



SunLine Transit Agency Fuel Cell Electric Bus Progress Report

Data Period Focus: Jan. 2020 through Jul. 2020

Leslie Eudy and Matthew Post
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Introduction

This report presents early results from a deployment of fuel cell electric buses (FCEBs) operated by SunLine Transit Agency in the Coachella Valley area of California. The five 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 mid-2019. The data period covers January 2020 through July 2020. NREL collects data on five 2019 model year compressed natural gas (CNG) buses as a baseline comparison at SunLine. These new CNG buses were phased into service beginning in April 2020.

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 five 40-ft FCEBs built by New Flyer with an electric propulsion system and a Ballard fuel cell system. The baseline buses are five 2019 model year New Flyer 40-ft CNG buses.

Bus use: SunLine'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: The FCEBs had an average fuel economy of 6.94 miles per kilogram of hydrogen, which equates to 7.84 mpdge. The CNG buses had an average fuel economy of 3.5 mpgge, which equates to 3.92 mpdge. The FCEB fuel economy was approximately 2 times higher than that of the CNG buses. The monthly fuel economy for the FCEB fleet ranged from a high of 9.09 in January, to a low of 6.01 in July. This drop in fuel economy correlates with the average high temperature when increased use of air conditioning lowers efficiency. The average high temperature in January was 72.7 compared to the average high in July of 112.4 degrees.

mpdge = miles per diesel gallon equivalent
mpgge = miles per gasoline gallon equivalent

Results Summary (continued)

Fuel use and cost: During the data period, SunLine fueled its FCEB fleet more than 630 times with an average fill amount of 21.85 kg. Daily dispensed hydrogen was 69 kg. The average monthly cost for hydrogen at SunLine varies. During the data period, the monthly hydrogen costs ranged from \$7.86/kg to more than \$12.89/kg. The average cost of hydrogen was \$10.10/kg. The CNG fuel cost for the data period was \$1.00 per gge. The FCEBs had an average fuel cost of \$1.46 per mile. The fuel cost for the CNG buses averaged \$0.28 per mile.

Availability: The per-bus availability for the FCEBs ranged from 53% to 89%. The average availability for the FCEBs was 77%. Most unavailable time for the FCEBs was due to general bus-related problems followed by propulsion system issues. This is not unusual for a new design in its first deployment. SunLine 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 96%. The average availability for the new CNG buses was 87%. Most downtime for the CNG buses was for general bus-related maintenance.

Results Summary (continued)

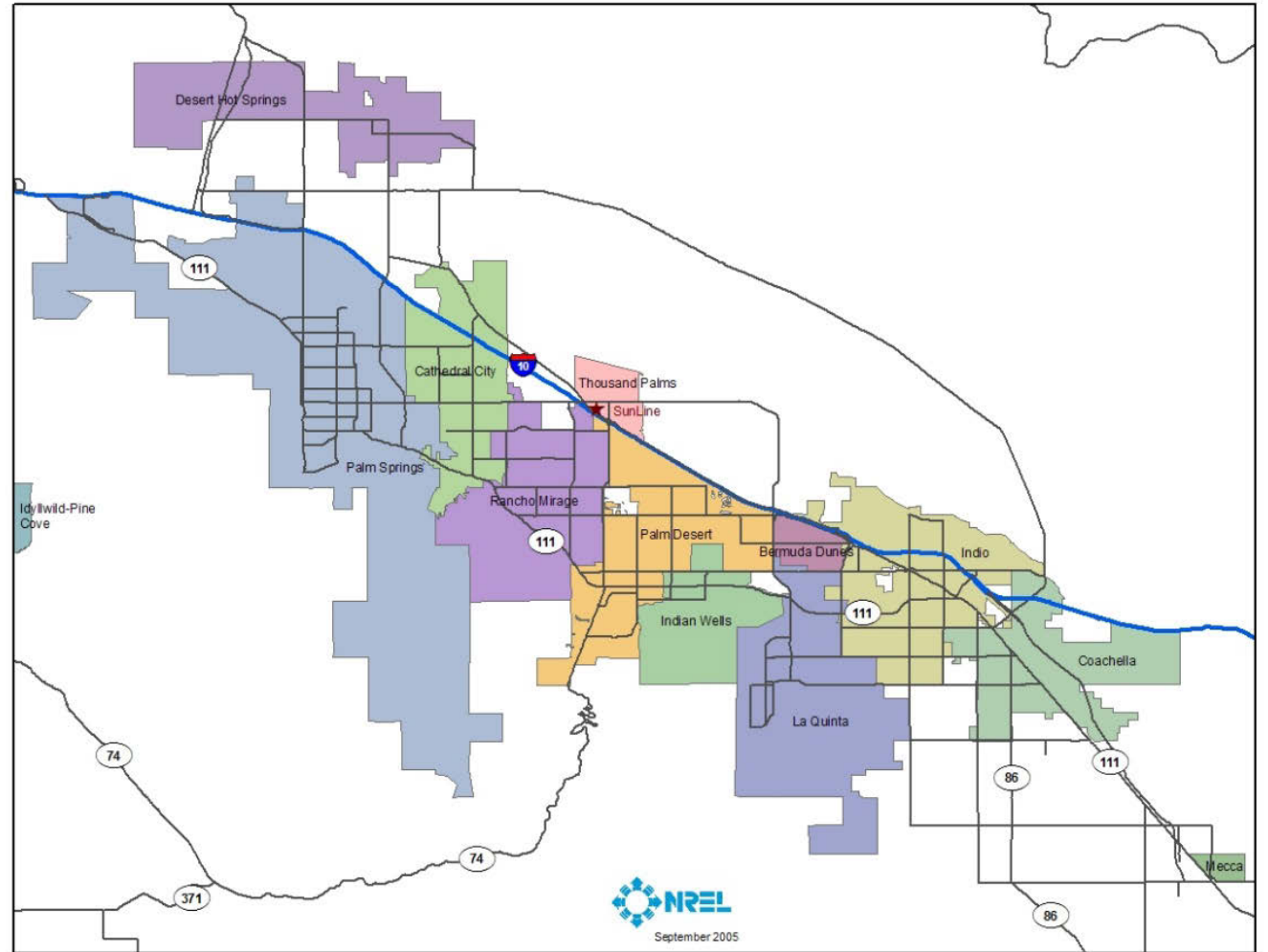
Maintenance cost: The cost to maintain the buses in the data period was \$0.22/mi for the FCEBs and \$0.16/mi for the CNG buses. Propulsion-system maintenance was \$0.06 for the FCEBs compared to \$0.02 for the CNG buses.

Note that both fleets of buses are under warranty and most repairs are covered by the OEM.

Fleet Profile

SunLine Transit Agency provides public transit services to Southern California's Coachella Valley. Headquartered in Thousand Palms, California, SunLine's service area covers more than 1,100 square miles, including nine member cities and a portion of Riverside County.

SunLine operates 15 local bus routes, one commuter route between Indio and San Bernardino, and paratransit service. The current bus fleet consists of 85 fixed route buses: 65 CNG buses, 16 FCEBs, and 4 battery electric buses.



Evaluation Buses

Vehicle System	FCEB	CNG
Number of buses	5	5
Bus manufacturer/model	New Flyer, Xcelsior	New Flyer, Xcelsior
Model year	2018	2019
Bus purchase cost	\$1.2 million	\$681,000
Length/width/height	40 ft/102 in./129.6 in.	40 ft/102 in./130.8 in.
Curb weight (lb.)	30,900	30,500
GVWR (lb.)	44,000	44,000
Hybrid system	Siemens	N/A
Fuel cell or engine	Ballard FCvelocity-HD85, 85 kW	Cummins L9N 280 hp @ 2,200 rpm
Energy storage	A123 Systems, lithium-ion, 100 kWh	N/A
Accessories	Electric	Mechanical
Fuel capacity	Gaseous hydrogen, 5 Type 4 composite cylinders, Agility Fuel Solutions, 37.5 kg at 5,000 psi	CNG, 6 carbon fiber cylinders, Agility Fuel Solutions, 19,770 scf @ 3,600 psi

Evaluation Buses

The five FCEBs were delivered in mid-2019, however, operation was limited due to insufficient hydrogen as SunLine was constructing and transitioning to its new station. The data period start for the FCEBs is January 2020. One of the buses (FC14) was removed from service in 2019 to repair body damage from an accident. The repair was completed in April 2020. This bus is included in the data beginning in May 2020.



The five baseline buses are SunLine's newest CNG fleet and were delivered and placed in service in early 2020. The start of the data period is April 2020 when the first of these buses went into service. NREL is phasing the remaining buses into the data as they are placed into service.



Infrastructure Description

In late 2019, SunLine completed construction of a new hydrogen station capable of fueling approximately 32 FCEBs. The station produces hydrogen on-site through electrolysis and is capable of 900 kg of hydrogen per day. The new station includes hydrogen dispensers in line with the CNG fueling island, which allows the FCEBs to be handled the same as the CNG bus fleet. The new station, which was commissioned in December 2019, replaced SunLine's older natural gas reformer that was not capable of producing enough hydrogen for the agency's growing FCEB fleet.

