



Orange County Transportation Authority Fuel Cell Electric Bus Progress Report

Data Period Focus: Feb. 2020 through Jul. 2021

Elizabeth Collins and Matthew Post
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Introduction

This report presents early results from a deployment of fuel cell electric buses (FCEBs) operated by Orange County Transportation Authority (OCTA) in Southern California. The ten FCEBs, produced by New Flyer, feature an electric drive propulsion system powered by a Ballard fuel cell system. The project team is collaborating with the U.S. Department of Energy (DOE) and DOE's National Renewable Energy Laboratory (NREL) to evaluate the buses in revenue service.

The goal of this evaluation is to compare the FCEB performance to that of conventional technology and to track progress over time toward meeting the technical targets set by DOE and the Department of Transportation (DOT). The FCEBs were delivered beginning in late-2019, and were placed in service on February 9, 2020. The data period covers February 2020 through July 2021. NREL collects data on ten 2016 model year compressed natural gas (CNG) buses as a baseline comparison at OCTA.

Each NREL evaluation tracks data and performance results for a specific transit agency operating a specific manufacturer's technology design. Results from different OEM designs will vary and are not necessarily representative of a specific technology. Results also will vary from agency to agency and even between facilities within the same agency. Readers should keep this in mind when using these results for decision making.

Results Summary

Bus fleets: This evaluation includes ten 40-ft FCEBs built by New Flyer with an electric propulsion system and a Ballard fuel cell system. The baseline buses are ten 2016 model year New Flyer 40-ft CNG buses.

Bus use: OCTA's average speed for its operation is around 13 mph. The agency reduced service in March 2020 due to the COVID-19 pandemic.

Fuel economy and cost: The FCEBs had an average fuel economy of 8.39 miles per kilogram of hydrogen, which equates to 9.48 mpdge. The CNG buses had an average fuel economy of 3.77 mpgge, which equates to 4.22 mpdge. The FCEB fuel economy was approximately 2.3 times that of the CNG buses. Average hydrogen costs were \$8.48/kg; CNG cost was \$1.12/gge. The FCEBs had an average fuel cost of \$1.01 per mile. The fuel cost for the CNG buses averaged \$0.36 per mile.

Fuel use: During the data period, OCTA fueled its FCEB fleet more than 2,530 times with an average fill amount of 20.17 kg. Daily dispensed hydrogen was 96 kg.

mpdge = miles per diesel gallon equivalent

mpgge = miles per gasoline gallon equivalent

Results Summary (continued)

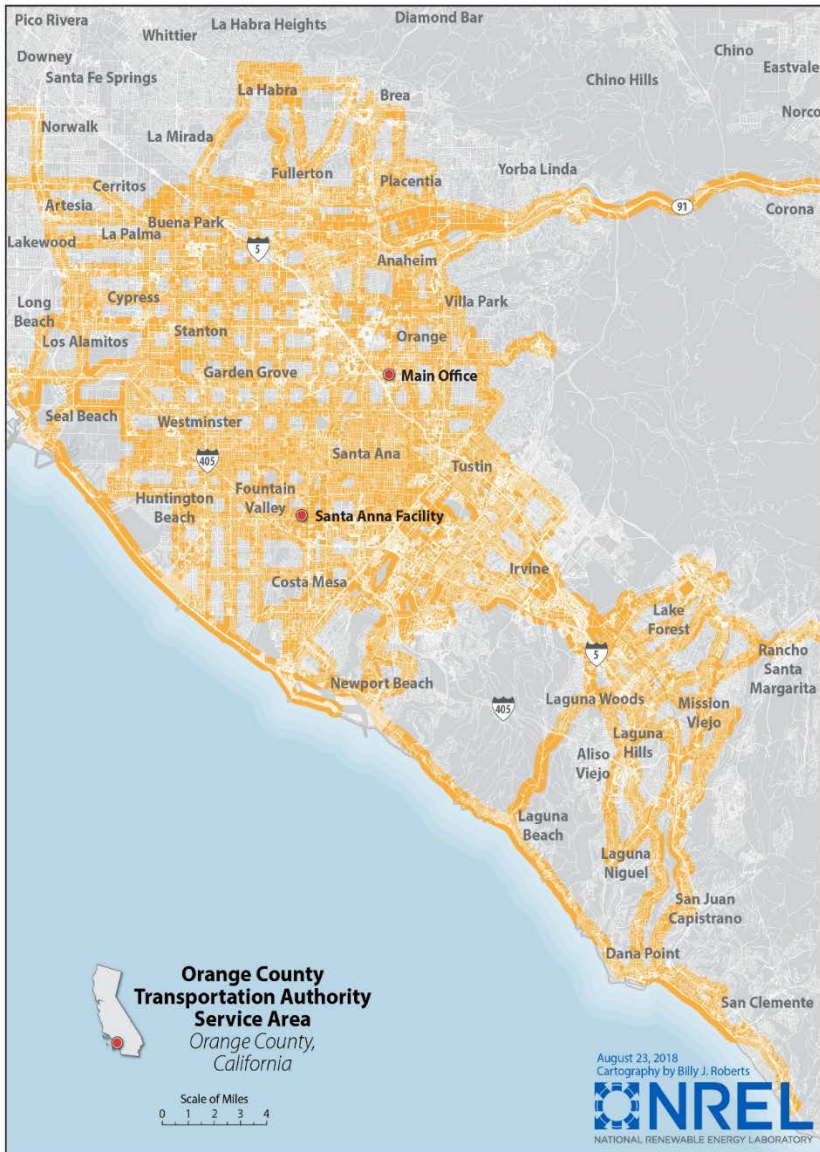
Availability: The average availability for the FCEB fleet was 62.5%. Most unavailable time for the FCEBs was due to general bus-related problems followed by battery issues. This is not unusual for a new design in its first deployment. OCTA is working with the OEM to identify the issues. The availability for the fleet is expected to increase over time as these early issues are resolved. The average availability for the fuel cell system was 94.9%. OCTA reports that its CNG bus availability averages 80% or better.

Maintenance cost: The cost to maintain the buses in the data period was \$0.46/mi for the FCEBs and \$0.66/mi for the CNG buses. Propulsion-system maintenance was \$0.12 for the FCEBs compared to \$0.29 for the CNG buses.

Note that the FCEBs are under warranty and most repairs are covered by the OEM. Much of the cost is labor to troubleshoot issues.

Fleet Profile

The Orange County Transportation Authority—OCTA — is Orange County California’s transportation agency, responsible for planning, financing and coordinating the county’s freeway, street and rail development, as well as managing countywide bus and paratransit service, rail service, and the 91 Express Lanes. The agency’s 62 fixed bus routes include local, community, express, and rail-connection service. The service area for OCTA covers 34 cities and unincorporated Orange County, California.



Evaluation Buses

Vehicle System	FCEB	CNG
Number of buses	10	10
Bus manufacturer/model	New Flyer, Xcelsior	New Flyer, Xcelsior
Model year	2018	2016
Bus purchase cost* (\$)	1.3 M	580,000
Length/width/height	41 ft/102 in./129.6 in.	40 ft/102 in./130.8 in.
Curb weight (lb.)	33,500	30,000
GVWR (lb.)	44,533	42,290
Hybrid system	Siemens ELFA2, Permanent Electronic Motor, 210 kW	N/A
Fuel cell or engine	Ballard FCvelocity-HD85, 85 kW	Cummins Westport ISL G 280 hp @ 2,200 rpm
Energy storage	A123 Systems, lithium-ion, 100 kWh	N/A
Accessories	Electric	Electric and Mechanical
Fuel capacity	Gaseous hydrogen, 5 Type 4 composite cylinders, Agility Fuel Solutions, 37.5 kg at 5,000 psi	CNG, 6 cylinders, Lincoln Composites 156 gge at 3,600 psi

FCEB



CNG



* Cost includes OCTA equipment, such as information technology equipment.

Infrastructure Description

OCTA's fueling station provides fuel to the FCEB fleet through liquid hydrogen delivery and storage. The new station was built in 2019 – fully commissioned in April of that year. The station includes an 18,000-gallon cryogenic storage tank. Two hydrogen dispensers, installed in line with the CNG fueling island, allow the FCEBs to be handled the same as the CNG bus fleet. Pre-cooling units operate at 10°C to help achieve a full fill without overheating the tanks.



Data Summary

Data Item	FCEB	CNG
Number of buses	10	10
Data period	2/20–7/21	2/20–7/21
Number of months	18	18
Total mileage in data period	427,885	808,781
Average odometer	50,094	255,920
Average monthly mileage per bus	2,510	4,541
Total FCPP ^a hours	34,849	—
Availability (85% is target)	62.5	73
Fuel economy (FCEB mi/kg or CNG mpgge ^b)	8.39	3.77
Fuel economy (mpdge ^c)	9.48	4.22
Miles between roadcalls (MBRC) – bus ^d	6,275	27,244
MBRC – propulsion system only ^d	8,964	38,920
MBRC – FC System only ^d	109,807	—
Total maintenance (\$/mile)	0.46	0.66
Maintenance – propulsion system only (\$/mile)	0.14	0.23

