process, in real- time. Learning-by-doing takes on new meaning as employees are immersed in actual work tasks, guided along the way by virtual, demonstrations. Mixed reality systems provide a virtual "live-assist" for on-the-job learning, making complex or multi-layered tasks less intimidating and cumbersome. Teaching becomes a live environment as the learner actively performs the tasks taught, at the same time. Mixed reality will transform traditional, one-dimensional, train-by-slide (decks) into a three-dimension, knowledge experience wherein learning becomes interactive to the object that is the focus of the training.

*Maintenance technician receives instruction using augmented reality headset.*

Virtual reality, for example, is ideal in preparing a new workforce to engage more frequently with high voltage systems. The application of a virtual reality headset offers the mechanic a chance to learn how to apply PPE, work on specific inspection steps (within an energy storage system) and make mistakes without consequence of injury to self, others, or damaging equipment. Implementing this mixed reality as a learning tool will reduce fear of shock, arch flash and other hazards as the process is practiced virtually providing a completely safe environment. It's the perfect application to troubleshoot, test, and practice new steps that many would otherwise shy away from or avoid.



*Trainer monitors technician and provides real-time instruction on actual maintenance repair.*

Similarly, augmented reality which incorporates mobile devices like smart phones, specialized glasses such as HoloLens or electronic tablets, introduces virtual objects or procedures into real world settings. Using special glasses, for example, would enable a mechanic looking at (or "pointing to") the fuel cell's air compressor and see, on screen (or, in the lens) a series of instructions to complete an inspection or removal process. All safety steps, inspection procedures, and recommended tools to perform the tasks correctly and accurately would display by voice command ensuring that work is completed at the pace of the worker or as led by a trainer.

# Workforce Development Production

To date, the District has successfully scheduled and produced over 26,798 hours of training in one or more of the eighteen (18) courses listed in the table below. Note that the courses are recorded alphabetically and by title in the first column. Secondly, the column entitled Hours represents the duration of each class. Finally, course content is developed for specific bus fleet(s) as is depicted in the second column.

**ZEB-Based Course Catalog**

| Course | Fleet | Hours |
|---|---|---|
| A123 Battery Training (Vendor) | Gillig Hybrid/ New Flyer FCEB | 8 |
| Ballard Fuel Cell - ZEB (Vendor) | New Flyer FCEB | 24 |
| Ballard Fuel Cell 1K hrs PMI | New Flyer FCEB | 4 |
| Digital Multimeter (Distance Learning) | ZEBs/Hybrid | 4 |
| Fuel Cell Power Plant - ZEB | New Flyer FCEB/ Van Hool FCEB | 8 |
| High Voltage Electrical Safety - ZEB (Vendor) | FCEB/BEB | 8 |
| High Voltage: Awareness and Safety (Distance Learning) | New Flyer FCEB and BEBs | 3 |
| Hydrogen FC Safety and Familiarization - ZEB | New Flyer FCEB | 8 |
| Hydrogen: Safety, Fueling, and Storage - ZEB (Distance Learning) | New Flyer FCEB | 3 |
| Lithium-ion Battery Familiarization - ZEB | ZEBs/Hybrid | 8 |
| New Flyer BEB Orientation - ZEB (Vendor) | New Flyer BEB | 3 |
| New Flyer BEB SRV/Maintenance - ZEB (Vendor) | New Flyer BEB | 24 |
| New Flyer FC Orientation - ZEB (Vendor) | New Flyer FCEB | 3 |
| New Flyer FCEB Maintenance - ZEB (Vendor) | New Flyer FCEB | 32 |
| New Flyer FCEB Safety & PM - ZEB (Vendor) | New Flyer FCEB | 8 |
| New Flyer Safety/Fam. FCEB/BEB - ZEB | New Flyer Safety | 24 |
| Siemens ELFA - ZEB (Vendor) | New Flyer FCEB and BEBs | 8 |
| XALT Battery - ZEB (Vendor) | New Flyer BEBs | 16 |

# Two-Week Technical Training Program

Another great example of in-house training can be found in the experiential, two-week technical (hands-on) fuel cell training program. This training is perhaps the most in-depth and notable course staff developed and helps mechanics' understanding and retention of the training as the individual learns by working alongside a zero-emission trainer. Mechanics learn how to practice safety measures, perform preventative maintenance, advanced diagnostics, and troubleshooting. What makes this course unique is that it mimics the advantages of an apprenticeship model in that the mechanic learns by doing alongside an expert, repeatedly.

# ZEB Program: Operational Performance

## ZEB Fleet Evaluation

The Capital and Operational Report expands the evaluation of the ZEB technologies beyond the initial 5X5 control fleet of the ZETBTA reports. The primary analysis will focus on evaluating zero-emission buses, but additional control bus and fleets have been added to complement the analysis. The buses included are all 40-foot units spanning manufacturing years 2016 through 2022. The mix includes fuel cell, battery electric, diesel, and diesel-hybrid technology. Unless otherwise noted, this analysis covers various propulsion technologies and buses for calendar year 2022 (Jan 1, 2022, through December 31, 2022).

The matrix below provides additional specifications of the report's bus fleet. The matrix includes the dates of activation of service, the cumulative life-to-date miles of the study, and the design specification types of the ninety-seven (97) buses. It is important to note, AC Transit uses a typical lead time of eighteen (18) months from order date to service activation, and it's based on the average bus order, delivery, and acceptance timeline experienced during recent procurements.

**Fleets Included in the 2022 Annual Report**

| FLEET | DIESEL (BASELINE) | DIESEL HYBRID | FUEL CELL ELECTRIC (FCEB) | | BATTERY ELECTRIC (BEB) | |
|---|---|---|---|---|---|---|
| | | | 7000 | 7030 | 8000 | 8006 |
| **Series Grouping** | 1600 | 1550 | 7000 | 7030 | 8000 | 8006 |
| **Year Model** | 2018 | 2016 | 2018 | 2022 | 2018 | 2021 |
| **Manufacturer** | Gillig | Gillig | New Flyer | New Flyer | New Flyer | Gillig |
| **Bus Purchase Cost** | $488,247 | $699,060 | $1,156,044 | $1,212,161 | $938,184 | $963,009 |
| **Energy/Fuel Capacity** | 120 gal | 120 gal | 38 kg | 38 kg | 466 kw | 444 kW |
| **Range Specification** | 450 miles | 500 miles | 300 miles | 300 miles | 180 miles | 130 miles |
| **Propulsion Design** | Conventional Diesel | Diesel/ Battery | Battery Dominant | Battery Dominant | Battery | Battery |
| **Battery Design** | N/A | Lithium-Ion | Lithium-Ion | Lithium-Ion | Lithium-Ion | Lithium-Ion |
| **Engine/Powerplant** | Cummins | Cummins | Ballard/A123 | A123 | Xalt Energy | Cummins |
| **Transmission/Propulsion** | Voith | BAE | Siemens | Siemens | Siemens | Cummins |
| **In Service Date** | Jan 2019 | Aug 2016 | Jan 2020 | Dec 2021 | May 2020 | Sep 2021 |
| **Life-to-Date Mileage** | 205,410 | 264,293 | 92,054 | 21,198 | 67,020 | 15,095 |
| **Funding Source** | Federal, Regional, Local | Federal, Regional, Local | State, Regional, Local | Federal, State, Local | Federal, Regional | Federal, State, Local |

# ZEB Technology Environmental Impacts

In recent years, there has been a growing concern about the impact of greenhouse gas emissions on the environment, and transportation has been identified as a major contributor to this problem. As a result, there has been a concerted effort to develop and deploy zero-emission buses (ZEBs) as a more sustainable and environmentally friendly alternative. ZEBs are powered by electricity or hydrogen fuel cells, which produce zero greenhouse gas emissions during operation. In this section, we will examine the environmental impact of ZEBs compared to traditional buses that run on diesel or hybrid diesel technology. We will explore various metrics, such as greenhouse gas emissions, carbon emissions, and energy rates, to assess the environmental benefits of ZEBs and the potential impact of their adoption on the environment.

While ZEBs have zero tailpipe emissions (Scope 1), it is important to acknowledge that they are not entirely emission-free when considering Scope 2 and Scope 3 emissions. Scope 2 emissions refer to the indirect emissions from the production of the electricity or hydrogen fuel that powers ZEBs, while Scope 3 emissions refer to the indirect emissions associated with the production of materials, parts, and components that go into building ZEBs, as well as their disposal.