Data Summary

Data Item	FCEB	CNG
Number of buses	5	5
Data period	1/20–7/20	4/20–7/20
Number of months	7	4
Total mileage in data period	102,997	53,623
Average odometer	34,687	18,282
Average monthly mileage per bus	3,322	4,469
Total FCPP ^a hours	7,688	—
Availability (85% is target)	76.9	65.2
Fuel economy (FCEB mi/kg or CNG mpgge ^b)	6.94	3.50
Fuel economy (mpdgc ^c)	7.84	3.92
Miles between roadcalls (MBRC) – bus ^d	11,444	10,725
MBRC – propulsion system only ^d	34,332	^e
MBRC – FC System only ^d	51,499	—
Total maintenance (\$/mile)	0.22	0.16
Maintenance – propulsion system only (\$/mile)	0.06	0.02

^a FCPP=fuel cell power plant

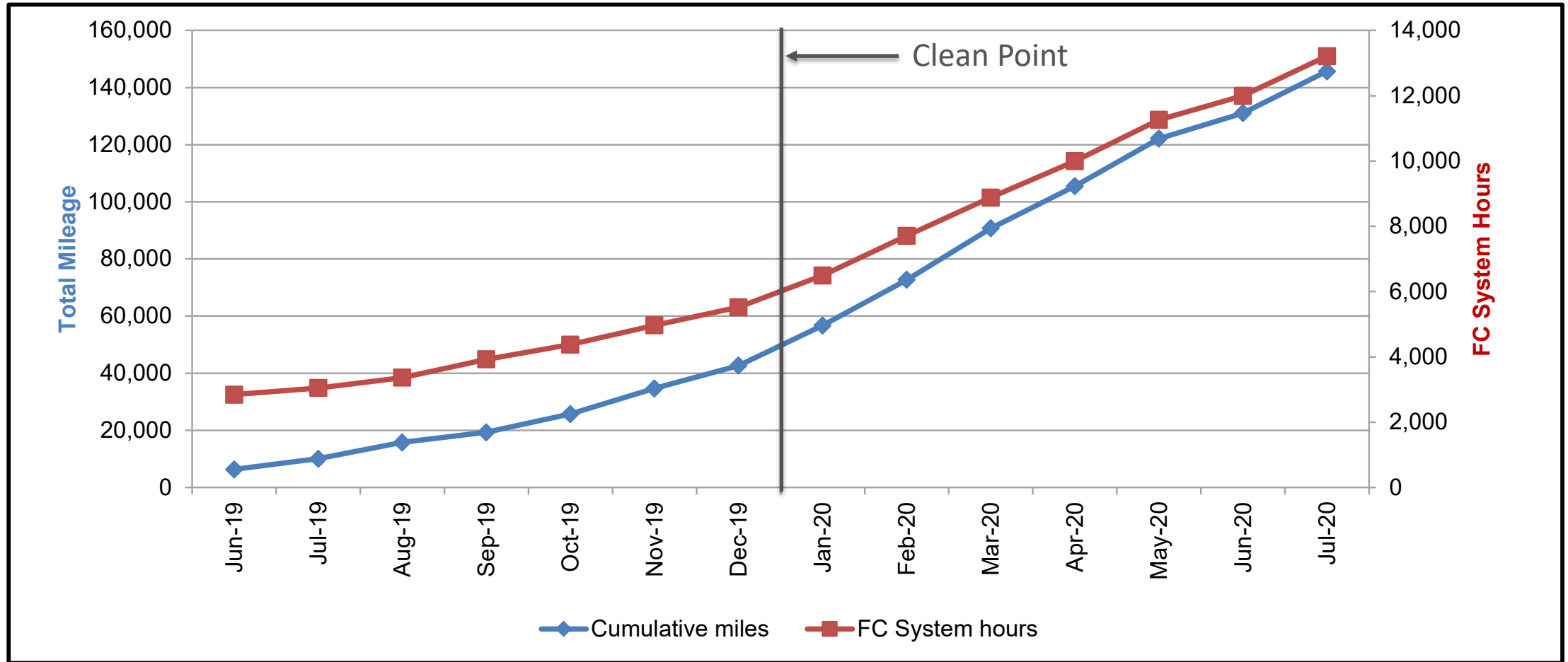
^b Miles per gasoline gallon equivalent.

^c Miles per diesel gallon equivalent.

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

^e To date, the CNG buses have not experienced a propulsion-system-related roadcall.

FCEB Total Miles and Hours



Fleet Average Monthly Miles by Bus

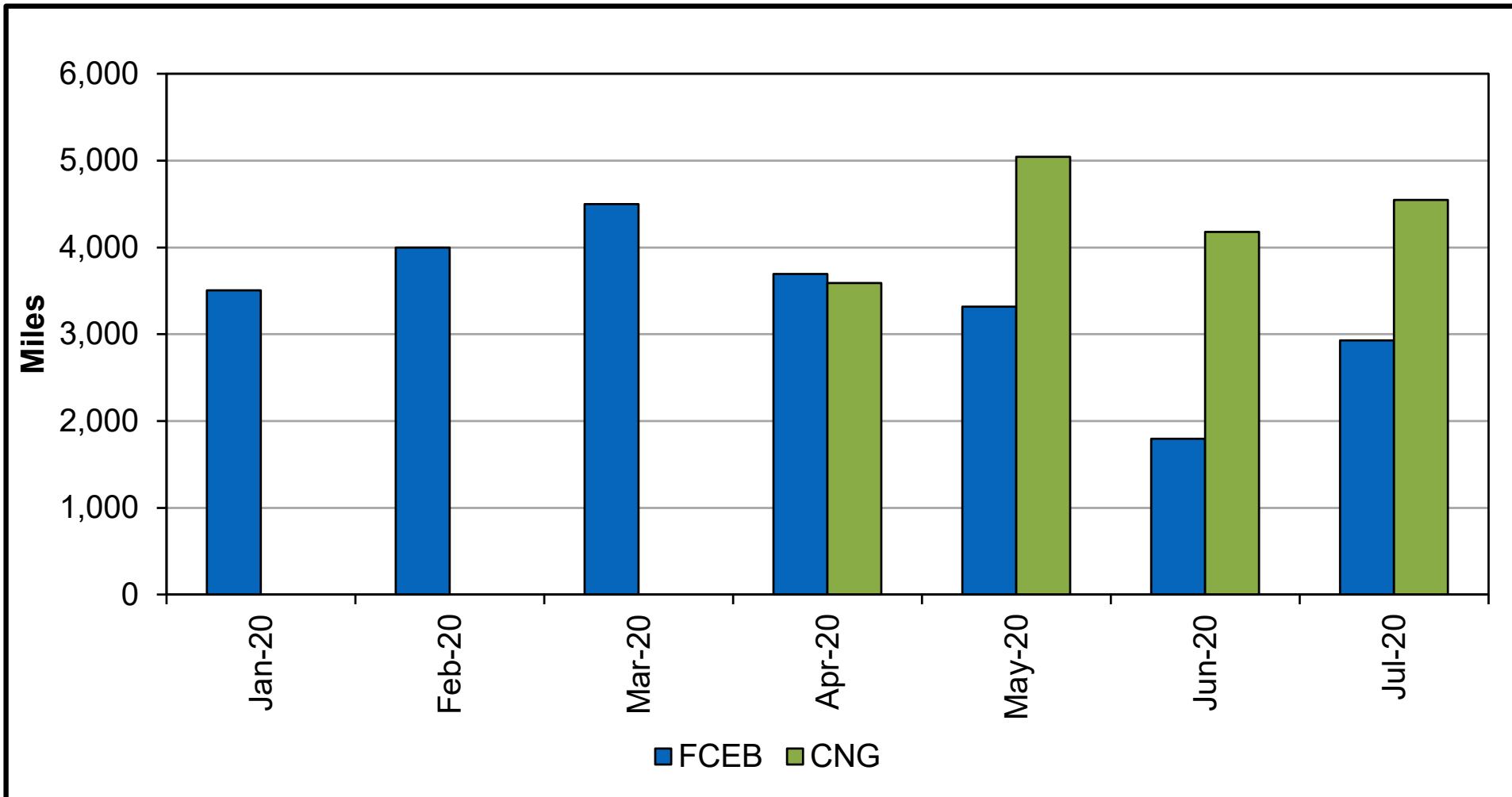
Bus	Miles	Bus Months	Average Monthly Mileage
FC14*	5,778	3	1,926
FC15	22,313	7	3,188
FC16	24,738	7	3,534
FC17	22,852	7	3,265
FC18	27,316	7	3,902
FCEB Fleet	102,997	31	3,322

Bus	Miles	Bus Months	Average Monthly Mileage
628	16,149	4	4,037
629^			
630	15,329	3	5,110
631	10,207	3	3,402
632	11,938	2	5,969
CNG Fleet	53,623	12	4,469

*FC14 was temporarily out of service through April 2020 for accident repair

^ bus 629 will be phased in in August 2020

Average Monthly Miles



Clean Point Average: FCEB: 3,322 miles; CNG: 4,469

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 time to handle scheduled and unscheduled maintenance. For SunLine, NREL calculates availability based on the planned service days. In February 2020, SunLine began planning the buses for service 7 days/week. Prior to that, planned service was weekdays. SunLine provides daily bus availability for the FCEBs and a reason for unavailability.

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 %	CNG # Days	CNG %
Planned work days	927		351	
Days available	713	76.9	229	65.2
Days unavailable	214	23.1	122	34.8
Fuel cell system	4	0	N/A	—
Engine	N/A	—	0	0
Transmission	N/A	—	12	3
Electric drive	10	1	N/A	—
Batteries	0	0	N/A	—
Preventive maintenance	48	5	33	9
General bus maintenance	152	16	77	22

New CNG buses being phased into service beginning in April 2020. Current data include 4 of 5 buses.

Monthly Availability by bus

Bus	Planned Days	Available Days	% Availability
FC14	92	49	53.3
FC15	207	151	72.9
FC16	211	163	77.3
FC17	207	163	78.7
FC18	210	187	89.0
FCEB Fleet	927	713	76.9