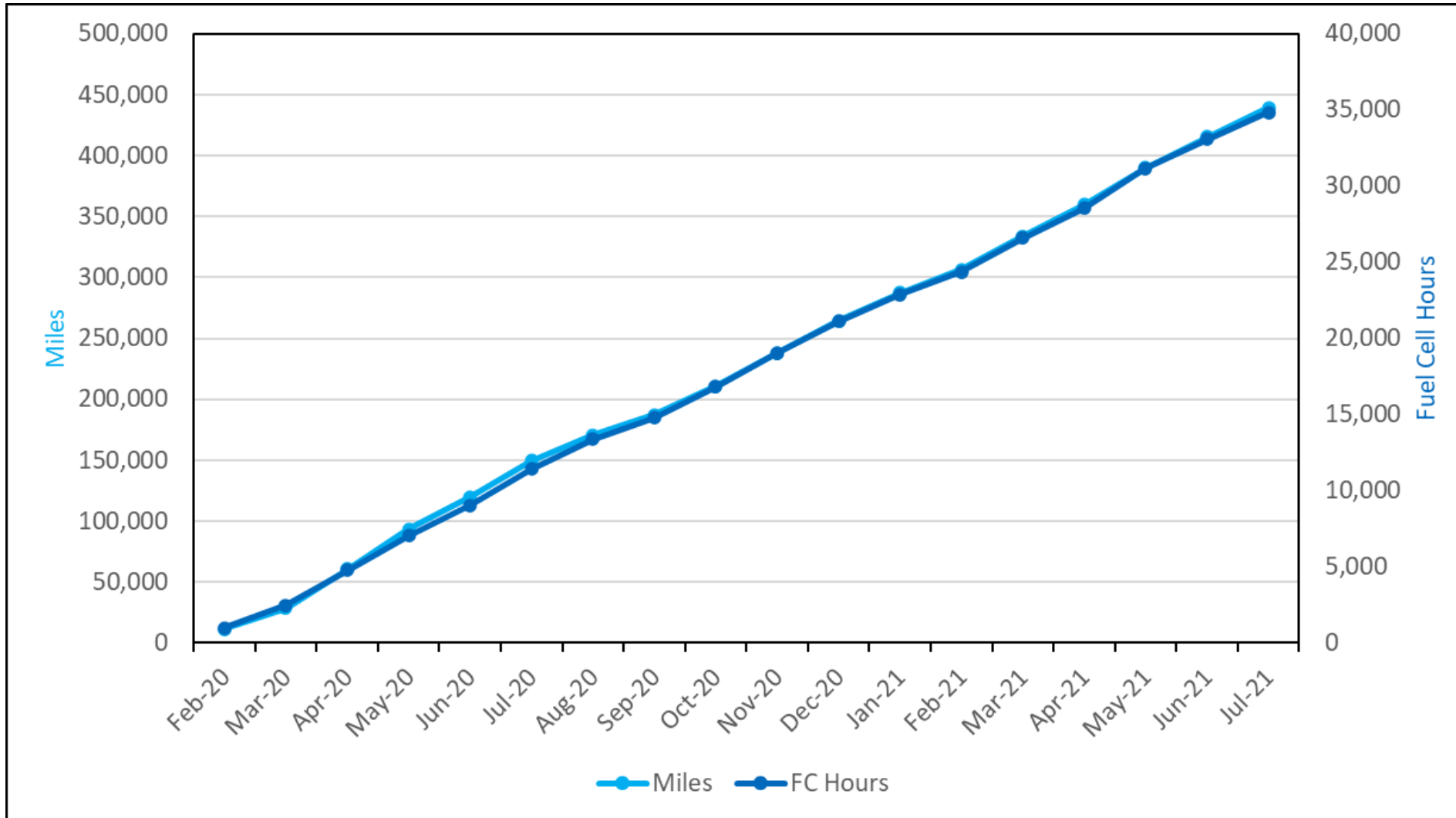
^a FCPP= fuel cell power plant

^b Miles per gasoline gallon equivalent.

^c Miles per diesel gallon equivalent.

^d MBRC for the FCEB data cumulative from the clean point of February 2020 through July 2020.

FCEB Total Miles and Hours



Totals
Miles = 439,277
Hours = 34,849

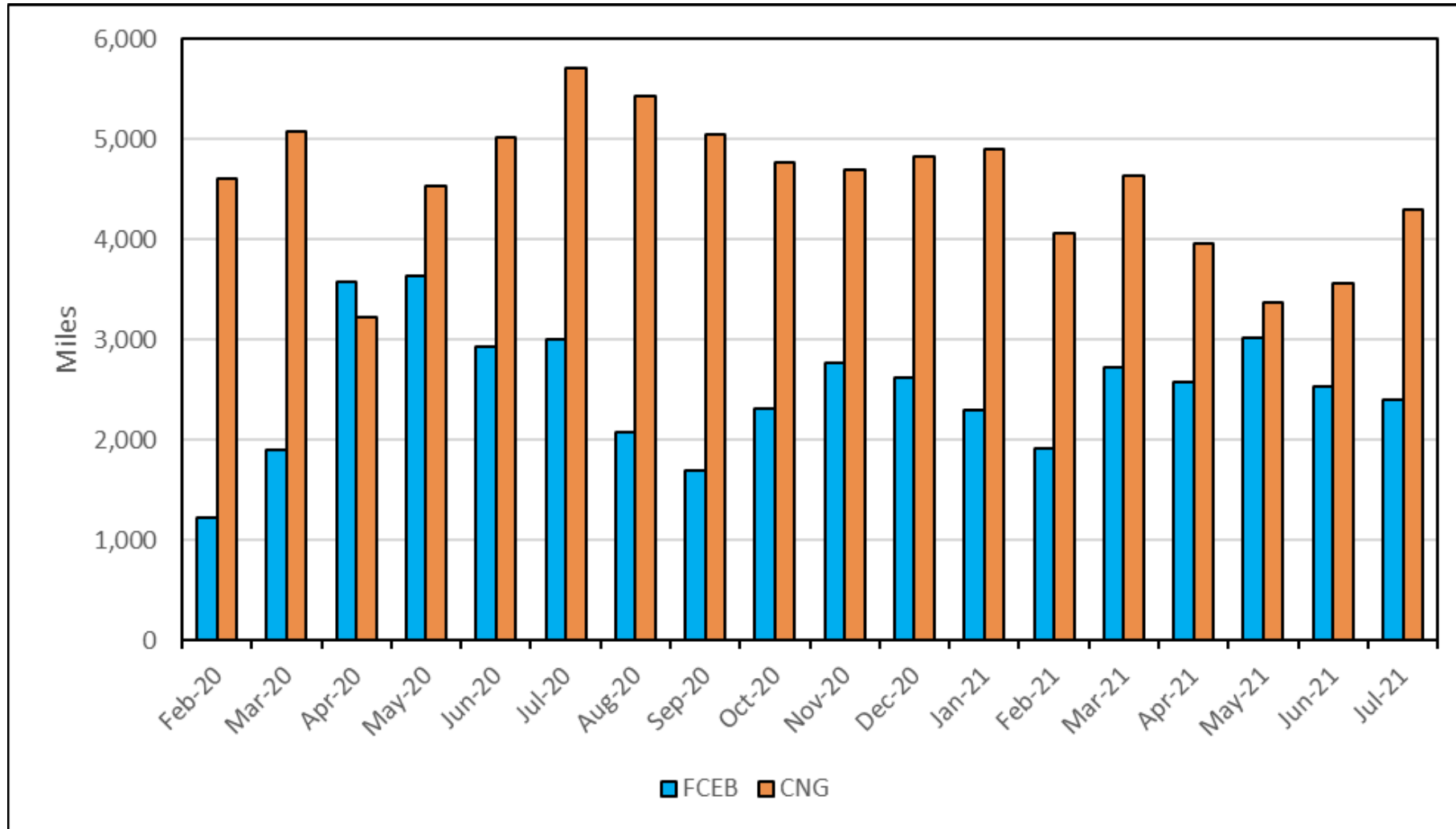
Fleet Average Monthly Miles by Bus

Bus	Miles	Bus Months	Average Monthly Mileage
1111	48,444	18	2,691
1112	34,002	18	1,889
1113	46,449	18	2,580
1114	49,018	18	2,723
1115	39,565	18	2,198
1116	52,477	18	2,915
1117	49,621	18	2,757
1118	44,929	18	2,496
1119	37,420	13	2,878
1120	37,302	18	2,072
FCEB Fleet	439,227	175	2,510

Bus	Miles	Bus Months	Average Monthly Mileage
5821	90,186	18	5,010
5822	92,906	18	5,161
5823	78,675	18	4,371
5824	85,307	18	4,739
5825	81,587	18	4,533
5826	73,581	18	4,088
5827	79,965	18	4,443
5828	88,464	18	4,915
5829	68,514	18	3,806
5830	78,137	18	4,341
CNG Fleet	817,321	180	4,541

Bus 1119 was being used for upgrade/testing during the early data period. Clean point is July 2020.

Average Monthly Miles



Overall

- FCEB = 2,510
- CNG = 4,541

Availability Analysis

Availability, which is a measure of reliability, is presented as the percentage of days the buses are actually available out of days that the buses are planned for passenger service. Buses available for service may have been used in passenger service, training, or for special events, or they may have been available but just not used. Buses unavailable for service may have had issues with the propulsion system (fuel cell system, electric drive system), general bus maintenance, or undergoing scheduled maintenance. Accidents are removed from the data—the bus is considered “not planned” during the repair time.

The data presented are based on availability for morning pull-out and don't necessarily reflect all-day availability. Transit agencies typically have a target of 85% availability for their fleets to allow for time to handle scheduled and unscheduled maintenance. For OCTA, NREL calculates availability based on the planned service days, which are typically every day. OCTA provides daily bus availability for the FCEBs and a reason for unavailability. Reasons for availability are based on the current open work orders. In some cases, a bus is down for multiple reasons. For those days, the unavailability reason is split between categories. For example, if a bus has open work orders for both general bus repair and PM, each category would be credited for 0.5 unavailable days.

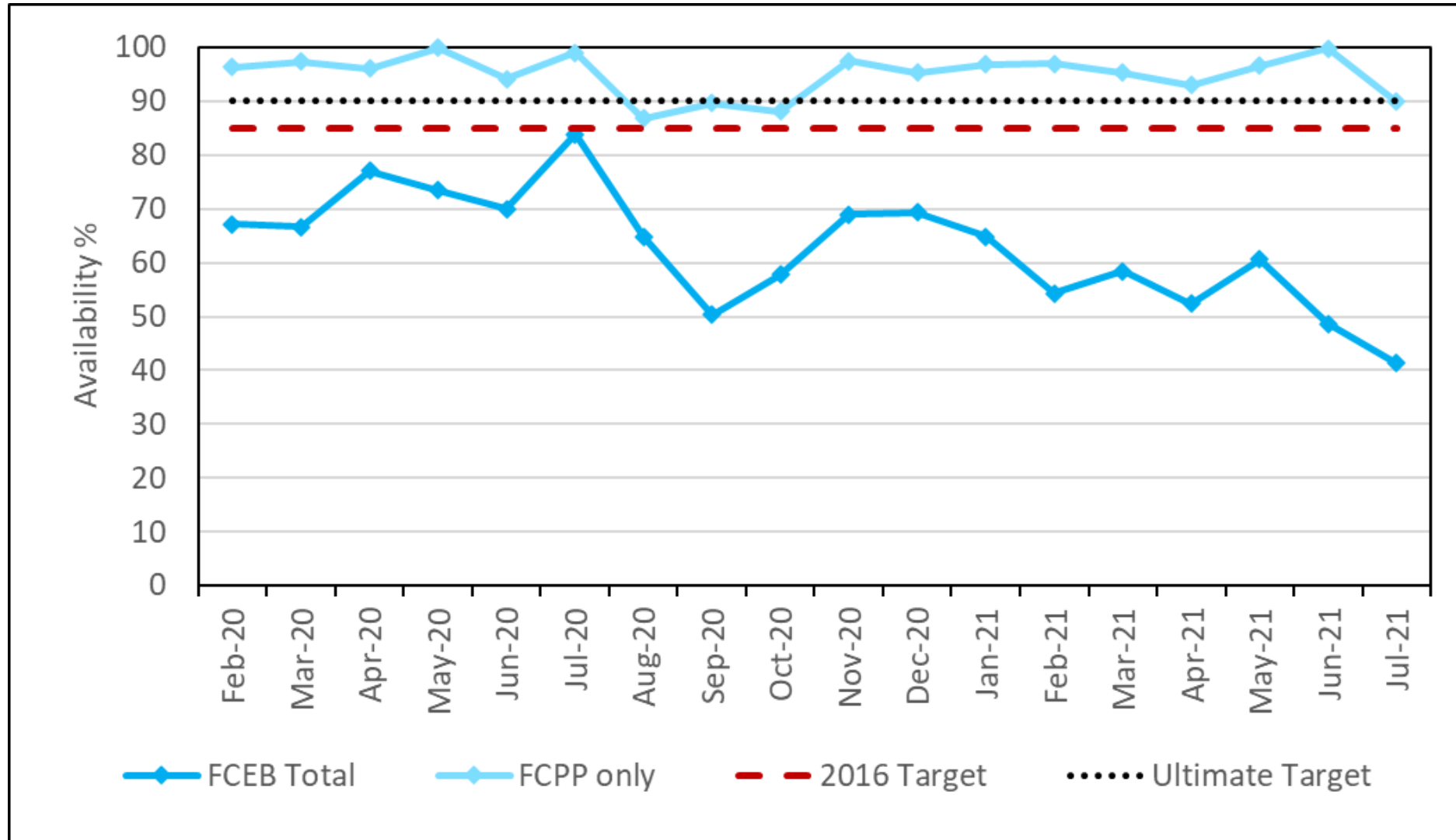
NREL presents availability as a monthly average trend and as overall availability. Unavailable time is separated into several categories to show the primary reason for downtime.