The exact number of emissions produced by ZEBs through these indirect sources varies depending on the specific fuel source used and the production processes involved. Therefore, while ZEBs offer a promising avenue for reducing greenhouse gas emissions in the transportation sector, it is important to carefully evaluate the entire life cycle of the bus, including both direct and indirect emissions, when assessing their environmental impact.

AC Transit launched a Sustainability Program in 2022 that intends to measure the baseline life cycle emissions of all the District's operations, including the ZEB fleet. For the purposes of this report, we only concern ourselves with Scope 1 emissions as compared to diesel fuel.

The figure below shows the total $CO_2$ emissions offset from operating the District's ZEB fleet in 2022. In total, ZEBs in this study offset emissions by 1,043 metric tons. This is approximately the equivalent of burning 1.15 million pounds of coal or supplying 131 homes with energy for a year. FCEB 7030 were the largest source of offset, due primarily to the number of bus and miles operated in the reporting period.

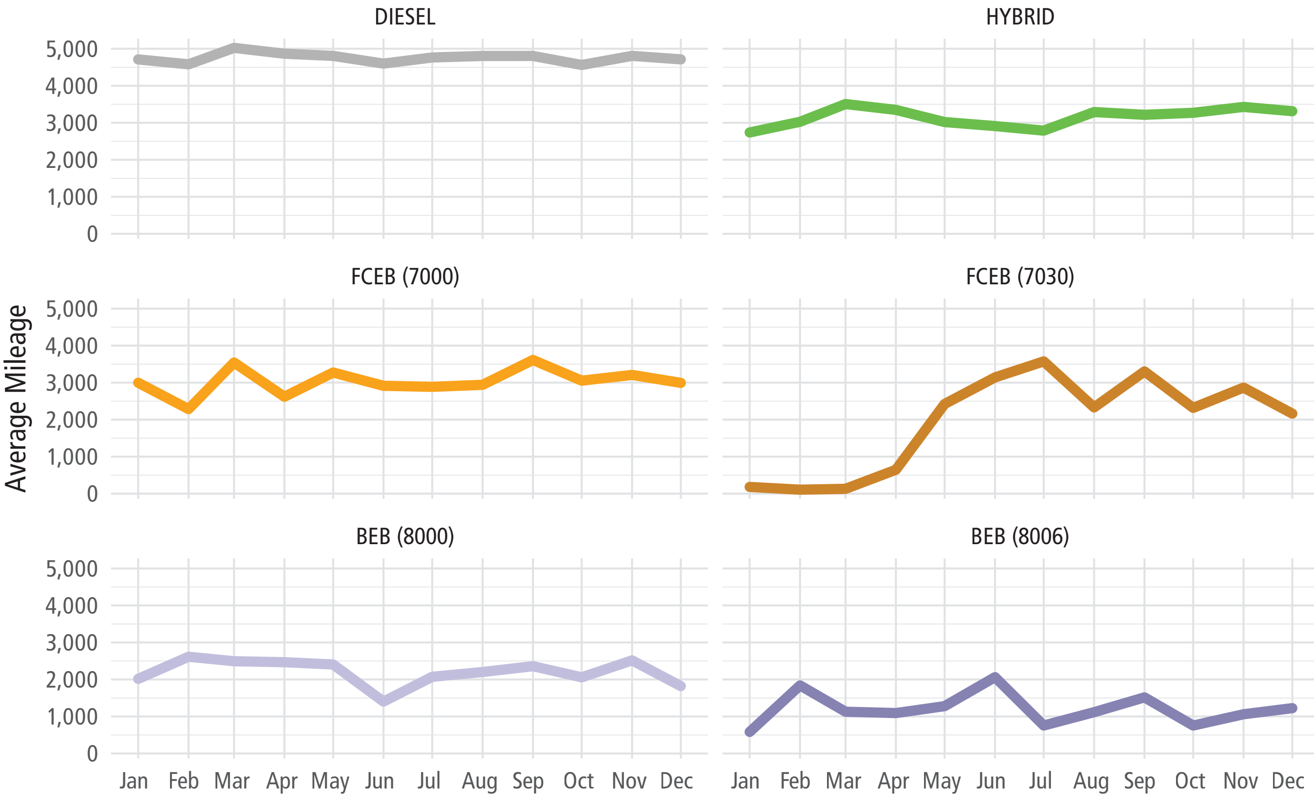
**ZEB Greenhouse Gas Equivalents, January 2022 – December 2022**

| | |
|---|---|
| Gallons of gasoline<br>**117,338** | Pounds of coal<br>**1,153,520** |
| BBQ propane cylinders<br>**43,449** | Barrels of oil<br>**2,425** |
| 1 year of Home Electricity<br>**202.9** | 1 Year of Home Energy<br>**131.3** |
| Smartphones charged<br>**126.86M** | Tanker trucks of gasoline<br>**13.80** |

# Bus Mileage

For zero-emission buses to be a viable alternative to traditional fossil fuel-powered buses, they must not only have a lower environmental impact, but also be efficient and cost-effective. This section focuses on the performance and efficiency of different ZEB technologies, including their mileage, fuel efficiencies, and energy rates. By comparing these metrics, we can gain a better understanding of the strengths and weaknesses of each technology. The performance over the next several years will inform purchasing decisions and our ZEB transition plan as we make our fleet 100% renewable by 2040.

**Fuel Monthly Mileage by Technology**




The figure above provides the average monthly bus mileage by technology. Based on this information, the following observations were noted:

- Diesel (1600) buses traveled the most miles in the year with a total of 57,060 miles, and this bus type has the highest mileage in most months.
- Hybrid (1550) buses' mileage shows a steady growth over the year, with the most significant increase from March to April.
- FCEB (7000) buses traveled the most miles in September, while the FCEB (7030) shows a sudden spike in miles traveled from May to July. This is due to a wider deployment of the 7030-fleet starting in May 2022.
- BEB (8000) buses traveled the most miles in February, and the BEB (8006) shows a sudden spike in miles traveled in June. This is due to a communication issue between the bus and the reader on the service island.

# Fuel and Energy Efficiency

In terms of relative performance differences, diesel buses traveled the most miles throughout the year, while the other bus types show variability in their mileage trends. Hybrid and FCEB (7000) bus types show a stable growth in mileage over the year, while FCEB (7030) and BEB (8006) types show the most variability in mileage.

**Fuel Efficiencies and Equivalent Comparison**

| | | Energy/Fuel | Fuel Efficiency | Efficiency Metric | Equivalent Efficiency | Equivalent Metric |
|---|---|---|---|---|---|---|
| **DIESEL** | | Diesel | 4.90 | Miles/Gal | 4.90 | M/DGE |
| **HYBRID** | | Diesel | 5.18 | Miles/Gal | 5.18 | M/DGE |
| **FCEB** | **7000** | Hydrogen | 7.46 | Miles/Kg | 8.29 | M/DGE |
| | **7030** | Hydrogen | 7.19 | Miles/Kg | 7.99 | M/DGE |
| **BEB** | **8000** | Electricity | 0.47 | Mile/kWh | 18.03 | M/DGE |
| | **8006** | Electricity | 0.56 | Mile/kWh | 21.52 | M/DGE |

The chart above compares the native fuel efficiency and equivalent efficiency of the various bus propulsion technologies.

- BEB 8006 has the highest fuel efficiency, with 21.5 miles per diesel gallon equivalency, followed closely by BEB 8000 at 18.0.
- FCEB 7000 and 7030 series have higher fuel efficiency compared to diesel and hybrid bus, but lower than the BEB types.
- The diesel buses have the lowest fuel efficiency among the bus types listed.

Overall, zero-emission buses, in particular BEB buses, have significantly higher energy efficiencies than fossil fuel bus.

**Energy Rate Comparison (2022 Annual Average)**

| DIESEL | HYDROGEN | ELECTRICITY |
|---|---|---|
| $3.86 / Gal | $8.72 / KG | $0.219 / kWh |

The figure above shows the average annual cost of energy in 2022. Energy prices are difficult to compare to one another because of the inherent differences in energy efficiencies from the specific propulsion technologies that make use of the fuels.

# Maintenance and Operational Cost Analysis

In addition to being a more environmentally friendly alternative, zero-emission buses must also be cost-effective. This section will focus on the cost analysis of different ZEB technologies, including their ongoing maintenance and operational costs. Moreover, we will examine the available energy credits for ZEBs, which could significantly reduce their operational costs. By comparing these metrics, we can gain a better understanding of the economic feasibility of adopting different ZEB technologies, and identify which technologies have the lowest operational costs and provide the best value for public resources.