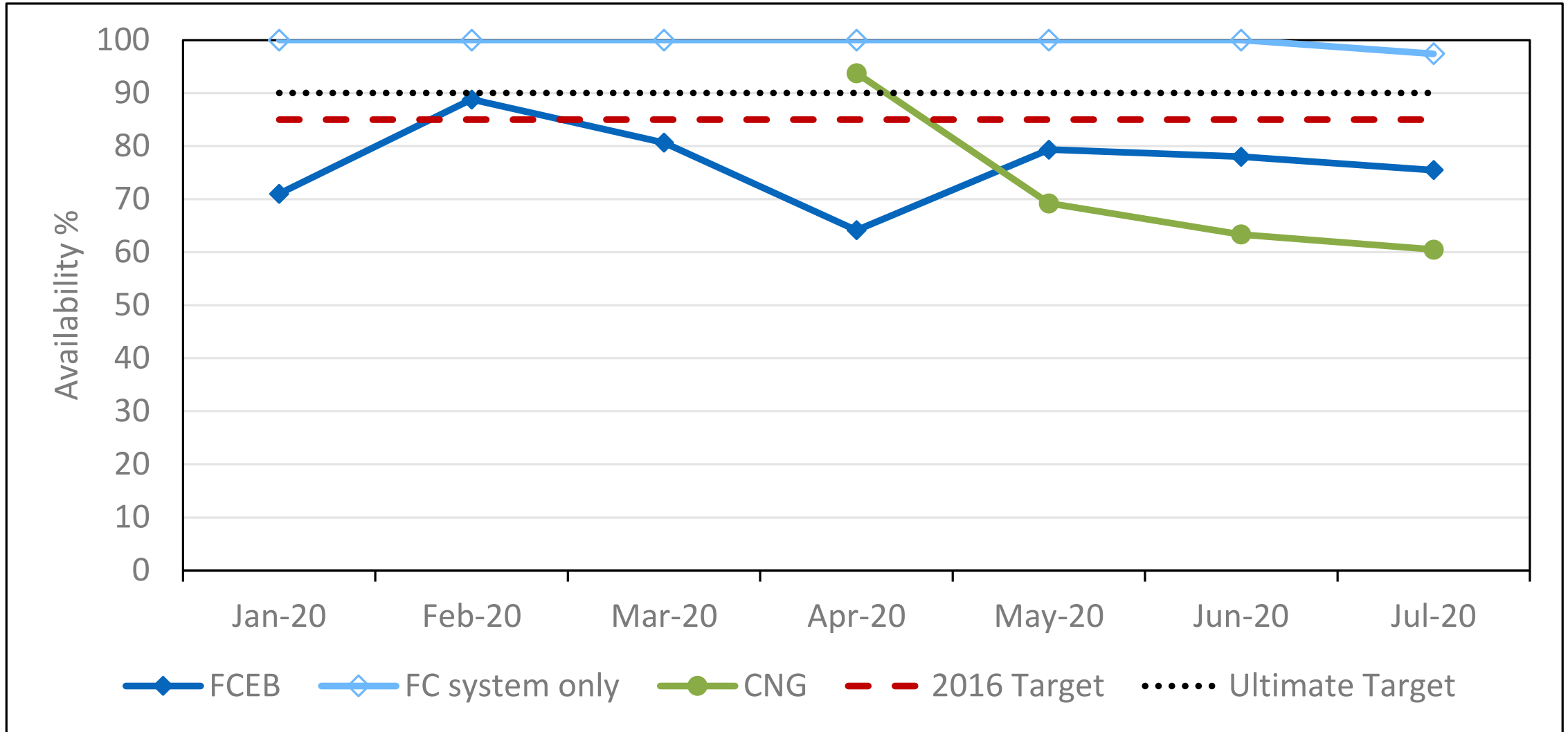
Bus	Planned Days	Available Days	% Availability
628	108	69	63.9
629			
630	92	66	71.7
631	90	47	52.2
632	61	47	77.0
CNG Fleet	351	229	65.2

Issues:

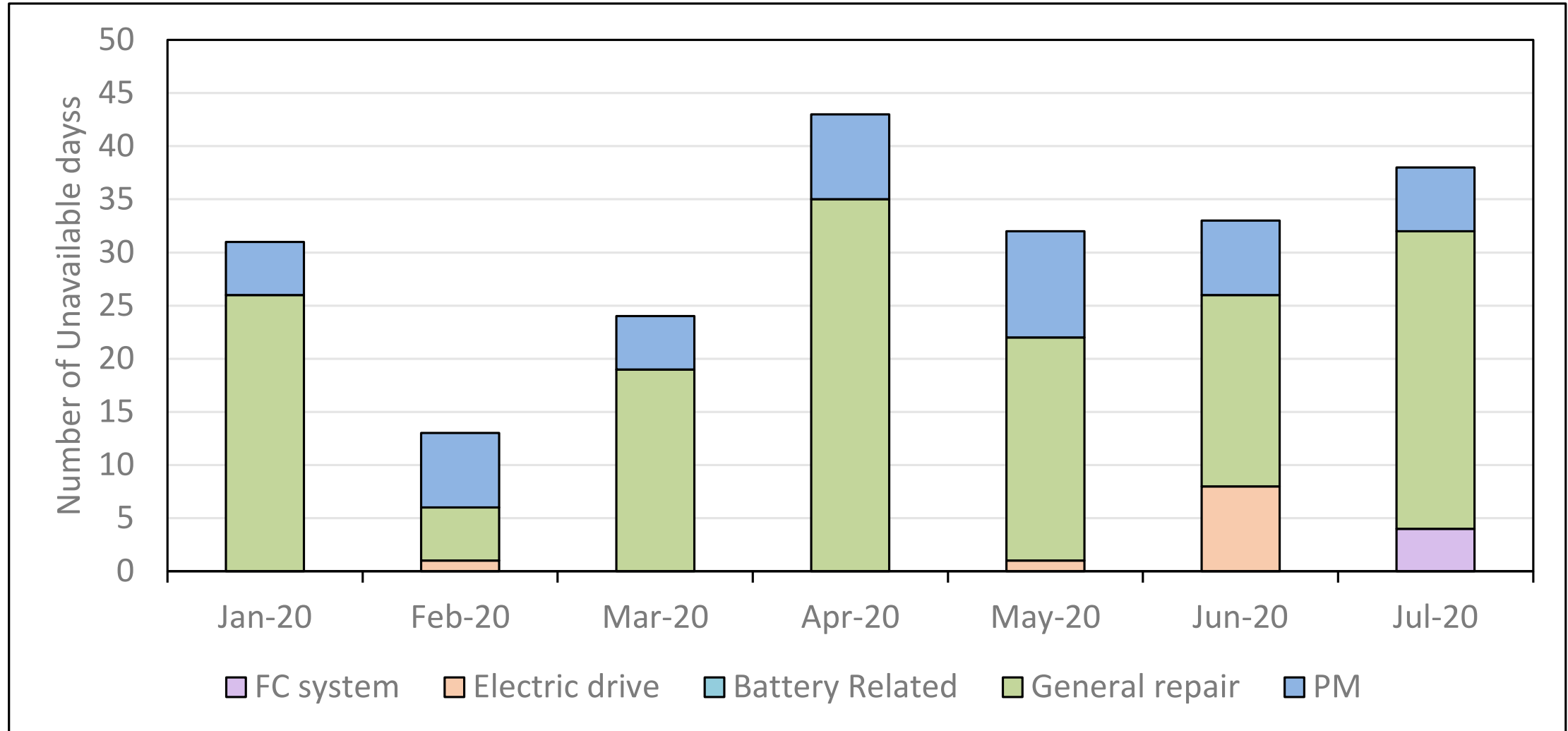
FC14: Not planned, off-site for accident repair until May 2020