Availability/Unavailability Summary

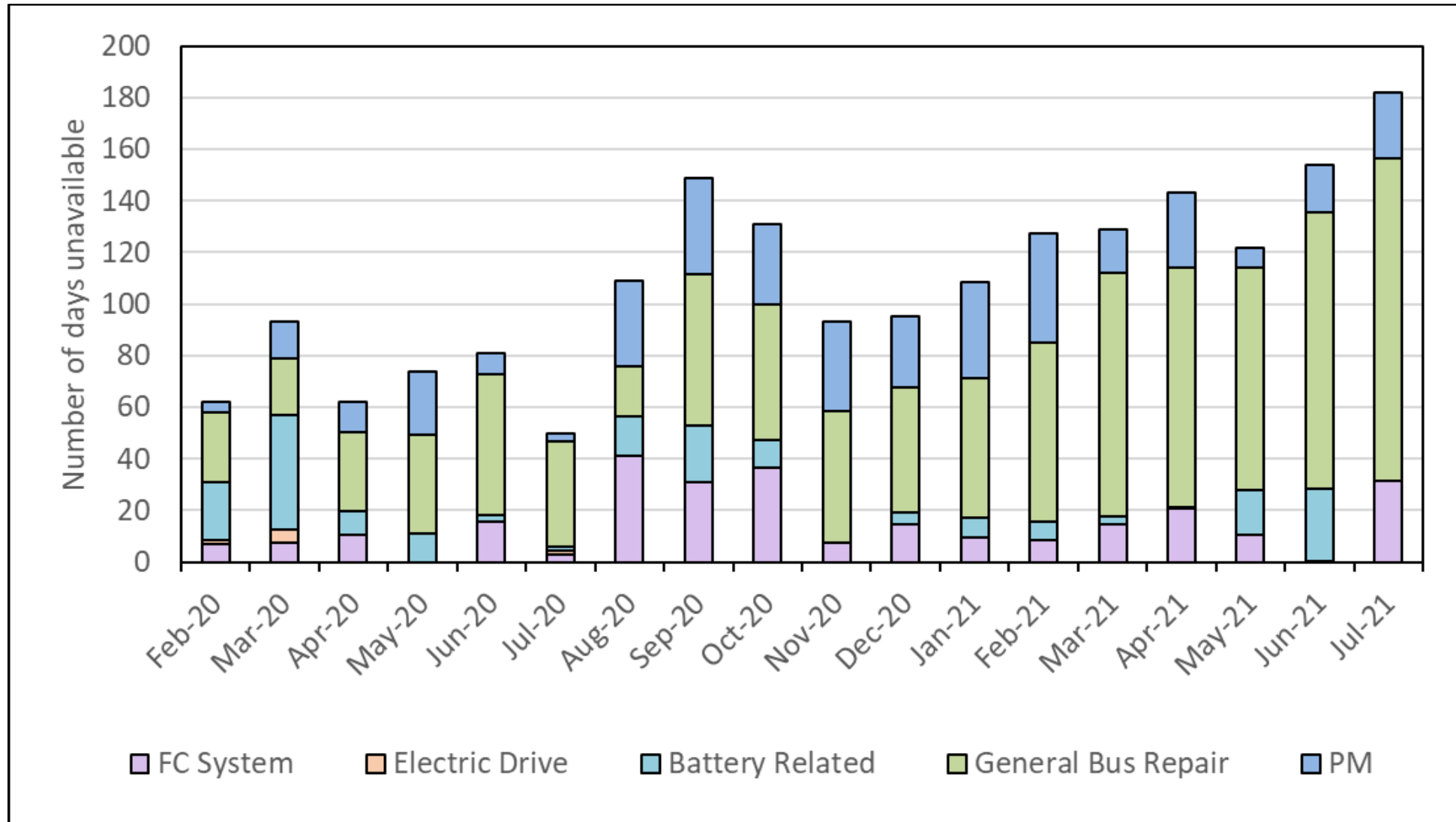
Category	FCEB # Days	FCEB %
Planned work days	5,247	
Days available	3,281	62.5
Days unavailable	1,966	37.5
Fuel cell system	269.4	5.1
Electric drive	8.0	0.2
Battery related	207.2	3.9
General bus maintenance	1073.4	20.5
Preventive maintenance (PM)	406.9	7.8

CNG baseline bus fleet availability is 80% or greater

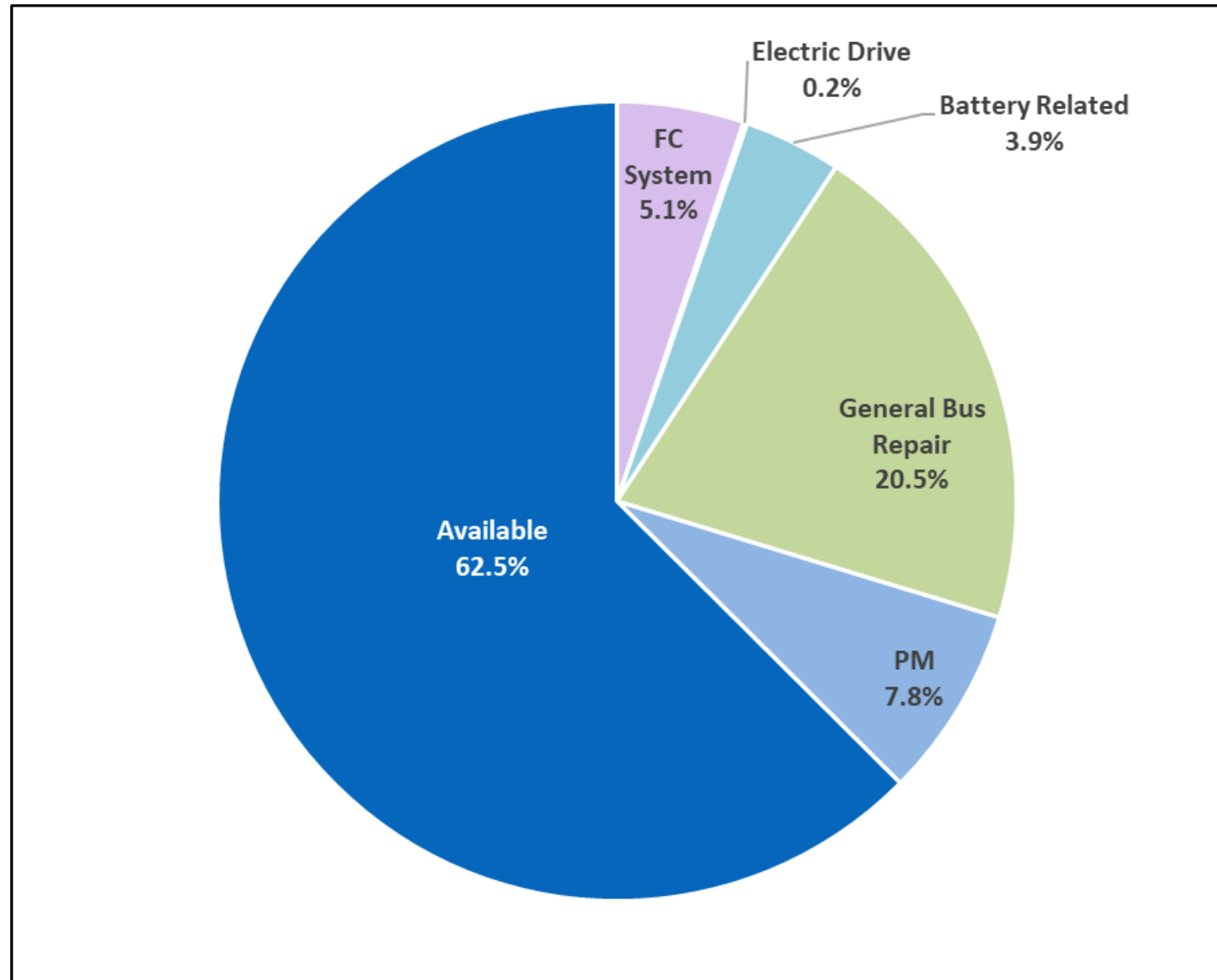
Monthly Availability



FCEB Monthly Unavailability Reasons



FCEB Overall Availability



Fuel Economy and Cost Analysis

OCTA provides individual fueling records for the FCEBs and CNG buses. CNG is typically dispensed in units of gge. NREL uses these records to calculate the CNG fuel economy in mpgge as well as mpdge. Hydrogen is tracked in kilograms; 1 kg of hydrogen has essentially the same energy content as a gallon of gasoline. To compare the fuel economy of the FCEBs to that of the baseline buses, NREL converts kg hydrogen to dge.

Conversions:

$$\text{gge CNG} * 0.895 = \text{dge}$$

$$\text{kg H}_2 * 0.885 = \text{dge}$$

OCTA provides monthly cost of hydrogen per kg and CNG per therm.

The average cost of hydrogen during the evaluation period was \$8.10/kg. The CNG fuel cost for the data period was \$1.22 per gge.