**Operational Cost/Mile Totals (January – December 2022)**

| METRIC | DIESEL | HYBRID | FCEB | | BEB | |
|---|---|---|---|---|---|---|
| | 1600 | 1550 | 7000 | 7030 | 8000 | 8006 |
| **Total Costs (Fleet-Wide)** | | | | | | |
| **Maintenance** | $2,010,431 | $1,342,002 | $420,425 | $646,501 | $147,789 | $26,811 |
| **Labor Hours** | 12,558 | 7,663 | 2,495 | 4,873 | 950 | 208 |
| **Energy (Fuel)** | $1,566,994 | $653,991 | $401,904 | $518,934 | $56,402 | $10,294 |
| **Total** | **$3,594,268** | **$2,006,396** | **$825,813** | **$1,171,625** | **$205,583** | **$37,457** |
| **Costs per Mile** | | | | | | |
| **Maintenance** | $1.02 | $1.52 | $1.22 | $1.53 | $1.21 | $1.01 |
| **Energy (Fuel)** | $0.79 | $0.74 | $1.17 | $1.23 | $0.46 | $0.39 |
| **Total** | **$1.82** | **$2.27** | **$2.40** | **$2.77** | **$1.68** | **$1.42** |
| **Bus Count** | 35 | 25 | 10 | 20 | 5 | 2 |
| **Avg Daily Bus Count** | 24.7 | 15.5 | 5.9 | 8.5 | 2.1 | 1.1 |
| **Total Mileage** | 1,973,317 | 883,386 | 343,903 | 423,181 | 122,604 | 26,450 |

The figure above shows a detailed breakdown of bus costs and CPM performance as well as the average daily bus counts in service. Based on this information, the District observed the following:

- The cost per mile for fuel is the lowest for the BEB 8006, followed by BEB 8000 and Hybrid 1550 bus. The highest cost per mile for fuel is for the FCEB 7030.
- The cost per mile for Maintenance is lowest for the BEB type 8006, followed by the Diesel 1600 and BEB 8000. The highest cost per mile for Maintenance is FCEB 7030.
- The total cost per mile is lowest for the BEB 8006, followed by the BEB 8000 and Diesel 1600. The highest total cost per mile is for the FCEB 7030.
- Some buses went into service part-way through 2022, where an average daily bus count was provided, which is the average number of buses that were in service on any given day throughout the 365 days of 2022. This is a normalization factor for computing per-bus costs.

# Warranties and Energy Credits

An important factor to adjust for in calculating and comparing costs are the costs that were recovered through warranty claims and low-carbon fuel standard (LCFS) credits. The chart below shows the warranties and credits recovered for each propulsion technology.

- The most significant warranties were for BEB 8006, which had a $71,400 warranty for an electric motor on Bus 8007, for which the vendor completed on-site repairs.
- An electronics-related warranty amounted to $19,800 on the BEB 8000 series.
- Three warranties related to the fuel cell power plant on FCEB 7000 totaled $13,500 each.
- Net battery electric credits totaled $26,500.
- Overall, cost recovery was most significant for FCEB 7000 at $167,400 and BEB 8006 at $100,700.

**ZEB Recovery Total: Warranties and LCFS Credits**

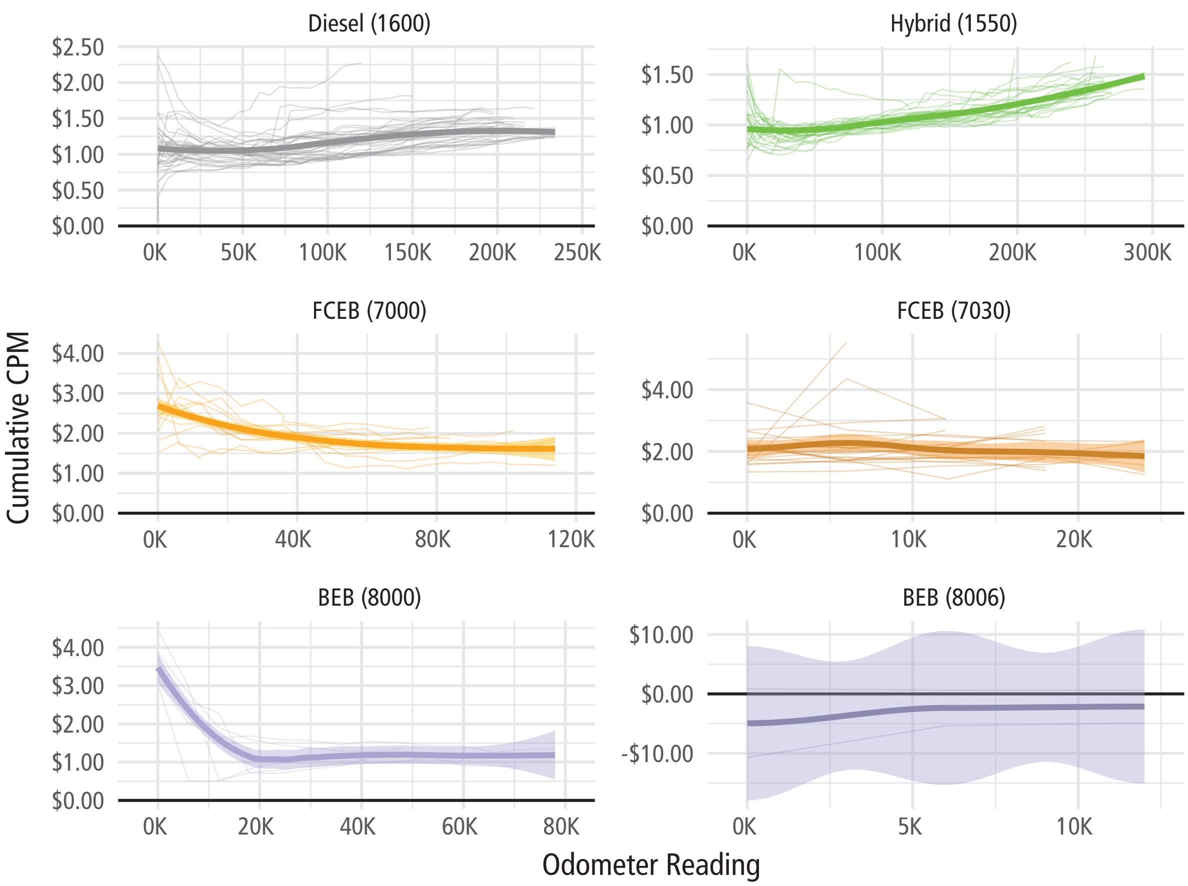
| TECHNOLOGY | | WARRANTY CLAIMS | WARRANTIES | NET CREDITS | TOTAL RECOVERY |
|---|---|---|---|---|---|
| DIESEL | 1600 | 38 | $32,562 | $0 | **$32,562** |
| HYBRID | 1550 | 33 | $32,432 | $0 | **$32,432** |
| FCEB | 7000 | 94 | $165,666 | $1,774 | **$167,441** |
| | 7030 | 147 | $52,498 | $2,568 | **$55,067** |
| BEB | 8000 | 27 | $64,148 | $17,121 | **$81,269** |
| | 8006 | 15 | $91,265 | $9,393 | **$100,658** |

To account for the cost per mile more accurately when operating a fleet, the recovered costs are applied to the operational costs.

# Cost Analytics/Observations

The District is in the process of analyzing how the cost per mile changes as the buses produce more miles when in service. Typically, older buses experience more mechanical failures, thus have higher costs of operation. The figure below provides the bus technology trends of the cumulative cost per mile that shows the normalization patter by the various fuel sources.