CNG bus 629 not yet in service

Monthly Availability

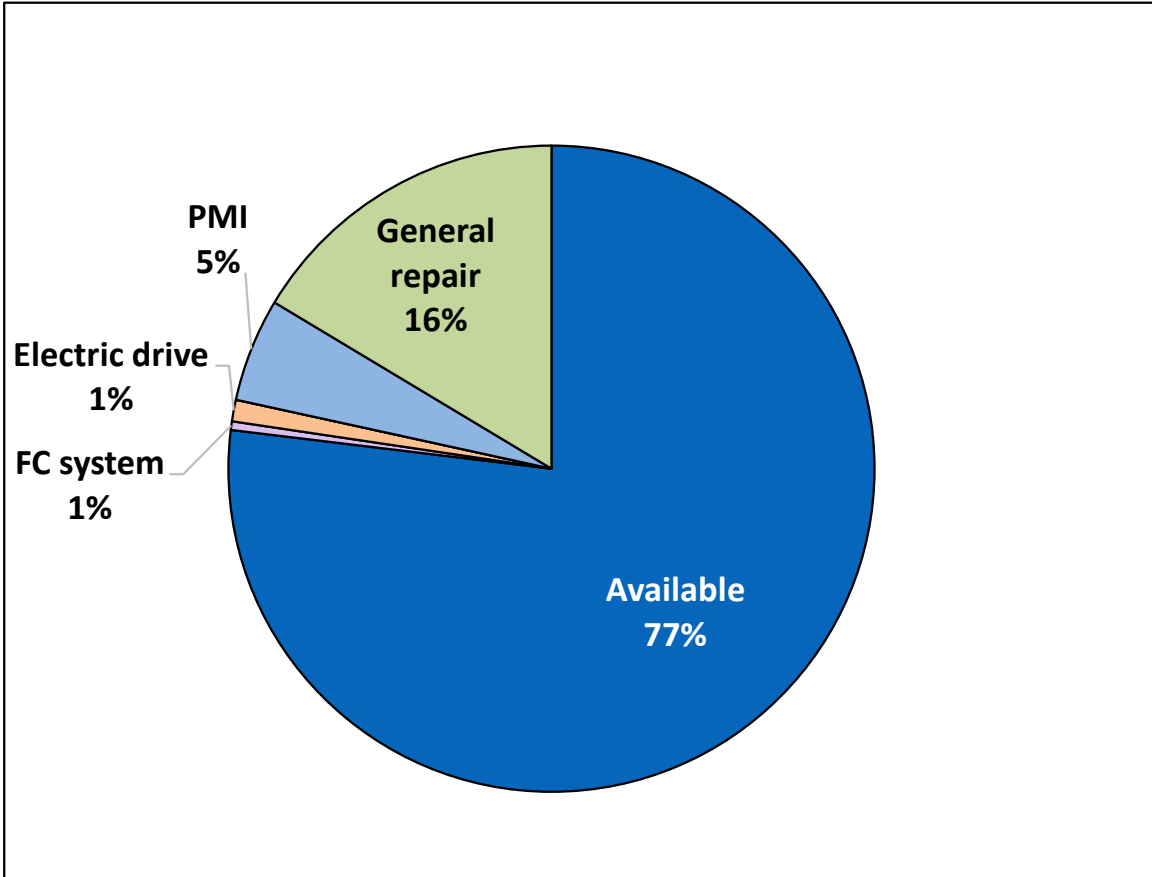


FCEB Monthly Unavailability Reasons

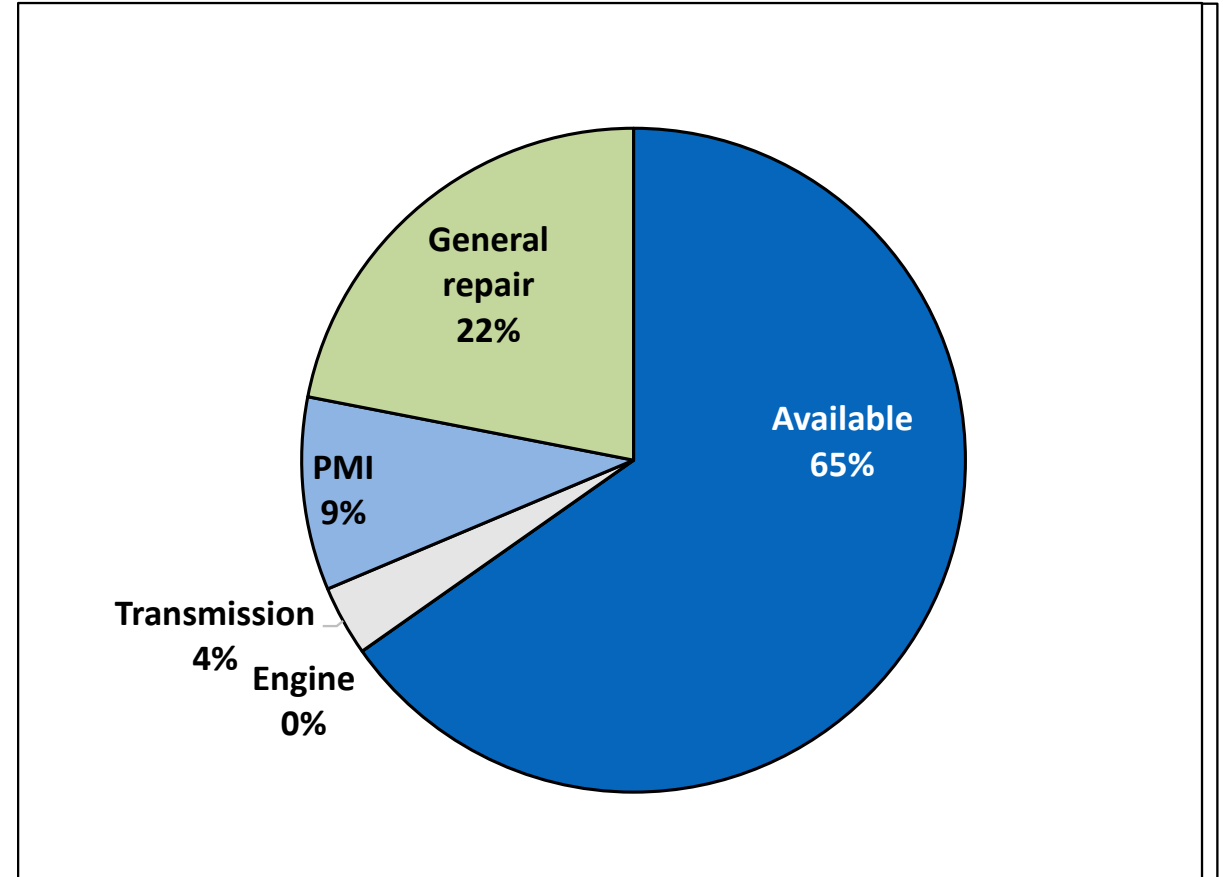


Overall Availability

FCEB



CNG



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:

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

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

SunLine provides monthly cost of hydrogen per kg and CNG per gge.

During the data period for the report, the agency has seen costs from \$7.88/kg to \$12.89/kg. The average cost of hydrogen during the evaluation period was \$10.10/kg. The CNG fuel cost for the data period was \$1.00 per gge.

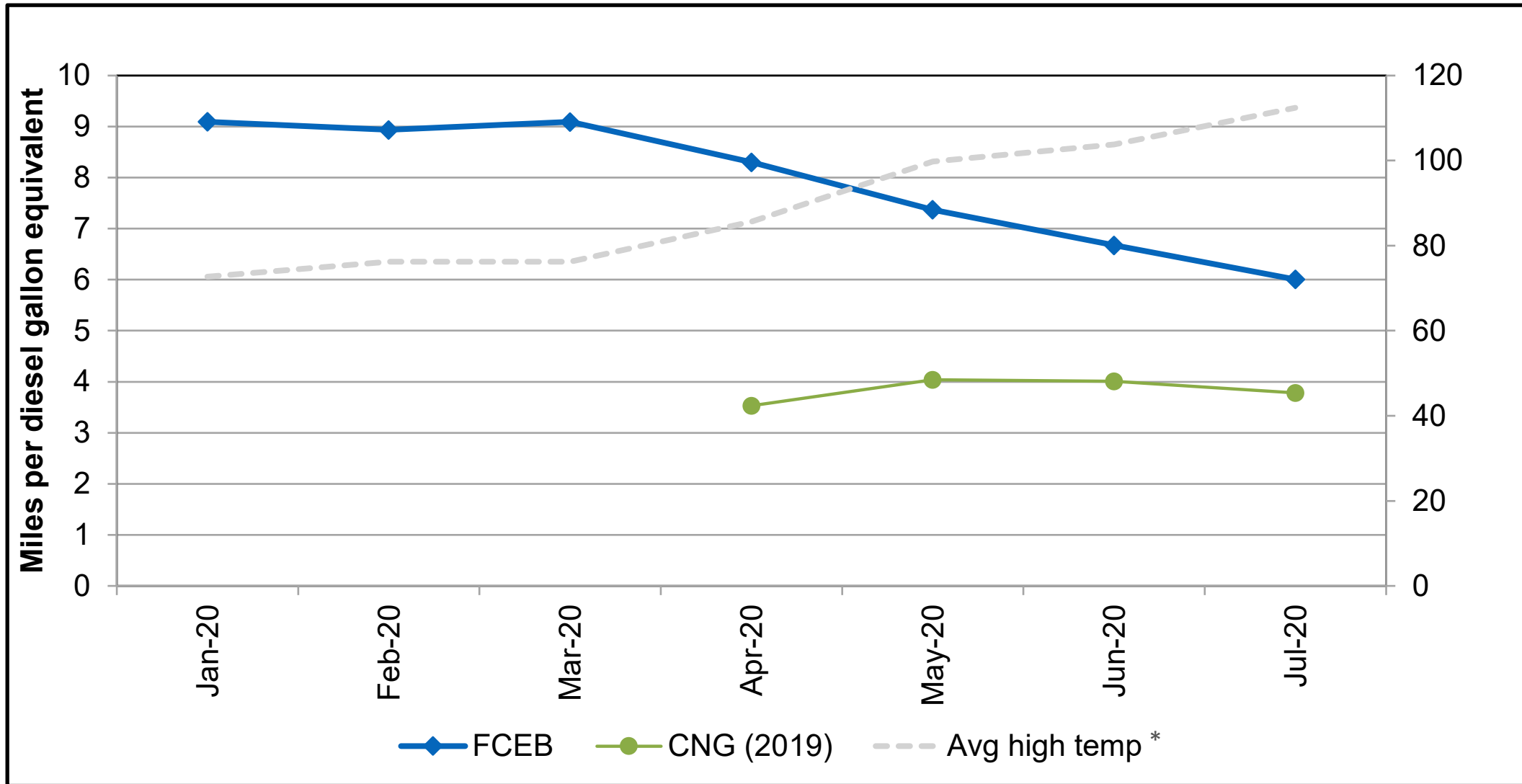
Fuel Economy by Bus

Bus	Miles	Hydrogen (kg)	mi/kg	Hydrogen (dgc)	Fuel economy (mpdgc)
FC14	5,370	808.4	6.64	715.4	7.51
FC15	20,677	2,964.4	6.98	2,623.3	7.88
FC16	23,392	3,337.2	7.01	2,953.3	7.92
FC17	21,635	3,117.4	6.94	2,758.8	7.84
FC18	24,696	3,580.8	6.90	3,168.8	7.79
FCEB Fleet	95,770	13,808.2	6.94	12,219.7	7.84

- FCEB fuel economy is 2 times that of the CNG buses.

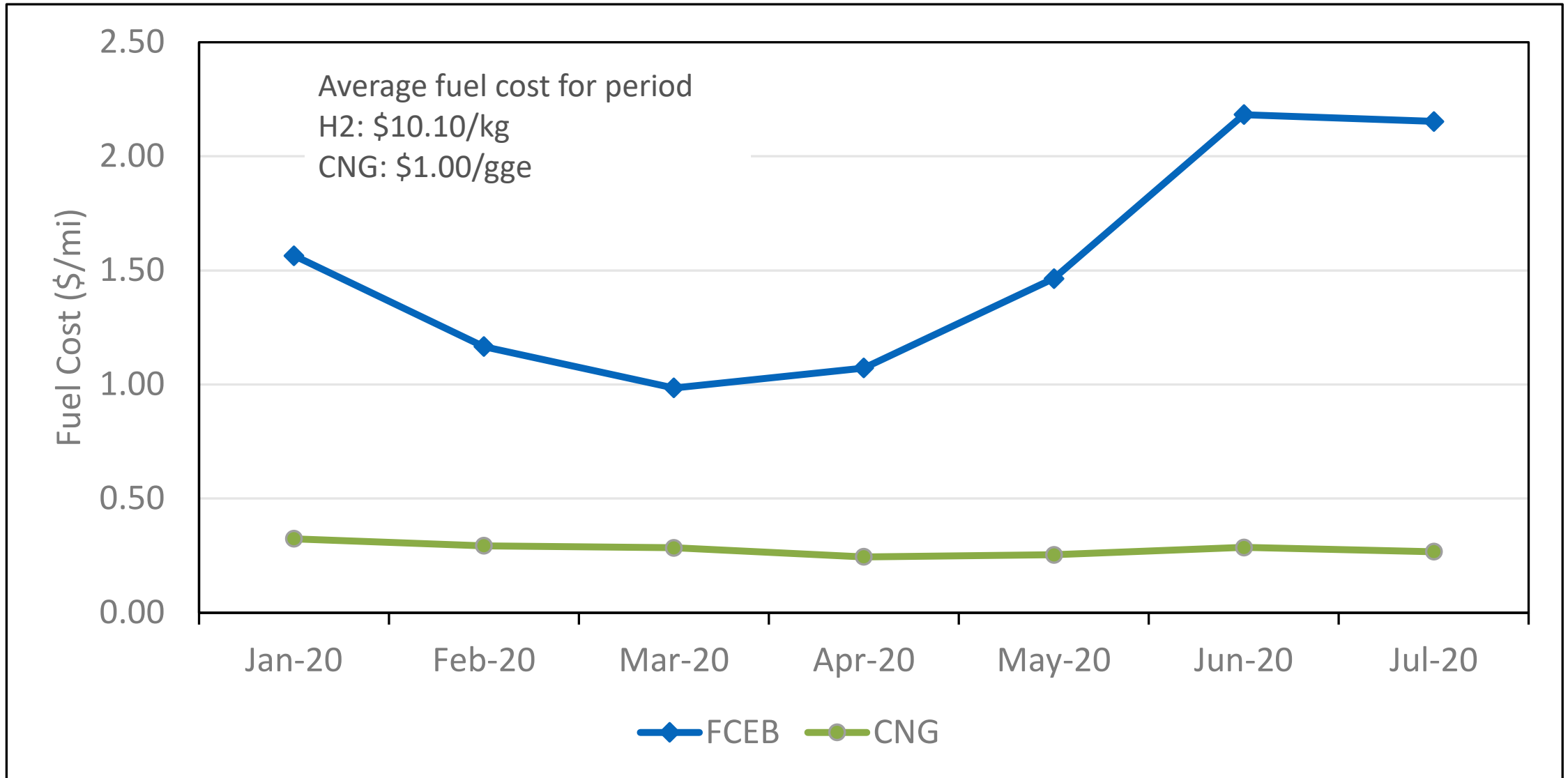
Bus	Miles	CNG (gge)	Miles/gge	CNG (dgc)	Fuel Economy (mpdgc)
628	16,117	4,680.1	3.44	4,188.7	3.85
629					
630	14,166	4,090.8	3.46	3,661.3	3.87
631	9,254	2,578.0	3.59	2,307.3	4.01
632	11,583	3,240.4	3.57	2,900.1	3.99
CNG Total	51,120	14,589.3	3.50	13,057.4	3.92

