



Orange County Transportation Authority Fuel Cell Electric Bus Progress Report

Data Period Focus: Feb. 2020 through Jul. 2020

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Table of Contents

<u>Introduction</u>	4
<u>Fleet Profile</u>	5
<u>Results Summary</u>	8
<u>Evaluation Buses Specification</u>	14
<u>Infrastructure Description</u>	16
<u>Data Summary</u>	17
<u>Fleet Mileage Accumulation</u>	20
<u>Availability Analysis</u>	23
<u>Fuel Economy and Cost Analysis</u>	30
<u>Reliability—Miles Between Roadcall</u>	38
<u>Maintenance Cost Analysis</u>	40
<u>Contacts</u>	96
<u>Acronyms and Abbreviations</u>	97
<u>Appendix: Fleet Summary Statistics</u>	100

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 2020. 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 17 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 8.67 miles per kilogram of hydrogen, which equates to 9.79 mpdge. The CNG buses had an average fuel economy of 3.8 mpgge, which equates to 4.24 mpdge. The FCEB fuel economy was approximately 2.3 times that of the CNG buses. Average hydrogen costs were \$8.10/kg; CNG cost was \$1.22/gge. The FCEBs had an average fuel cost of \$0.93 per mile. The fuel cost for the CNG buses averaged \$0.32 per mile.

Fuel use: During the data period, OCTA fueled its FCEB fleet more than 883 times with an average fill amount of 18.96 kg. Daily dispensed hydrogen was 95 kg.

mpdge = miles per diesel gallon equivalent

mpgge = miles per gasoline gallon equivalent

Results Summary (continued)

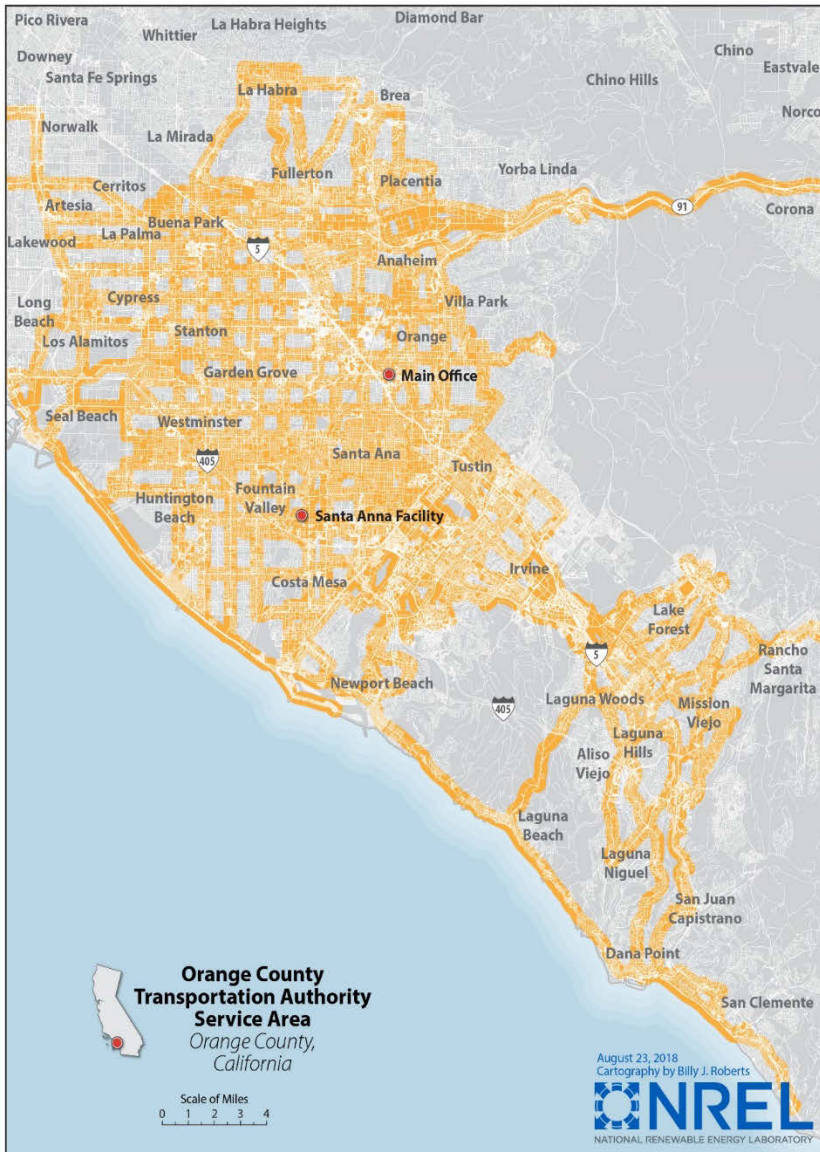
Availability: The average availability for the FCEB fleet was 73.6%. Most unavailable time for the FCEBs was due to general bus-related problems followed by battery issues. This is not unusual for a new design in its first deployment. OCTA is working with the OEM to identify the issues. The availability for the fleet is expected to increase over time as these early issues are resolved. The average availability for the fuel cell system was 97.3%. OCTA reports that its CNG bus availability averages 80% or better.

Maintenance cost: The cost to maintain the buses in the data period was \$0.42/mi for the FCEBs and \$0.43/mi for the CNG buses. Propulsion-system maintenance was \$0.14 for the FCEBs compared to \$0.16 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	2/20–7/20	2/20–7/20
Number of months	6	6
Total mileage in data period	149,148	281,694
Average odometer	21,131	202,357
Average monthly mileage per bus	2,720	4,695
Total FCPP ^a hours	11,434	—
Availability (85% is target)	73.6	≥85
Fuel economy (FCEB mi/kg or CNG mpgge ^b)	8.67	3.80
Fuel economy (mpdge ^c)	9.79	4.24
Miles between roadcalls (MBRC) – bus ^d	7,124	31,299
MBRC – propulsion system only ^d	7,874	46,949
MBRC – FC System only ^d	74,802	—
Total maintenance (\$/mile)	0.42	0.43
Maintenance – propulsion system only (\$/mile)	0.14	0.16

