SR 21-284a,
Attachment 1

ZERO EMMISSION PROGRAM

Zero Emission Transit Bus Technology Analysis

Volume 2

REPORT PERIOD : JANUARY 2021 – JUNE 2021

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Leading the way to a
ZERO EMISSION FUTURE.

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Author and Acknowledgements

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Development of this technology analysis involved the contributions of a broad array of staff members, and is supported by the AC Transit Board of Directors as a core mission to achieve a 100 percent zero-emission bus fleet before 2040.

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Abstract

The Zero Emission Transit Bus Technology Analysis (ZETBTA) is designed to meaningfully analyze the various transit bus technologies that AC Transit operates. This report, Volume 2, is the second edition of the study which includes results from the fuel-cell electric bus (FCEB), battery electric bus (BEB), diesel hybrid bus, and conventional diesel bus technologies control fleet. There are five different technologies being evaluated: two different fuel-cell electric system designs, along with the other technologies. Five of each bus technology types are included in this study; hence the original nickname of the report was the 5X5 Transit Bus Technology Analysis. While AC Transit recognized the value of operating five different transit bus technologies by the same agency on the same routes in the same service environment, we realized that over 20 years of experience operating zero emission bus (ZEB) technologies afforded the opportunity to go much further. We integrated lessons learned and best practices gleaned from our extensive experience in deploying ZEB technologies, including developing innovative workforce training programs, data integration and management, and transit deployment viability. When selecting cost and performance data to include in this analysis, AC Transit carefully considered key performance indicators (KPI) that align with our Strategic Plan and ZEB Rollout Plan to guide the implementation of ZEB fleets. This approach provides data results that helped assess which ZEB technology can best meet the operational requirements of the District while being financially efficient and sustainable.

Volume 2 of the Zero Emission Transit Bus Technology Analysis report is an enhanced version from the first publication. The additional results presented in this reporting period include the following that are key takeaways from the initial report:

1 – The inclusion of performance and operating costs of the ZEB infrastructure

2 – Appendix that displays performance and cost comparisons between the two publications

3 – Reinventing ZEB workforce training

Acronyms

Alameda-Contra Costa Transit District	AC Transit/The District
Application Programing Interface	API
Battery Electric Bus	BEB
Business Intelligence	BI
California Air Resources Board	CARB
California Code of Regulations	CCR
Carbon Dioxide	CO_2
Cost per Mile	CPM
Data Integration and Management Environment	DIME
Direct Current – Fast Charging	DC-Fast Charging
Disadvantaged Communities	DAC
Division in Emeryville	D2
Division in Oakland	D4
Doctor of Philosophy	PhD
Environmental Protection Agency	EPA
Fuel Cell Electric Bus	FCEB
Gallon	Gal
Green House Gasses, Regulated Emissions, and Energy use in Transportation	GREET
Heating, Ventilation and Air Conditioning	HVAC
Key Performance Indicators	KPI
Kilogram	Kg
Kilowatt	Kw
Kilowatt-Hour	kWH
Labor and Materials	L&M
Learning Management System	LMS
Leland Stanford Junior University	Stanford University
Liquid Hydrogen	LH_2
Low Carbon Fuel Standard	LCFS
Miles between Chargeable Road Calls	MBCRC
Miles per Diesel Gallon Equivalents	M/DGE
Operations and Maintenance	O&M
Original Equipment Manufacture	OEM
Pacific Gas & Electric Business High Use Electric Vehicle	PG&E's BEV-0
Personal Protective Equipment	PPE
Senate Bill	SB
Stanford Energy Corporate Affiliate	SECA
Structured Query Language	SQL
To Be Determined	TBD
Zero Emission Bus	ZEB
Zero Emission Transit Bus Technology Analysis	ZETBTA
24-Hours, 7 Days a Week	24/7
5 Buses of the 5 Fleet Groups	5x5

About AC Transit

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 a 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.

AC Transit is a recognized leader in zero-emission buses (ZEB), both nationally and internationally. Our transit district has been aggressively pursuing opportunities and determining the feasibility of reduced emission and zero-emission technologies for nearly 20 years. 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.

As a result, we have emerged as a vanguard in both testing and comparing the costs and results of various conventional and zero-emission fuel technologies in a public transit environment. This report is the second volume of AC Transit's data gathering and research, which will determine which transit bus technology and infrastructure best meets the needs of our service.

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 much 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).

Zero Emission Bus Program Overview

Spanning the past two decades, AC Transit has built the most comprehensive ZEB Program in the United States, expanding 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. Currently there are twenty-six (26) active ZEBs used in service, which include seven (7) 40-foot battery electric buses and nineteen (19) 40-foot fuel-cell electric buses, and one (1) 60-foot hydrogen fuel-cell electric demonstration bus. 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 consecutively. The six (6) depot DC-fast charging stations, installed in 2020, provide a maximum output of 125kW per charging station. 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 accommodate 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 ZEB's. As the District's ZEB fleet expands, our transit district will have a growing revenue source 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 forty-one (41) ZEB's that includes the combination of twenty-one (21) 40-foot battery electric buses and twenty (20) 40-foot fuel-cell electric buses that will have the latest advancements in zero-emission technology. AC Transit forecasts the deployment of sixty-seven (67) ZEBs into revenue service by early 2023.

Transit Bus Technology Summary

This is the second publication of the Zero Emission Transit Bus Technology Analysis report, representing data collected on energy, capital and operating costs, performance metrics, mileage, reliability, and availability from January 2021 through June 2021. This open source report is AC Transit's contribution to the transit industry, offering an invaluable roadmap for agencies seeking to transition fleets to 100% zero emission.

The study reflects the transit industry's first ever, side-by-side evaluation of ZEB technologies by a single transit agency, in the same service environment using the same ZEB bus manufacturers, in a comparison to AC Transit's conventional diesel bus technologies.

The 5x5 matrix includes the bus grouping attributes and data summaries captured for the reporting period of this publication. Included in the report are the deployment statistics that the buses were assigned to using guiding principles of the the District's Clean Corridor Plan that identifies routes serving disadvantaged communities.

Figure 1, below, provides an overview of the five (5) fleet groups utilized in the study and the summary statistics during the report period, the Diesel fleet had the highest fleet mileage (120,749), where the BEB had the lowest mileage (54,275). The FCEB had the lowest cost per mile (CPM) when applying warranty and LCFS credits ($0.58), however the Legacy Fuel Cells had the highest CPM ($4.07) as they have been outside the warranty period. The Diesel fleet was the most reliable (12,075 MBCRC) and available (96%), however produced the most carbon emissions (298 Metric Tons of CO_2). The Legacy Fuel Cell fleet was the least reliable (2,531 MBCRC), and the BEB was the least available (47%). Additional details highlighting the matrix conclusions is found in the 5x5 data summary section of this report.

Figure 1: 5x5 Vehicle Matrix

FLEET	DIESEL (BASELINE)	DIESEL HYBRID	FUEL CELL ELECTRIC (FCEB)	BATTERY ELECTRIC (BEB)	LEGACY FUEL CELL
Series Grouping	1600	1550	7000	8000	FC
Technology Type	Diesel	Hybrid	Fuel Cell	Battery	Fuel Cell
Bus Qty	5	5	5	5	5
Manufacturer	Gillig	Gillig	New Flyer	New Flyer	Van Hool
Year	2018	2016	2019	2019	2010
Length	40′	40′	40′	40′	40′
Data Summary (January - June 2021)					
Fleet Mileage	120,749	98,189	88,389	54,275	70,859
Cost/Mile	$1.41	$1.80	$1.97	$2.02	$4.07
Cost/Mile (w/ credits)	$1.37	$1.78	$0.58	$0.69	$4.07
Emissions (CO_2 **Metric Tons)**	298	182	0	0	0
Fleet Availability	96%	75%	69%	47%	68%
Reliability (MBCRC)	12,075	4,091	6,314	3,618	2,531

Bus Fleet Specifications

The buses selected are all 40-foot local route units spanning manufacturing years 2010 through 2019. The mix includes fuel cell, battery electric, diesel, and diesel-hybrid technology. The study's buses represent the four propulsion technologies currently under comparison at other transit agencies. However, our unprecedented distinction is that never before have all four technologies been critically tested under the ownership of one agency. AC Transit included our legacy fuel cell bus in the study to gauge its performance against the latest zero emission technology on the market.

Figure 2, below, provides additional specifications of the study's bus fleet. The matrix includes the dates of activation of service, the cumulative life-to-date miles, and the design specification types of the twenty-five (25) buses. It is important to note, AC Transit uses a typical lead time of eighteen (18) months from order date to service activation, and is based on the average bus order, delivery, and acceptance timeline experienced during recent procurements.

Figure 2: Bus Specification Matrix

FLEET	**DIESEL (BASELINE)**	**DIESEL HYBRID**	**FUEL CELL ELECTRIC (FCEB)**	**BATTERY ELECTRIC (BEB)**	**LEGACY FUEL CELL**
Series Grouping	1600	1550	7000	8000	FC
Manufacturer	Gillig	Gillig	New Flyer	New Flyer	Van Hool
Bus Purchase Cost	$488,247	$699,060	$1,156,044	$938,184	$1,232,095
Energy/Fuel Capacity	120 gal	120 gal	38 kg	466 kw	40 kg
OEM Range Specification	480 miles	600 miles	300 miles	200 miles	220 miles
Propulsion Design	Conventional Diesel	Diesel/ Battery	Battery Dominant	Battery	Fuel Cell Dominant
Battery Design	N/A	Lithium-Ion	Lithium-Ion	Lithium-Ion	Lithium-Ion
Engine/Powerplant	Cummins	Cummins	Ballard/A123	Xalt Energy	UTC/EnerDel
Transmission/Propulsion	Voith	BAE	Siemens	Siemens	Siemens
In Service Date	Jan 2018	Aug 2016	Jan 2020	May 2020	Aug 2011

Facility Infrastructure Specifications

Zero-emission technology buses operate out of both the Oakland (Division 4) and the Emeryville (Division 2) facilities. At the Oakland Division, AC Transit's infrastructure includes six (6) stationary battery chargers to support our Battery Electric Buses (BEB) and a vapor compression hydrogen station to support Fuel Cell Electric Buses (FCEB). Our transit district has recently updated to a liquid compression hydrogen station at the Emeryville Division. Currently, only the Oakland Division is equipped to support both Fuel Cell Electric (FCEB) and Battery Electric Buses (BEB) and therefore, the study is localized here.