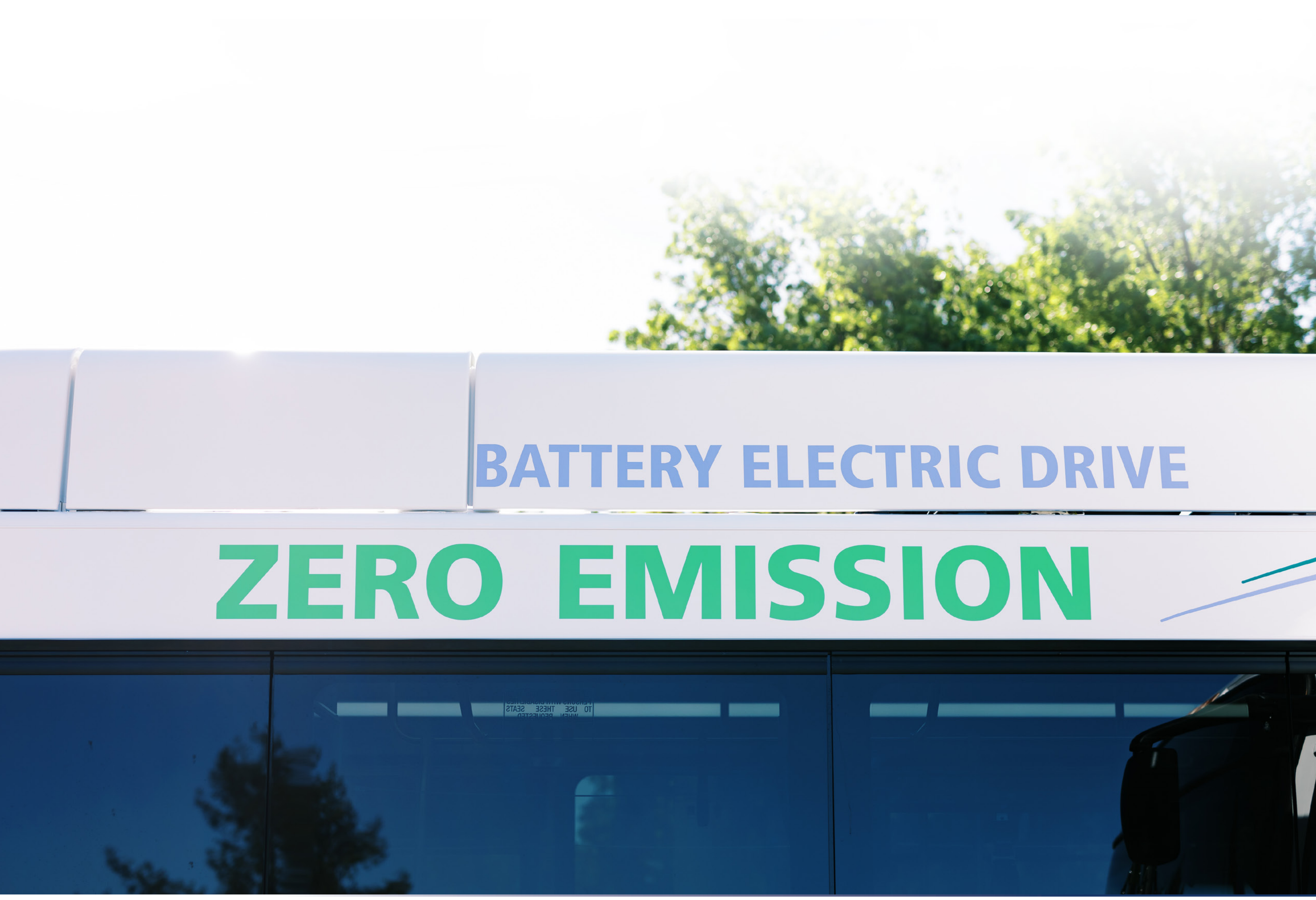
**Cumulative Operating Cost per Mile**
***by Mileage Grouping (2022$)***



When observing the trend in the figure above, the District found that the right-most value of each fuel source reflects the entirety of costs associated with operating the bus on a cost-per-mile basis, including energy costs, work orders and warranty credits. This can be adjusted for inflation, as a bus can span 14 years of service or more. For example, Hybrid starts off around $0.95 per mile but the right-most value is about $1.49 per mile. This means that initially it was cheaper to run, but the final operating costs are closer to $1.49 over the lifespan of this fleet.

More notably, the lightly shaded area reflects the range of values for the bus within that fleet. There is much more variability and uncertainty in BEB and FCEB fleets than there are in Diesel and Hybrid. While this is partly due to sample size issues (35 diesel, 25 hybrid, 7 BEB and 30 FCEB), the variability in FCEB cannot be explained by sample size alone. The normalized trend in CPM shows decreasing costs but remain relatively unstable compared to Diesel and Hybrid fuel sources.

The cost per mile across all propulsion types starts off high for the first couple thousand miles. Except for FCEB, these costs normalize after about 15,000 miles. Overall, Diesel and Hybrid buses are more consistent and cheaper to operate than ZEB. However, the trend in FCEB may approach that of Diesel and Hybrid as it operates more miles. BEB has significant variability in costs, and further study with more buses is required to understand the true costs over time.

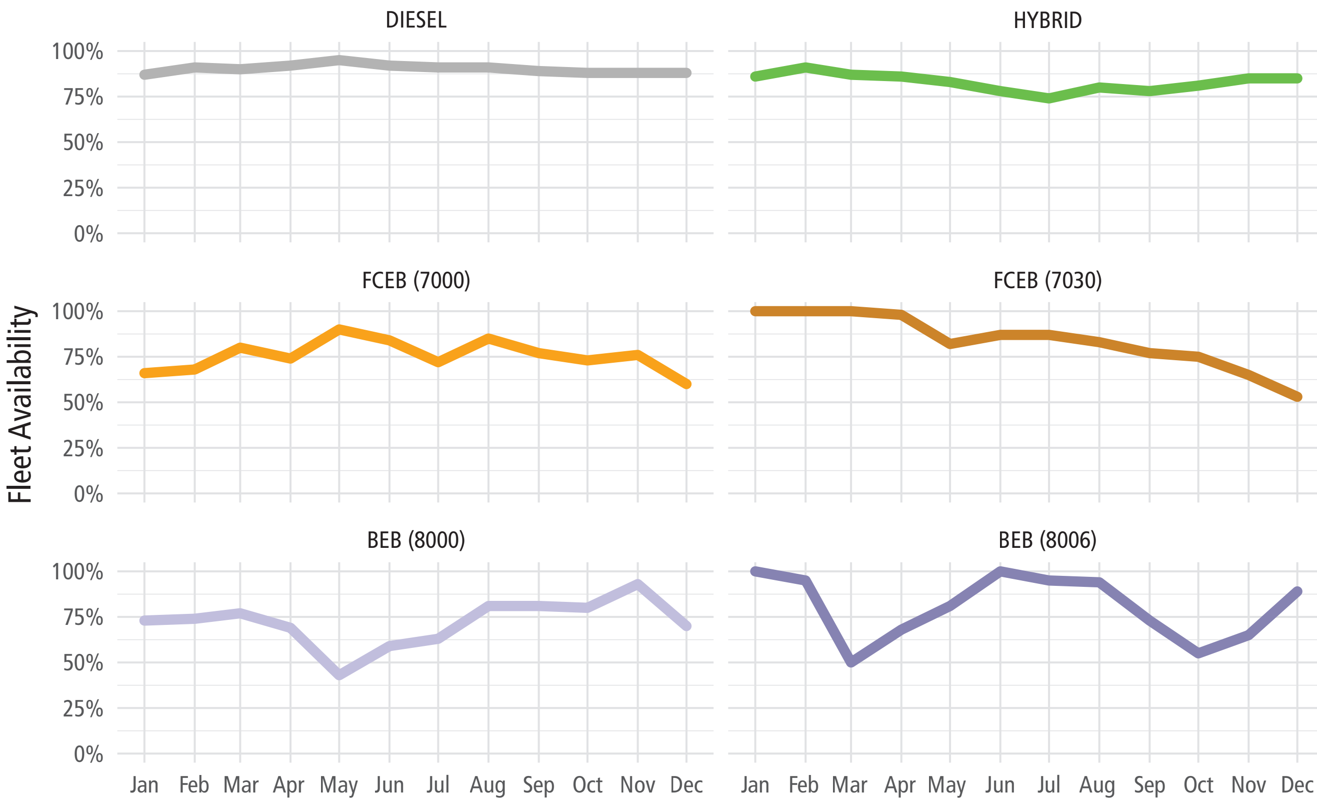


# Bus Availability

In addition to environmental considerations, the reliability and availability of zero-emission buses (ZEBs) is a critical factor when evaluating their potential as a replacement for traditional diesel and hybrid diesel buses. ZEBs are a relatively new technology and are still undergoing development and refinement, which can affect their reliability and availability in various ways.

In this section, we will examine the reliability and availability of ZEBs based on data from existing ZEB deployments. We will evaluate the performance of ZEBs in terms of their ability to operate on a consistent basis and meet their required schedules, as well as examine the factors that contribute to their reliability and availability. By analyzing the data, we can gain insight into the challenges and opportunities of using ZEBs and identify areas for improvement to make ZEBs a more reliable and available option for sustainable transportation.