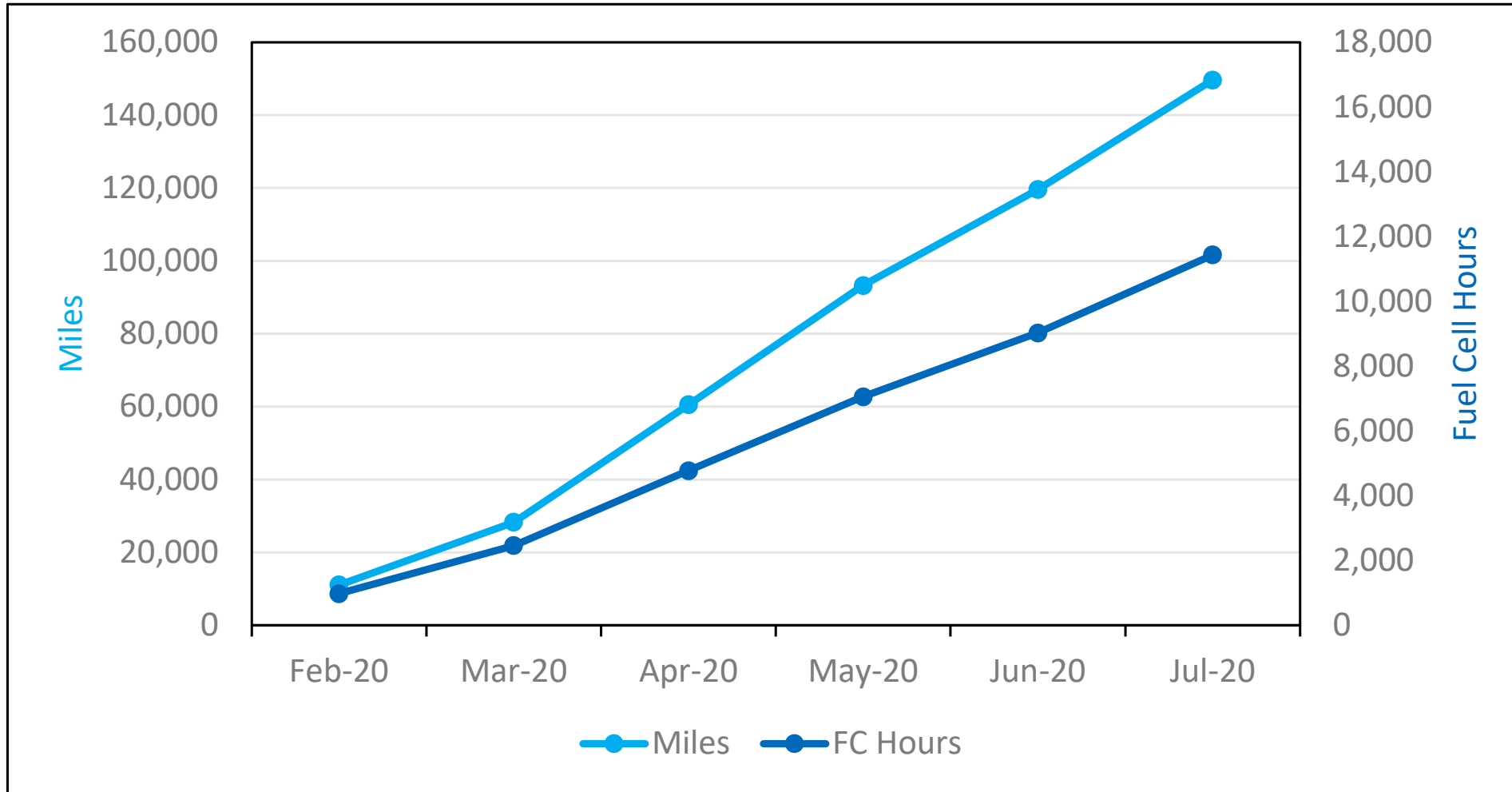
^a FCPP= fuel cell power plant

^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 = 149,604
Hours = 11,434

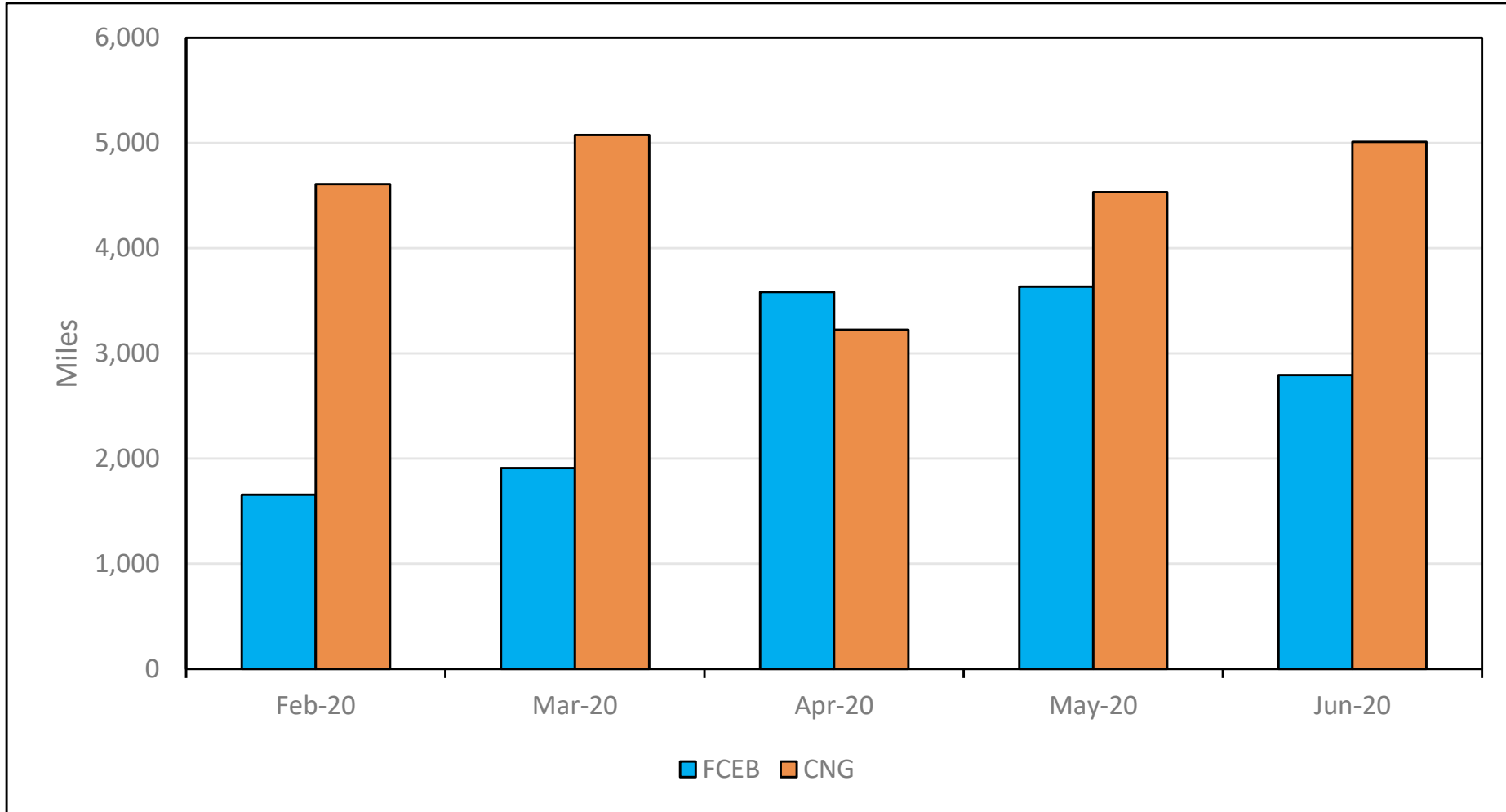
Fleet Average Monthly Miles by Bus

Bus	Miles	Bus Months	Average Monthly Mileage
1111	17,301	6	2,883
1112	14,710	6	2,452
1113	17,469	6	2,911
1114	18,741	6	3,124
1115	16,458	6	2,743
1116	16,819	6	2,803
1117	10,911	6	1,819
1118	19,474	6	3,246
1119	2,207	1	2,207
1120	15,514	6	2,586
FCEB Fleet	149,604	55	2,720

Bus	Miles	Bus Months	Average Monthly Mileage
5821	33,361	6	5,560
5822	35,196	6	5,866
5823	25,243	6	4,207
5824	28,589	6	4,765
5825	25,012	6	4,169
5826	26,867	6	4,478
5827	26,122	6	4,354
5828	25,575	6	4,263
5829	27,101	6	4,517
5830	28,627	6	4,771
CNG Fleet	281,694	60	4,695

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

Average Monthly Miles



Overall

- FCEB = 2,720
- CNG = 4,695

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.

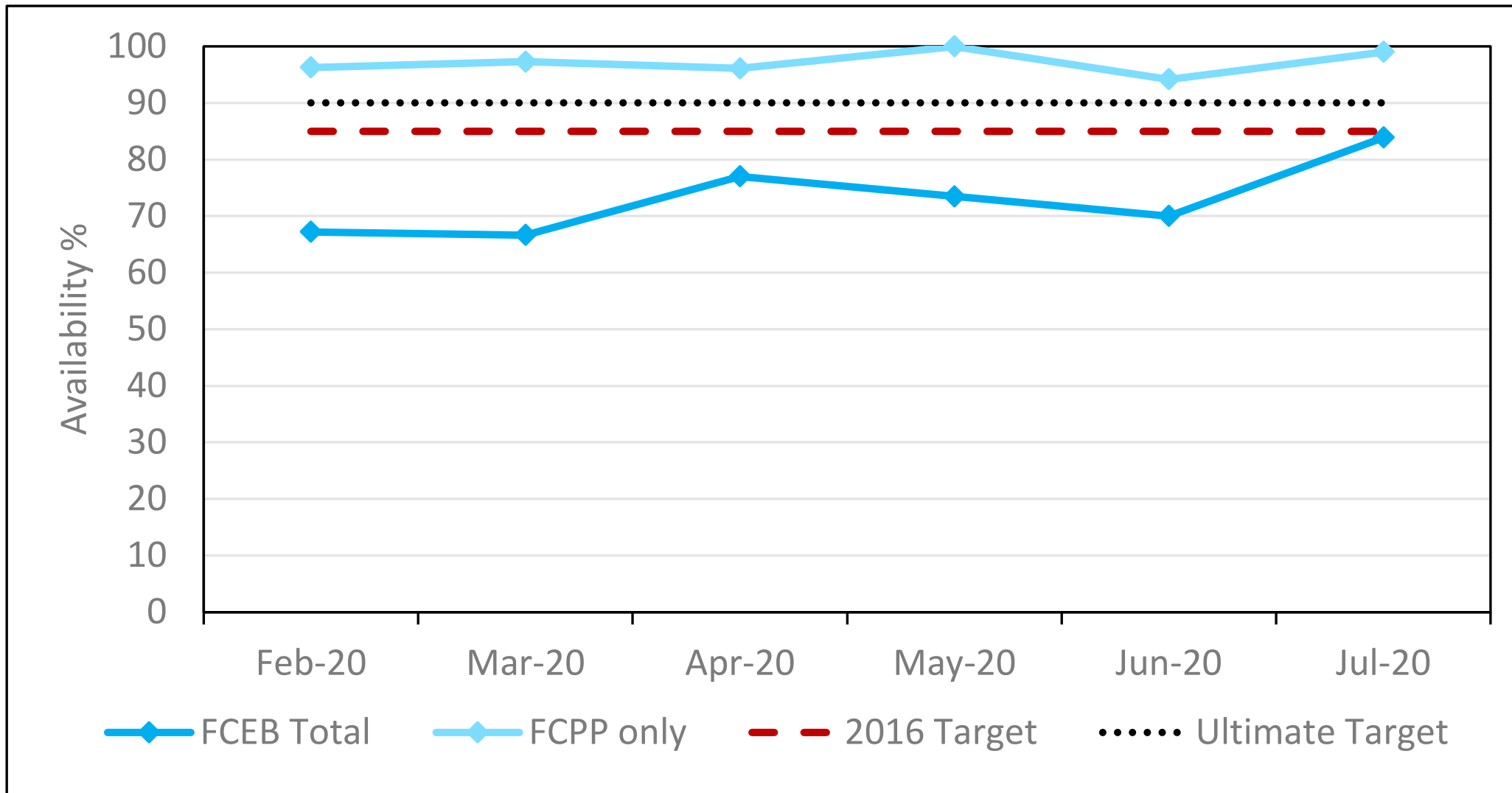
NREL presents availability as a monthly average trend and as overall availability. Unavailable time is separated into several categories to show the primary reason for downtime.