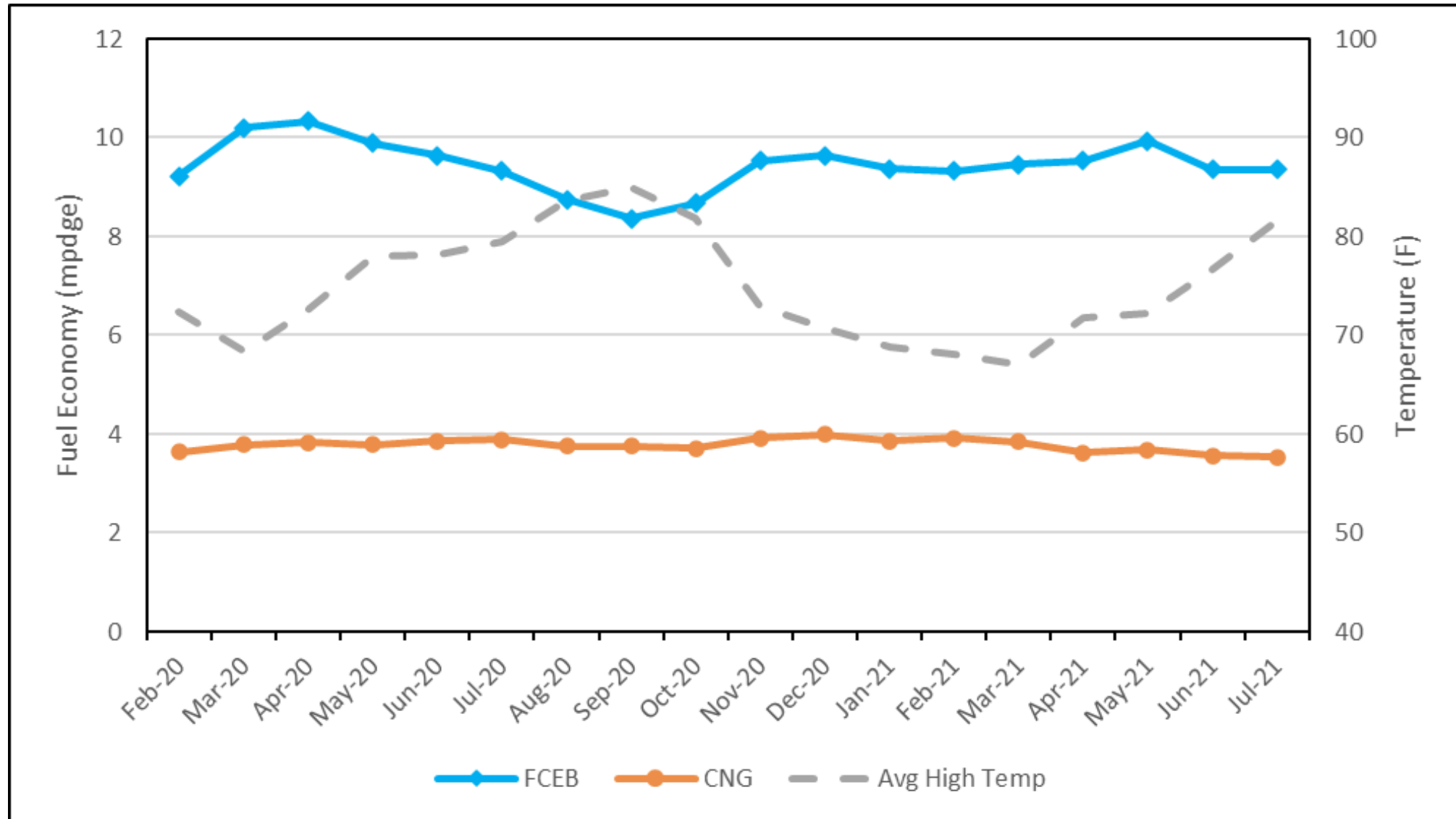
Fuel Economy by Bus

Bus	Miles	Hydrogen (kg)	mi/kg	Diesel gallon Equiv.	Fuel economy (mpdge)
1111	51,453	6,493.4	7.92	5,746.4	8.95
1112	30,239	3,625.8	8.34	3,208.6	9.42
1113	43,820	5,161.4	8.49	4,567.6	9.59
1114	46,937	5,451.0	8.61	4,823.9	9.73
1115	38,540	4,674.2	8.25	4,136.5	9.32
1116	51,574	5,835.4	8.84	5,164.1	9.99
1117	48,285	5,933.7	8.14	5,251.1	9.20
1118	43,369	5,218.9	8.31	4,618.5	9.39
1119	37,420	4,301.7	8.70	3,806.8	9.83
1120	36,247	4,331.2	8.37	3,832.9	9.46
FCEB Fleet	427,885	51,026.7	8.39	45,156.4	9.48

Bus	Miles	CNG (gge)	Miles per gge	CNG (dge)	Fuel Economy (mpdge)
5821	89,045	22,055.3	4.04	19,739.5	4.51
5822	92,668	23,900.2	3.88	21,390.7	4.33
5823	78,524	23,335.7	3.36	20,885.5	3.76
5824	84,309	20,763.4	4.06	18,583.2	4.54
5825	80,859	21,845.8	3.70	19,552.0	4.14
5826	73,682	19,545.2	3.77	17,492.9	4.21
5827	78,809	20,579.5	3.83	18,418.6	4.28
5828	87,069	22,330.4	3.90	19,985.7	4.36
5829	66,013	18,516.0	3.57	16,571.8	3.98
5830	77,805	21,386.6	3.64	19,141.0	4.06
CNG Total	808,781	214,258.0	3.77	191,760.9	4.22

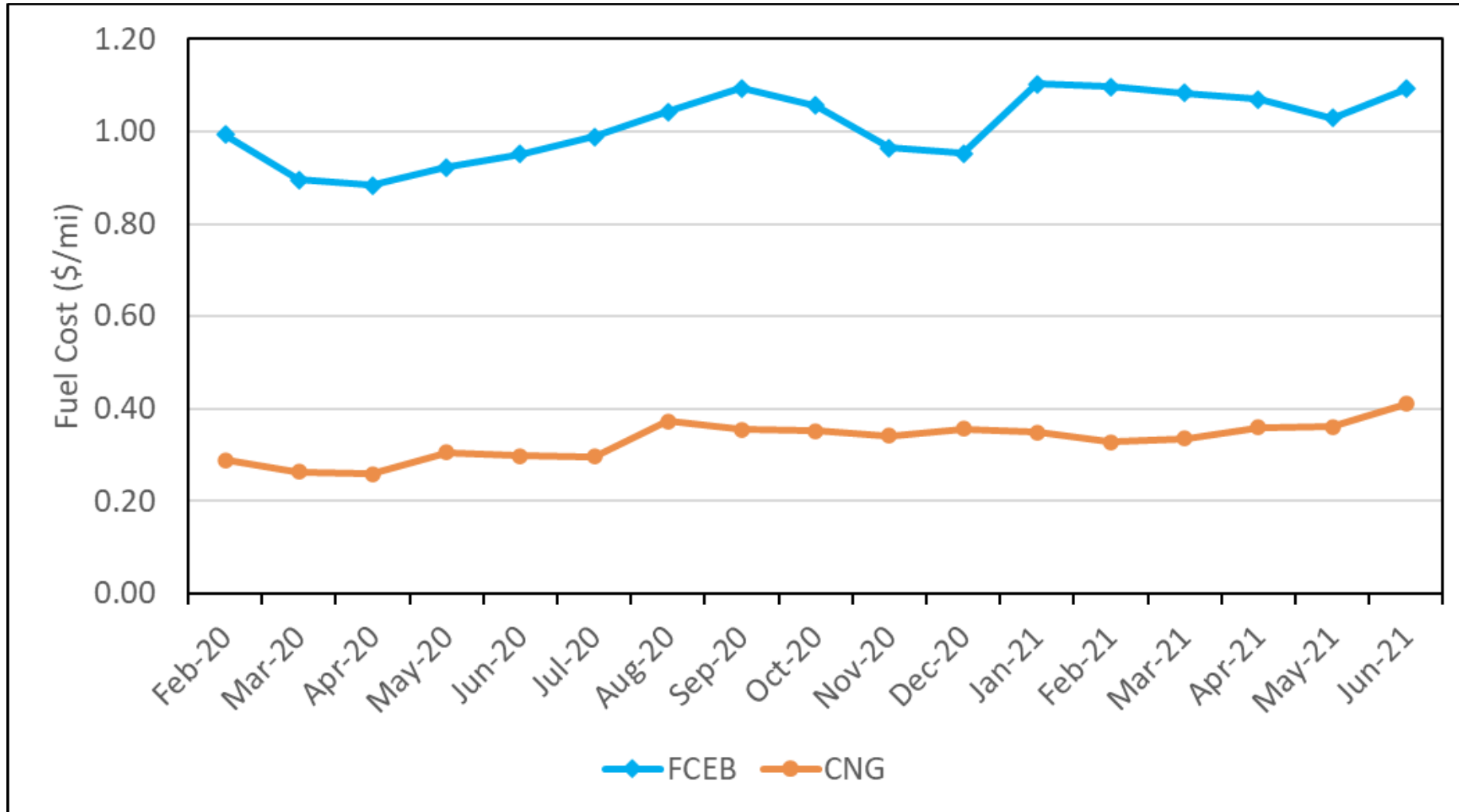
- FCEB fuel economy is 2.25 times that of the CNG buses.

Monthly Average Fuel Economy



*Average monthly high temperatures at John Wayne Airport in Santa Ana, CA. Data acquired from www.ncdn.noaa.gov