Monthly Average Fuel Economy

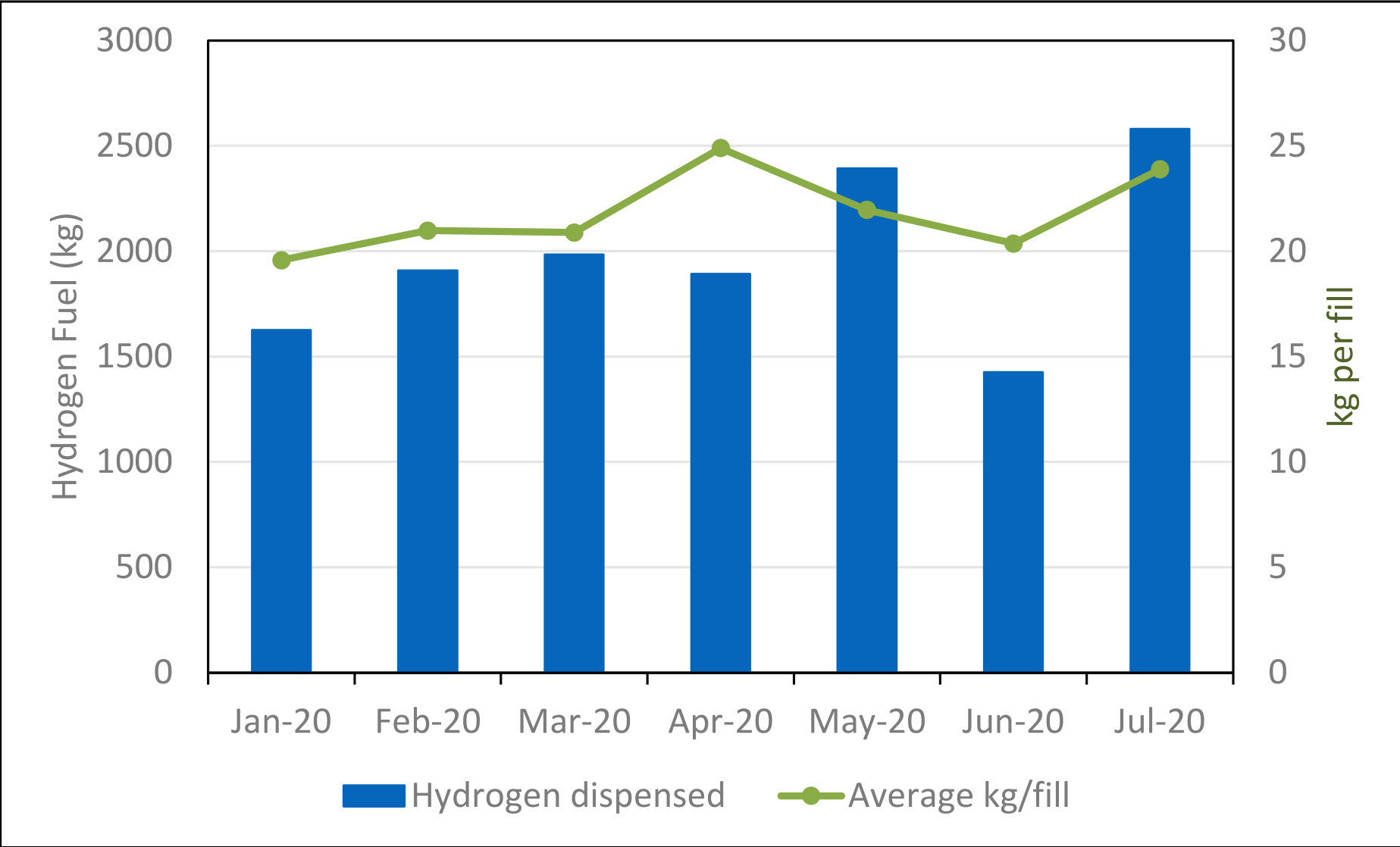


*Average monthly high temperatures at Palm Springs, CA airport. Data acquired from www.ncdn.noaa.gov

Monthly Average Fuel Cost Per Mile



Fleet Hydrogen Use

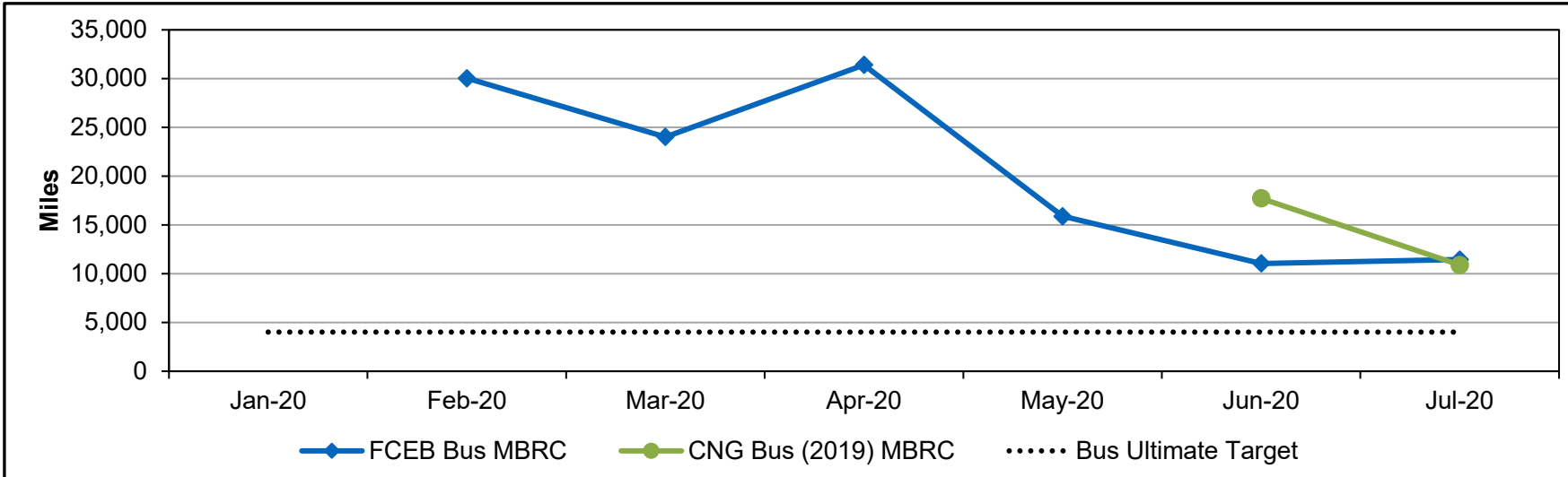


Roadcall Analysis

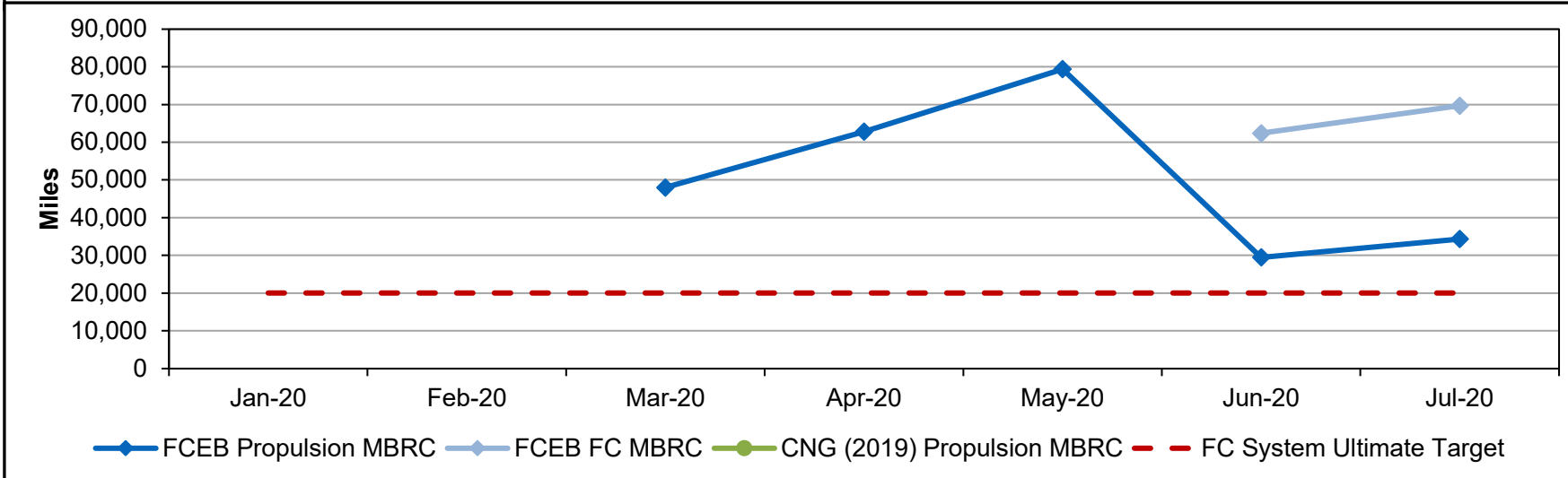
A roadcall or revenue vehicle system failure is defined as a failure of an in-service bus that causes the bus to be replaced on route or causes a significant delay in schedule. If the problem with the bus can be repaired during a layover and the schedule is kept, this is not considered a roadcall. The 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	11,444	10,725
Propulsion MBRC	34,332	-
FC System MBRC	51,449	N/A



Note: As of July 31, the CNG buses had not experienced a propulsion related roadcall

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 SunLine. 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.