Figure 3, below, provides an overview of the facility infrastructure that supports the ZEB fleets and includes summary statistics for the reporting period. Included in the study are the operating and maintenance (O&M) costs, availability, and reliability operating statistics. The BEB and FCEB facilities achieved 100% availability and were reliable over 99% of the time during the reporting period. Costs for the BEB technology at the Oakland facility were covered under warranty. The costs for the FCEB include the nitrogen tank and hydrogen tank maintenance activities. Additional information on the facility operating statistics are detailed in the following sections.

Figure 3: Existing Facility Matrix

	BATTERY ELECTRIC BUS	**FUEL CELL ELECTRIC BUS**	
	Oakland Facility	**Oakland Facility**	**Emeryville Facility**
Facility Description			
Current Status	Operational	Operational	Operational
In Service Date	2020	2014	Upgraded 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	Six ChargePoint CPE250s	Messer IC-50 Ionic Compressor	Messer Dual ADC MP-100 Cryogenic Pumps
Related Hardware	Six - 100A/480V Circuits	Ambient Vaporizer	High Pressure Vaporizers
Fueling Location	West Wall of Facility	Fuel Island	Fuel Island
System Capacity	62.5 kW combinable to 125kW	9,000 Gal LH_2 Storage 360 kg per day	15,000 LH_2 Storage 1,750 kg per fueling window
Daily Vehicle Capacity	12 per fueling window	13 per 12-hour window	65 per 12-hour window
Charge/Fueling Time	5.5 hours per charge	7.5 minutes per fill	6.5 minutes per fill
Funding Source	Federal, Regional	Federal, State, Regional	State, Regional
Operating Statistics: January – June 2021			
Total O&M Cost	$132.18**	$111,798	$110,406
Availability	100%	100%	100%
Reliability	99.6%	100%	99.6%

* Cost to upgrade the Emeryville hydrogen facility from vapor compression to liquid compression.

**Covered under warranty.

Battery Electric Infrastructure

BUILT:
2020

COST:
$896,937

Oakland Battery Electric Bus Infrastructure

The battery charging infrastructure at the Oakland (D4) Division was built in 2020 at a total cost of $896,937. The configuration consists of six stationary ChargePoint CPE250 chargers and one mobile CPE250 shop charger. The chargers operate at 62.5 kW in stand-alone mode. In paired mode, two chargers will combine to charge a single vehicle at 125 kW. These chargers are currently covered by manufacturer warranty so there is no operations and maintenance (O&M) agreement in place. During the report period, the BEB charger had a coolant hose that failed which was replaced by the manufacturer under warranty. The failure did not impact the availability of the charger.

Hydrogen Infrastructure

Oakland Hydrogen Station

The hydrogen station at the Oakland Division was built in 2014 at a total cost of $6.3 million. The station includes a 9,000 gallon liquid hydrogen storage tank, ambient vaporizers, an IC-50 ionic compressor, and 360 kg of high-pressure gaseous storage. The station also includes an electrolyzer that produces up to 65 kg of green hydrogen per day. Two dispensers were installed in the fuel island that are aligned with the diesel dispensers making the bus servicing process seamless. This station has a fueling capacity for thirteen (13) buses per 12-hour fueling window. The Oakland hydrogen station is maintained by an O&M agreement with a vendor. The monthly cost of this O&M, covering operations, preventative maintenance, and corrective maintenance, is $14,833. The liquid hydrogen tank maintenance is $3,800. Operations includes maintaining a remote monitoring and alarm system to support 24/7 operations, including the immediate dispatch of a technician upon alarm. Preventative maintenance includes regular and planned activities to all equipment on a weekly, monthly, or annual basis. Monthly inspections and certifications of liquid storage (hydrogen or nitrogen) are also included. The District plans to upgrade the Oakland hydrogen station with liquid pumps once funding is secured.

BUILT:
2014
COST:
$6,300,308

The Emeryville Hydrogen Station

The hydrogen station at the Emeryville Division was originally built in 2011 at a cost of $5.1 million, exclusively for heavy-duty bus fueling of the project. In 2020, the station was upgraded at a cost of $4.4 million. Upgrades to the station includes a 15,000-gallon liquid hydrogen storage tank, dual ADC MP-100 Cryogenic Pumps, high pressure vaporizers, and 360kg high-pressure gaseous storage. Two dispensers were installed in the fuel island, alongside the diesel dispensers, making the bus servicing process seamless. The upgraded station can fuel 65 FCEBs in the 12-hour fueling window. The Emeryville hydrogen station is maintained by a O&M agreement with a vendor. The monthly cost of this O&M covering operations, preventative maintenance, and corrective maintenance is $11,851, with $5,950 for liquid hydrogen tank, and $600 nitrogen tank maintenance. Operations includes maintaining a remote monitoring and alarm system to support 24/7 operations, including the immediate dispatch of a technician upon alarm. Preventative maintenance includes regular and planned activities to all equipment on a weekly, monthly, or annual basis. Monthly inspections and certifications of liquid storage (hydrogen and nitrogen) is also included. During the report period, the station had a leak in the hydrogen fuel nozzle that was replaced by the maintenance contractor. The repair did not impact the availability of the station.

BUILT:
2011
COST:
$5,100,000
2020 UPGRADE:
$4,424,644

Facility Investment Projects

AC Transit has design plans for two additional BEB charging facilities by 2024. Infrastructure to accommodate up to twenty-size (26) additional charging stations is underway at the Emeryville (D2) facility. This project is fully funded with completion forecasted for 2022.

In 2023, the District is planning to construct a charging facility that will support twenty-five (25) to fifty (50) BEB charging stations. This facility will effectively be a BEB charging barn that will feature an overhead charging distribution. This project is in the planning phase and is already fully funded.

Figure 4: Facility Planned Projects

	BATTERY ELECTRIC BUS		**FUEL CELL ELECTRIC BUS**
	Emeryville Facility	**Oakland Facility**	**Oakland Facility**
Facility Description			
Current Status	Future	Future	Future (Upgrade)
In Service Date	Planned 2021	Planned 2023	TBD
Type of Fuel	Electric	Electric	Hydrogen
Technology	Distributed Charging	Distributed Charging	Liquid Compression
Core Hardware	TBD	TBD	Dual ADC MP-100 Cryo Pumps
Related Hardware	Electrical Service TBD	Electrical Service TBD	High Pressure Vaporizers
Fueling Location	South Wall of Facility	Bus Yard Overhead Trellis	Fuel Island
Operating Capacities			
Core Hardware	12-16 Charging Stations	25-50 Charging Stations	Dual ADC MP-100 Cryo Pumps
System Capacity	TBD	TBD	15,000 LH_2 Storage 1,750 kg per fueling window
Daily Vehicle Capacity	12-16 per fueling window	25-50 per fueling window	65 per 12-hour window
Charge/Fueling Time	TBD	TBD	6.5 minutes per fill

Environmental Impact

The District uses the 1600 series standard diesel bus fleet as the baseline control group and compares each other fleet to measure the environmental impact. Carbon dioxide (CO_2) is the primary greenhouse gas that is used for analyzing the environmental benefit in this study. The CO_2 comparison is measured in metric tons from tank-to-wheel that is calculated by using a carbon emission conversion methodology from the Environmental Protection Agency (EPA). The subsequent table demonstrates the ZEB CO_2 reduction in various greenhouse gas equivalents based on 274 metric tons saved from the ZEB fleet deployments.[1]

Figure 5: ZEB Greenhouse Gas Equivalents

–30,832 Gallons of gasoline consumed

–29,916 Gallons of diesel consumed

–302,848 Pounds of coal burned

–3.6 Tanker trucks worth of gasoline

–33 Homes' energy use for one year

–49.8 Homes' electricity use for one year

–1.5 Railcars' worth of coal burned

–634 Barrels of oil consumed

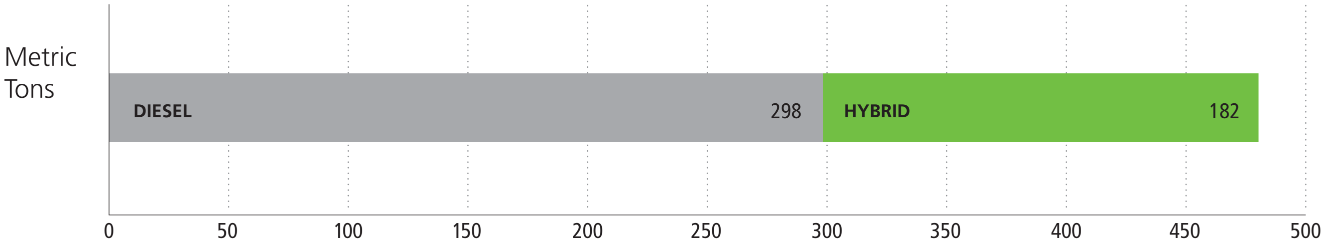
–11,201 Propane cylinders used for home barbeques

–0.0001 Coal-fired power plants in one year

–33,330,085 Number of Cell phones charged

The following figure compares the carbon emissions by fleet technologies. For the reporting period, the diesel and hybrid vehicles combined to produce 480 CO_2 metric tons compared to the ZEB fleets (7000, 8000, Legacy Series) that had zero emissions.