Monthly Average Fuel Cost Per Mile



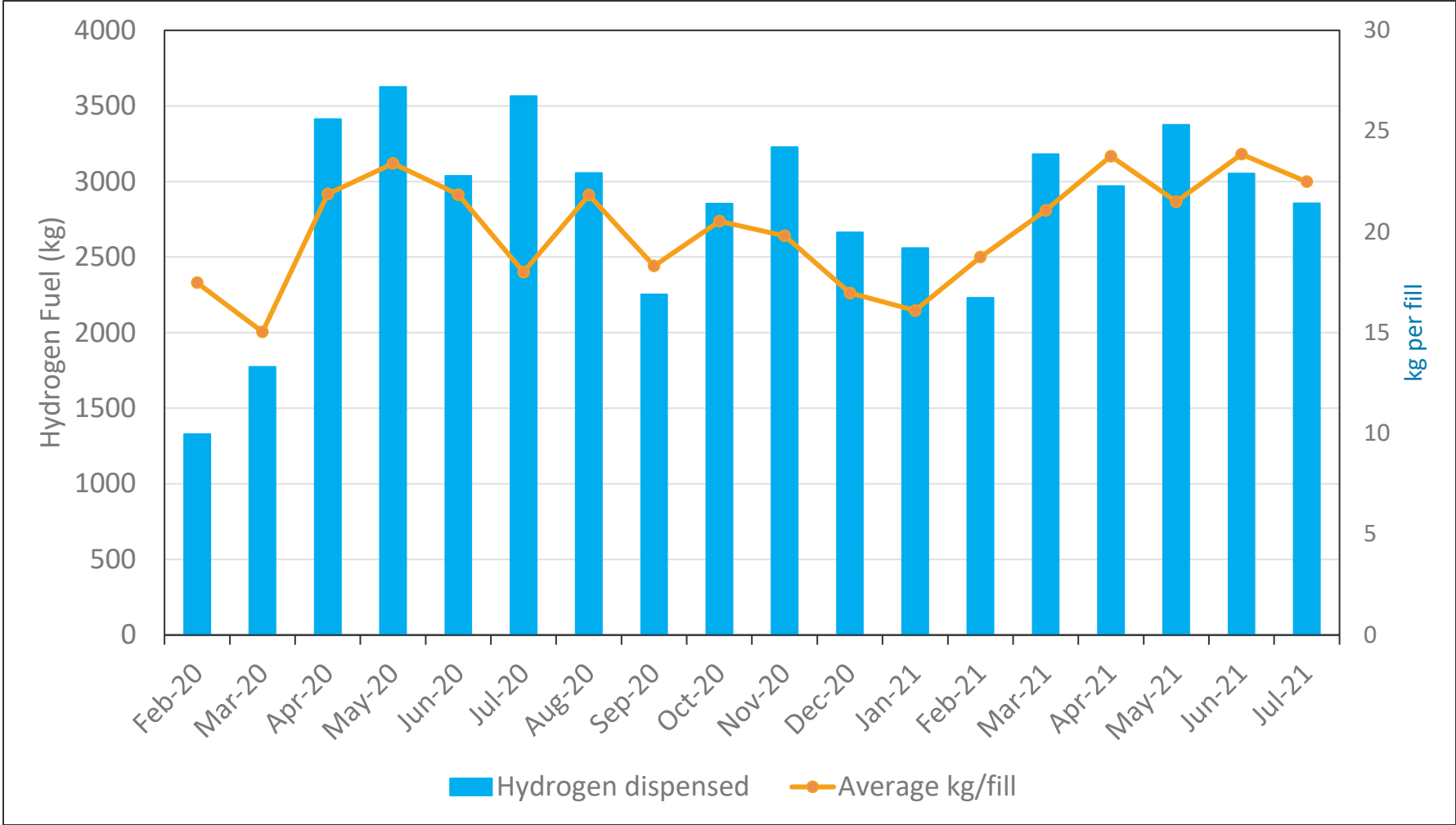
Average fuel cost

- H2 = \$8.44 /kg
- CNG = \$1.25 /gge

Average cost per mile

- H2 = \$1.01
- CNG = \$0.33

Fleet Hydrogen Use



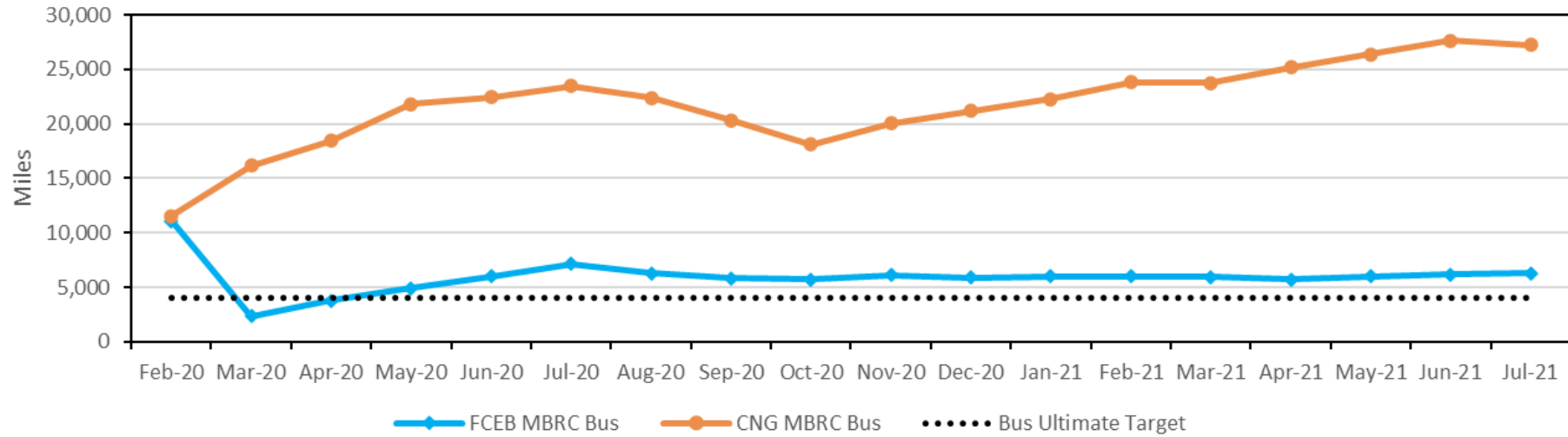
Overall
Daily kg Hydrogen: 95.56
H2 kg/fill: 20.17

Roadcall Analysis

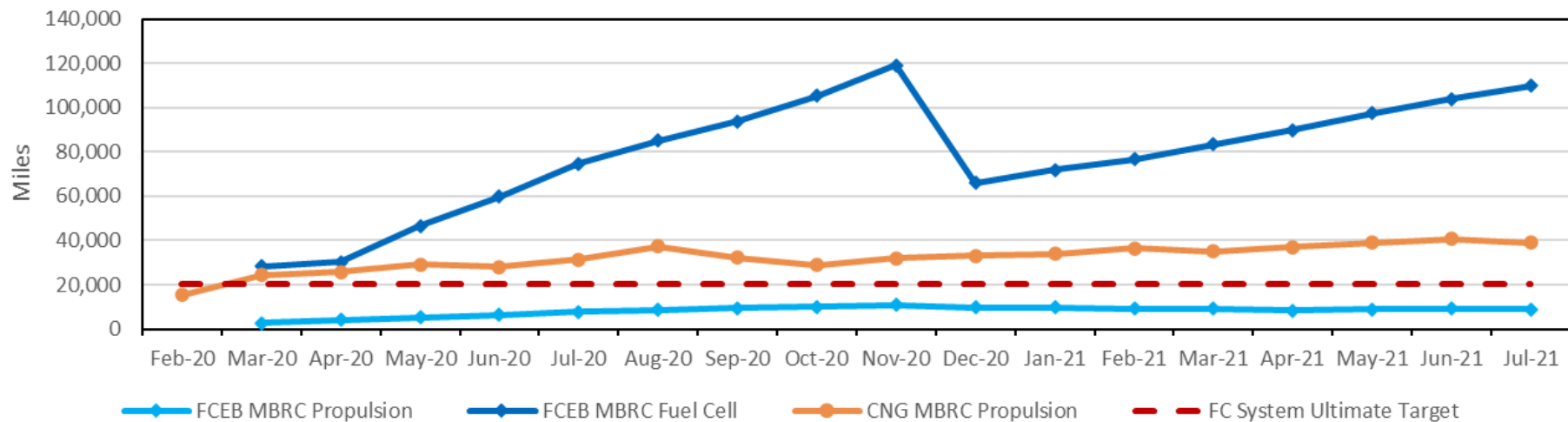
A roadcall or revenue vehicle system failure is defined as a failure of an in-service bus that causes the bus to be replaced on route or causes a significant delay in schedule. If the problem with the bus can be repaired during a layover and the schedule is kept, this is not considered a roadcall. The analysis described here includes only roadcalls that were caused by “chargeable” failures. Chargeable roadcalls include systems that can physically disable the bus from operating on route, such as interlocks (doors, air system), engine, or things that are deemed to be safety issues if operation of the bus continues. They do not include roadcalls for things such as problems with radios, fareboxes, or destination signs.

The transit industry measures reliability as mean distance between failures, also documented as MBRC. NREL tracks MBRC by total roadcalls, propulsion-related roadcalls, and fuel cell (FC) system-related roadcalls. Total roadcalls includes all chargeable roadcalls. “Propulsion-related roadcall” is a subset of total roadcalls and includes all roadcalls due to propulsion-related systems including the FC system (or engine for a conventional bus), electric drive, fuel, exhaust, air intake, cooling, non-lighting electrical, transmission systems, and hydraulics. The FC system-related roadcalls, a subset of the propulsion-related roadcalls, and MBRC are included for the FCEBs.

Cumulative MBRC



	FCEB	CNG
Bus MBRC	6,275	27,244
Propulsion MBRC	8,964	38,920
FC system MBRC	109,807	N/A



Maintenance Analysis

NREL collects all work orders for the evaluation buses to calculate a maintenance cost per mile. Costs for accident-related repairs which are extremely variable from bus to bus, were eliminated from the analysis. Warranty costs are not included in the cost-per-mile calculations because those costs are covered in the capital cost of the buses. For consistency, NREL uses a constant \$50 per hour. This does not reflect an average rate for OCTA. Cost per mile is calculated as follows:

$$\text{Cost per mile} = [(\text{labor hours} * 50) + \text{parts cost}] / \text{mileage}$$

NREL calculates total cost per mile, scheduled maintenance cost per mile, and unscheduled maintenance cost per mile. NREL also categorizes maintenance cost by system to provide insight into which systems have the most costs for each technology. Parts for scheduled maintenance, such as filters and fluids, are included in the specific system categories. For example, oil and oil filters are included in the power plant (engine) subsystem parts costs, while air filters are included in the air intake subsystem parts costs.

The propulsion system costs are of particular interest. Propulsion-related vehicle systems include the exhaust, fuel, engine, FC system, battery modules, electric propulsion, air intake, cooling, non-lighting electrical, transmission systems, and hydraulics. These systems have been separated to highlight maintenance costs most directly affected by the advanced propulsion system changes for the buses.