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.

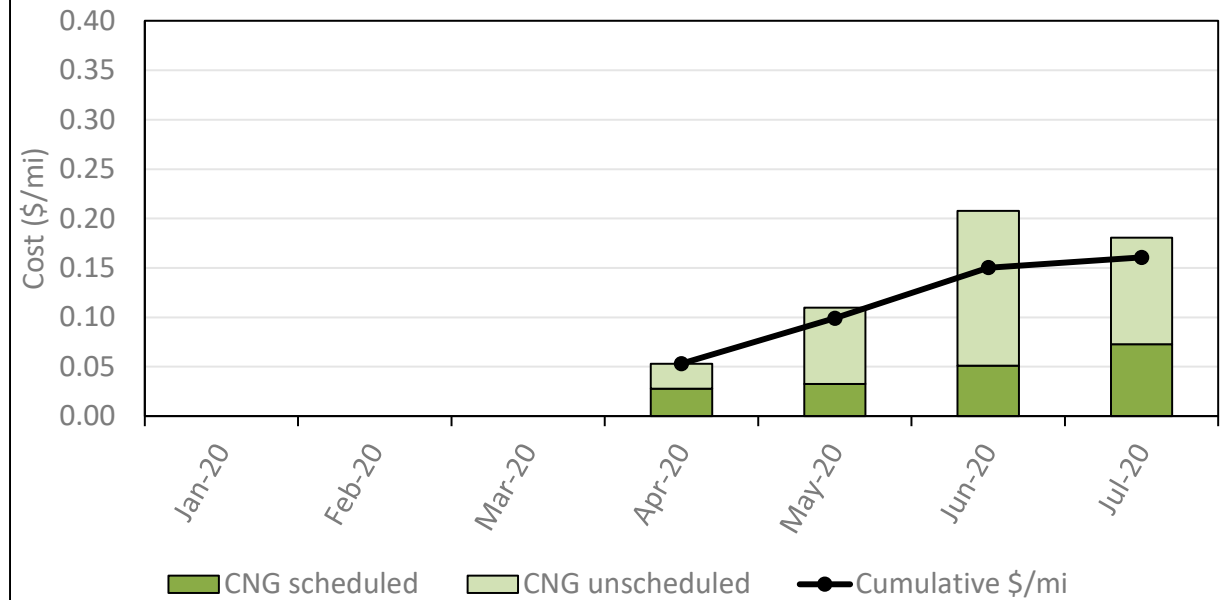
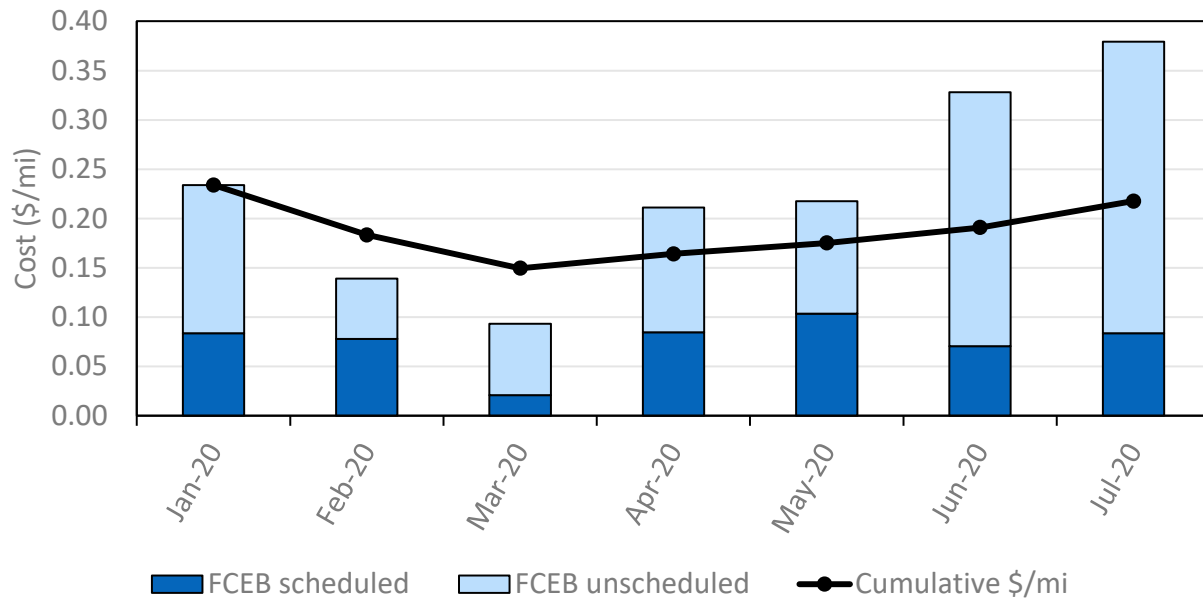
Maintenance Analysis Results

Bus	Mileage	Parts (\$)	Labor hours	Scheduled Cost (\$/mi)	Unscheduled Cost (\$/mi)	Total Cost per Mile (\$)
FC14	5,778	948.09	25.0	0.05	0.33	0.38
FC15	22,313	1,696.14	95.8	0.12	0.17	0.29
FC16	24,738	432.80	97.0	0.08	0.13	0.21
FC17	22,852	107.34	70.5	0.04	0.12	0.16
FC18	27,316	659.54	83.3	0.07	0.11	0.18
FCEB Fleet	102,997	3,843.91	371.5	0.07	0.14	0.22

Bus	Mileage	Parts (\$)	Labor hours	Scheduled Cost (\$/mi)	Unscheduled Cost (\$/mi)	Total Cost per Mile (\$)
628	16,149	668.99	60.8	0.06	0.17	0.23
629						
630	15,329	210.95	31.0	0.04	0.07	0.11
631	10,207	359.57	32.8	0.07	0.13	0.20
632	11,938	83.19	21.3	0.04	0.06	0.10
CNG Fleet	53,623	1,322.70	145.8	0.05	0.11	0.16

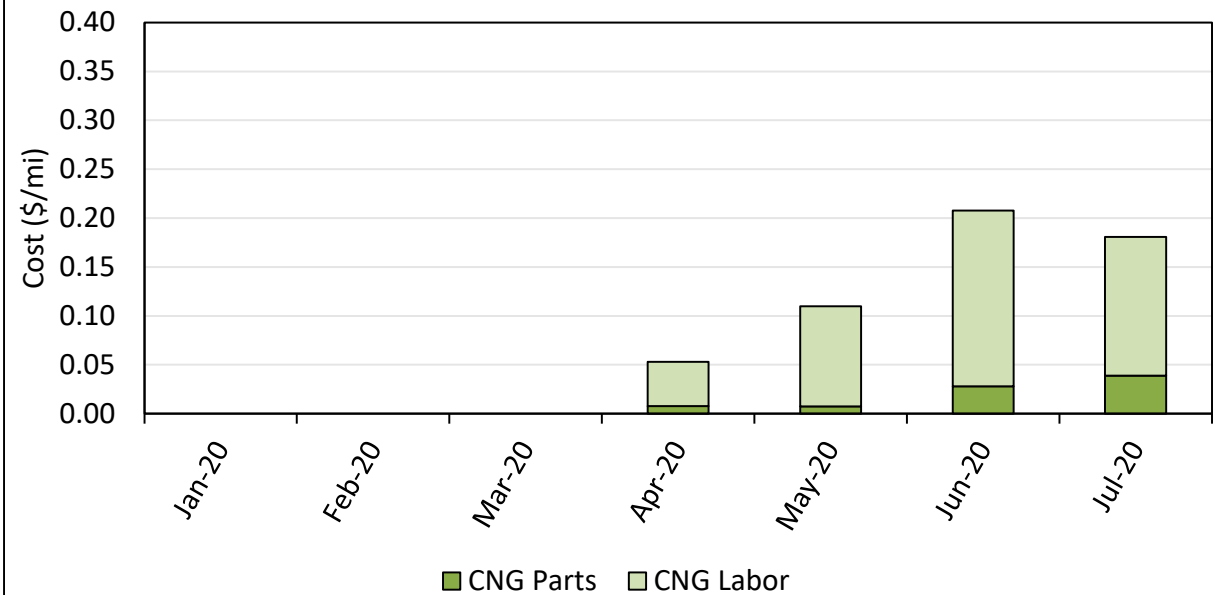
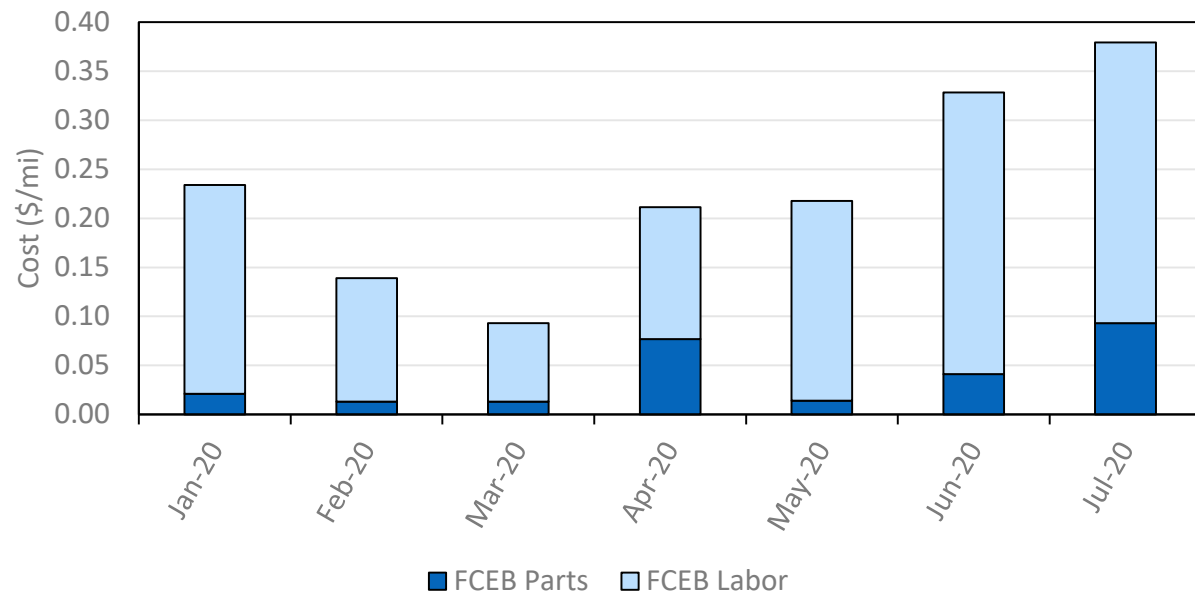
Note: Both the FCEBs and CNG buses are under warranty.