Figure 6: Carbon Emissions (CO_2)



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[1] EPA Calculator: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

5X5 Data Summaries

Fleet Mileage

An ideal mileage target is operating the bus approximately 150 miles per day over a 30-day period. A bus achieves 4,500 miles per month giving a test fleet a total of 22,500 miles per month. zero-emission and diesel-hybrid bus mileage can decrease during March, June, August, and December; operator sign-up months. These decreases are primarily attributed to the training demands of new operators who are unfamiliar with the test fleet buses. This is not the case for diesel bus, which are available at all operating divisions.

FCEB availability of both the BEB and Legacy fleets resulted in drastically reduced miles compared to the other fleets in the analysis. The Legacy FC fleet mileage peaked early in the period but declined due to limited availability of two (2) buses. The Diesel and FCEB fleet remained constant during the period.

Figure 7: Mileage by Technology (January 2021 – June 2021)

TECHNOLOGY	JAN	FEB	MAR	APR	MAY	JUNE	TOTAL
DIESEL	20,869	19,127	21,478	20,045	19,237	19,995	**120,749**
HYBRID	15,718	14,696	14,973	18,410	16,759	17,633	**98,189**
FCEB	18,445	15,024	15,866	12,027	11,737	15,290	**88,389**
BEB	13,371	7,754	7,380	4,419	8,474	12,877	**54,275**
LEGACY FC	18,535	12,209	12,284	9,676	8,926	9,229	**70,859**

Fuel Cell Powerplant Operating Hours

The fuel cell powerplant is a critical component to keep a hydrogen bus operational like the diesel engine is on conventional bus. The lifecycle of a fuel cell powerplant is best measured in hours of operation. The table below provides some insight to the age of our Legacy fuel cell fleet compared to the newer fuel cell fleet. The Legacy fleet has an average lifetime fuel cell operating hour of 26,389 compared to 4,485 on the newer buses. At the end of this reporting period, five (5) Legacy buses had exceeded 30,000 service hours without any major repairs or rehab maintenance. FC7 and FC12 have lower hours because they have spare replacement fuel cell powerplants that were installed after the original powerplant was decommissioned. The buses participating in the study are highlighted in the following tables.

Figure 8: FCEB Powerplant Operating Hours (January 2021 - June 2021)

FCEB	**Study Fleet**					**Additional Fleet**				
Bus ID	7017	7018	7019	7020	7021	7022	7023	7024	7025	7026
Hours	1,491	1,812	2,374	1,122	2,316	1,310	1,814	1,292	1,128	1,358
Average	1,823					1,380				
	1,602									

Fuel Efficiencies

AC Transit utilized the Argonne National Laboratory GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) model,[2] to construct Miles Per Gallon Equivalents (M/DGE) for the various energy fuels utilized. The GREET model has been adopted by government agencies, including the California Air Resources Board (CARB), industries, and academic institutions for its uniformity in deriving fuel economy equivalents, based on energy density, and emission estimates by type of fuel.

Figure 9: Fuel Efficiencies and Equivalents (January 2021 – June 2021)

TECHNOLOGY	Energy/Fuel	Fuel Efficiency	Efficiency Metric	Equivalent Efficiency	Equivalent Metric
DIESEL	Diesel	4.13	Miles/Gal	4.13	M/DGE
HYBRID	Diesel	5.49	Miles/Gal	5.49	M/DGE
FCEB	Hydrogen	7.89	Miles/Kg	8.76	M/DGE
BEB	Electricity	0.41	Mile/kWh	15.50	M/DGE
LEGACY FC	Hydrogen	4.76	Miles/Kg	5.29	M/DGE

AC Transit experienced the following relative fuel efficiencies using the GREET comparison model in the diesel equivalent format. The BEB buses achieved the highest fuel economy at 15.50 M/DGE, followed by FCEB's at 8.76 M/DGE.

Maintenance and Energy Costs

Cost per mile (CPM) is an industry standard when calculating cost comparison between fleets. Operating expenses are divided by the vehicles mileage to calculate the CPM. It is important that costs are viewed in two categories when comparing costs between fleet groups: Labor and Materials (Maintenance), and Energy. For this analysis, energy is diesel, hydrogen, or electricity, which is labeled as fuel in most budgets.

The fleet groups in this study use three type of energy sources required by the design of the bus technology. The energy rates are based on the purchased price of the diesel and hydrogen fuel where the electricity rate was based on the monthly utility bill consumption. The kilowatt-hour (kWh) and cost breakdown can be applied to the BEB fleet because a separate meter was installed at the charging station.

Out of the three energy sources used by AC Transit, the current price of hydrogen creates the largest CPM costs increase. Our transit district has been able to successfully manage the cost of electricity on PG&E's BEV-2 rate with the five (5) battery electric bus fleet thus far.

Figure 10: Energy/Fuel Rate (January 2021 – June 2021)

SOURCE	DIESEL	HYDROGEN	ELECTRICITY
Rate/Metric	$2.10/ Gal	$7.79/ KG	$0.189/ KWH

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[2] Argonne National Laboratory: https://greet.es.anl.gov/

The most cost effective for the reporting period was the diesel fleet with a $1.41 CPM. The ZEB technologies edged slightly higher with the FCEB at $1.97 and BEB at $2.02 CPM. The Legacy fleet was the most expensive with a $4.07 CPM. Hydrogen fuel currently has a high cost which significantly raises the CPM for the fuel cell bus fleet. It is expected that as the market continues to expand, the cost of hydrogen fuel may decrease lowering the CPM to a more favorable position.

Figure 11: Operational Cost/Mile Totals (January 2021 – June 2021)

COST/MILE	DIESEL	HYBRID	FCEB	BEB	LEGACY FC
Maintenance	$0.90	$1.42	$0.98	$1.55	$2.43
Energy (Fuel)	$0.51	$0.39	$0.99	$0.46	$1.64
Total	**$1.41**	**$1.80**	**$1.97**	**$2.02**	**$4.07**

When reviewing the energy costs across the test fleets, the FCEB was nearly double the costs of the diesel fleet. During the period, the diesel and fuel cell were similar in labor and material costs. The legacy fuel cell fleet (fuel cell dominant design) was significantly more expensive than the newer fuel cell fleet (battery dominant design), evidenced by the higher costs in the maintenance and energy categories.

Figure 12: Maintenance & Energy Cost (January 2021 – June 2021)

TOTAL	DIESEL	HYBRID	FCEB	BEB	LEGACY FC
Maintenance Cost (L&M)	$108,091	$139,187	$86,760	$84,258	$172,059
Energy Cost (Fuel)	$61,662	$37,975	$87,306	$25,109	$115,999

Credits and Warranties

AC Transit has a warranty recovery program, which identifies warranty claims, records and enforces claims against manufacturers, coordinates repairs to the bus fleet, and processes repair reimbursements performed by employees in-house. The figure below summarizes the value of warranty claims recovered by ZEB battery and fuel cell technology fleet buses with additional details in the subsequent section.

Figure 13: ZEB Recovery Total

TECHNOLOGY	WARRANTIES	CREDITS	TOTAL RECOVERY
FUEL CELL	$122,494	—	$122,494
BATTERY ELECTRIC	$43,799	$28,389	$72,188

Low Carbon Fuel Standards (LCFS) Credit

In January 2020, the District hired a third-party vendor to assist with the management of ZEB Program LCFS credits. To date, clean fuel total nearly $144,000. The revenue collected for calendar year 2020 is $115,391. The amount collected in 2021 (Q1 and Q2) is estimated to be $28,389. The credits are differentiated by vehicle type and highlighted in the table below.

Figure 14: Annual Energy Credits

VEHICLE TYPE	2020				2021		TOTAL
	JAN - MAR	APR - JUN	JUL - SEP	OCT - DEC	JAN - MAR	APR - JUN (est.)	
FUEL CELL	$55,224	$1,443	$4,561	$3,077			$64,305
BATTERY ELECTRIC	$9,113	$12,122	$16,356	$13,496	$15,615	$12,774	$79,476
TOTAL	**$64,337**	**$13,565**	**$20,918**	**$16,573**	**$15,615**	**$12,774**	**$143,782**

The revenue stream includes a brokerage fee and offsets from AC Transit alternative energy sources such as the solar panel facilities. The transit district forecasts this new revenue stream to increase as ZEB fleet increases over the next two years. In addition to a reliable revenue stream, LCFS credits have flexible applications, which may be used to offset either capital or operating expenses (such as hydrogen and fuel expenses).

The fleet's CPM can be adjusted with the applied warranties and Low Carbon Fuel Standard (LCSF) credits. The credits are a growing revenue source through the State and can only be applied to the ZEB fleet. For the reporting period, Figure 15 provides the adjusted CPM where the FCEB and BEB fleets had the most reductions due to the offsetting LCFS and warranty credits.

Figure 15: Operational Cost/Mile with Applied Credits (January 2021 – June 2021)

COST/MILE	DIESEL	HYBRID	FCEB	BEB
Adjusted CPM	$1.37	$1.78	$0.58	$0.69

Fleet Availability

Fleet availability is a measurement of the bus readiness, specifically, for 7:00 am pull out. The percentage is calculated by dividing the number of planned workdays by the number of workdays each bus was available for service. Training and special events are included in the available count because the vehicle is deemed operationally ready for service. The cause of the unavailability is categorized by system components to show issues and normalize routine scheduled maintenance and unscheduled repairs within the test fleets.