Availability Summary

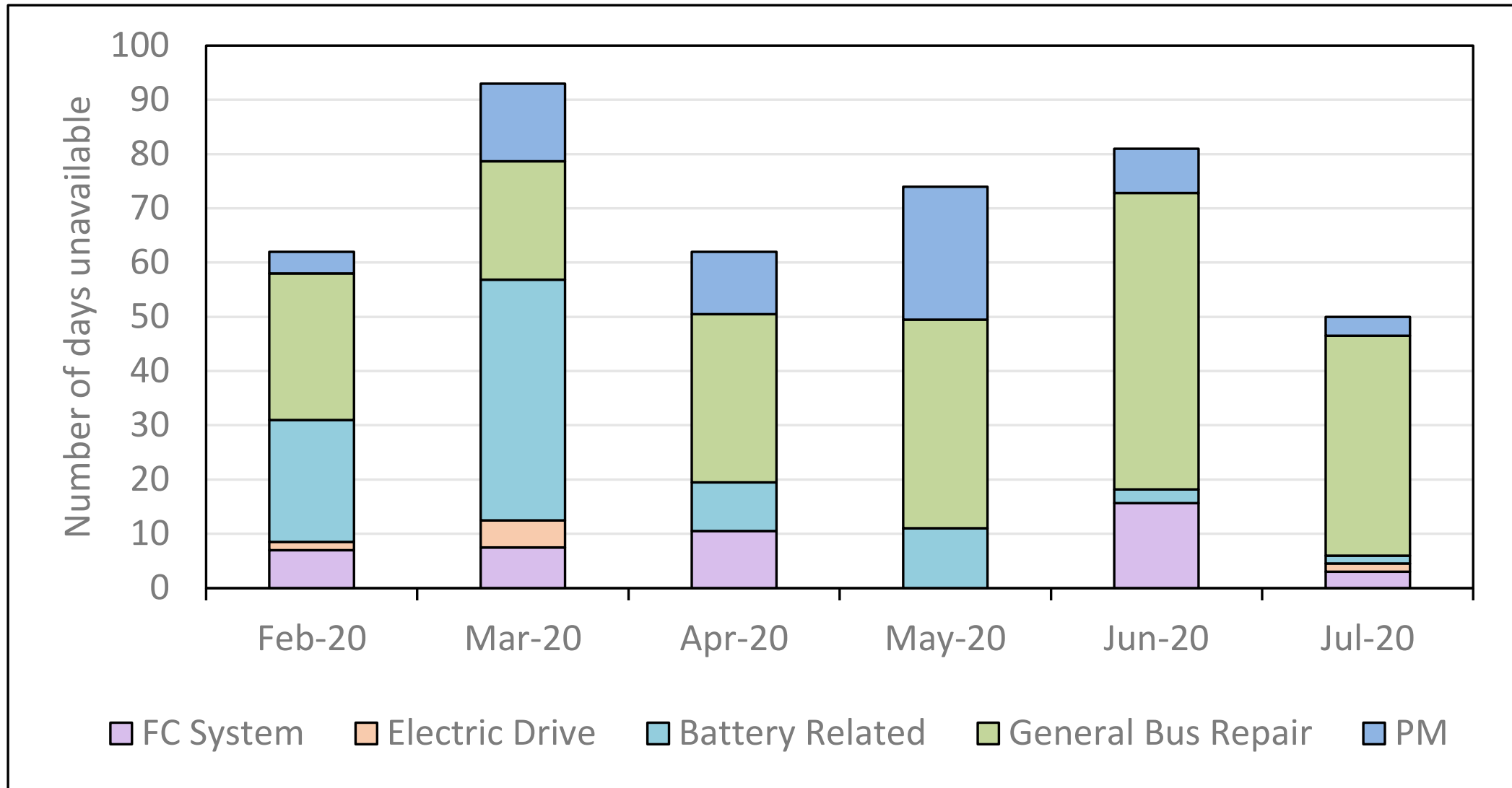
Category	FCEB # Days	FCEB %
Planned work days	1,597	
Days available	1,175	73.6
Days unavailable	422	26.4
Fuel cell system	43.7	2.7
Electric drive	8.0	0.5
Battery related	90.8	5.7
General bus maintenance	213.5	13.4
Preventive maintenance (PM)	66.0	4.1

CNG baseline bus fleet availability is 80% or greater

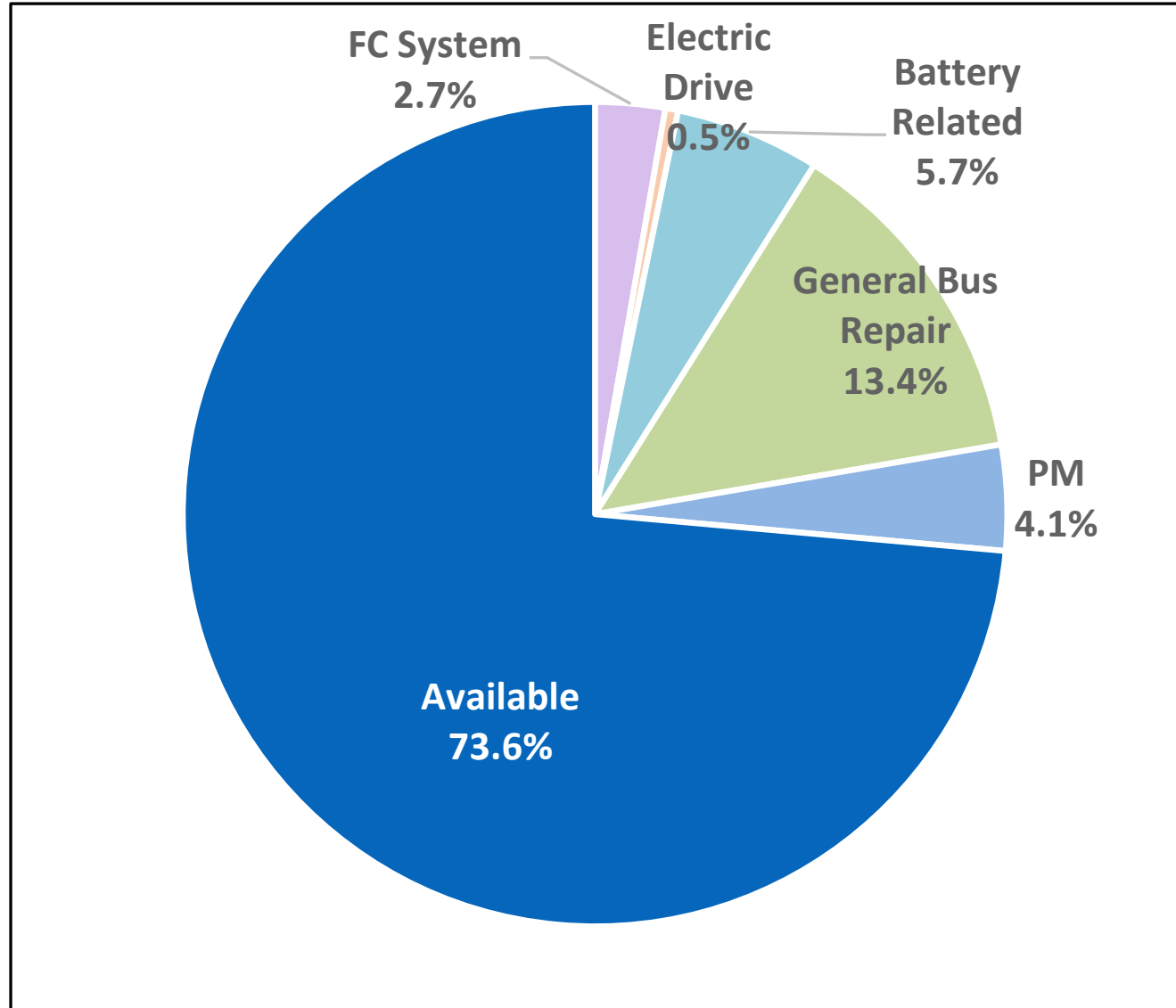
Monthly Availability



FCEB Monthly Unavailability Reasons



FCEB Overall Availability



Fuel Economy and Cost Analysis

SunLine 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.