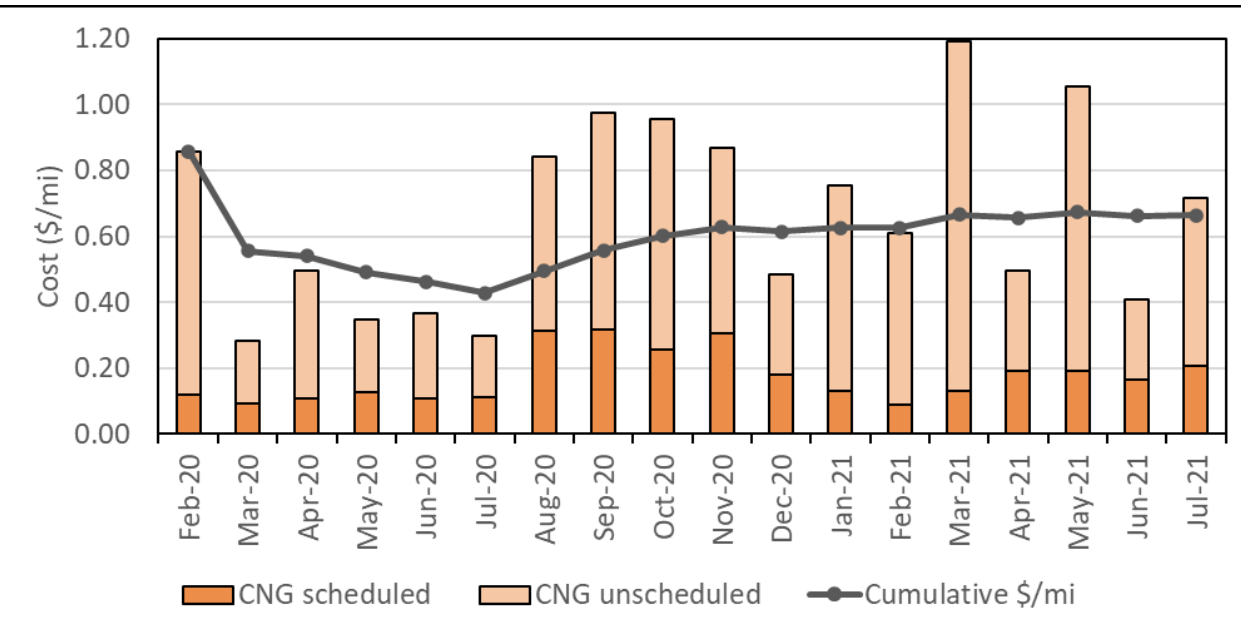
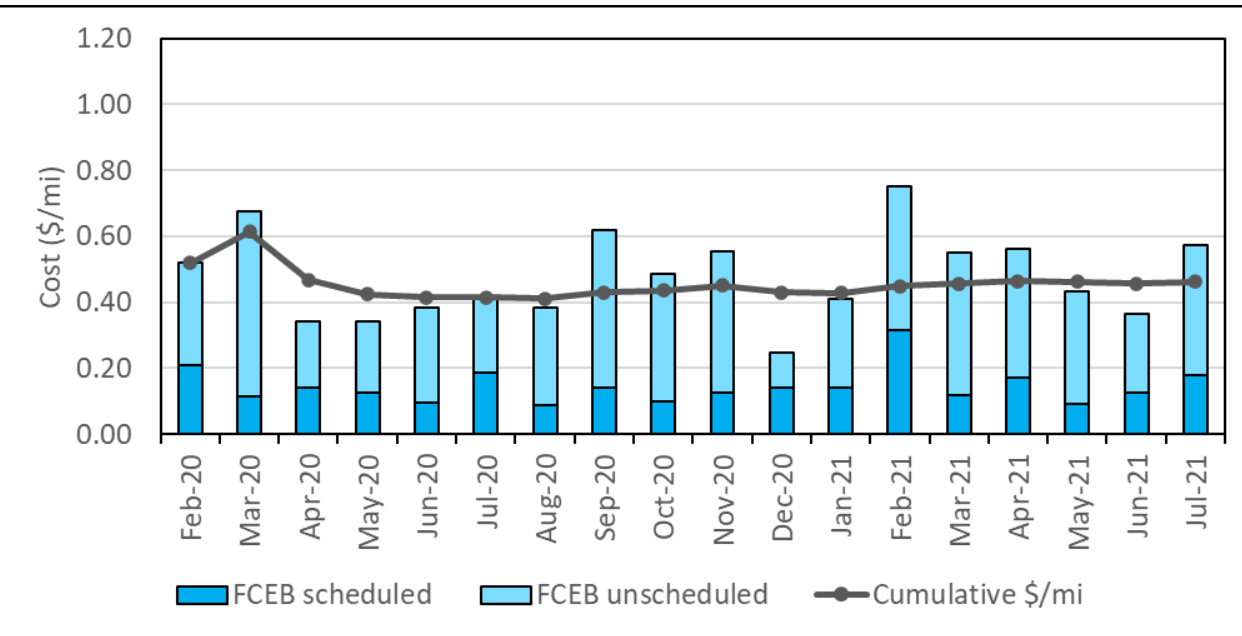
Maintenance Analysis Results

Bus	Mileage	Parts (\$)	Labor hours	Total Cost per Mile (\$)
1111	48,444	5,578.48	373.9	0.50
1112	34,002	3,175.58	297.0	0.53
1113	46,449	5,592.92	426.8	0.58
1114	49,018	4,677.07	368.5	0.47
1115	39,565	4,502.45	248.8	0.43
1116	52,477	3,913.35	343.6	0.40
1117	49,621	5,871.03	378.0	0.50
1118	44,929	2,859.72	309.3	0.41
1119	37,420	1,988.18	252.2	0.39
1120	37,299	1,574.54	272.8	0.41
FCEB Fleet	439,224	39,733.32	3,270.8	0.46

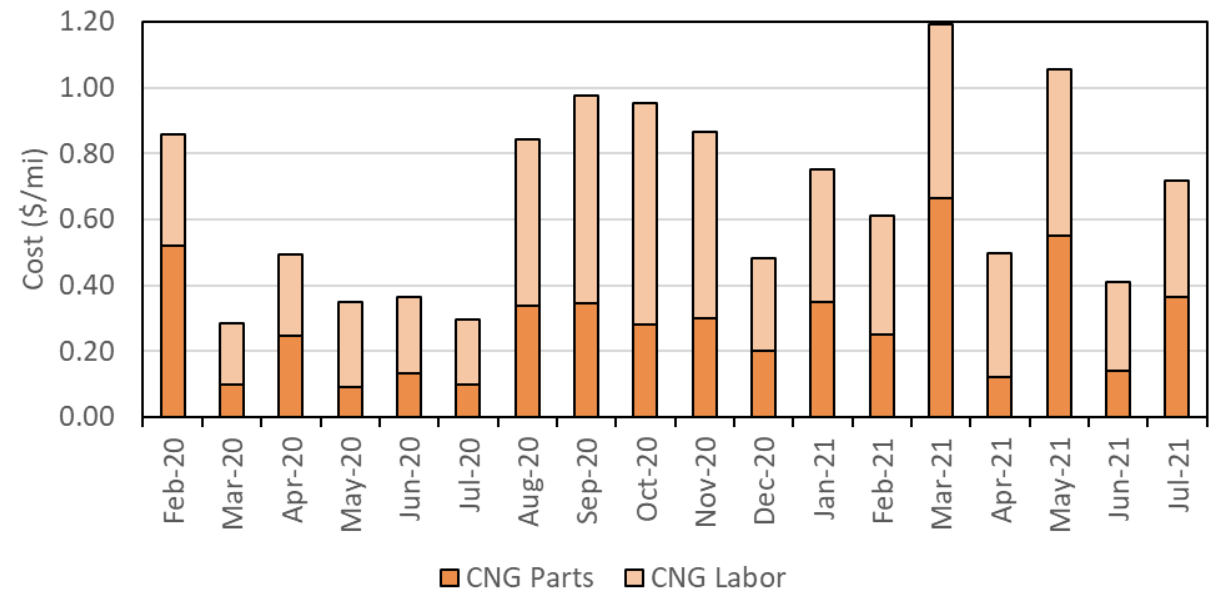
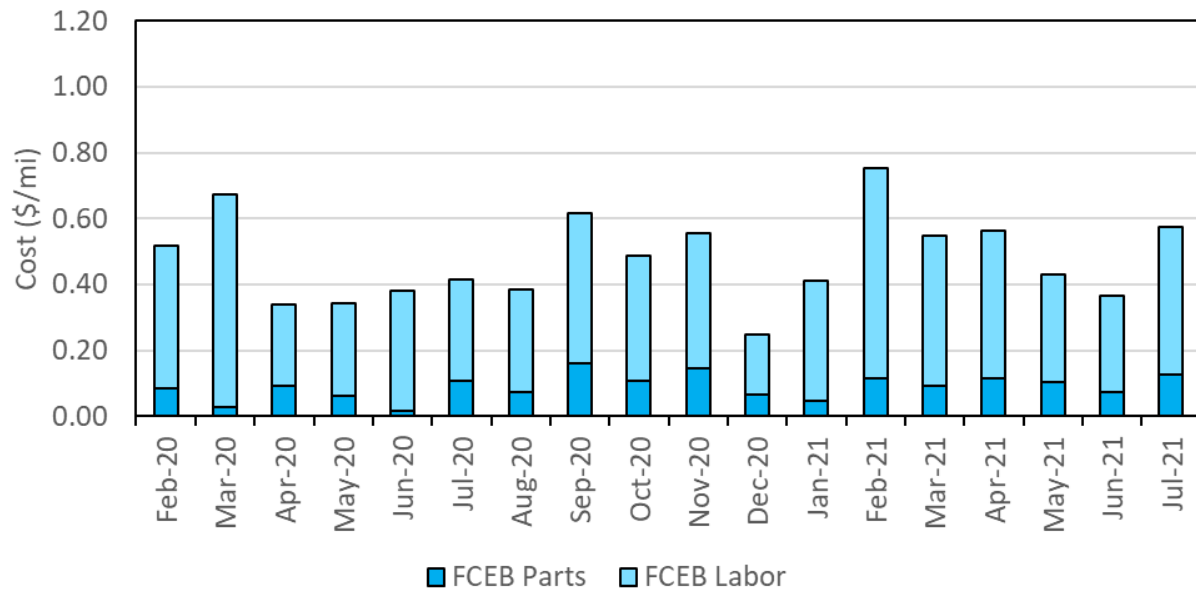
Bus	Mileage	Parts (\$)	Labor hours	Total Cost per Mile (\$)
5821	90,186	24,839.74	648.0	0.63
5822	92,906	38,808.85	860.3	0.88
5823	78,675	22,583.38	537.5	0.63
5824	85,307	19,072.31	650.5	0.60
5825	81,587	19,720.90	642.0	0.64
5826	73,581	18,225.86	600.7	0.66
5827	79,965	20,996.82	596.8	0.64
5828	88,464	16,921.16	678.6	0.57
5829	68,514	26,166.63	579.0	0.80
5830	78,137	21,033.76	498.8	0.59
CNG Fleet	817,321	228,369.41	6,292.1	0.66

Note: the FCEBs are under warranty, while the CNG buses are not under warranty.