The BEB fleet experienced long out-of-service periods due to high-voltage battery and parts availability problems contributing 65% of the total days lost in the 47% average availability of the planned workdays. The FCEB and Legacy FC fleets achieved an average availability of 69% and 68% due to defects that occurred throughout the test period. The Diesel fleet averaged over 96% availability. Since transit operators are allowed a 20% bus spare ratio, an availability rating of 85% or higher would not impact service delivery. However, an availability rating of 90% or higher is desirable and expected.

Figure 16: Availability by Technology (January 2021 – June 2021)

TECHNOLOGY	JAN	FEB	MAR	APR	MAY	JUN
DIESEL	97%	98%	95%	95%	97%	96%
HYBRID	76%	74%	67%	79%	79%	75%
FCEB	81%	79%	81%	49%	52%	70%
BEB	58%	43%	53%	21%	38%	69%
LEGACY FC	88%	66%	68%	63%	59%	62%

Reliability (Miles between Chargeable Road Calls)

Miles Between Chargeable Road Calls (MBCRC) is a standard maintenance performance indicator that measures the vehicle miles between mechanical failures during revenue service. Road calls may cause a delay in service and necessitate removing buses from service until repairs are made.

Figure 17: Miles between Chargeable Road Calls (January 2021 – June 2021)

TECHNOLOGY	JAN	FEB	MAR	APR	MAY	JUN
DIESEL	20,869	19,127	10,739	20,045	19,237	3,999
HYBRID	2,245	7,348	4,991	6,137	3,352	4,408
FCEB	9,222	15,024	5,289	12,027	1,956	7,645
BEB	4,457	3,877	3,690	2,210	4,237	3,219
LEGACY FC	6,178	2,442	2,457	1,613	1,785	2,307

Road call failures are categorized by system and component and used to direct maintenance activities to eliminate the root cause. Provided below are the road call categories that include the failures related to the components.

- **Common System Failures** – For this report, one broad category was designated for systems common to all buses: air system, low voltage electrical, brakes, steering, HVAC, etc.
- **Engine/ Fuel Cell** – Energy generating systems used to power or propel the vehicle. The fuel cell includes various balance of plant supporting and auxiliary components.
- **Fuel System** – Diesel and Hydrogen storage issues and faults.
- **High Voltage Systems** – Storage and distribution of high voltage electricity is utilized to power drive motors and store energy.
- **Transmission/ Electric Drive** – Systems to provide the power to the differential

Figure 18: Road Calls by System (July 2020 - December 2020)

SYSTEM	DIESEL	HYBRID	FCEB	BEB	LEGACY FC	TOTAL
Common System Failures	7	12	8	7	10	**44**
Engine/Fuel Cell System	3	11	3		10	**27**
Fuel System			1	1	5	**7**
High Voltage System			1	7	3	**11**
Transmission/Electric Drive		1	1			**2**
Total	**10**	**24**	**14**	**15**	**28**	**91**

For the reporting period, the Diesel fleet had ten (10) road calls with three (3) related to the exhaust system, two (2) related to a driver's seat and the others not concentrated in any specific system.

The Hybrid fleet had 24 road calls, elevent (11) of which were for engine issues with six (6) related to the coolant system. The FCEB fleet had fourteen (14) road calls, four (4) relating to the fuel cell/fuel system and two (2) related to the high voltage/traction motor system.

Two buses had repeat failures related to a driver sunshade and steering system. The BEB fleet had fifteen (15) road calls, with eight (8) due to the high voltage batteries and state of charge issues. The Legacy FC fleet had twenty-eight (28) road calls, of which fifteen (15) were fuel cell/fuel system and three (3) high voltage battery related with the remainder related to common system failures.

Clean Corridor Deployments

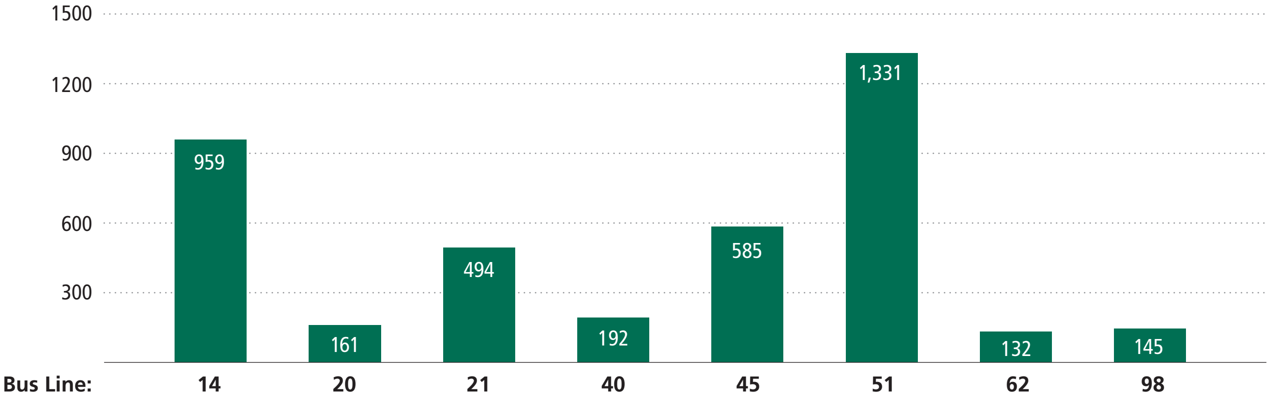
The State of California Legislature passed SB 535 in 2012 requiring 25 percent of investments from the Cap & Trade program be spent in Disadvantaged Communities (DACs). The legislation carried with it methodology for identifying those communities' using information about income, race, pollution, and 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 5X5 plan features lines only assigned to communities identified as DACs in the Clean Corridors Plan. Exhibit A.1 illustrates which lines had buses from this program deployed on them between July 1 and December 31, 2020. The results indicate that Lines 14, 21, 51A, and 98 were the primary lines covered in this program, with lines 54, 45, 40, and 20 used less often. All of these lines are included within the Clean Corridors program so compliance with DAC assignments is excellent. These lines were chosen for the following reasons:

1) They serve disadvantaged communities that could benefit from reduced emissions from ZEB vehicles.
2) They operate out of Division 4.
3) They have high ridership.
4) With the exception of Line 40, they are typically assigned 40-foot buses.
5) 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.

These lines for the core of the service network in East Oakland and have been operating with weekday schedules since August 2020 when the emergency service levels implemented in March 2020 were adjusted to return high-ridership lines to weekday service levels (from 7-day Sunday levels) to reduce pass-ups.

The only change recommended by staff is to remove Line 40 from the deployment list for this program as it should be assigned 60-foot buses 100 percent of the time and being in this program could lead to pass-ups given the 25 buses are all 40-foot coaches.

Figure 19: ZEB Deployments by Line

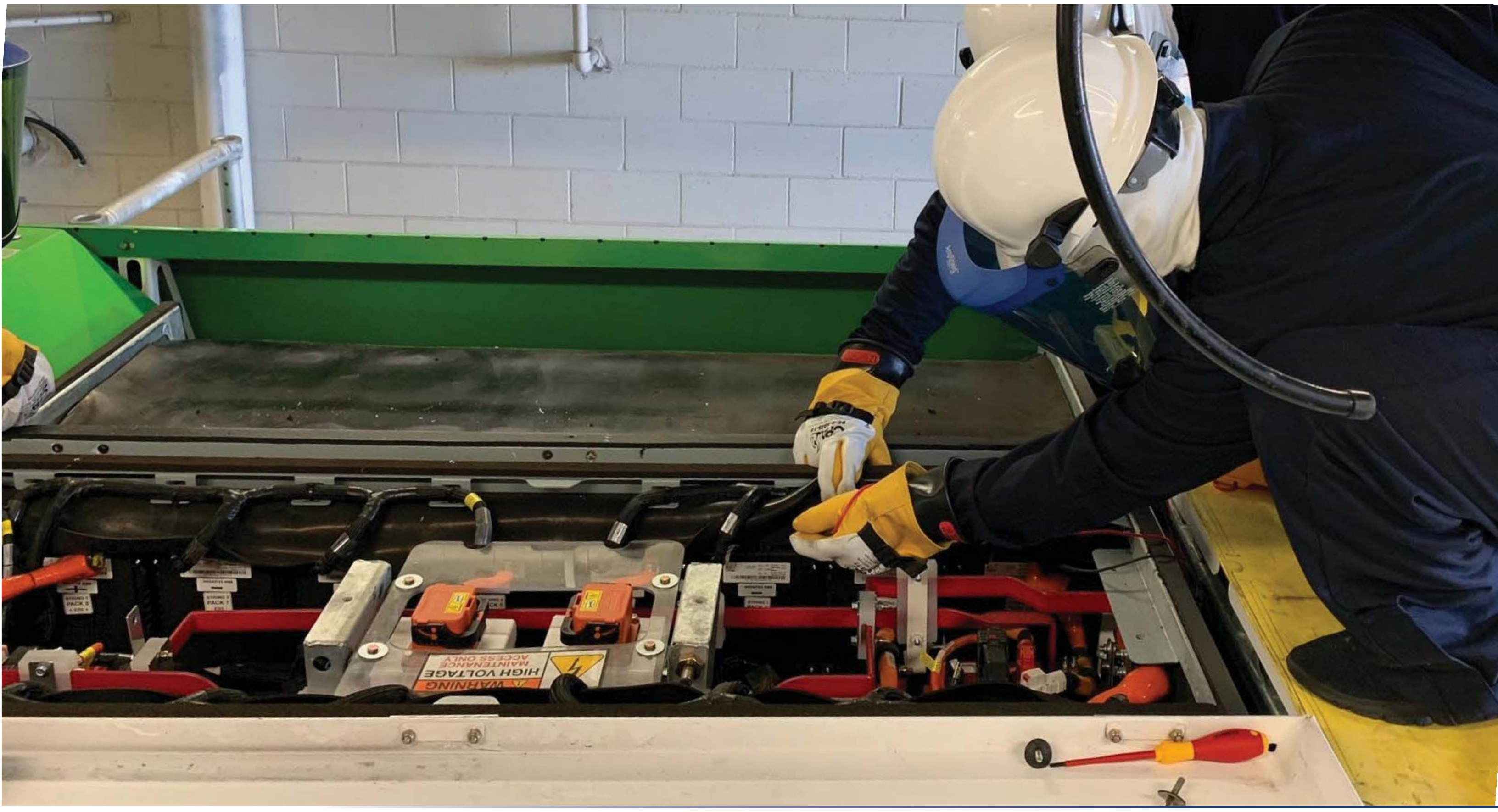


Workforce Development

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.