**Monthly Bus Availability by Technology**




One of the most important indicators of reliability is availability, which is whether a bus can make morning pull-out. Morning pull-out refers to the first bus trip of the day, which is often the busiest and most critical in terms of meeting schedules and ensuring that passengers can get to their destinations on time. If a bus is unable to make morning pull-out, it can cause delays and disruptions that can have a ripple effect throughout the rest of the day. Therefore, it is essential to ensure that ZEBs are reliable enough to make morning pull-out consistently. This can be affected by various factors such as battery range and charging infrastructure, as well as the maintenance and repair history of the bus. By analyzing data on ZEB reliability and availability, we can identify patterns and trends that can help us better understand the factors that contribute to reliable performance, and develop strategies to improve ZEB reliability in the future.

The figure above provides the availability by bus technology, where the District observed the following:

- Diesel and hybrid buses have the highest monthly availability rates among all the fleet types, with diesel averaging 90% and hybrid at 83% for 2022.
- FCEB 7000 and 7030 have lower monthly availability rates compared to diesel and hybrid buses, with FCEB 7000 averaging 75% and FCEB 7030 at 82%.
- FCEB 7030 experienced a significant decrease in availability in November (65%) and December (53%) due to warranty repairs needed from the OEM.
- Battery electric buses (BEBs) have the lowest monthly availability rates as well as the most variability (even accounting for sample size), with BEB 8000 averaging at 72% and BEB 8006 at 80%. These lower rates are due to parts shortages and warranty repairs needed.
- FCEB 7000 had the lowest availability rate in January (66%) but increased significantly in March (80%). It then remained above 70% for the rest of the year, except for October (73%).

# Bus Reliability

Another critical indicator of reliability is the number of chargeable road calls a bus experiences throughout the year. Chargeable road calls refer to situations where a bus breaks down or experiences a malfunction while in service and needs to be taken off the road for repairs. While some road calls are unavoidable, excessive road calls can result in service disruptions and inconvenience for passengers, as well as increased Maintenance and repair costs for transit agencies. In addition to identifying the number of road calls a ZEB experiences, it is also important to track the cause of each road call, as this can help pinpoint any underlying issues or trends that need to be addressed. By understanding the factors that contribute to road calls, the District can develop proactive strategies to reduce the number of road calls, increase reliability, and improve the overall performance of ZEBs.

Because road calls are largely a function of the miles traveled within a fleet, we typically normalize this metric with mileage and report the miles between chargeable road calls (MBCRC). The higher MBCRC the better, as it implies a bus remains operational longer before an issue occurs. The chart below shows the total road calls and MBCRC across the study fleets.

**Miles Between Chargeable Road Calls (January – December 2022)**

| TECHNOLOGY | | Major | Minor | Total | Mileage | MBCRC |
|---|---|---|---|---|---|---|
| DIESEL | | 28 | 102 | 130 | 1,973,317 | 15,179 |
| HYBRID | | 60 | 44 | 104 | 883,386 | 8,494 |
| FCEB | 7000 | 27 | 19 | 46 | 343,903 | 7,476 |
| | 7030 | 32 | 28 | 60 | 423,181 | 7,053 |
| BEB | 8000 | 3 | 7 | 10 | 122,604 | 12,260 |
| | 8006 | 1 | 1 | 2 | 26,450 | 13,225 |

Based on the road call information, the District observed the following:

- Diesel buses perform the highest, at about 15,200 miles between chargeable road calls.
- The electric buses perform similarly to one another and follow closely behind diesel, at 12,300 and 13,200 miles respectively.
- The hydrogen-powered buses perform the lowest, traveling approximately 7,100 to 7,500 miles between road calls.

**Road Calls By System (January – December 2022)**

| SYSTEM | DIESEL | HYBRID | FCEB | | BEB | | TOTAL |
|---|---|---|---|---|---|---|---|
| | | | 7000 | 7030 | 8000 | 8006 | |
| Common System Failures | 57 | 41 | 19 | 28 | 6 | 0 | 151 |
| Engine/Fuel Cell System | 67 | 54 | 5 | 11 | 0 | 0 | 137 |
| Fuel System | 5 | 2 | 8 | 16 | 0 | 0 | 31 |
| High Voltage System | 0 | 7 | 13 | 4 | 2 | 1 | 27 |
| Transmission/Electric Drive | 1 | 0 | 1 | 1 | 2 | 1 | 6 |
| Total | 130 | 104 | 46 | 60 | 10 | 2 | 352 |

The chart above groups the road calls into 5 major systems which allows us to evaluate the reliability of the zero-emission technology systems on the buses. This is a simple method to see how these new systems compare, the District observed the following:

- Common system failures found on both conventional and zero-emission buses is one of the largest contributors to road calls.
- Zero-emission propulsion system failure on the FCEB and BEB were lower than the Diesel propulsion system failure.
- Zero-emission technology systems are not less reliable than conventional technology.

# Clean Corridors ZEB Deployments

The State of California Legislature passed SB 535 in 2012 requiring 25 percent of investments from the Cap & Trade program be spent in Disadvantaged Communities (DACs). The legislation carried with it a methodology for identifying those communities' using information about income, race, pollution, and other factors. The state routinely updates state-wide maps of communities they identify as DACs. The focus on investments in disadvantaged communities is aimed at improving public health, quality of life and economic opportunity in California's most burdened communities and at the same time reducing pollution that causes climate change.

The deployments features lines only assigned to communities identified as DACs in the AC Transit Board-adopted Clean Corridors Plan (SR 20-017). By prioritizing ZEB deployment in these areas, the plan aims to reduce the environmental impact of transit operations, improve air quality, and enhance the mobility of underserved communities while promoting social equity. The figure below illustrates which lines had buses from this program deployed on them between January 1 and June 30, 2022. The results indicate that Lines 14, 20, 21, 45, 51A, 90 and 98 had the highest number deployments within the Clean Corridors program which meet the compliance of the DAC assignments. These lines were chosen for the following reasons:

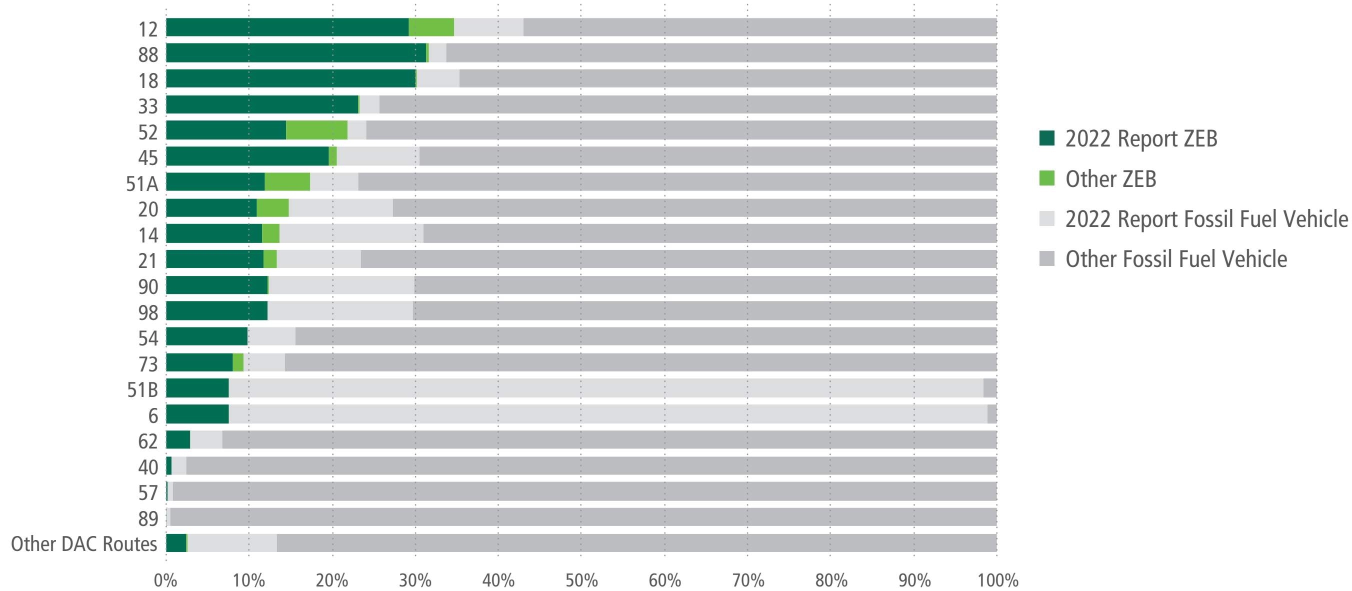
1) Serve disadvantaged communities that could benefit from reduced emissions from ZEB bus.