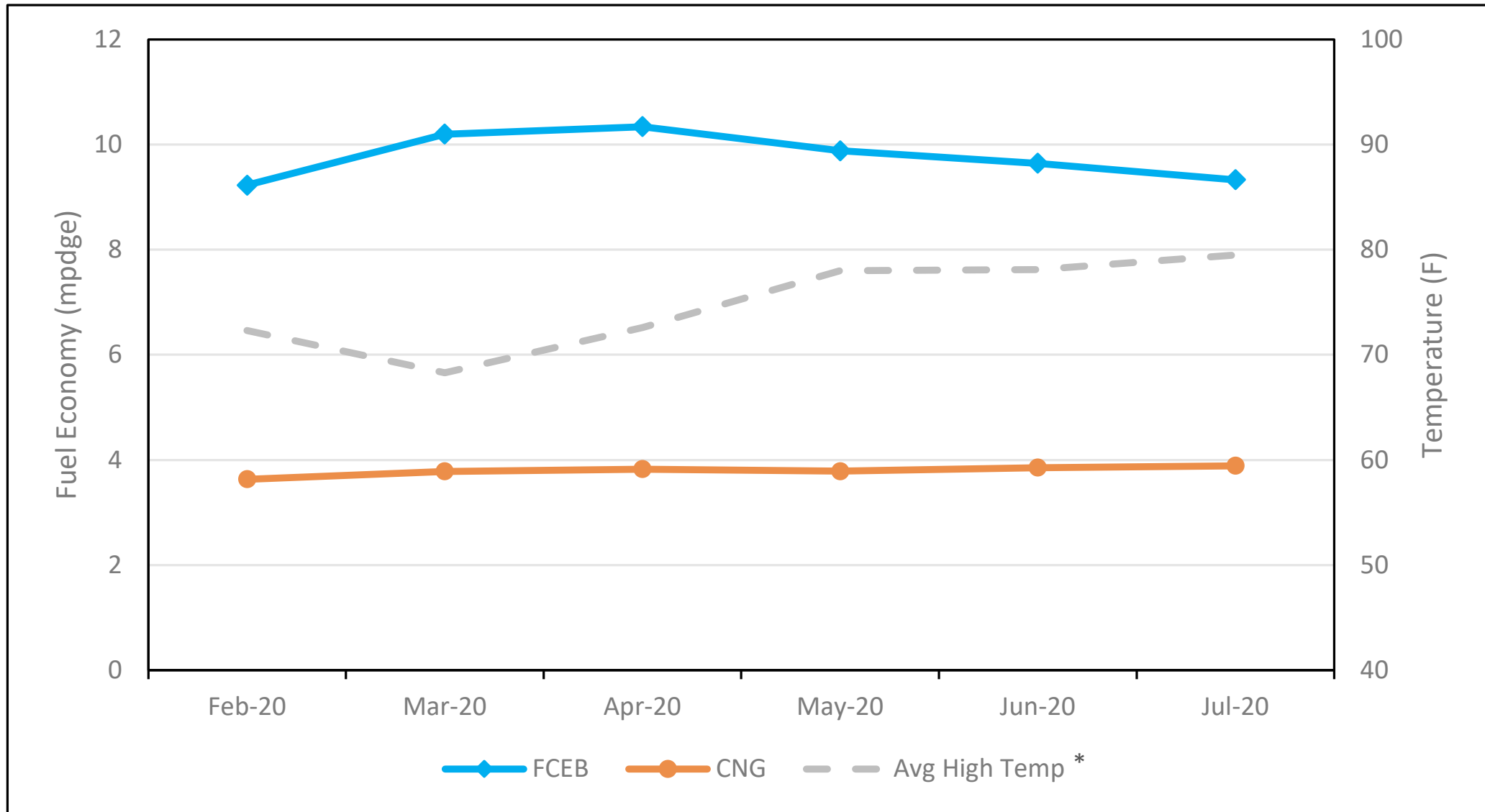
Fuel Economy by Bus

Bus	Miles	Hydrogen (kg)	mi/kg	Diesel gallon Equiv.	Fuel economy (mpdge)
1111	17,403	2,126.8	8.18	1,882.1	9.25
1112	13,925	1,622.6	8.58	1,435.9	9.70
1113	16,898	1,954.3	8.65	1,729.4	9.77
1114	17,973	1,956.6	9.19	1,731.5	10.38
1115	15,918	1,842.4	8.64	1,630.4	9.76
1116	16,547	1,785.5	9.27	1,580.1	10.47
1117	10,911	1,280.0	8.52	1,132.7	9.63
1118	18,709	2,180.8	8.58	1,929.9	9.69
1119	2,207	284.7	7.75	251.9	8.76
1120	14,657	1,712.0	8.56	1,515.0	9.67
FCEB Fleet	145,148	16,745.5	8.67	14,819.0	9.79

Bus	Miles	CNG (gge)	Miles per gge	CNG (dge)	Fuel Economy (mpdge)
5821	33,361	8,248.3	4.04	7,382.3	4.52
5822	35,196	8,758.5	4.02	7,838.8	4.49
5823	25,244	7,300.5	3.46	6,533.9	3.86
5824	28,589	7,101.7	4.03	6,356.0	4.50
5825	25,012	6,676.5	3.75	5,975.4	4.19
5826	26,867	6,999.4	3.84	6,264.5	4.29
5827	26,122	7,092.5	3.68	6,347.8	4.12
5828	25,575	7,019.4	3.64	6,282.3	4.07
5829	27,101	7,209.9	3.76	6,452.8	4.20
5830	28,627	7,787.3	3.68	6,969.6	4.11
CNG Total	281,694	74,193.9	3.80	66,403.5	4.24

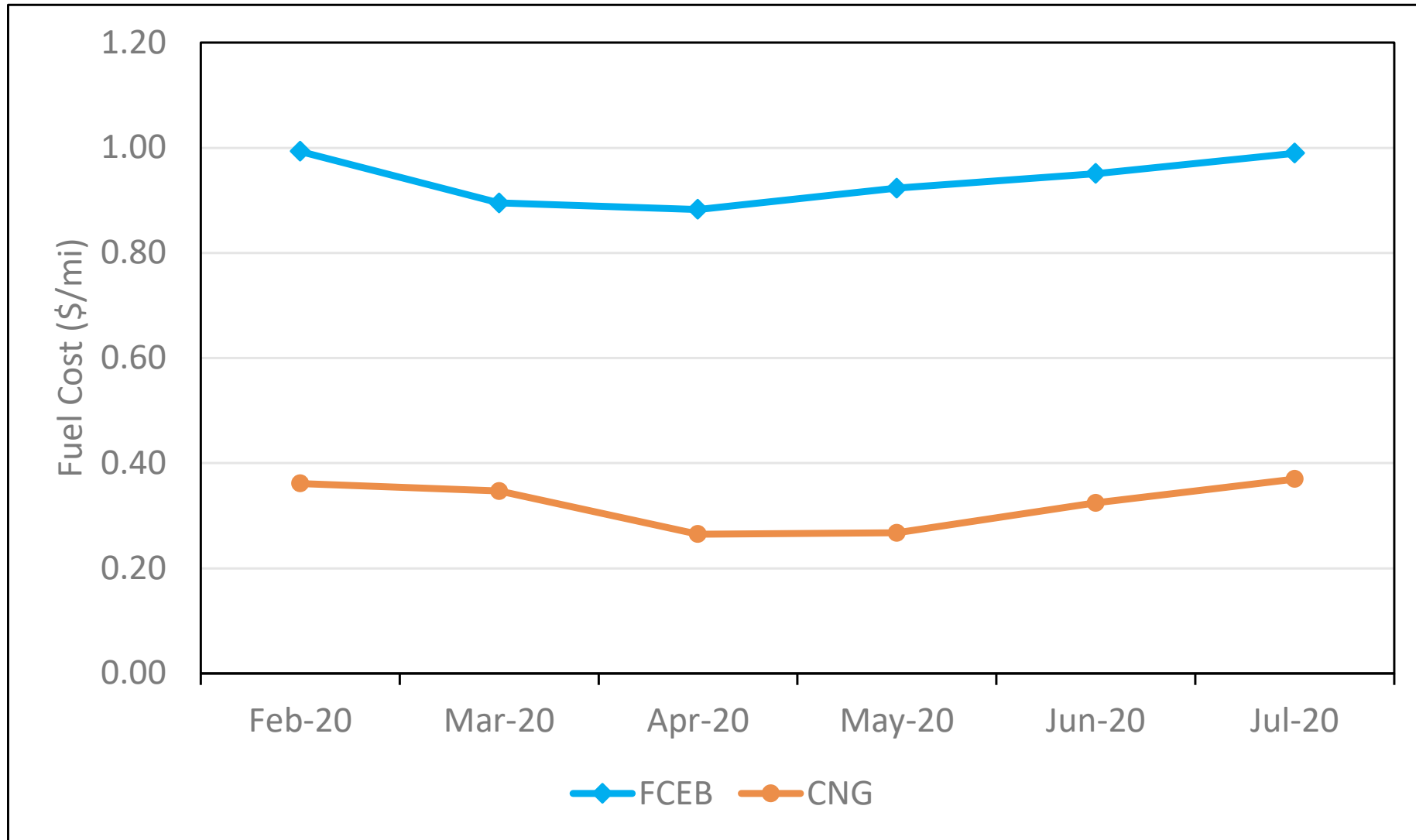
- FCEB fuel economy is 2.31 times that of the CNG buses.