Total ZEB Workforce Development Production

To date, the District has successfully scheduled and produced over 23,131 hours of training in one or more of the nineteen (19) 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 third column.

Figure 20: ZEB-based Course Catalog

Course	Hours	Fleet
A123 Battery Training (Vendor)	8	Gillig Hybrid/ New Flyer FCEB
Ballard Fuel Cell - ZEB (Vendor)	24	New Flyer FCEB
Ballard Fuel Cell 1K Hrs PMI	4	New Flyer FCEB
Digital Multimeter (Distance Learning)	4	ZEBs/Hybrid
Fuel Cell Power Plant - ZEB	8	New Flyer FCEB/ Van Hool FCEB
High Voltage Electrical Safety - ZEB (Vendor)	8	FCEB/BEB
High Voltage: Awareness and Safety (Distance Learning)	3	VH/New Flyer FCEB and BEBs
Hydrogen FC Safety and Familiarization - ZEB	8	Van Hool FCEB
Hydrogen Fuel Cell Bus Hands-On - ZEB	240	Van Hool FCEB
Hydrogen: Safety, Fueling, and Storage - ZEB (Distance Learning)	3	VH/New Flyer FCEB
Lithium Ion Battery Familiarization - ZEB	8	ZEBs/Hybrid
New Flyer BEB Orientation - ZEB (Vendor)	3	New Flyer BEB
New Flyer BEB Srv/Maintenance - ZEB (Vendor)	24	New Flyer BEB
New Flyer FC Orientation - ZEB (Vendor)	3	New Flyer FCEB
New Flyer FCEB Maintenance - ZEB (Vendor)	32	New Flyer FCEB
New Flyer FCEB Safety & PM - ZEB (Vendor)	8	New Flyer FCEB
New Flyer Safety/Fam. FCEB/BEB - ZEB	24	New Flyer Safety
Siemens ELFA - ZEB (Vendor)	8	VH/New Flyer FCEB and BEBs
XALT Battery - ZEB (Vendor)	16	New Flyer BEBs

Learning Management System

All training is planned and scheduled via a learning management system (LMS) located on the District's intranet site known as MyACT. This site serves as the main portal for transportation and maintenance department management to access available courseware, class schedules, and enroll staff. Moreover, the LMS provides users the functionality to query data, from researching staff attendance to classes completed per employee (including details related to bus types, routes, and/or by topics). This functionality is critical in being able to track training progress and to identify skill-set gaps that may warrant training campaigns as needed to ameliorate specific key performance indicators.

Maintenance Training Plan

Procuring fuel cell electric (FCEB) or battery electric (BEB) ZEBs requires coordination with internal stakeholders and OEMs, as well as prioritizing classes for specific employees based on high voltage exposure levels. The following outlines a general maintenance training plan.

Basic Courses: Familiarization and Safety

Training coordinates with OEMs and internal stakeholders to schedule staff to attend OEM bus familiarization and safety orientations. This is a standard, scheduled first-step practice when receiving any new bus (not just ZEBs). This training is foundational and impacts all mechanics and service employees (i.e., those who clean, fuel, and park).

Familiarization/safety orientation is an OEM-led class and content typically includes high voltage safety awareness, personal protective equipment (PPE), safety measures, and preventive maintenance. This course is presented to each shift at each affected operating division upon delivery of the bus. As this course is an overview, or high-level review, it is approximately three hours per session. In addition to mechanics and service employees, maintenance supervisory staff and maintenance trainers are required to attend.

Bus Component Courses

Additional OEM classes, beyond that of familiarization and safety include, but are not limited to, air systems, brakes, steering/suspension, door operations, electrical/multiplex systems (from schematics to ladder logics), computer and diagnostic systems, to include troubleshooting pathways. These bus component-based courses are scheduled for all mechanics at those locations where ZEB infrastructure and support exists. Courses entail moderate-to-high voltage level of exposure and therefore also, include maintenance trainers and maintenance supervisors. Often courses are scheduled quarterly and repeat as necessary. While these course topics are not specifically ZEB technologies, they are pertinent in that these are not static products/components. Performing preventive maintenance inspections and diagnostics on these products may impact or adversely affect ZEB functionality if not done correctly.

Advanced Courses

More advanced courses are initially taught by sub-component suppliers and scheduling is often coordinated through the OEM. For example, an OEM will work with staff to schedule the fuel cell manufacturer to teach the specifics of their product(s). Courses taught by sub-component suppliers usually address energy storage systems, electric-propulsion and/or fuel cell systems to name a few. Sub-component, supplier-led courses often include topics from safety and high voltage awareness to component functionality and troubleshooting diagnostics. As with Bus Component Courses the same operational staff are scheduled for these classes and training schedules are quarterly and repeat as necessary.

In-House Production

New technology requires strong partnerships with both OEM and sub-component suppliers. The learning curve is steep at first but flattens with practice and experience. The District's ultimate goal is for maintenance trainers to teach classes with less reliance on OEMs in the long run. To that end, some ZEB-based courses are now taught by staff and include the following topics: safety awareness for high-voltage systems and high-pressure hydrogen, operational start-up/shut-down and emergency procedures, familiarization with location and functions of major fuel cell and battery electric components, fueling of fuel cell and charging of battery electric buses.

Working partnerships with OEMs has helped tremendously in gaining knowledge experience. These partnerships are structured pedagogically as well. OEMs often rely on training staff to learn how to translate engineering processes into mechanical procedures. The District has a rich history of acquiring training aides or modules used specifically to diminish these gaps between theoretical constructs and praxis.

The newest evolution in this effort is an actual OEM fuel cell module complete with air and coolant kits, poster training aids, related tool and diagnostic accessories as well. This resource was funded by a California Air Resources Board grant and has literally been turned into one of the first-ever fully functioning fuel cell power plant training systems. This innovation in curriculum development engages mechanics, for example, to perform required preventive maintenance in 1,000 and 5,000-hour inspections. Mechanics can practice all the required steps on this training aid first, make mistakes safely, and turn each challenge into a teaching moment. And that's just the beginning, we anticipate developing fault code troubleshooting exercises as well. These innovations in teaching establish new skills and confidence, and dramatically decrease learning curves when performing the same tasks on live ZEBs. Future curriculum development will focus on creating similar training modules for energy storage, electric low floor axle, and hydrogen storage systems.

Moreover, we are exploring the possibilities of implementing virtual and augmented reality systems. Virtual reality is ideal in preparing a new workforce to engage more frequently with high voltage systems. Reducing fear of shock, arch flash and other hazards can be attained by engaging in a virtual world first. Virtual reality offers the mechanic a chance to learn how to use PPE and work with energy storage systems, for example, and make mistakes without consequence of injury to self, others, or damaging equipment. Similarly, augmented reality which incorporates mobile devices such as smart phones or electronic tablets introduces virtual objects into real world settings. By using an electronic tablet, for example, a mechanic can point to an object and on the screen will be a series of instructional steps which can also include safety practices and/or recommended tools to use in perform tasks. AC Transit is reinventing how workforce training will be successful into the future and for generations to come.

5-Week Technical Training Program

Another great example of in-house training can be found in the experiential, five-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.

Synchronous Learning

Finally, the newest in-house development is in how training is delivered. Staff has successfully developed courseware designed for synchronous learning environments or online interactivity. These live, interactive online classes enable maintenance trainers and mechanics from all operating divisions to engage together, virtually, and safely (especially during the current pandemic). Equally significant, mechanics can attend classes without having to leave their respective shops for the entire day. Training times are shorter, normally two to three hours, compared to more traditional in-person eight-hour classes. It should be noted that not all topics are well suited for this environment. Current courses (as identified in the table below) include the following: Digital Multimeter; High Voltage: Awareness and Safety; and Hydrogen: Safety, Fueling, and Storage. More courses are in development.