2) They have high ridership.

3) Except for Line 40, they are typically assigned 40-foot buses.

4) They are generally flat, with only one line–54–heading into the Oakland hills. All other lines go no higher than the Macarthur/580 corridor.

**DAC Corridors Distribution of Zeb Trip Deployments**




The primary lines for the core service network in East Oakland have been operating with weekday schedules since August 2020. The adjustment was made from the emergency service (7-day Sunday levels) to reduce pass-ups as higher ridership returned to the lines.

The chart below tracks how the ZEBs were deployed in 2022. Each route was classified as a route serving a DAC or another route. The proportion of trips that occurred on a DAC route or another route was calculated. The results show that over 91% to 99% of ZEB deployments occurred on DAC routes. This means that we are largely meeting the goal of utilizing ZEBs in Disadvantaged Communities as outlined in the Clean Corridor Plan.

**Zeb Deployment by Route Type (January – December 2022)**

| | | DAC Route | Other Routes |
|---|---|---|---|
| **DIESEL** | | 54.6% | 45.4% |
| **HYBRID** | | 98.2% | 1.8% |
| **FCEB** | **7000** | 98.0% | 2.0% |
| | **7030** | 91.2% | 8.8% |
| **BEB** | **8000** | 99.8% | 0.2% |
| | **8006** | 99.9% | 0.1% |

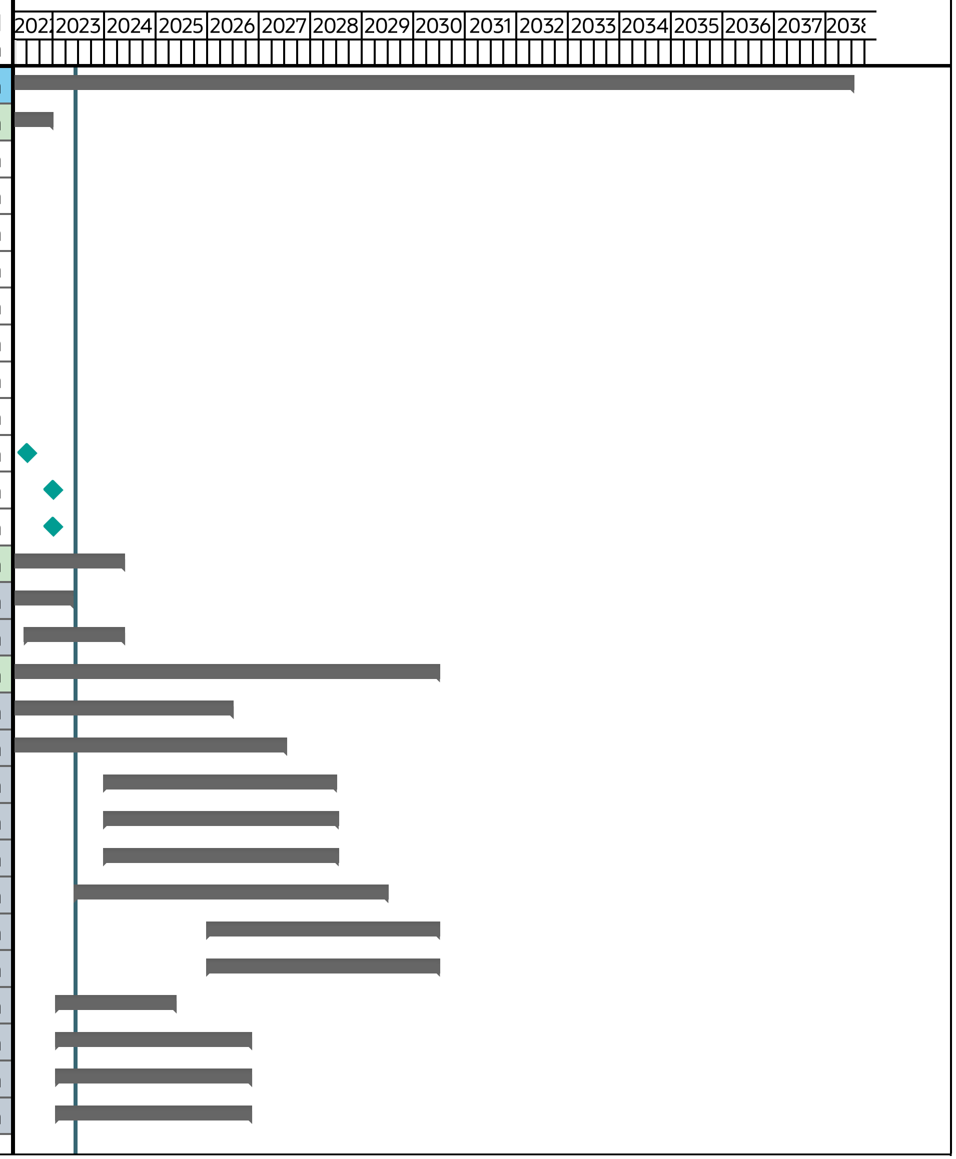
The deployment of buses to the DAC routes answers how we are using the available resources. The chart below demonstrates the trip distribution of the ZEB fleets on our DAC routes where routes 12, 88 and 18 experienced 30 to 35% of the trips operated assigned to a zero-emission bus.

# Appendix A: ZEB Program Integrated Master Schedule (pg 1 of 3)

ZEB-IMS 2304

ZEB Program Investments Master Schedule

| Name | Planned Duration |
|---|---|
| ZEB Program Investments Master Schedule | 397m |
| Major Milestones | 215m |
| Start ZEB Vehicle and Infrastructure Investments (2005) | 0m |
| Constructed D4 Hydrogen Infrastructure (2015) | 0m |
| Constructed D2 Hydrogen Maintenance Bay-P2027 (20… | 0m |
| Purchased 10 Fuel Cell Buses (2019) | 0m |
| Constructed D4 Battery Electric Infrastructure (2019) | 0m |
| Purchased 5 Battery Electric Buses (2019) | 0m |
| Constructed D4 Battery Electric Infrastructure-P2115 (2… | 0m |
| AC Transit ZEB Rollout Plan v1 (Res No. 20-029) (2020) | 0m |
| AC Transit ZEB Transition Plan v2 (Revised for Bil and IC… | 0m |
| Purchased 40 ZEBs (20 FC, 20 BEB)-P2175 | 0m |
| Purchased 3 Battery Electric Buses-P2166 | 0m |
| 2022 thru 2026 | 102m |
| D2 BEB Chargers-P2183 | 90m |
| D4 BEB Chargers-P2184 | 102m |
| 2024 thru 2028 | 175m |
| 9 - Articulated FCEB | 127m |
| 17 - Battery Electric Buses | 127m |
| 18 - Over the road FCEB | 55m |
| 92 - 40ft FCEB | 55m |
| 20 - 40ft BEB | 55m |
| 28 - Articulated FCEB | 74m |
| 40 - 40ft FCEB | 55m |
| 5 - 40ft BEB | 55m |
| D4 Hydrogen Station | 28m |
| CMF ZEB Maintenance Bay Upgrade- Body Shop (7 Bays) | 46m |
| CMF ZEB Maintenance Bay Upgrade- Dyno (4 Bays) | 46m |
| CMF ZEB Maintenance Bay Upgrade- Maintenance (10 … | 46m |