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



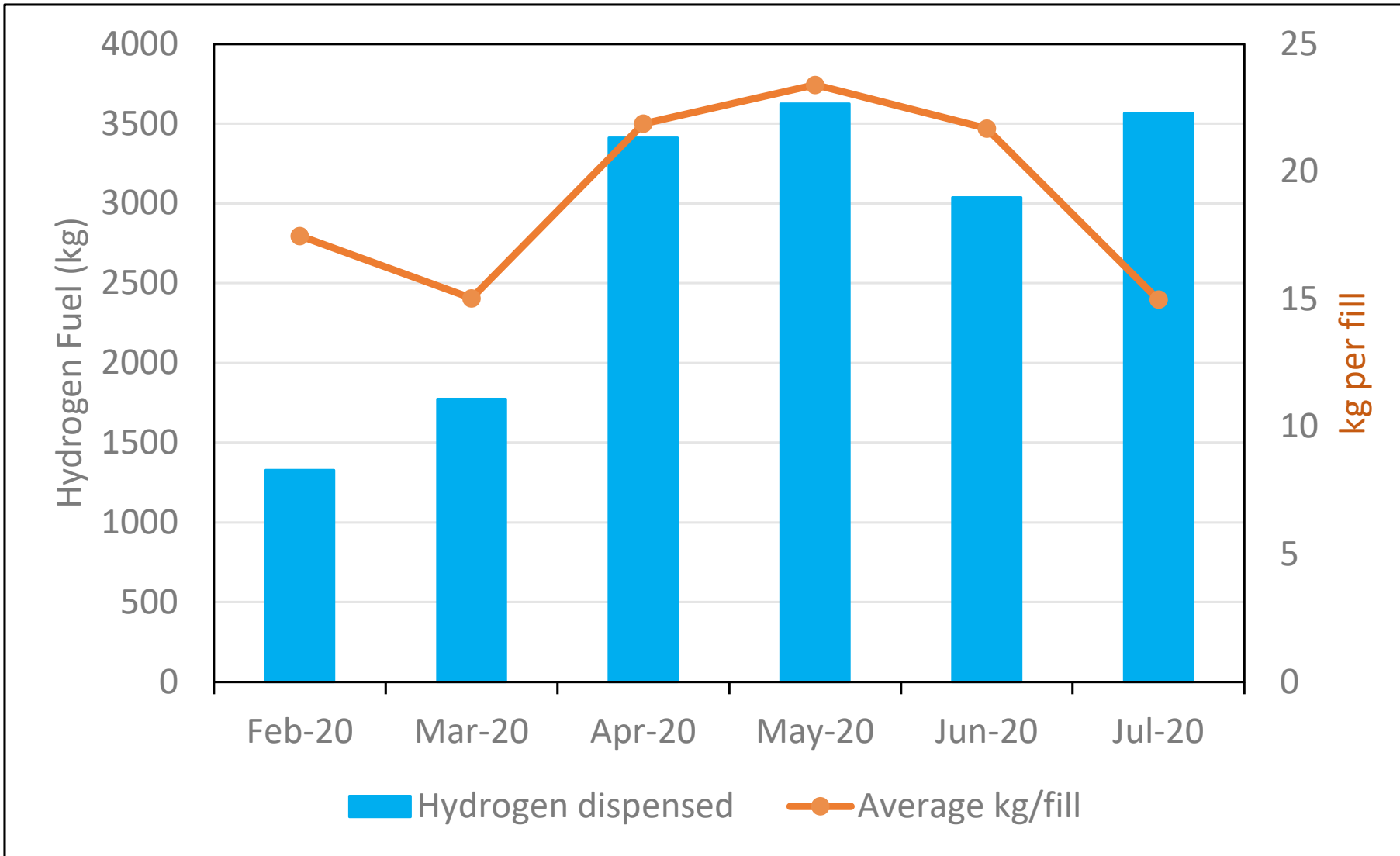
Average fuel cost

- H2 = \$8.10 /kg
- CNG = \$1.22 /gge

Average cost per mile

- H2 = \$0.93
- CNG = \$0.32

Fleet Hydrogen Use



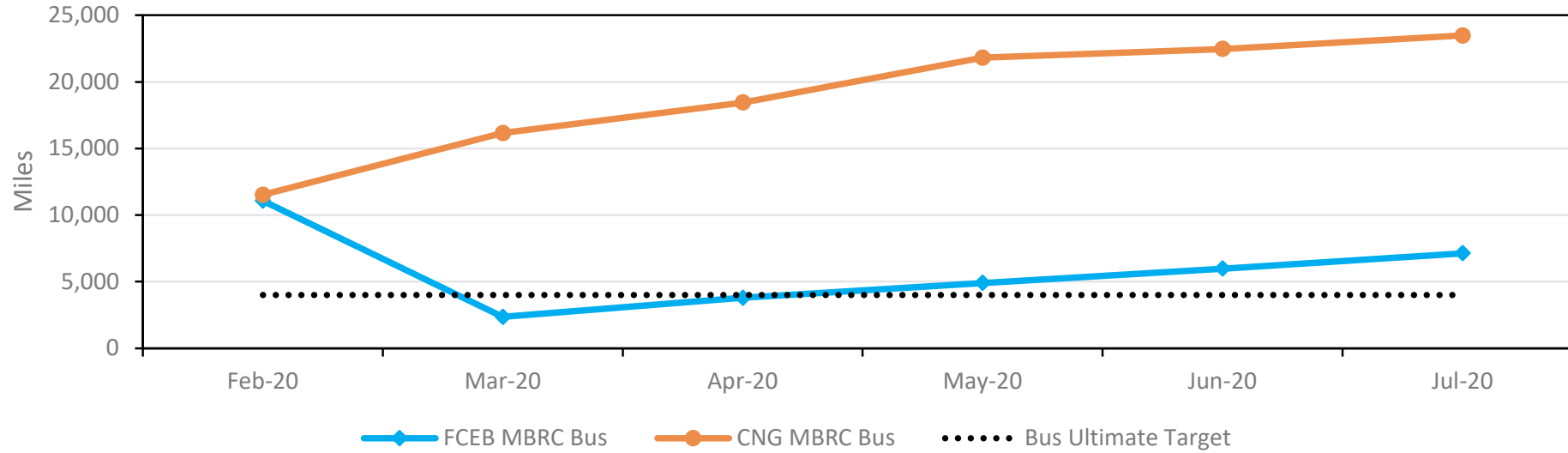
Overall
Daily kg Hydrogen: 95.14
H2 kg/fill: 18.96

Roadcall Analysis

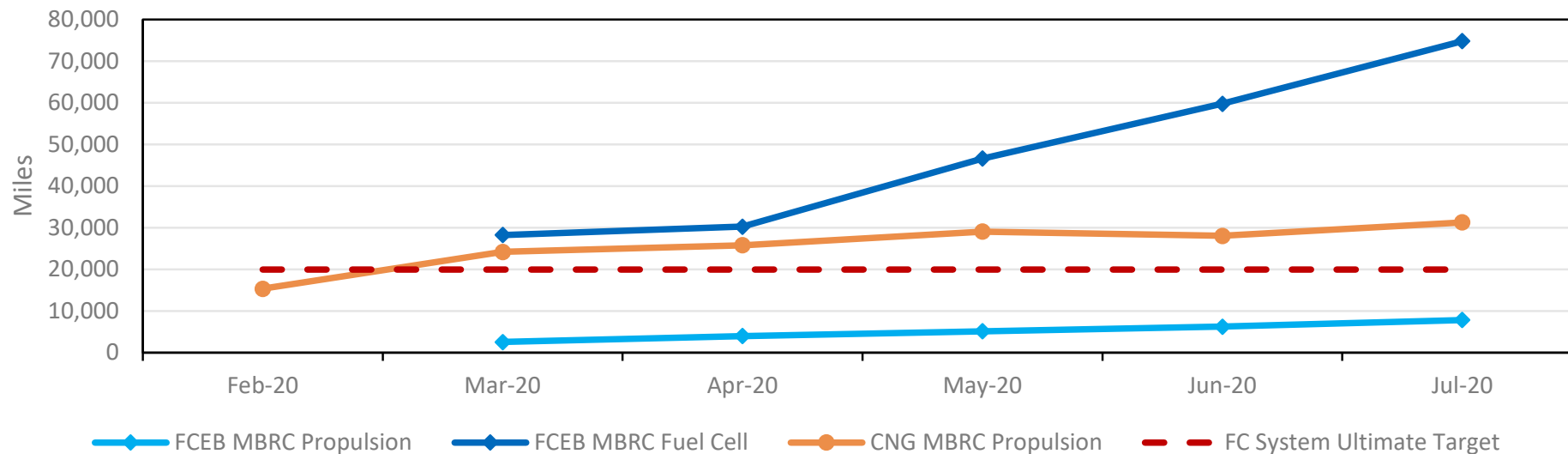
A roadcall or revenue vehicle system failure is defined as a failure of an in-service bus that causes the bus to be replaced on route or causes a significant delay in schedule. If the problem with the bus can be repaired during a layover and the schedule is kept, this is not considered a roadcall. The 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	7,124	23,474
Propulsion MBRC	7,874	31,299
FC system MBRC	74,802	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.