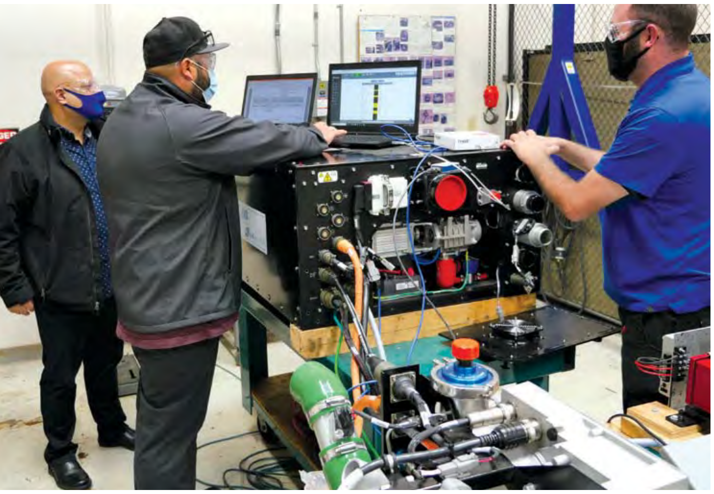
The ZEB Evolution

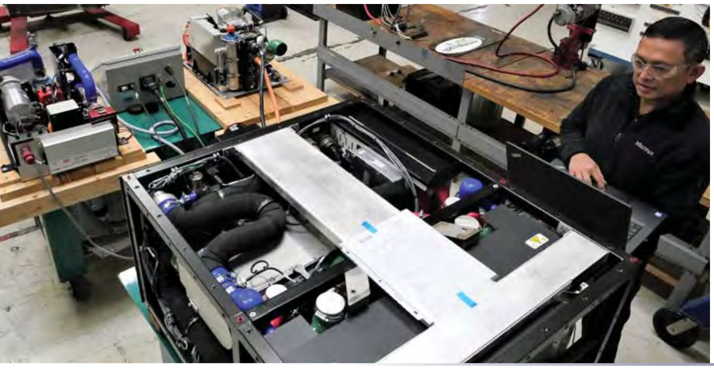
Putting it all together, what does it take to work on ZEBs? There are as many theories about this as there are training programs. As technologies emerge, so too do theories of requisite course criteria. At the highest level, though, the District's workforce development can best be shown in the table below. The hours are estimates, but the training time invested is indicative of the evolution of a mechanic's proficiency working on either FCEBs and/or BEBs.

Figure 21: Mechanic Development

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

AC Transit has spent the last twenty years learning-by-doing. This existential approach toward ZEB technology has yielded some of the best practices in the industry. Preparing mechanics will continue to evolve as experiences, training, and OEM partnerships burgeon.





Data Integration & Management Environment

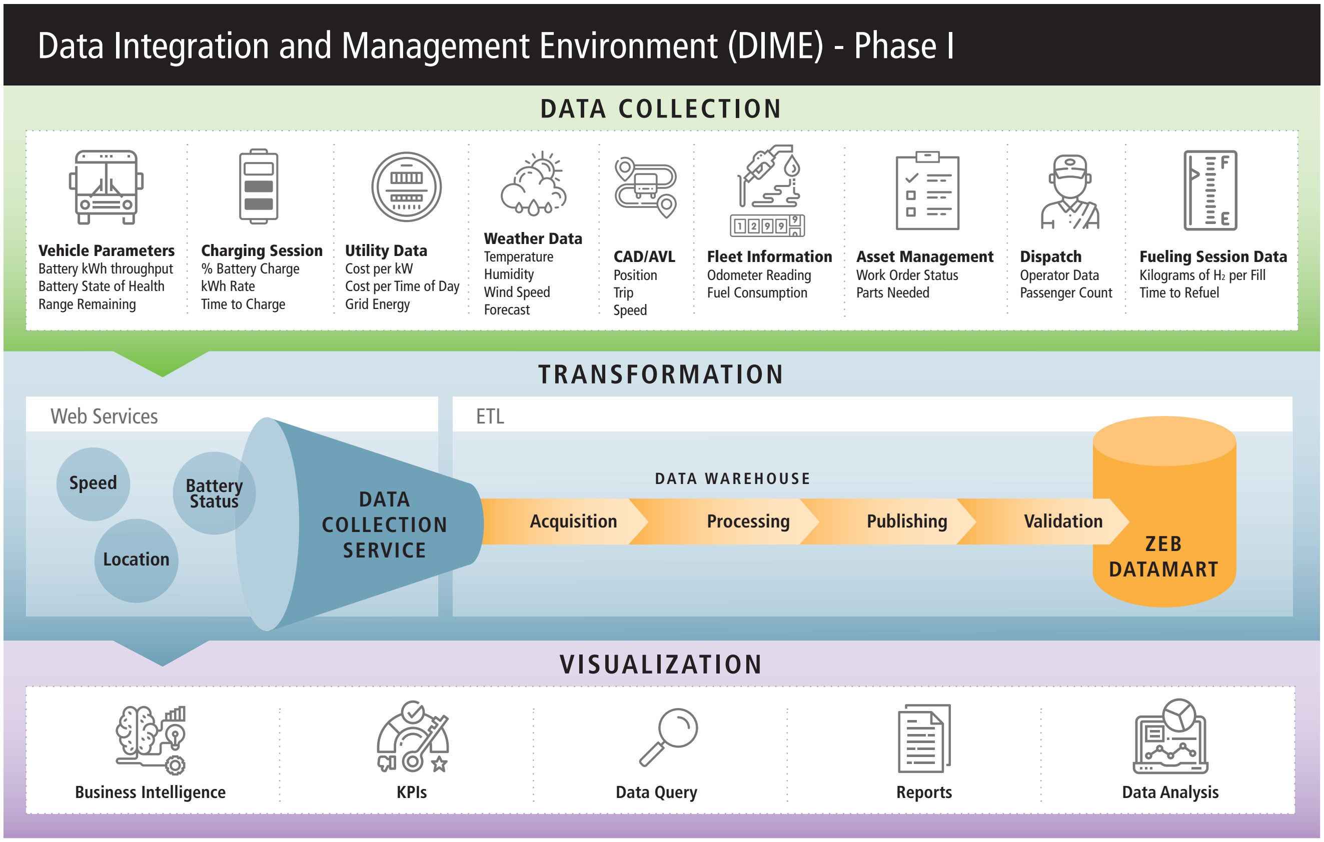
AC Transit has developed a set of tools and processes in preparation for the ZEB program and its technology environment. The District recognizes the importance of advancing data quality, consistency, accuracy, reliability, and processes to address systems integration, security, compliance, regulatory requirements, decision-maker, and stakeholders' expectations.

The ZEB Data Integration and Management Environment (DIME) consist of 3 levels:

DIME facilitates accessing all the different data elements across multiple data sources, including a new Data Warehouse infrastructure to validate, manipulate and make all this information available to both internal and external customers. All the information contained in the reports is extracted directly from AC Transit's Enterprise Platform.

Data collection, transformation, and visualization of the energy and performance data are obtained directly from the District's various equipment and energy vendors, such as vehicle parameters; automatic vehicle location and speed; fluid consumption and mileage; charging station or utility usage; battery and fuel cell health, charging, status and throughput; asset and parts refits for reliability and other factors.

Figure 22: DIME Phase One



Data Collection

Data Collection layer eliminates manual steps and intervention in data ingestion from multiple systems to provide consistent precision. It integrates various external vendor Application Programming Interface (API) web services and multiple internal District systems. The Data Collection pipeline functions holistically as below.

- Identify various systems from where data will be collected, established, and test secured connectivity to their data collection API end points.
- Secure Configuration Management repository and update processes to the current administration and future enhancements
- Complete control of integration behavior and flow to accommodate each vendor's API requirements: Transport layer: TLS versions, Communication layer: Certificates.
- Authentication layer: Username/Password, OAuth, Session Token, data request Sync vs. Async, and fully integrated technology stack selection according to usage and need.
- Automated Self-Healing Data Collection processes and technologies that re-connect and re-process pending data collection automatically once an outage is resolved.
- Messaging tool to monitor and ensure expected data volume, velocity, and verity during Data Ingestion.
- Audit and Quality Assurance processes and tools to ensure robust and reliable connectivity and consistency in the overall Data Collection.
- Configuration to meet near future potential data growth with scalability, multi-platform support, and advanced security features considering ZEB technology and vendor partnerships are evolving trends.

Transformation

The Transformation layer addresses data extraction and transformation processes while maintaining the quality and availability of ZEB data. In this process, data is verified, cleaned, and stored on a secure Enterprise Datawarehouse SQL Server. This current layer functions and forthcoming roadmap features are listed below:

- Data Collection Service and related processes being rolled out to ensure data precision and accuracy.
- ZEB Data Model and Data Mart based on business requirements are being developed
- On-Demand data processing will also be integrated in future implementation phases

Visualization

Data has become one of the most strategic and critical assets for any organizational business decision makings. The Visualization layer encompasses data-driven decision analytics from accurate, reliable, and accessible enterprise data platforms. The forthcoming Cloud platform and Business Intelligence (BI) Visualization tools are to include the following features:

- The District is upgrading the existing Enterprise Datawarehouse to advance with cloud-based BI tool to offer modern data visualizations.
- Tools for users to request and check the delivery status of new BI datasets.

- Audit and monitoring tools for data and role-based access security
- BI and Visualization matrix for usage incorporating feedback for constant improvement aligned with business needs and priorities to run Business Intelligence and Machine Learning models
- Capacity Planning and analysis of existing compute resources against current and forthcoming Business Applications, Vehicle events, IoT/sensors data feed, Enterprise Databases, Data Lakes, Data Warehouses, and Business Intelligence platforms
- End-to-end testing from Vehicle Data Collection to Business Intelligence, including workload stress tests synchronizing compute resources with data growth.
- On-Demand data visualization is on the roadmap for future development

Conclusion

Conducting a study of this magnitude is not a simple task. Understanding there is a vast difference with technology maturity between the various fleets included in the study, AC Transit acknowledges initial results may not reflect what develops over time. Internal combustion engine transit bus technology has been evolving for over a century, zero-emissions transit bus technology has been in demonstrations for about two decades and largely commercially available in the United States for less than that. As with any new advanced technology deployment, unexpected conditions may arise when buses are placed in service. What makes a tremendous difference, is the level of collaboration, support, and response from the bus and infrastructure manufacturer to resolve challenges and evolve the technology.