Scheduled and Unscheduled Maintenance Cost



Parts and Labor Maintenance Cost



Maintenance Cost by System

The vehicle systems include the following:

- Propulsion-related systems—Repairs for exhaust, fuel, engine, electric motors, fuel cell modules, battery modules, propulsion control, non-lighting electrical (charging, cranking, and ignition), air intake, cooling, hydraulics, and transmission
- Cab, body, and accessories—Includes body, glass, and paint repairs following accidents; cab and sheet metal repairs on seats and doors; and accessory repairs such as hubodometers and radios
- PMI (preventive maintenance inspections)—Labor for preventive maintenance
- Brakes
- Frame, steering, and suspension
- Heating, ventilation, and air conditioning (HVAC)
- Lighting
- Axles, wheels, and drive shaft
- Air system, general
- Tires


Maintenance Cost per Mile by System

System	FCEB		CNG	
	Cost per Mile (\$)	Percent of Total (%)	Cost per Mile (\$)	Percent of Total (%)
Propulsion-related	0.119	25.8	0.288	43.4
Cab, body, and accessories	0.173	37.4	0.170	25.6
PMI	0.096	20.7	0.070	10.5
Brakes	0.008	1.8	0.066	9.9
Frame, steering, and suspension	0.011	2.3	0.012	1.8
HVAC	0.007	1.5	0.011	1.7
Lighting	0.004	0.8	0.006	0.9
Air, general	0.036	7.9	0.029	4.4
Axles, wheels, and drive shaft	0.006	1.3	0.011	1.7
Tires	0.003	0.6	0.001	0.1
Total	0.462	100	0.664	100

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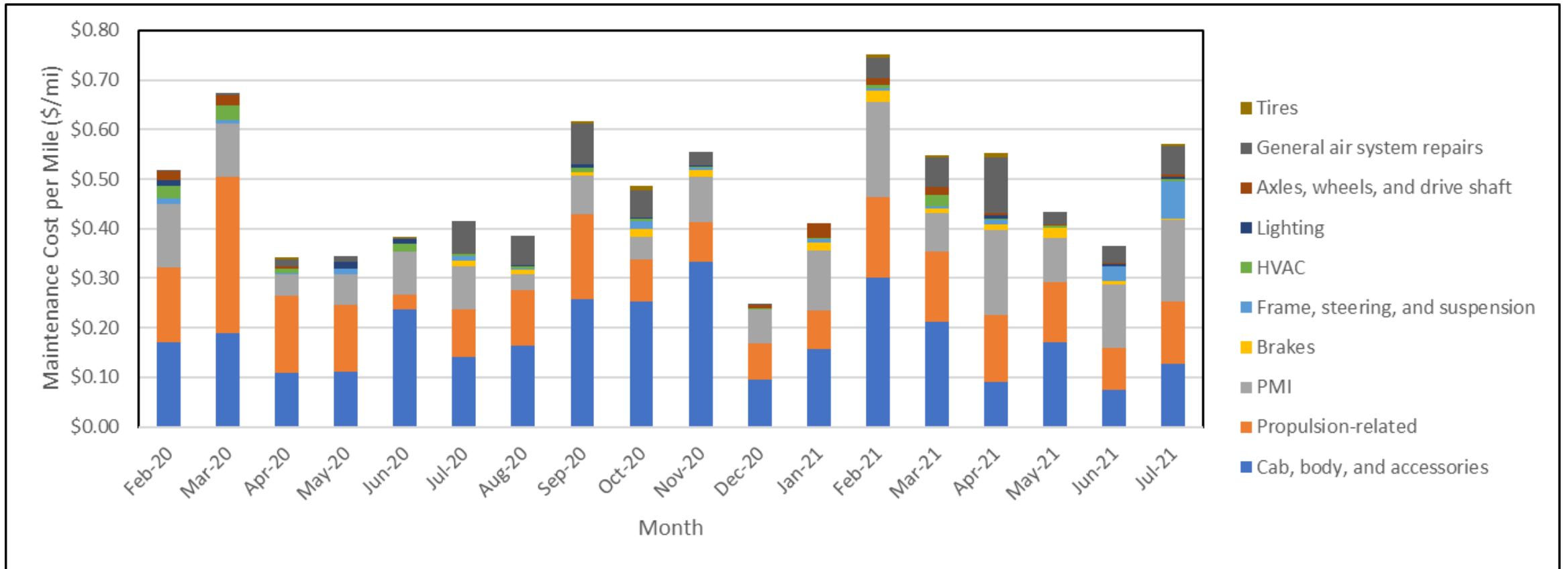
 Highest cost

 Second highest cost

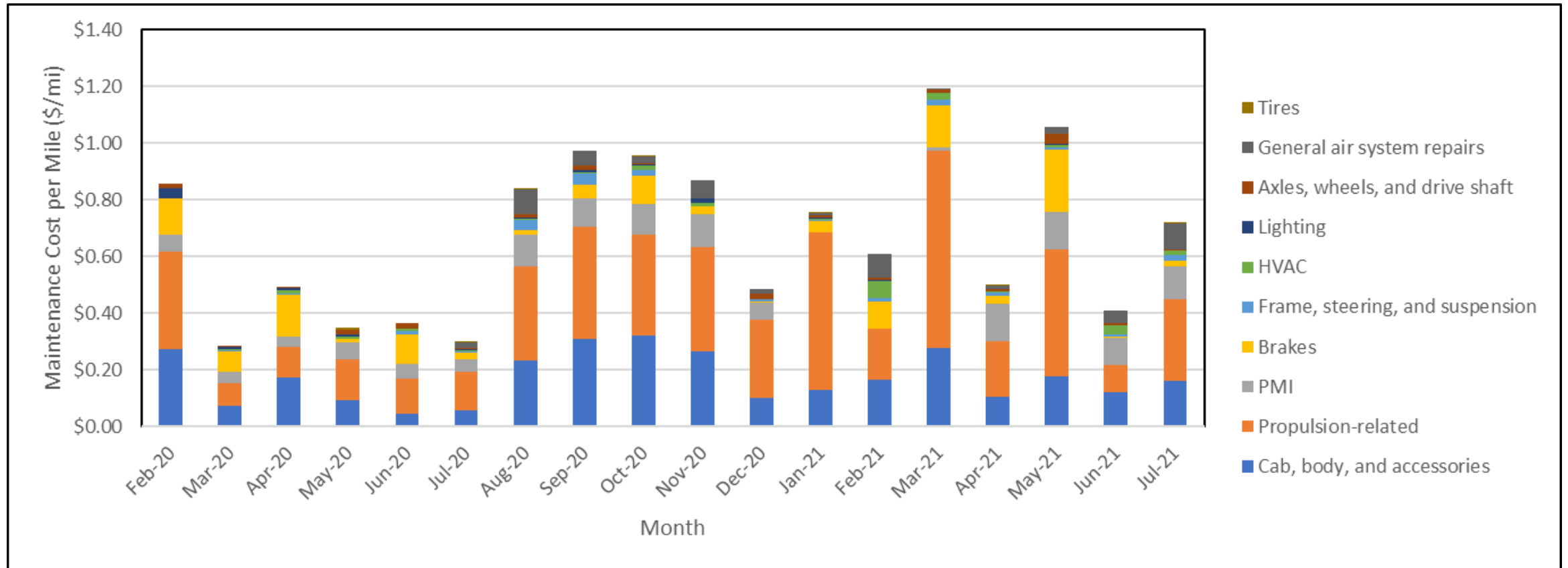
 Third highest cost

- For the FCEB fleet, the systems with the highest cost were propulsion-related; cab, body, and accessories; and PMI. For the CNG fleet, the systems with the highest cost were also propulsion-related; cab, body, and accessories; and PMI.
- Overall costs for the FCEBs are similar to that of the CNG buses.

Maintenance Cost by System: FCEBs



Maintenance Cost by System: CNG Buses



Propulsion-Related Maintenance Costs by Subsystem

Maintenance System		FCEB	CNG	Maintenance System		FCEB	CNG
Mileage		439,224	817,321	Non-Lighting Electrical System (General Electrical, Charging, Cranking, Ignition)	Parts cost (\$)	315.50	34,256.73
Total Propulsion-Related Systems (Total of all systems in table)	Parts cost (\$)	15,868.70	136,716.19		Labor hours	131.0	185.0
	Labor hours	731.5	1,974.3		Total cost (\$)	6,865.50	43,506.73
	Total cost (\$)	52,443.70	235,428.69		Total cost (\$) per mile	0.016	0.053
	Total cost (\$) per mile	0.119	0.288	Air Intake System	Parts cost (\$)	1,079.23	3,323.65
Exhaust System	Parts cost (\$)	0.00	5,753.34		Labor hours	0.0	31.0
	Labor hours	0.0	55.5		Total cost (\$)	1,079.23	4,873.65
	Total cost (\$)	0.00	8,528.34		Total cost (\$) per mile	0.002	0.006
	Total cost (\$) per mile	0.000	0.010	Cooling System	Parts cost (\$)	344.59	4,064.72
Fuel System	Parts cost (\$)	116.50	18,737.30		Labor hours	33.0	246.8
	Labor hours	120.0	720.5		Total cost (\$)	1,994.59	16,402.22
	Total cost (\$)	6,116.50	54,762.30		Total cost (\$) per mile	0.005	0.020
	Total cost (\$) per mile	0.014	0.067	Transmission System	Parts cost (\$)	0.00	51,510.46
Powerplant System (Fuel Cell System for FCEBs)	Parts cost (\$)	12,999.46	19,058.42		Labor hours	1.0	118.0
	Labor hours	259.0	615.5		Total cost (\$)	50.00	57,410.46
	Total cost (\$)	25,949.46	49,833.42		Total cost (\$) per mile	0.000	0.070
	Total cost (\$) per mile	0.059	0.061	Hydraulic System	Parts cost (\$)	0.00	11.57
Electric Propulsion System	Parts cost (\$)	1,013.42	0.00		Labor hours	0.0	2.0
	Labor hours	187.5	0.0		Total cost (\$)	0.00	111.57
	Total cost (\$)	10,388.42	0.00		Total cost (\$) per mile	0.000	0.000
	Total cost (\$) per mile	0.024	0.000				

Parts cost include items regularly replaced as part of scheduled maintenance. Scheduled parts make up 90% of the FC System parts

Contacts

NREL

Matthew Post

Phone: 303-275-3829

Email: Matthew.Post@nrel.gov

Orange County Transportation Authority

Cliff Thorne

Phone: 714-560-9975

Email: cthorne@octa.net

Acronyms and Abbreviations

CNG	compressed natural gas	kW	kilowatt
dge	diesel gallon equivalent	kWh	kilowatt-hour
DOE	U.S. Department of Energy	lb.	pound
FC	fuel cell	MBRC	miles between roadcalls
FCEB	fuel cell electric bus	mi	mile
ft	feet	mpdge	miles per diesel gallon equivalent
FTA	Federal Transit Administration	mpgge	miles per gasoline gallon equivalent
gge	gasoline gallon equivalent	mph	miles per hour
GVWR	gross vehicle weight rating	NREL	National Renewable Energy Laboratory
hp	horsepower	PM	preventive maintenance
HVAC	heating, ventilation, and air conditioning	PMI	preventive maintenance inspection
in.	inch	psi	pounds per square inch
kg	kilogram		

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Appendix: Fleet Summary Statistics

Fleet Summary Statistics

	FCEB	CNG
Number of vehicles	10	10
Period used for fuel and oil analysis	Feb 2020 -Jul 2021	Feb 2020 -Jul 2021
Total number of months in period	18	18
Fuel and oil analysis base fleet mileage	427,162	808,781
Period used for maintenance analysis	Feb 2020 -Jul 2021	Feb 2020 -Jul 2021
Total number of months in period	18	18
Maintenance analysis base fleet mileage	439,224	817,321
Average monthly mileage per vehicle	2,579	4,541
Availability	62.5	≥85
Fleet fuel usage in kg hydrogen or gge CNG	51,026.7	214,258.0
Roadcalls	70	30
Total MBRC	6,275	27,244
Propulsion roadcalls	49	21
Propulsion MBRC	8,964	38,920
Fleet mi/kg hydrogen (FCEB), mi/gge (CNG)	8.37	3.77
Representative fleet mpg (energy equiv.)	9.46	4.22
Fuel cost per kg hydrogen or gge CNG	8.48	1.15
Fuel cost per mile	1.013	0.361
Total scheduled repair cost per mile	0.142	0.177
Total unscheduled repair cost per mile	0.321	0.487
Total maintenance cost per mile	0.463	0.664
Total operating cost per mile	1.476	1.025