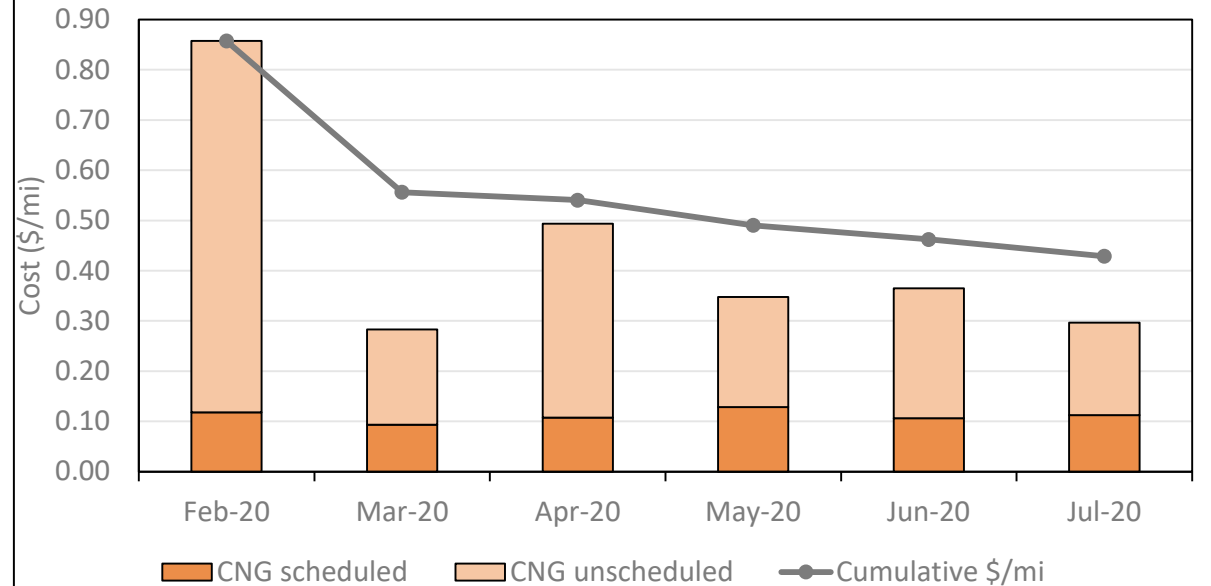
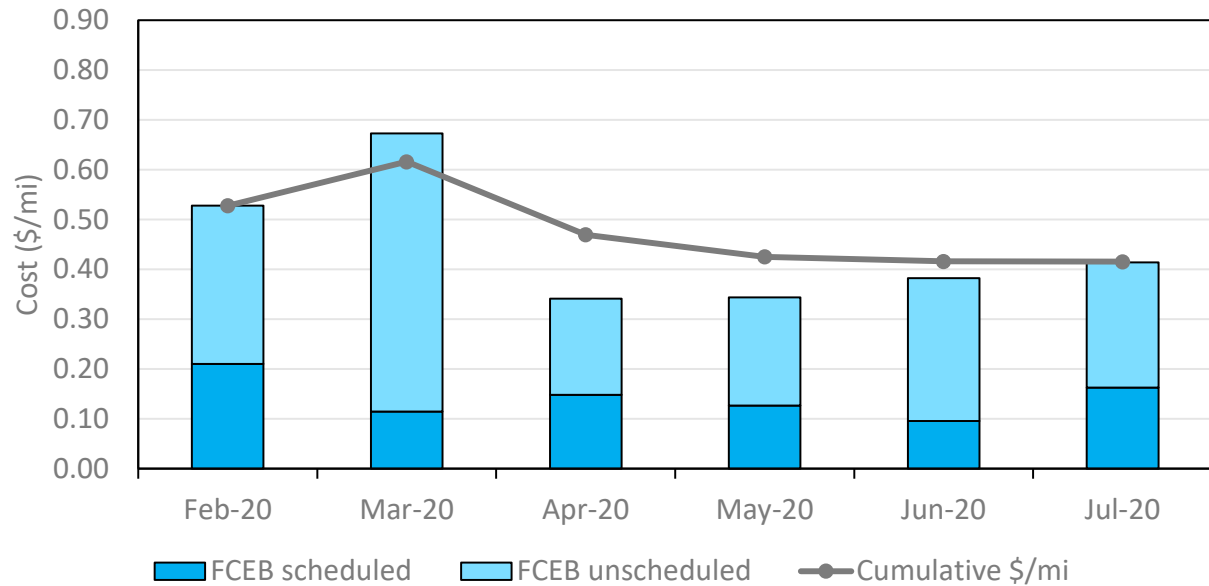
Maintenance Analysis Results

Bus	Mileage	Parts (\$)	Labor hours	Total Cost per Mile (\$)
1111	17,301	1,839.82	149.5	0.54
1112	14,710	918.59	105.0	0.42
1113	17,469	1,628.65	149.0	0.52
1114	18,741	1,860.90	133.0	0.45
1115	16,458	1,449.38	84.8	0.35
1116	16,819	349.67	90.0	0.29
1117	10,911	640.68	111.0	0.57
1118	19,474	1,048.64	105.3	0.32
1119	2,207	0.00	12.0	0.27
1120	15,514	567.09	97.5	0.35
FCEB Fleet	149,604	10,303.41	1,037.0	0.42

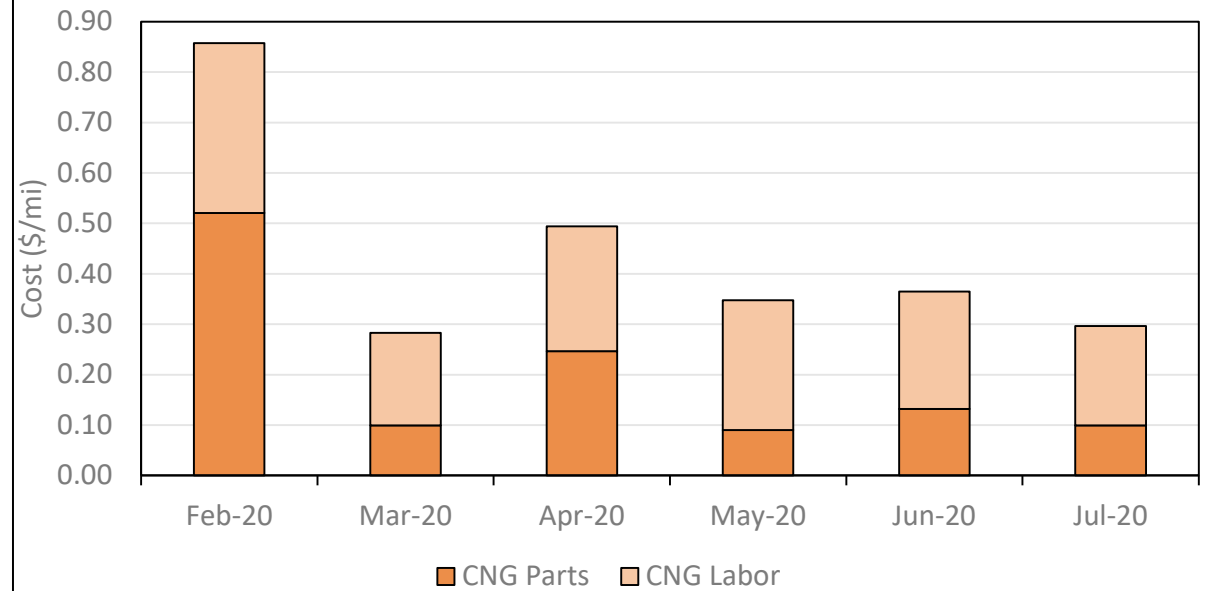
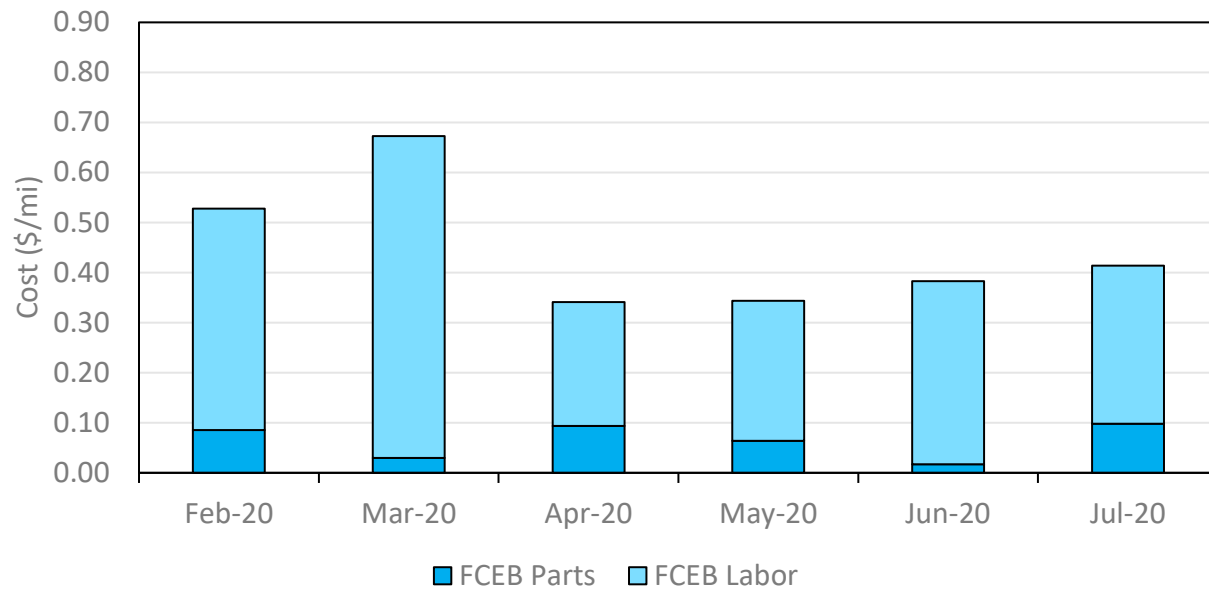
Bus	Mileage	Parts (\$)	Labor hours	Total Cost per Mile (\$)
5821	33,361	4,182.48	149.5	0.35
5822	35,196	2,535.53	141.5	0.27
5823	25,243	15,528.25	194.5	1.00
5824	28,589	2,781.90	122.5	0.31
5825	25,012	4,096.92	111.0	0.39
5826	26,867	3,743.47	135.5	0.39
5827	26,122	4,478.14	124.5	0.41
5828	25,575	3,929.03	127.5	0.40
5829	27,101	7,467.43	136.0	0.53
5830	28,627	4,660.43	105.3	0.35
CNG Fleet	281,694	53,403.57	1,347.8	0.43

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	0.136	32.8	0.156	37.3
Cab, body, and accessories	0.153	36.7	0.111	26.5
PMI	0.078	18.9	0.049	11.7
Brakes	0.002	0.6	0.077	18.4
Frame, steering, and suspension	0.006	1.4	0.004	0.9
HVAC	0.011	2.7	0.005	1.1
Lighting	0.005	1.3	0.011	2.5
Air, general	0.018	4.2	0.004	0.9
Axles, wheels, and drive shaft	0.005	1.2	0.001	0.3
Tires	0.001	0.3	0.001	0.3
Total	0.415	100	0.419	100