What we have outlined here is more than AC Transit's study for zero emission transition, but instead, a foundation for how we can transition together

Next Steps

AC Transit will continue to deploy the ZETBTA control fleet and collect performance data to provide a follow up report for the review period of July to December 2021. This report is anticipated to have more robust data sets for the analysis as initial deployment "shake-out" challenges have been addressed and limitations related to the pandemic subside. Release of the report is targeted for the summer of 2022.

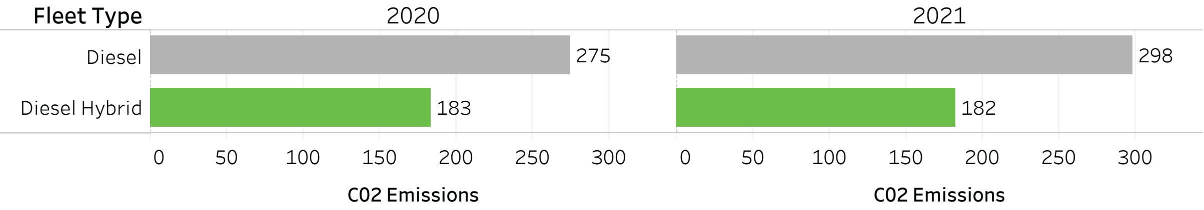
Appendix: Data Summary Trend

APPENDIX [A-1]

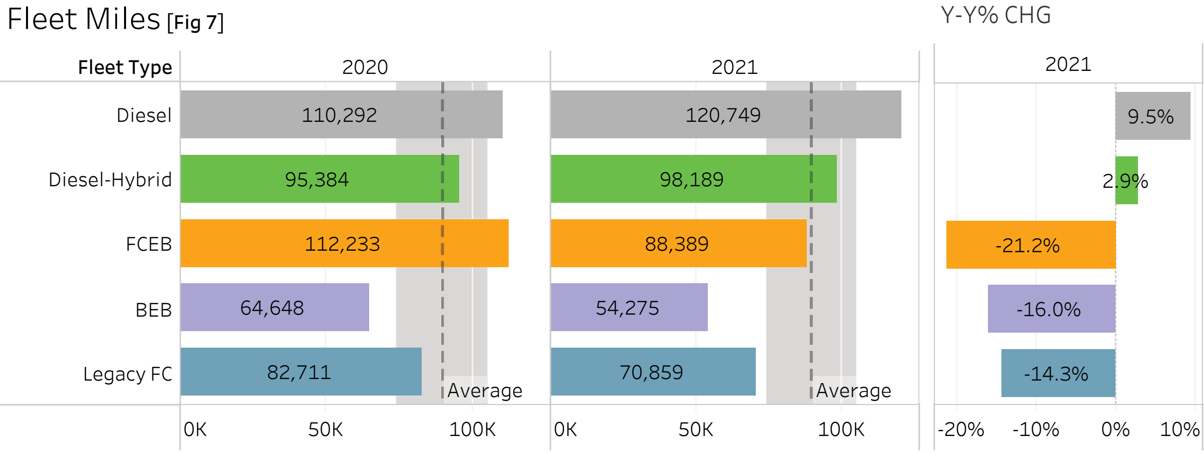
Fleet Type

⬜ Diesel 🟩 Diesel-Hybrid 🟧 FCEB 🟪 BEB 🟦 Legacy FC

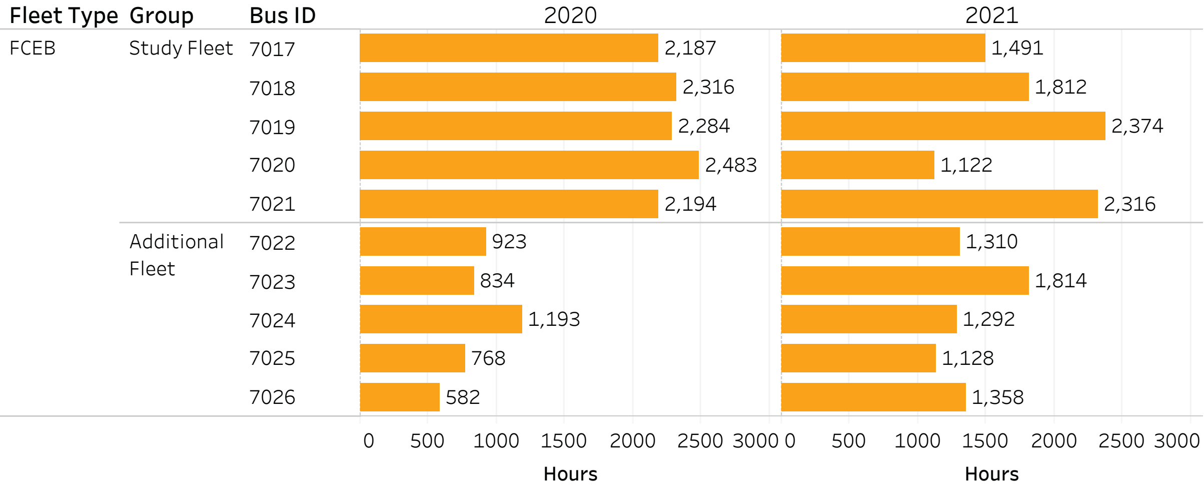
Carbon Emissions (CO2) [FIG 6]



Fleet Miles [Fig 7]



FCEB Operating Hours [FIG 8]



APPENDIX [A-2]

ZEB Facility [Fig 3]

2021

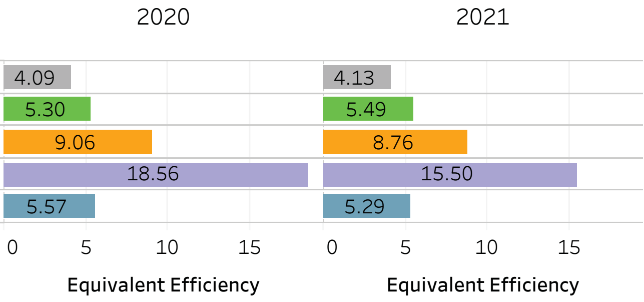
Fleet Type	Battery Electric Bus	Fuel Cell Electric Bus	Fuel Cell Electric Bus
Facility	Oakland Facility	Oakland Facility	Emeryville Facility
Total O&M Cost	Under Warranty	$111,798	$110,406
Availability	100%	100%	100%
Reliability	99.6%	99.4%	99.8%

Fleet Type

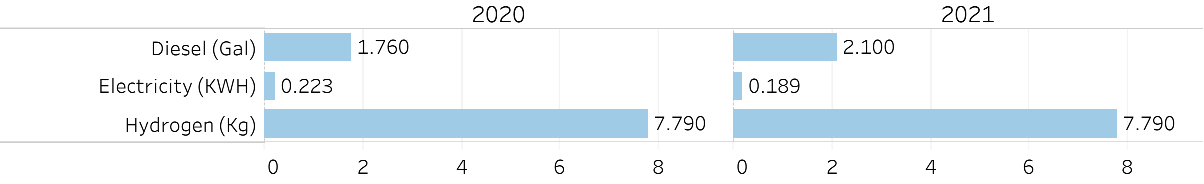
■ Diesel
🟩 Diesel-Hybrid
🟧 FCEB
🟪 BEB
🟦 Legacy FC

Fuel - Equivalent Efficiency [FIG 9]

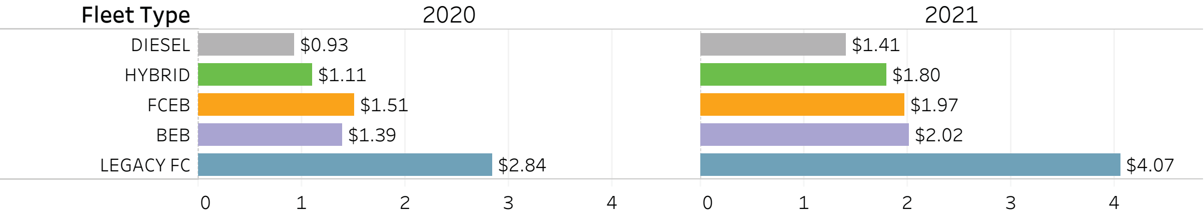
Fleet Type	**Energy/ Fuel**	**Efficiency Metric**	**Equivalent Metric**	2020	2021
Diesel	Diesel	Miles/Gal	M/DGE	4.09	4.13
Diesel-Hybrid	Diesel	Miles/Gal	M/DGE	5.30	5.49
FCEB	Hydrogen	Miles/Kg	M/DGE	9.06	8.76
BEB	Electricity	kWh/Mile	M/DGE	18.56	15.50
Legacy FC	Hydrogen	Miles/Kg	M/DGE	5.57	5.29



Energy/Fuel Rate [FIG 10]



Cost Per Mile [FIG 11]