Maintenance Cost Summary

Maintenance Cost Summary

	FCEB	CNG
Fleet mileage	439,224	817,321
Total parts cost	39,733.32	228,369.41
Total labor hours	3265.3	6293.1
Average labor cost (@ \$50.00 per hour)	163,262.50	314,654.17
Total maintenance cost	202,995.82	543,023.58
Total maintenance cost per bus	20,299.58	54,302.36
Total maintenance cost per mile	0.46	0.66

Propulsion System Maintenance Cost Summary

	FCEB	CNG
Total Engine/Fuel-Related Systems (ATA VMRS 27, 30, 31, 32, 33, 41, 42, 43, 44, 45, 46, 65)		
Parts cost	15,868.70	136,716.19
Labor hours	731.5	1974.3
Average labor cost	36,575.00	98,712.50
Total cost (for system)	52,443.70	235,428.69
Total cost (for system) per bus	5,244.37	23,542.87
Total cost (for system) per mile	0.12	0.29

Maintenance Cost by Vehicle System

	FCEB	CNG
Exhaust System (ATA VMRS 43)		
Parts cost	0.00	5,753.34
Labor hours	0.0	55.5
Average labor cost	0.00	2,775.00
Total cost (for system)	0.00	8,528.34
Total cost (for system) per bus	0.00	852.83
Total cost (for system) per mile	0.000	0.01
Fuel System (ATA VMRS 44)		
Parts cost	116.50	18,737.30
Labor hours	120	720.5
Average labor cost	6,000.00	36,025.00
Total cost (for system)	6,116.50	54,762.30
Total cost (for system) per bus	611.65	5,476.23
Total cost (for system) per mile	0.01	0.07
Power Plant (Engine) (ATA VMRS 45)		
Parts cost	12,999.46	19,058.42
Labor hours	259	615.5
Average labor cost	12,950.00	30,775.00
Total cost (for system)	25,949.46	49,833.42
Total cost (for system) per bus	2,594.95	4,983.34
Total cost (for system) per mile	0.06	0.06

Maintenance Cost by Vehicle System

	FCEB	CNG
Electric Propulsion (ATA VMRS 46)		
Parts cost	1,013.42	0.00
Labor hours	187.5	0.0
Average labor cost	9,375.00	0.00
Total cost (for system)	10,388.42	0.00
Total cost (for system) per bus	1,038.84	0.00
Total cost (for system) per mile	0.02	0.000
Electrical System (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)		
Parts cost	315.50	34,256.73
Labor hours	131	185
Average labor cost	6,550.00	9,250.00
Total cost (for system)	6,865.50	43,506.73
Total cost (for system) per bus	686.55	4,350.67
Total cost (for system) per mile	0.02	0.05
Air Intake System (ATA VMRS 41)		
Parts cost	1,079.23	3,323.65
Labor hours	0	31
Average labor cost	0.00	1,550.00
Total cost (for system)	1,079.23	4,873.65
Total cost (for system) per bus	107.92	487.37
Total cost (for system) per mile	0.00	0.01

Maintenance Cost by Vehicle System

	FCEB	CNG
Cooling System (ATA VMRS 42)		
Parts cost	344.59	4,064.72
Labor hours	33	246.75
Average labor cost	1,650.00	12,337.50
Total cost (for system)	1,994.59	16,402.22
Total cost (for system) per bus	199.46	1,640.22
Total cost (for system) per mile	0.00	0.02
Hydraulic System (ATA VMRS 65)		
Parts cost	0.00	11.57
Labor hours	0.0	2
Average labor cost	0.00	100.00
Total cost (for system)	0.00	111.57
Total cost (for system) per bus	0.00	11.16
Total cost (for system) per mile	0.000	0.00
General Air System (ATA VMRS 10)		
Parts cost	7,268.30	12,731.38
Labor hours	174	222.5
Average labor cost	8,700.00	11,125.00
Total cost (for system)	15,968.30	23,856.38
Total cost (for system) per bus	1,596.83	2,385.64
Total cost (for system) per mile	0.04	0.03

Maintenance Cost by Vehicle System

	FCEB	CNG
Brake System (ATA VMRS 13)		
Parts cost	806.93	23,499.24
Labor hours	56.5	608.5
Average labor cost	2,825.00	30,425.00
Total cost (for system)	3,631.93	53,924.24
Total cost (for system) per bus	363.19	5,392.42
Total cost (for system) per mile	0.01	0.07
Transmission (ATA VMRS 27)		
Parts cost	0.00	51,510.46
Labor hours	1	118
Average labor cost	50.00	5,900.00
Total cost (for system)	50.00	57,410.46
Total cost (for system) per bus	5.00	5,741.05
Total cost (for system) per mile	0.00	0.07
Inspections Only - No Parts Replacements (101)		
Parts cost	0.00	0.00
Labor hours	839.75	1142
Average labor cost	41,987.50	57,100.00
Total cost (for system)	41,987.50	57,100.00
Total cost (for system) per bus	4,198.75	5,710.00
Total cost (for system) per mile	0.10	0.07

Maintenance Cost by Vehicle System

	FCEB	CNG
Cab, Body, and Accessories Systems (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)		
Parts cost	15,071.20	44,347.28
Labor hours	1216.25	1892.8333
Average labor cost	60,812.50	94,641.67
Total cost (for system)	75,883.70	138,988.94
Total cost (for system) per bus	7,588.37	13,898.89
Total cost (for system) per mile	0.17	0.17
HVAC System (ATA VMRS 01)		
Parts cost	232.62	3,728.85
Labor hours	57	106
Average labor cost	2,850.00	5,300.00
Total cost (for system)	3,082.62	9,028.85
Total cost (for system) per bus	308.26	902.88
Total cost (for system) per mile	0.01	0.01
Lighting System (ATA VMRS 34)		
Parts cost	4.16	1,824.18
Labor hours	31.5	65.5
Average labor cost	1,575.00	3,275.00
Total cost (for system)	1,579.16	5,099.18
Total cost (for system) per bus	157.92	509.92
Total cost (for system) per mile	0.00	0.01

Maintenance Cost by Vehicle System

	FCEB	CNG
Frame, Steering, and Suspension (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)		
Parts cost	291.39	3,753.07
Labor hours	86.75	116.25
Average labor cost	4,337.50	5,812.50
Total cost (for system)	4,628.89	9,565.57
Total cost (for system) per bus	462.89	956.56
Total cost (for system) per mile	0.01	0.01
Axle, Wheel, and Drive Shaft (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)		
Parts cost	190.02	1,769.22
Labor hours	48.5	150.25
Average labor cost	2,425.00	7,512.50
Total cost (for system)	2,615.02	9,281.72
Total cost (for system) per bus	261.50	928.17
Total cost (for system) per mile	0.01	0.01
Tire (ATA VMRS 17)		
Parts cost	0.00	0.00
Labor hours	23.5	15
Average labor cost	1,175.00	750.00
Total cost (for system)	1,175.00	750.00
Total cost (for system) per bus	117.50	75.00
Total cost (for system) per mile	0.00	0.00

Fleet Summary Statistics: SI Units

	FCEB	CNG
Number of vehicles	10	10
Period used for fuel and oil analysis	Feb 2020 -Jul 2021	Feb 2020 -Jul 2021
Total number of months in period	18	18
Fuel and oil analysis base fleet kilometers	233,587	1,315,315
Period used for maintenance analysis	Feb 2020 -Jul 2021	Feb 2020 -Jul 2021
Total number of months in period	18	18
Maintenance analysis base fleet kilometers	706,843	1,315,315
Average monthly kilometers per vehicle	4,151	7,307
Availability	62.5	≥85
Fleet fuel in FCEB kg/CNG L	16,745.5	280,854.3
Roadcalls	130	51
Total KBRC	5,437	25,790
Propulsion roadcalls	49	21
Propulsion KBRC	14,425	62,634
Representative fleet fuel consumption (L/100 km)	7.17	
H2 cost per kg/ CNG cost per liter	24.01	21.35
Fuel cost per km	8.10	0.32
Total scheduled repair cost per km	0.58	0.07
Total unscheduled repair cost per km	0.09	0.11
Total maintenance cost per km	0.20	0.30
Total operating cost per km	0.29	0.41

Maintenance Cost Summary: SI Units

Maintenance Cost Summary

	FCEB	CNG
Fleet mileage	706,843	1,315,315
Total parts cost	39,733.32	228,369.41
Total labor hours	3,265.3	6,293.1
Average labor cost (@ \$50.00 per hour)	163,262.50	314,654.17
Total maintenance cost	202,995.82	543,023.58
Total maintenance cost per bus	20,299.58	54,302.36
Total maintenance cost per kilometer	0.09	0.04

Propulsion System Maintenance Cost Summary

	FCEB	CNG
Total Engine/Fuel-Related Systems (ATA VMRS 27, 30, 31, 32, 33, 41, 42, 43, 44, 45, 46, 65)		
Parts cost	15,868.70	136,716.19
Labor hours	731.5	1974.3
Average labor cost	36,575.00	98,712.50
Total cost (for system)	52,443.70	235,428.69
Total cost (for system) per bus	5,244.37	23,542.87
Total cost (for system) per kilometer	0.07	0.18

Part Replacement Occurrences

This analysis indicates the number of work orders that requires a part to be replaced. The entire system, indicated by the VMRS code, is not replaced. Instead, it is a part within the system that has been replaced. This does not include work orders where only labor is needed.

Part Replacement Occurrences

	FCEB All data	CNG All data
Part Replacement Number of Occurrences		
Exhaust System (ATA VMRS 43)	0	38
Fuel System (ATA VMRS 44)	12	499
Power Plant (Engine) (ATA VMRS 45)	151	583
Electric Propulsion (ATA VMRS 46)	5	0
Electrical System (ATA VMRS 30, 31, 32, 33)	13	179
Air Intake System (ATA VMRS 41)	41	80
Cooling System (ATA VMRS 42)	6	159
Hydraulic System (ATA VMRS 65)	0	5
General Air System (ATA VMRS 10)	114	115
Brake System (ATA VMRS 13)	83	337
Transmission (ATA VMRS 27)	0	55
Cab, Body, and Accessories (ATA VMRS 02, 50, 71)	387	804
HVAC System (ATA VMRS 01)	8	31
Lighting System (ATA VMRS 34)	8	49
Frame, Steering, and Suspension (VRMS 14, 15, 16)	26	44
Axle, Wheel, and Drive Shaft (ATA VMRS 11, 18, 22, 24)	12	33
Tire (ATA VMRS 17)	0	27

FCEB Total Miles =
439,224

CNG Total Miles =
817,321

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