Scheduled and Unscheduled Maintenance Cost



- Scheduled costs make up 34% of the FCEB fleet cost and 32% of the CNG bus fleet cost

Parts and Labor Maintenance Cost



- Most costs for both fleets are for labor: 83% for the FCEBs and 85% for the CNG buses
- April and July parts for the FCEBs include cost for low-voltage batteries

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	0.063	29.0	0.024	15.2
Cab, body, and accessories	0.055	25.3	0.064	39.5
PMI	0.071	32.6	0.036	22.6
Brakes	0.002	1.1	0.002	1.3
Frame, steering, and suspension	0.007	3.2	0.001	0.9
HVAC	0.016	7.5	0.016	9.9
Lighting	0.000	0.1	0.015	9.3
Air, general	0.000	0.2	0.002	1.2
Axles, wheels, and drive shaft	0.000	0.0	0.000	0.0
Tires	0.002	0.9	0.000	0.0
Total	0.218	100	0.161	100

Color coding:

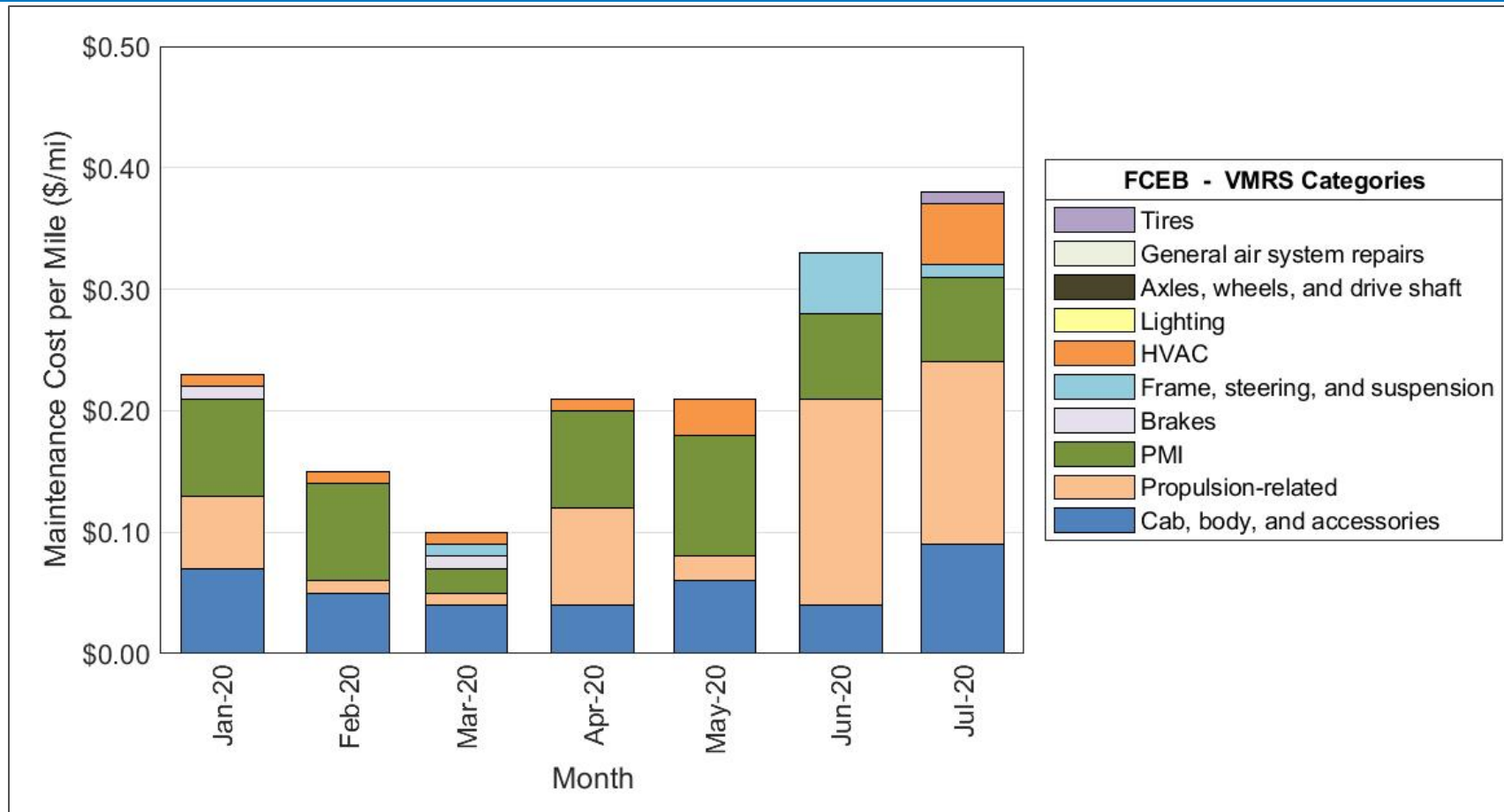
 Highest cost

 Second highest cost

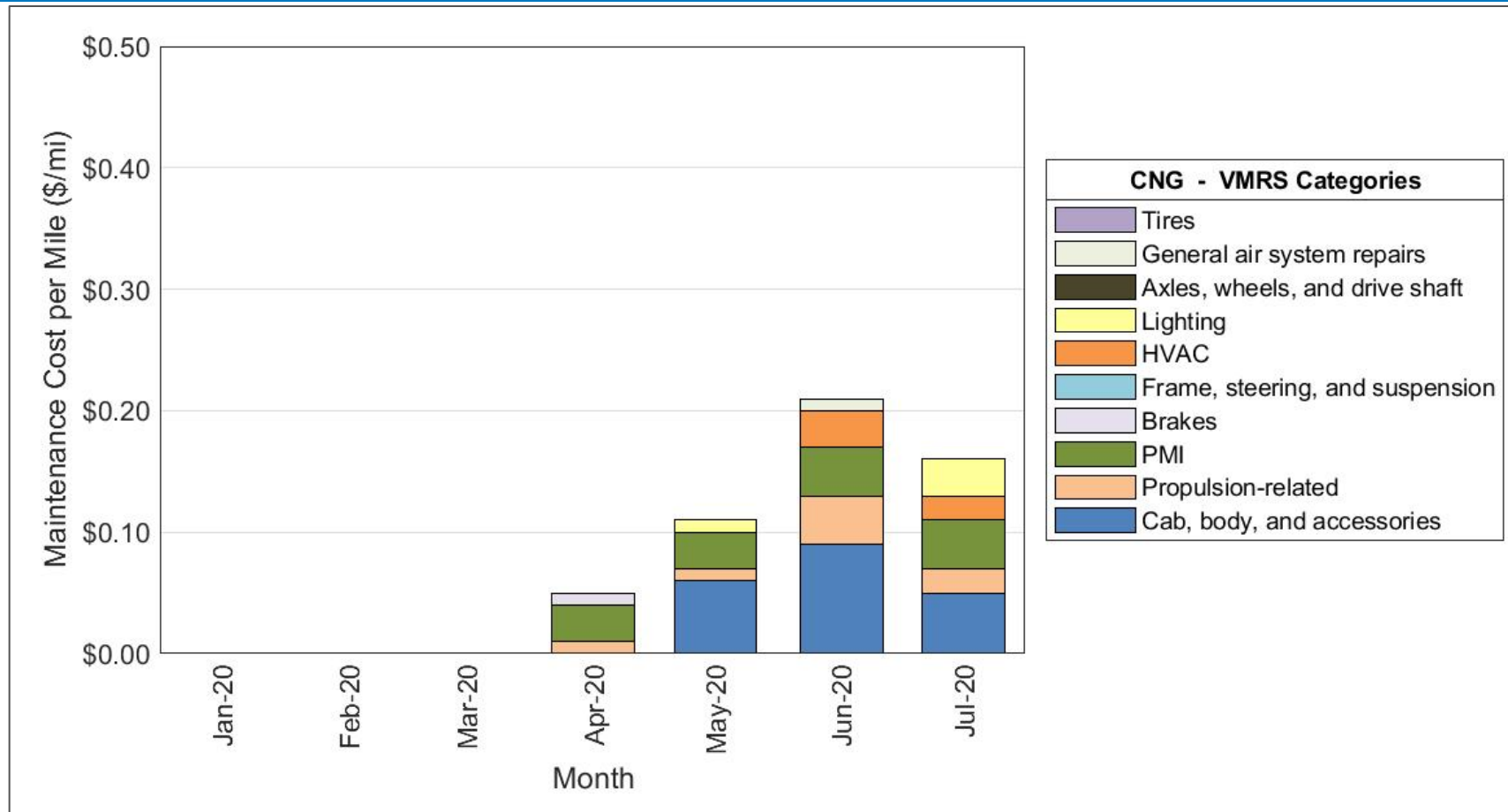
 Third highest cost

- For the FCEB fleet, the systems with the highest cost were PMI; propulsion-related; and cab, body, and accessories. For the CNG fleet, the systems with the highest cost were cab, body, and accessories; PMI; and propulsion-related.
- Overall costs for the FCEBs were 33% higher than 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		102,997	53,623	Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)	Parts cost (\$)	1,978.98	0.00
Total Propulsion-Related Systems (Roll-Up of All Systems)	Parts cost (\$)	2,671.58	524.63		Labor hours	27.8	7.0
	Labor hours	76.5	15.8		Total cost (\$)	3,366.48	350.00
	Total cost (\$)	6,496.58	1,312.13		Total cost (\$) per mile	0.033	0.007
	Total cost (\$) per mile	0.063	0.024	Air Intake System Repairs	Parts cost (\$)	0.00	0.00
Exhaust System Repairs	Parts cost (\$)	0.00	0.00		Labor hours	0.0	0.0
	Labor hours	0.0	0.0		Total cost (\$)	0.00	0.00
	Total cost (\$)	0.00	0.00		Total cost (\$) per mile	0.000	0.000
	Total cost (\$) per mile	0.000	0.000	Cooling System Repairs	Parts cost (\$)	3.88	0.00
Fuel System Repairs	Parts cost (\$)	0.00	0.00		Labor hours	9.0	0.5
	Labor hours	0.8	0.0		Total cost (\$)	453.88	25.00
	Total cost (\$)	37.50	0.00		Total cost (\$) per mile	0.004	0.000
	Total cost (\$) per mile	0.000	0.000	Transmission System Repairs	Parts cost (\$)	46.93	5.10
Powerplant System Repairs (Fuel Cell System for FCEBs)	Parts cost (\$)	341.82	519.53		Labor hours	0.0	4.8
	Labor hours	35.8	3.5		Total cost (\$)	46.93	242.60
	Total cost (\$)	2,129.32	694.53		Total cost (\$) per mile	0.000	0.005
	Total cost (\$) per mile	0.021	0.013	Hydraulic System Repairs	Parts cost (\$)	0.00	0.00
Electric Propulsion System Repairs	Parts cost (\$)	299.97	0.00		Labor hours	0.0	0.0
	Labor hours	3.3	0.0		Total cost (\$)	0.00	0.00
	Total cost (\$)	462.47	0.00		Total cost (\$) per mile	0.000	0.000
	Total cost (\$) per mile	0.004	0.000				