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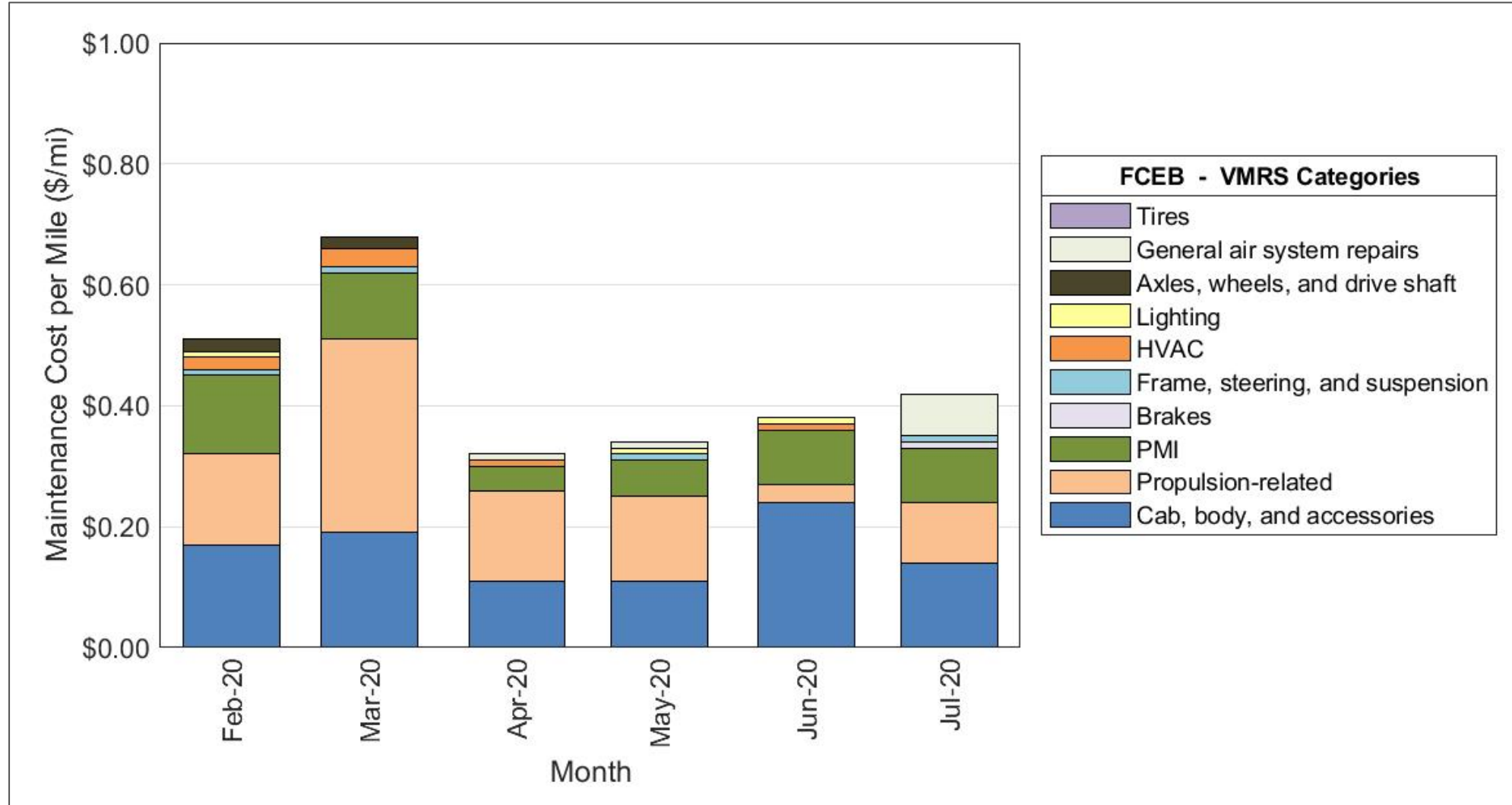
 Highest cost

 Second highest cost

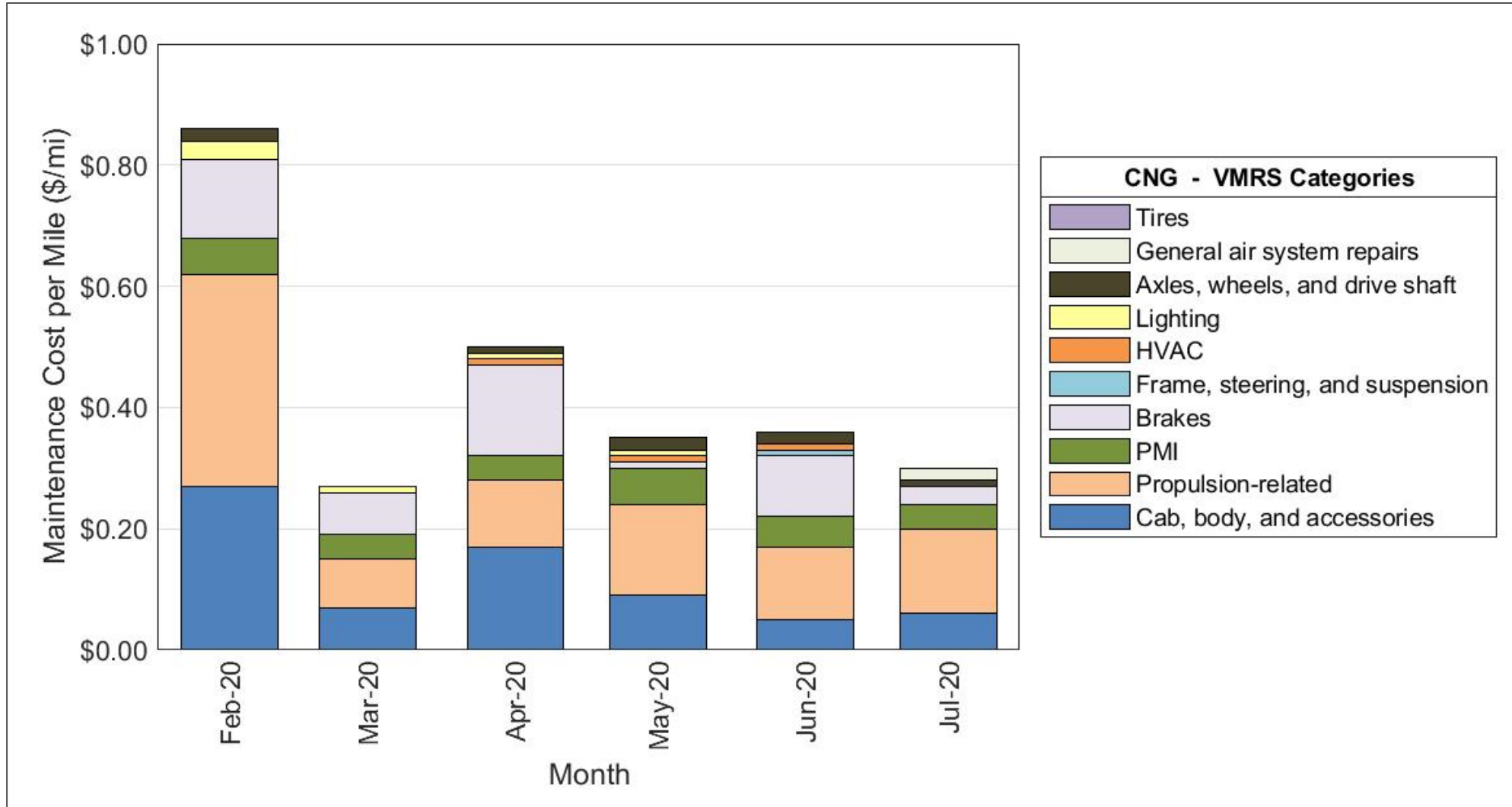
 Third highest cost

- 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 propulsion-related; cab, body, and accessories; and brakes.
- 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		149,604	281,694	Non-Lighting Electrical System (General Electrical, Charging, Cranking, Ignition)	Parts cost (\$)	44.37	4,648.13
Total Propulsion-Related Systems (Total of all systems in table)	Parts cost (\$)	5,761.87	23,316.94		Labor hours	23.0	24.0
	Labor hours	292.5	414.8		Total cost (\$)	1,194.37	5,848.13
	Total cost (\$)	20,386.87	44,054.44		Total cost (\$) per mile	0.008	0.021
	Total cost (\$) per mile	0.136	0.156	Air Intake System	Parts cost (\$)	84.13	326.41
Exhaust System	Parts cost (\$)	0.00	1,595.60		Labor hours	0.0	10.0
	Labor hours	0.0	0.0		Total cost (\$)	84.13	826.41
	Total cost (\$)	0.00	1,595.60		Total cost (\$) per mile	0.001	0.003
	Total cost (\$) per mile	0.000	0.006	Cooling System	Parts cost (\$)	10.30	1,168.82
Fuel System	Parts cost (\$)	4.57	3,931.62		Labor hours	9.5	59.0
	Labor hours	29.0	128.3		Total cost (\$)	485.30	4,118.82
	Total cost (\$)	1,454.57	10,344.12		Total cost (\$) per mile	0.003	0.015
	Total cost (\$) per mile	0.010	0.037	Transmission System	Parts cost (\$)	0.00	6,161.45
Powerplant System (Fuel Cell System for FCEBs)	Parts cost (\$)	4,274.48	5,484.92		Labor hours	0.0	36.5
	Labor hours	94.0	157.0		Total cost (\$)	0.00	7,986.45
	Total cost (\$)	8,974.48	13,334.92		Total cost (\$) per mile	0.000	0.028
	Total cost (\$) per mile	0.060	0.047	Hydraulic System	Parts cost (\$)	0.00	0.00
Electric Propulsion System	Parts cost (\$)	1,344.02	0.00		Labor hours	0.0	0.0
	Labor hours	137.0	0.0		Total cost (\$)	0.00	0.00
	Total cost (\$)	8,194.02	0.00		Total cost (\$) per mile	0.000	0.000
	Total cost (\$) per mile	0.055	0.000				