# Appendix A: ZEB Program Integrated Master Schedule (pg 2 of 3)

ZEB-IMS 2304

ZEB Program Investments Master Schedule

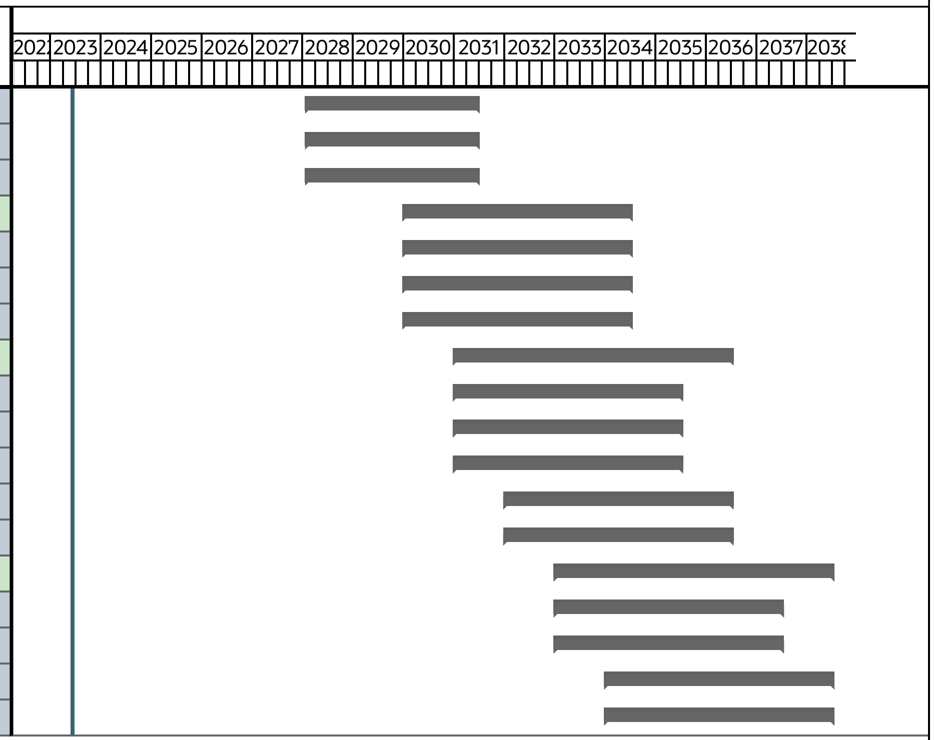
| Name | Planned Duration |
|---|---|
| CMF ZEB Maintenance Bay Upgrade- Paint Booth (1 Bay) | 46m |
| CMF ZEB Maintenance Bay Upgrade- Prep Booth (2 Bays) | 46m |
| D2 ZEB Maintenance Bay Upgrade- Body Shop (2 Bays) | 46m |
| D2 ZEB Maintenance Bay Upgrade- Maintenance (12 Ba... | 46m |
| D2 ZEB Maintenance Bay Upgrade- Paint Booth (1 Bay) | 24m |
| D2 ZEB Maintenance Bay Upgrade- Tire Shop (2 Bays) | 42m |
| D4 ZEB Maintenance Bay Upgrade- Body Shop (3 Bays) | 42m |
| D4 ZEB Maintenance Bay Upgrade- Maintenance (12 Ba... | 46m |
| D4 ZEB Maintenance Bay Upgrade- Paint Booth (1 Bay) | 46m |
| D4 ZEB Maintenance Bay Upgrade- Tire Shop (2 Bays) | 46m |
| D6 Hydrogen Station 100+ Buses | 46m |
| D6 ZEB Maintenance Bay Upgrade- Body Shop (4 Bays) | 46m |
| D6 ZEB Maintenance Bay Upgrade- Dyno (2 Bays) | 46m |
| D6 ZEB Maintenance Bay Upgrade- Maintenance (14 Ba... | 46m |
| D6 ZEB Maintenance Bay Upgrade- Paint Booth (1 Bay) | 46m |
| 2026 thru 2030 | 90m |
| 27 - Articulated FCEB | 55m |
| 10 - 40ft BEB | 55m |
| 19 - 40ft BEB | 55m |
| D3 Hydrogen Station 104 Buses | 42m |
| D3 ZEB Maintenance Bay Upgrade- Body Shop (1 Bays) | 42m |
| D3 ZEB Maintenance Bay Upgrade- Maintenance (12 Ba... | 42m |
| D3 ZEB Maintenance Bay Upgrade- Paint Booth (1 Bay) | 42m |
| D3 ZEB Maintenance Bay Upgrade- Steam Bay (1 Bay) | 42m |
| D3 ZEB Maintenance Bay Upgrade- Tire Shop (1 Bay) | 42m |
| D4 BEB Charging Infrastructure Expansion - 26 Buses | 42m |
| D4 Hydrogen Station Expansion to 150+ Buses-P2211 | 42m |
| D6 BEB Charging Infrastructure-32 Buses | 42m |
| D6 Hydrogen Station Expansion 10 150+ Buses | 42m |

# Appendix A: ZEB Program Integrated Master Schedule (pg 3 of 3)

ZEB-IMS 2304

ZEB Program Investments Master Schedule

| Name | Planned Duration |
|---|---|
| D2 BEB Charging Infrastructure Expansion - 70 Buses | 42m |
| D2 Hydrogen Station Expansion to 150+ Buses | 42m |
| D4 BEB Charging Infrastructure Expansion - 24 Buses | 42m |
| 2028 thru 2032 | 55m |
| 86 - 40ft FCEB | 55m |
| 31 - 40ft BEB | 55m |
| 15 - Double decker FCEB | 55m |
| 2030 thru 2034 | 67m |
| 11-Articulated FCEB | 55m |
| 61 - 40ft FCEB | 55m |
| 20 - 30ft BEB | 55m |
| 7 - Over The Road FCEB | 55m |
| 5 - 40ft BEB | 55m |
| 2032 thru 2036 | 67m |
| 50 - Over the road FCEB | 55m |
| 44 - 40ft BEB | 55m |
| 23 - Articulated FCEB | 55m |
| 24 - 40ft BEB | 55m |



# Appendix B: Bus Procurement Projects

**Current Bus Projects by Phase**

| Phase | Project Description | CIP Funding Year | CIP Estimate |
|---|---|---|---|
| Board Approval Process | Replace (9) Articulated Fuel Cell Buses | 2024 | $18,664,236 |
| | Replace (17) 40ft Battery Electric Buses | 2025 | $18,853,000 |
| | Replace (25) 40ft Fuel Cell Buses | 2025 | $31,025,000 |
| | Replace (23) Articulated Fuel Cell Buses | 2026 | $36,846,000 |
| | Replace (25) 40ft Fuel Cell Buses | 2027 | $32,800,000 |
| | Replace (20) 40ft Fuel Cell Buses | 2028 | $24,000,000 |
| | Replace (92) 40ft Fuel Cell Buses | 2028 | $147,200,000 |

**Future Bus Procurement Projects Required for 2040 ICT Carb Compliance**

| Project Description | Projected CIP Funding Year | Cost Estimate |
|---|---|---|
| Purchase 40 BEBs | 2026 | $77,440,000 |
| Purchase 5 BEBs | 2028 | $8,470,000 |
| Purchase 27 FCEBs | 2029 | $67,230,000 |
| Purchase 10 BEBs | 2029 | $17,430,000 |
| Purchase 19 BEBs | 2030 | $34,048,000 |
| Purchase 86 FCEBs | 2032 | $185,760,000 |
| Purchase 31 BEBs | 2032 | $58,590,000 |
| Purchase 15 FCEBs | 2032 | $64,800,000 |
| Purchase 11 FCEBs | 2033 | $30,470,000 |
| Purchase 61 FCEBs | 2033 | $135,176,000 |
| Purchase 20 BEBs | 2033 | $38,780,000 |
| Purchase 7 FCEBs | 2034 | $23,856,000 |
| Purchase 5 BEBs | 2034 | $9,940,000 |
| Purchase 50 FCEBs | 2035 | $174,600,000 |
| Purchase 44 BEBs | 2035 | $89,628,000 |
| Purchase 23 FCEBs | 2036 | $68,540,000 |
| Purchase 24 BEBs | 2036 | $50,064,000 |

# Appendix C: Infrastructure Projects

**Current Infrastructure Projects by Phase**

| Phase | Project Description | CIP Funding Year | CIP Estimate | Expenditures |
|---|---|---|---|---|
| Construction | D2 BEB Charging Infrastructure | 2021 | $6,145,106 | $1,418,683 |
| | D4 BEB Charging Infrastructure & Microgrid | 2022 | $13,894,052 | $335,177 |
| | D4 Hydrogen Station Upgrade | 2023 | $9,101,230 | $46,160 |
| Board Approval Process | CMF ZEB Maint Bay Upgrade - Body Shop - 7 Bays (2024) | 2024 | $1,620,000 | |
| | CMF ZEB Maint Bay Upgrade - Maintenance - 10 Bays (2024) | 2024 | $2,100,000 | |
| | D2 ZEB Maint Bay Upgrade - Body Shop - 2 Bays (2024) | 2024 | $810,000 | |
| | D2 ZEB Maint Bay Upgrade - Paint Booth - 1 Bay (2024) | 2024 | $540,000 | |
| | D2 ZEB Maint Bay Upgrade - Tire Shop - 2 Bays (2024) | | | |
| | D4 ZEB Maint Bay Upgrade - Tire Shop - 2 Bays (2024) | 2024 | $810,000 | |
| | D6 Hydrogen Station - 100+ Buses (2024) | 2024 | $14,500,000 | |