Contacts

NREL

Leslie Eudy

Phone: 303-275-4412

Email: leslie.eudy@nrel.gov

SunLine Transit Agency

Harman Singh

Phone: 760-343-3456

Email: hsingh@sunline.org

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		

Appendix: Fleet Summary Statistics

Fleet Summary Statistics

	FCEB	CNG
Number of vehicles	5	5
Period used for fuel and oil analysis	1/20–7/20	4/20–7/20
Total number of months in period	7	4
Fuel and oil analysis base fleet mileage	95,770	51,120
Period used for maintenance analysis	1/20–7/20	4/20–7/20
Total number of months in period	7	4
Maintenance analysis base fleet mileage	102,997	53,623
Average monthly mileage per vehicle	3,322	4,469
Availability	76.9	65.2
Fleet fuel usage in kg hydrogen or gge CNG	13,808.2	14,589.3
Roadcalls	9	5
Total MBRC	11,444	10,725
Propulsion roadcalls	3	0
Propulsion MBRC	34,332	
Fleet mi/kg hydrogen (FCEB), mi/gge (CNG)	6.94	3.50
Representative fleet mpg (energy equiv.)	7.84	3.92
Fuel cost per kg hydrogen or gge CNG	10.10	1.00
Fuel cost per mile	1.456	0.276
Total scheduled repair cost per mile	0.074	0.052
Total unscheduled repair cost per mile	0.144	0.109
Total maintenance cost per mile	0.218	0.161
Total operating cost per mile	1.673	0.437

Maintenance Cost Summary

Maintenance Cost Summary

	FCEB	CNG
Fleet mileage	102,997	53,623
Total parts cost	3,843.91	1,322.70
Total labor hours	372	146
Average labor cost (@ \$50.00 per hour)	18,575.00	7,287.50
Total maintenance cost	22,419	8,610
Total maintenance cost per bus	4,483.78	1,722.04
Total maintenance cost per mile	0.218	0.161

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	2,671.58	524.63
Labor hours	76.50	15.75
Average labor cost	3,825.00	787.50
Total cost (for system)	6,496.58	1,312.13
Total cost (for system) per bus	1,299.32	262.43
Total cost (for system) per mile	0.063	0.024

Maintenance Cost by Vehicle System

	FCEB	CNG
Exhaust System Repairs (ATA VMRS 43)		
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
Fuel System Repairs (ATA VMRS 44)		
Parts cost	0.00	0.00
Labor hours	0.8	0.0
Average labor cost	37.50	0.00
Total cost (for system)	37.50	0.00
Total cost (for system) per bus	7.50	0.00
Total cost (for system) per mile	0.000	0.000
Power Plant (Engine) Repairs (ATA VMRS 45)		
Parts cost	341.82	519.53
Labor hours	35.8	3.5
Average labor cost	1,787.50	175.00
Total cost (for system)	2,129.32	694.53
Total cost (for system) per bus	425.86	138.91
Total cost (for system) per mile	0.021	0.013

Maintenance Cost by Vehicle System

	FCEB	CNG
Electric Propulsion Repairs (ATA VMRS 46)		
Parts cost	299.97	0.00
Labor hours	3.3	0.0
Average labor cost	162.50	0.00
Total cost (for system)	462.47	0.00
Total cost (for system) per bus	92.49	0.00
Total cost (for system) per mile	0.004	0.000
Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)		
Parts cost	1,978.98	0.00
Labor hours	27.8	7.0
Average labor cost	1,387.50	350.00
Total cost (for system)	3,366.48	350.00
Total cost (for system) per bus	673.30	70.00
Total cost (for system) per mile	0.033	0.007
Air Intake System Repairs (ATA VMRS 41)		
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

Maintenance Cost by Vehicle System

	FCEB	CNG
Cooling System Repairs (ATA VMRS 42)		
Parts cost	3.88	0.00
Labor hours	9.0	0.5
Average labor cost	450.00	25.00
Total cost (for system)	453.88	25.00
Total cost (for system) per bus	90.78	5.00
Total cost (for system) per mile	0.004	0.000
Hydraulic System Repairs (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 Repairs (ATA VMRS 10)		
Parts cost	0.00	0.00
Labor hours	1.0	2.0
Average labor cost	50.00	100.00
Total cost (for system)	50.00	100.00
Total cost (for system) per bus	10.00	20.00
Total cost (for system) per mile	0.000	0.002

Maintenance Cost by Vehicle System

	FCEB	CNG
Brake System Repairs (ATA VMRS 13)		
Parts cost	112.16	28.04
Labor hours	2.8	1.8
Average labor cost	137.50	87.50
Total cost (for system)	249.66	115.54
Total cost (for system) per bus	49.93	23.11
Total cost (for system) per mile	0.002	0.002
Transmission Repairs (ATA VMRS 27)		
Parts cost	46.93	5.10
Labor hours	0.0	4.8
Average labor cost	0.00	237.50
Total cost (for system)	46.93	242.60
Total cost (for system) per bus	9.39	48.52
Total cost (for system) per mile	0.000	0.005
Inspections Only - No Parts Replacements (101)		
Parts cost	0.00	0.00
Labor hours	146.0	39.0
Average labor cost	7,300.00	1,950.00
Total cost (for system)	7,300.00	1,950.00
Total cost (for system) per bus	1,460.00	390.00
Total cost (for system) per mile	0.071	0.036

Maintenance Cost by Vehicle System

	FCEB	CNG
Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)		
Parts cost	895.54	317.81
Labor hours	95.8	61.8
Average labor cost	4,787.50	3,087.50
Total cost (for system)	5683.0	3405.3
Total cost (for system) per bus	1,136.61	681.06
Total cost (for system) per mile	0.055	0.064
HVAC System Repairs (ATA VMRS 01)		
Parts cost	104.47	0.00
Labor hours	31.8	17.0
Average labor cost	1,587.50	850.00
Total cost (for system)	1692.0	850.0
Total cost (for system) per bus	338.39	170.00
Total cost (for system) per mile	0.016	0.016
Lighting System Repairs (ATA VMRS 34)		
Parts cost	16.31	452.22
Labor hours	0.0	7.0
Average labor cost	0.00	350.00
Total cost (for system)	16.3	802.2
Total cost (for system) per bus	3.26	160.44
Total cost (for system) per mile	0.000	0.015

Maintenance Cost by Vehicle System

	FCEB	CNG
Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)		
Parts cost	43.85	0.00
Labor hours	13.5	1.5
Average labor cost	675.00	75.00
Total cost (for system)	718.9	75.0
Total cost (for system) per bus	143.77	15.00
Total cost (for system) per mile	0.007	0.001
Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)		
Parts cost	0.00	0.00
Labor hours	0.0	0.0
Average labor cost	0.00	0.00
Total cost (for system)	0.0	0.0
Total cost (for system) per bus	0.00	0.00
Total cost (for system) per mile	0.000	0.000
Tire Repairs (ATA VMRS 17)		
Parts cost	0.00	0.00
Labor hours	4.3	0.0
Average labor cost	212.50	0.00
Total cost (for system)	212.5	0.0
Total cost (for system) per bus	42.50	0.00
Total cost (for system) per mile	0.002	0.000

Fleet Summary Statistics: SI Units

	FCEB	CNG
Number of vehicles	5	5
Period used for fuel and oil analysis	1/20–7/20	4/20–7/20
Total number of months in period	7	4
Fuel and oil analysis base fleet kilometers	154,123	82,267
Period used for maintenance analysis	1/20–7/20	4/20–7/20
Total number of months in period	7	4
Maintenance analysis base fleet kilometers	165,753	86,295
Average monthly kilometers per vehicle	2,974	3,999
Availability	76.9	65.2
Fleet fuel in FCEB kg/CNG L	13,808.2	55,226.4
Roadcalls	9	5
Total KBRC	18,417	17,259
Propulsion roadcalls	3	0
Propulsion KBRC	55,251	
Representative fleet fuel consumption (L/100 km)	30.01	67.13
H2 cost per kg/ CNG cost per liter	10.10	0.26
Fuel cost per km	0.905	0.177
Total scheduled repair cost per km	0.046	0.032
Total unscheduled repair cost per km	0.089	0.068
Total maintenance cost per km	0.135	0.100
Total operating cost per km	1.040	0.277

Maintenance Cost Summary: SI Units

Maintenance Cost Summary

	FCEB	CNG
Fleet mileage	165,753	86,295
Total parts cost	3,843.91	1,322.70
Total labor hours	372	146
Average labor cost (@ \$50.00 per hour)	18,575.00	7,287.50
Total maintenance cost	22,419	8,610
Total maintenance cost per bus	4,483.78	1,722.04
Total maintenance cost per kilometer	0.135	0.100

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	2,671.58	524.63
Labor hours	76.50	15.75
Average labor cost	3,825.00	787.50
Total cost (for system)	6,496.58	1,312.13
Total cost (for system) per bus	1,299.32	262.43
Total cost (for system) per kilometer	0.039	0.015

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