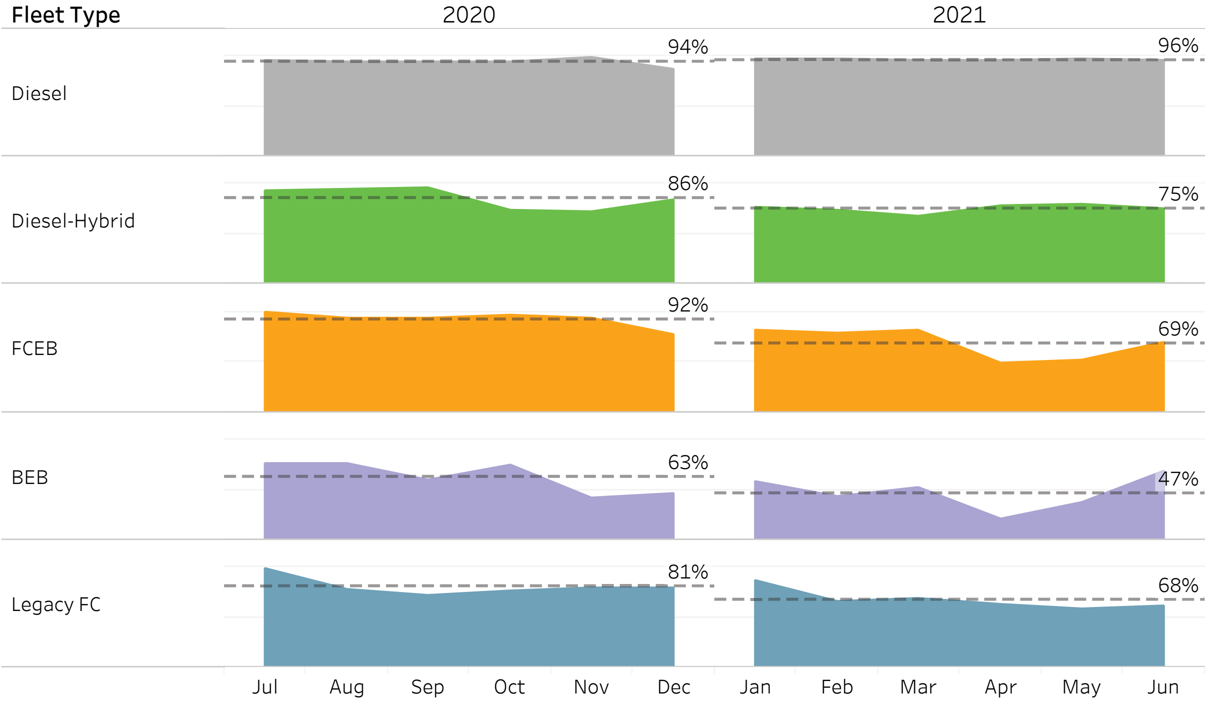


APPENDIX [A-3]

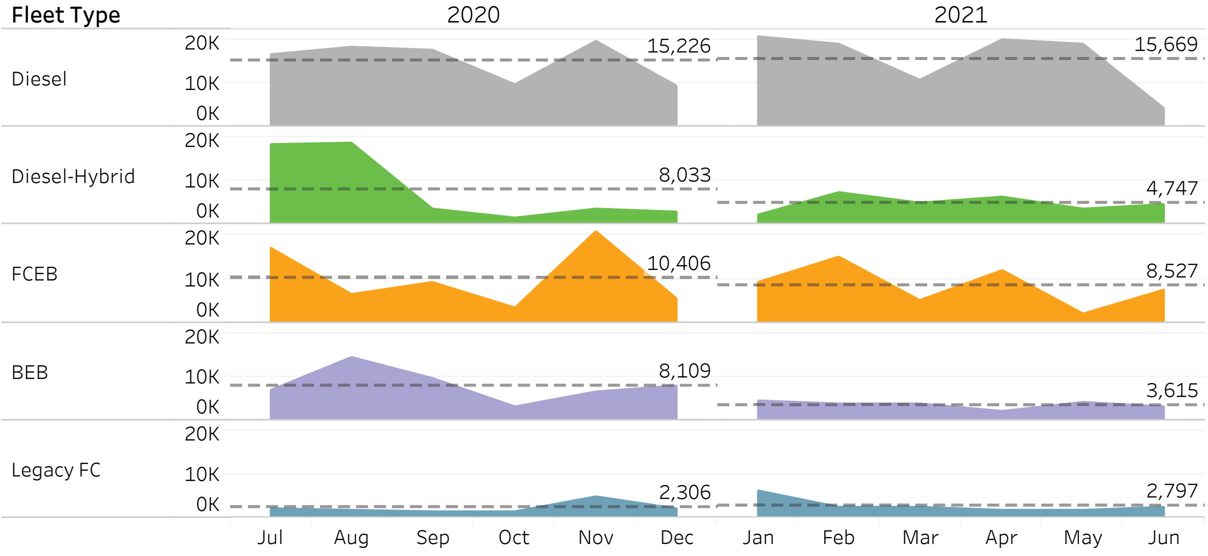
Fleet Type

⬜ Diesel 🟩 Diesel-Hybrid 🟧 FCEB 🟪 BEB 🟦 Legacy FC

Fleet Availability [FIG 16]



Miles Between Road Calls [FIG 17]

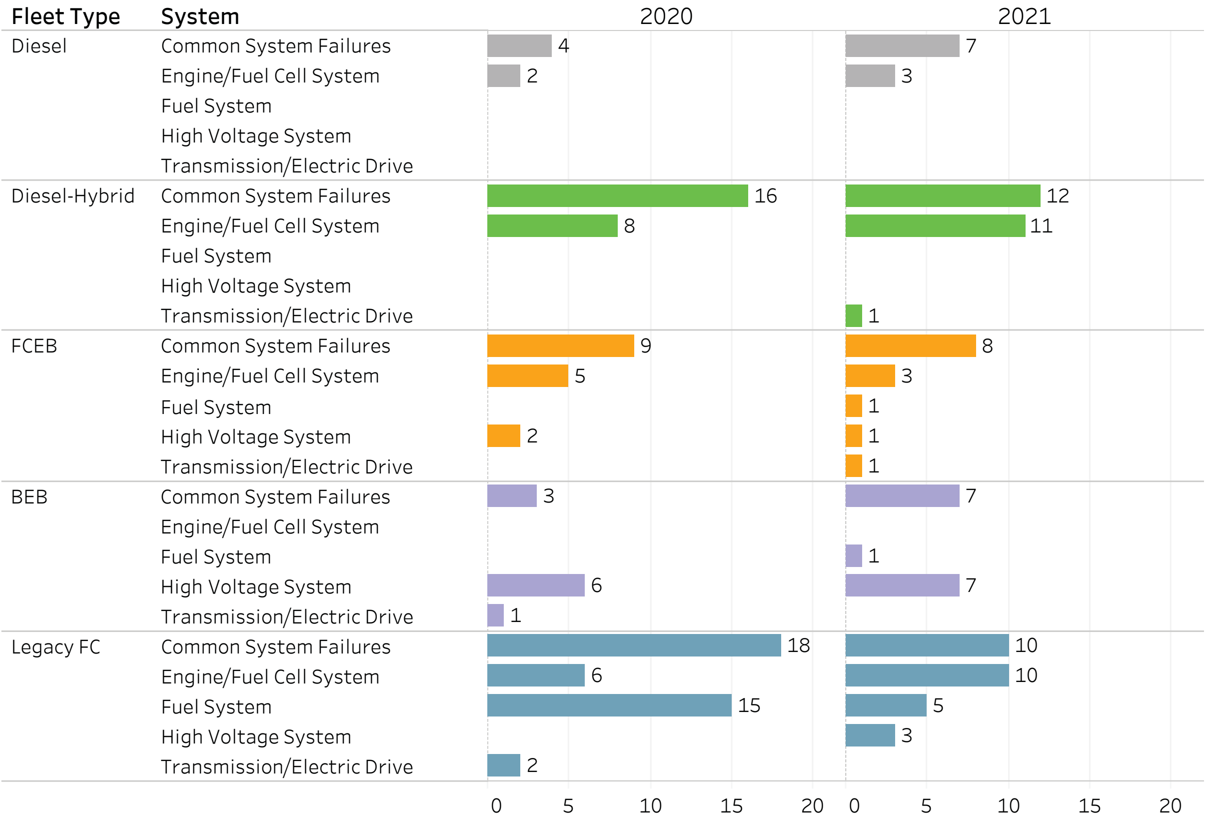


APPENDIX [A-4]

Fleet Type

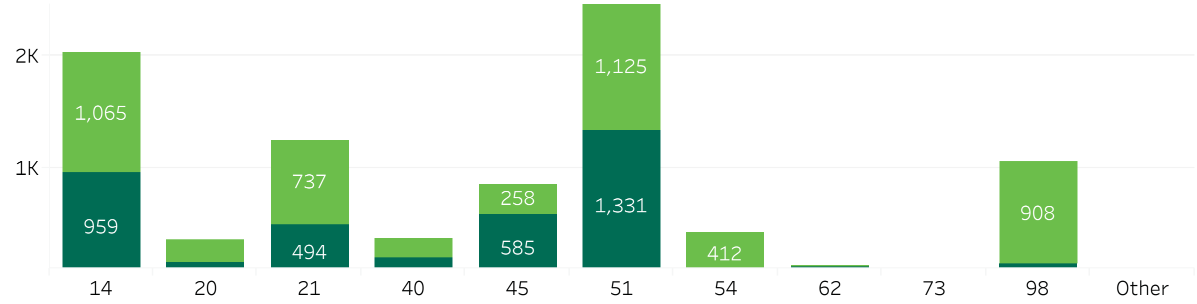
⬜ Diesel 🟩 Diesel-Hybrid 🟧 FCEB 🟪 BEB 🟦 Legacy FC

Road Calls by System [FIG 18]



🟩 2020 ■ 2021

ZEB Deployments by Line [FIG 19]



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