# Appendix C: Infrastructure Projects

**Future Infrastructure Projects Required for 2040 ICT Carb Compliance**

| Project Description | Projected CIP Year | Cost Estimate |
|---|---|---|
| CMF ZEB Maint Bay Upgrade - Dyno - 4 Bays (2024) | 2024 | $1,080,000 |
| CMF ZEB Maint Bay Upgrade - Paint Booth - 1 Bay (2024) | 2024 | $540,000 |
| CMF ZEB Maint Bay Upgrade - Prep Booth - 2 Bay (2024) | 2024 | $810,000 |
| D2 BEB Charging Infrastructure Expansion - 70 Buses (2031) | 2031 | $19,680,000 |
| D2 Hydrogen Station Expansion - to 150+ Buses (2031) | 2031 | $9,840,000 |
| D2 ZEB Maint Bay Upgrade - Maintenance - 12 Bays (2024) | 2024 | $2,160,000 |
| D3 Hydrogen Station - 104 Buses (2030) | 2024 | $14,820,000 |
| D3 ZEB Maint Bay Upgrade - Body Shop - 1 Bay (2030) | 2024 | $780,000 |
| D3 ZEB Maint Bay Upgrade - Maintenance 12 Buses (2030) | 2024 | $3,120,000 |
| D3 ZEB Maint Bay Upgrade - Paint Booth - 1 Bay (2030) | 2024 | $780,000 |
| D3 ZEB Maint Bay Upgrade - Steam Bay - 1 Bay (2030) | 2024 | $780,000 |
| D3 ZEB Maint Bay Upgrade - Tire Shop - 1 Bay (2030) | 2024 | $780,000 |
| D4 BEB Charging Infrastructure Expansion - 24 Buses (2034) | 2034 | $13,160,000 |
| D4 BEB Charging Infrastructure Expansion - 26 Buses (2027) | 2027 | $16,500,000 |
| D4 Hydrogen Station Expansion - to 150+ Buses (2030) | 2030 | $9,360,000 |
| D4 ZEB Maint Bay Upgrade - Body Shop - 3 Bays (2024) | 2024 | $1,080,000 |
| D4 ZEB Maint Bay Upgrade - Maintenance - 12 Bays (2024) | 2024 | $2,160,000 |
| D4 ZEB Maint Bay Upgrade - Paint Booth - 1 Bay (2024) | 2024 | $540,000 |
| D6 BEB Charging Infrastructure - 32 Buses (2030) | 2030 | $12,480,000 |
| D6 Hydrogen Station Expansion - to 150+ Buses (2030) | 2030 | $9,360,000 |
| D6 ZEB Maint Bay Upgrade - Body Shop - 4 Bays (2024) | 2024 | $1,080,000 |
| D6 ZEB Maint Bay Upgrade - Dyno - 2 Bays (2024) | 2024 | $810,000 |
| D6 ZEB Maint Bay Upgrade - Maintenance - 14 Bays (2024) | 2024 | $2,160,000 |
| D6 ZEB Maint Bay Upgrade - Paint Booth - 1 Bay (2024) | 2024 | $540,000 |
| D4 BEB Charging Infrastructure Expansion - 24 Buses (2034) | 2034 | $10,080,000 |

# Appendix D: ZEB Investment Build Sheet

| Investment Type | Pre-2023 Expenditures | ZEB Transition Forecast Cost (2022 Dollars) | Program Estimated Cost | Potential Grant Funding | Funding Gap (Shortfall) |
|---|---|---|---|---|---|
| **Bus** | **$97,200,000** | **$1,599,957,000** | **$1,697,157,000** | **$987,200,000** | **($612,757,000)** |
| Existing FCEB | $66,900,000 | | $66,900,000 | | |
| Existing BEB | $30,300,000 | | $30,300,000 | | |
| Diesel Bus Replacement w/ZEB | | $1,599,957,000 | $1,599,957,000 | $987,200,000 | |
| **Infrastructure** | **$55,800,000** | **$172,930,000** | **$228,730,000** | **$143,300,000** | **($29,630,000)** |
| Division 2 | $33,800,000 | $39,985,000 | $73,785,000 | | |
| Hydrogen Stations | $31,500,000 | $9,840,000 | $41,340,000 | | |
| Charging Stations | $2,300,000 | $25,825,000 | $28,125,000 | | |
| Maintenance Bays | $0 | $4,320,000 | $4,320,000 | | |
| Division 3 | $0 | $21,060,000 | $21,060,000 | | |
| Hydrogen Stations | $0 | $14,820,000 | $14,820,000 | | |
| Maintenance Bays | $0 | $6,240,000 | $6,240,000 | | |
| Division 4 | $22,000,000 | $66,285,000 | $88,285,000 | | |
| Hydrogen Stations | $20,400,000 | $18,460,000 | $38,860,000 | | |
| Charging Stations | $1,600,000 | $43,235,000 | $44,835,000 | | |
| Maintenance Bays | $0 | $4,590,000 | $4,590,000 | | |
| Division 6 | $0 | $39,390,000 | $39,390,000 | | |
| Hydrogen Stations | $0 | $22,320,000 | $22,320,000 | | |
| Charging Stations | $0 | $12,480,000 | $12,480,000 | | |
| Maintenance Bays | $0 | $4,590,000 | $4,590,000 | | |
| CMF | $0 | $6,210,000 | $6,210,000 | | |
| Maintenance Bays | $0 | $6,210,000 | $6,210,000 | | |
| **Supporting Projects** | **$253,708** | **$20,796,292** | **$21,050,000** | **—** | **($20,796,292)** |
| Non-Revenue Fleet Replacement | $0 | $2,250,000 | $2,250,000 | | |
| TEC Modernization (ZEBU) | $210,635 | $17,789,365 | $18,000,000 | | |
| ZEB Data Platform | $43,073 | $756,927 | $800,000 | | |
| **Program Total** | **$153,253,708** | **$1,772,253,292** | **$1,925,507,000** | **$1,130,500,000** | **($663,183,292)** |

# Appendix E: ZEB Performance Datasets (CY2022)

**Bus Mileage by Technology (Average)**

| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DIESEL | | 4,712 | 4,580 | 5,024 | 4,866 | 4,807 | 4,599 | 4,765 | 4,805 | 4,806 | 4,562 | 4,808 | 4,714 | **57,060** |
| HYBRID | | 2,738 | 3,026 | 3,506 | 3,348 | 3,019 | 2,911 | 2,788 | 3,290 | 3,216 | 3,270 | 3,428 | 3,313 | **37,859** |
| FCEB | 7000 | 2,997 | 2,285 | 3,543 | 2,619 | 3,273 | 2,914 | 2,886 | 2,941 | 3,612 | 3,053 | 3,208 | 2,993 | **36,200** |
| | 7030 | 181 | 107 | 130 | 645 | 2,423 | 3,141 | 3,574 | 2,330 | 3,303 | 2,317 | 2,866 | 2,162 | **25,647** |
| BEB | 8000 | 2,016 | 2,614 | 2,493 | 2,466 | 2,405 | 1,402 | 2,072 | 2,201 | 2,358 | 2,058 | 2,516 | 1,820 | **26,272** |
| | 8006 | 582 | 1,839 | 1,128 | 1,092 | 1,279 | 2,062 | 756 | 1,116 | 1,516 | 755 | 1,060 | 1,225 | **14,427** |

**Availability Rate By Technology (Average)**

| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DIESEL | | 87% | 91% | 90% | 92% | 95% | 92% | 91% | 91% | 89% | 88% | 88% | 88% | **90%** |
| HYBRID | | 86% | 91% | 87% | 86% | 83% | 78% | 74% | 80% | 78% | 81% | 85% | 85% | **83%** |
| FCEB | 7000 | 66% | 68% | 80% | 74% | 90% | 84% | 72% | 85% | 77% | 73% | 76% | 60% | **75%** |
| | 7030 | 100% | 100% | 100% | 98% | 82% | 87% | 87% | 83% | 77% | 75% | 65% | 53% | **82%** |
| BEB | 8000 | 73% | 74% | 77% | 69% | 43% | 59% | 63% | 81% | 81% | 80% | 93% | 70% | **72%** |
| | 8006 | 100% | 95% | 50% | 68% | 81% | 100% | 95% | 94% | 73% | 55% | 65% | 89% | **80%** |

1600 Franklin Street
Oakland, CA 94612

actransit.org
**@rideact**

0257-23 060923

*Leading the way to a* **ZERO EMISSION FUTURE.**