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

Contacts

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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	2/20–7/20	2/20–7/20
Total number of months in period	6	6
Fuel and oil analysis base fleet mileage	145,148	281,694
Period used for maintenance analysis	2/20–7/20	2/20–7/20
Total number of months in period	6	6
Maintenance analysis base fleet mileage	149,604	281,694
Average monthly mileage per vehicle	2,720	4,695
Availability	73.6	≥85
Fleet fuel usage in kg hydrogen or gge CNG	16,745.5	74,193.9
Roadcalls	21	9
Total MBRC	7,124	31,299
Propulsion roadcalls	19	6
Propulsion MBRC	7,874	46,949
Fleet mi/kg hydrogen (FCEB), mi/gge (CNG)	8.67	3.80
Representative fleet mpg (energy equiv.)	9.79	4.24
Fuel cost per kg hydrogen or gge CNG	8.10	1.22
Fuel cost per mile	0.935	0.322
Total scheduled repair cost per mile	0.143	0.111
Total unscheduled repair cost per mile	0.273	0.318
Total maintenance cost per mile	0.415	0.429
Total operating cost per mile	1.350	0.751

Maintenance Cost Summary

Maintenance Cost Summary

	FCEB	CNG
Fleet mileage	149,604	281,694
Total parts cost	10,303.41	53,403.57
Total labor hours	1,037	1,348
Average labor cost (@ \$50.00 per hour)	51,850.00	67,387.50
Total maintenance cost	62,153	120,791
Total maintenance cost per bus	6,215.34	12,079.11
Total maintenance cost per mile	0.415	0.429

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	5,761.87	23,316.94
Labor hours	292.50	414.75
Average labor cost	14,625.00	20,737.50
Total cost (for system)	20,386.87	44,054.44
Total cost (for system) per bus	2,038.69	4,405.44
Total cost (for system) per mile	0.136	0.156

Maintenance Cost by Vehicle System

	FCEB	CNG
Exhaust System (ATA VMRS 43)		
Parts cost	0.00	1,595.60
Labor hours	0.0	0.0
Average labor cost	0.00	0.00
Total cost (for system)	0.00	1,595.60
Total cost (for system) per bus	0.00	159.56
Total cost (for system) per mile	0.000	0.006
Fuel System (ATA VMRS 44)		
Parts cost	4.57	3,931.62
Labor hours	29.0	128.3
Average labor cost	1,450.00	6,412.50
Total cost (for system)	1,454.57	10,344.12
Total cost (for system) per bus	145.46	1,034.41
Total cost (for system) per mile	0.010	0.037
Power Plant (Engine) (ATA VMRS 45)		
Parts cost	4,274.48	5,484.92
Labor hours	94.0	157.0
Average labor cost	4,700.00	7,850.00
Total cost (for system)	8,974.48	13,334.92
Total cost (for system) per bus	897.45	1,333.49
Total cost (for system) per mile	0.060	0.047

Maintenance Cost by Vehicle System

	FCEB	CNG
Electric Propulsion (ATA VMRS 46)		
Parts cost	1,344.02	0.00
Labor hours	137.0	0.0
Average labor cost	6,850.00	0.00
Total cost (for system)	8,194.02	0.00
Total cost (for system) per bus	819.40	0.00
Total cost (for system) per mile	0.055	0.000
Electrical System (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)		
Parts cost	44.37	4,648.13
Labor hours	23.0	24.0
Average labor cost	1,150.00	1,200.00
Total cost (for system)	1,194.37	5,848.13
Total cost (for system) per bus	119.44	584.81
Total cost (for system) per mile	0.008	0.021
Air Intake System (ATA VMRS 41)		
Parts cost	84.13	326.41
Labor hours	0.0	10.0
Average labor cost	0.00	500.00
Total cost (for system)	84.13	826.41
Total cost (for system) per bus	8.41	82.64
Total cost (for system) per mile	0.001	0.003

Maintenance Cost by Vehicle System

	FCEB	CNG
Cooling System (ATA VMRS 42)		
Parts cost	10.30	1,168.82
Labor hours	9.5	59.0
Average labor cost	475.00	2,950.00
Total cost (for system)	485.30	4,118.82
Total cost (for system) per bus	48.53	411.88
Total cost (for system) per mile	0.003	0.015
Hydraulic System (ATA VMRS 65)		
Parts cost	0.00	0.00
Labor hours	0.0	0.0
Average labor cost	0.00	0.00
Total cost (for system)	0.00	0.00
Total cost (for system) per bus	0.00	0.00
Total cost (for system) per mile	0.000	0.000
General Air System (ATA VMRS 10)		
Parts cost	1,156.98	504.14
Labor hours	29.5	10.5
Average labor cost	1,475.00	525.00
Total cost (for system)	2,631.98	1,029.14
Total cost (for system) per bus	263.20	102.91
Total cost (for system) per mile	0.018	0.004

Maintenance Cost by Vehicle System

	FCEB	CNG
Brake System (ATA VMRS 13)		
Parts cost	151.54	11,077.29
Labor hours	4.0	212.5
Average labor cost	200.00	10,625.00
Total cost (for system)	351.54	21,702.29
Total cost (for system) per bus	35.15	2,170.23
Total cost (for system) per mile	0.002	0.077
Transmission (ATA VMRS 27)		
Parts cost	0.00	6,161.45
Labor hours	0.0	36.5
Average labor cost	0.00	1,825.00
Total cost (for system)	0.00	7,986.45
Total cost (for system) per bus	0.00	798.64
Total cost (for system) per mile	0.000	0.028
Inspections Only - No Parts Replacements (101)		
Parts cost	0.00	0.00
Labor hours	234.5	277.0
Average labor cost	11,725.00	13,850.00
Total cost (for system)	11,725.00	13,850.00
Total cost (for system) per bus	1,172.50	1,385.00
Total cost (for system) per mile	0.078	0.049

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	2,975.38	15,997.37
Labor hours	397.0	306.5
Average labor cost	19,850.00	15,325.00
Total cost (for system)	22825.4	31322.4
Total cost (for system) per bus	2,282.54	3,132.24
Total cost (for system) per mile	0.153	0.111
HVAC System (ATA VMRS 01)		
Parts cost	130.05	158.10
Labor hours	31.0	23.0
Average labor cost	1,550.00	1,150.00
Total cost (for system)	1680.0	1308.1
Total cost (for system) per bus	168.00	130.81
Total cost (for system) per mile	0.011	0.005
Lighting System (ATA VMRS 34)		
Parts cost	4.16	1,455.47
Labor hours	15.5	31.0
Average labor cost	775.00	1,550.00
Total cost (for system)	779.2	3005.5
Total cost (for system) per bus	77.92	300.55
Total cost (for system) per mile	0.005	0.011

Maintenance Cost by Vehicle System

	FCEB	CNG
Frame, Steering, and Suspension (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)		
Parts cost	123.42	155.69
Labor hours	14.5	17.5
Average labor cost	725.00	875.00
Total cost (for system)	848.4	1030.7
Total cost (for system) per bus	84.84	103.07
Total cost (for system) per mile	0.006	0.004
Axle, Wheel, and Drive Shaft (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)		
Parts cost	0.00	738.57
Labor hours	14.5	48.0
Average labor cost	725.00	2,400.00
Total cost (for system)	725.0	3138.6
Total cost (for system) per bus	72.50	313.86
Total cost (for system) per mile	0.005	0.011
Tire (ATA VMRS 17)		
Parts cost	0.00	0.00
Labor hours	4.0	7.0
Average labor cost	200.00	350.00
Total cost (for system)	200.0	350.0
Total cost (for system) per bus	20.00	35.00
Total cost (for system) per mile	0.001	0.001

Fleet Summary Statistics: SI Units

	FCEB	CNG
Number of vehicles	10	10
Period used for fuel and oil analysis	Feb-Jul 2020	Feb-Jul 2020
Total number of months in period	6	6
Fuel and oil analysis base fleet kilometers	233,587	453,330
Period used for maintenance analysis	Feb-Jul 2020	Feb-Jul 2020
Total number of months in period	6	6
Maintenance analysis base fleet kilometers	240,757	453,330
Average monthly kilometers per vehicle	4,377	7,555
Availability	73.6	≥85
Fleet fuel in FCEB kg/CNG L	16,745.5	280,854.3
Roadcalls	21	9
Total KBRC	11,465	50,370
Propulsion roadcalls	19	6
Propulsion KBRC	12,671	75,555
Representative fleet fuel consumption (L/100 km)	7.17	0.00
H2 cost per kg/ CNG cost per liter	24.01	61.95
Fuel cost per km	8.100	0.322
Total scheduled repair cost per km	0.581	0.200
Total unscheduled repair cost per km	0.089	0.069
Total maintenance cost per km	0.170	0.198
Total operating cost per km	0.839	0.466

Maintenance Cost Summary: SI Units

Maintenance Cost Summary

	FCEB	CNG
Fleet mileage	240,757	453,330
Total parts cost	10,303.41	53,403.57
Total labor hours	1,037	1,348
Average labor cost (@ \$50.00 per hour)	51,850.00	67,387.50
Total maintenance cost	62,153	120,791
Total maintenance cost per bus	6,215.34	12,079.11
Total maintenance cost per kilometer	0.258	0.266

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	5,761.87	23,316.94
Labor hours	292.50	414.75
Average labor cost	14,625.00	20,737.50
Total cost (for system)	20,386.87	44,054.44
Total cost (for system) per bus	2,038.69	4,405.44
Total cost (for system) per kilometer	0.085	0.097

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