



SunLine Transit Agency Fuel Cell Electric Bus Progress Report

Data Period Focus: Jan. 2020 through Dec. 2021

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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 December 2021. 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 14 mph. The agency reduced service in March 2020 due to the COVID-19 pandemic.

Fuel economy: The FCEBs had an average fuel economy of 7.05 miles per kilogram of hydrogen, which equates to 7.97 mpdge. The CNG buses had an average fuel economy of 3.70 mpgge, which equates to 4.14 mpdge. The FCEB fuel economy was slightly less than 2 times higher than that of the CNG buses. The monthly fuel economy for the FCEB fleet ranged from a high of 9.75 in December 2021, to a low of 5.71 in July 2021. 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 69.5 compared to the average high in July of 109.9 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 2,200 times with an average fill amount of 19.85 kg. Daily dispensed hydrogen was 65.57 kg. The average monthly cost for hydrogen at SunLine varies. During the data period, the monthly hydrogen costs ranged from \$7.88/kg to more than \$21.04/kg. The average cost of hydrogen was \$13.79/kg. The CNG fuel cost for the data period was \$1.27 per gge. The FCEBs had an average fuel cost of \$1.96 per mile. The fuel cost for the CNG buses averaged \$0.33 per mile.

Availability: The per-bus availability for the FCEBs ranged from 39% to 90%. The average availability for the FCEBs was 72%. Most unavailable time for the FCEBs was due to general bus-related problems followed by planned maintenance and inspections. This is not unusual for a new design in a recent 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 91%. The average availability for the new CNG buses was 73%. 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 \$0.35/mi for the FCEBs and \$0.29/mi for the CNG buses. Propulsion-system maintenance was \$0.12 for the FCEBs compared to \$0.06 for the CNG buses.

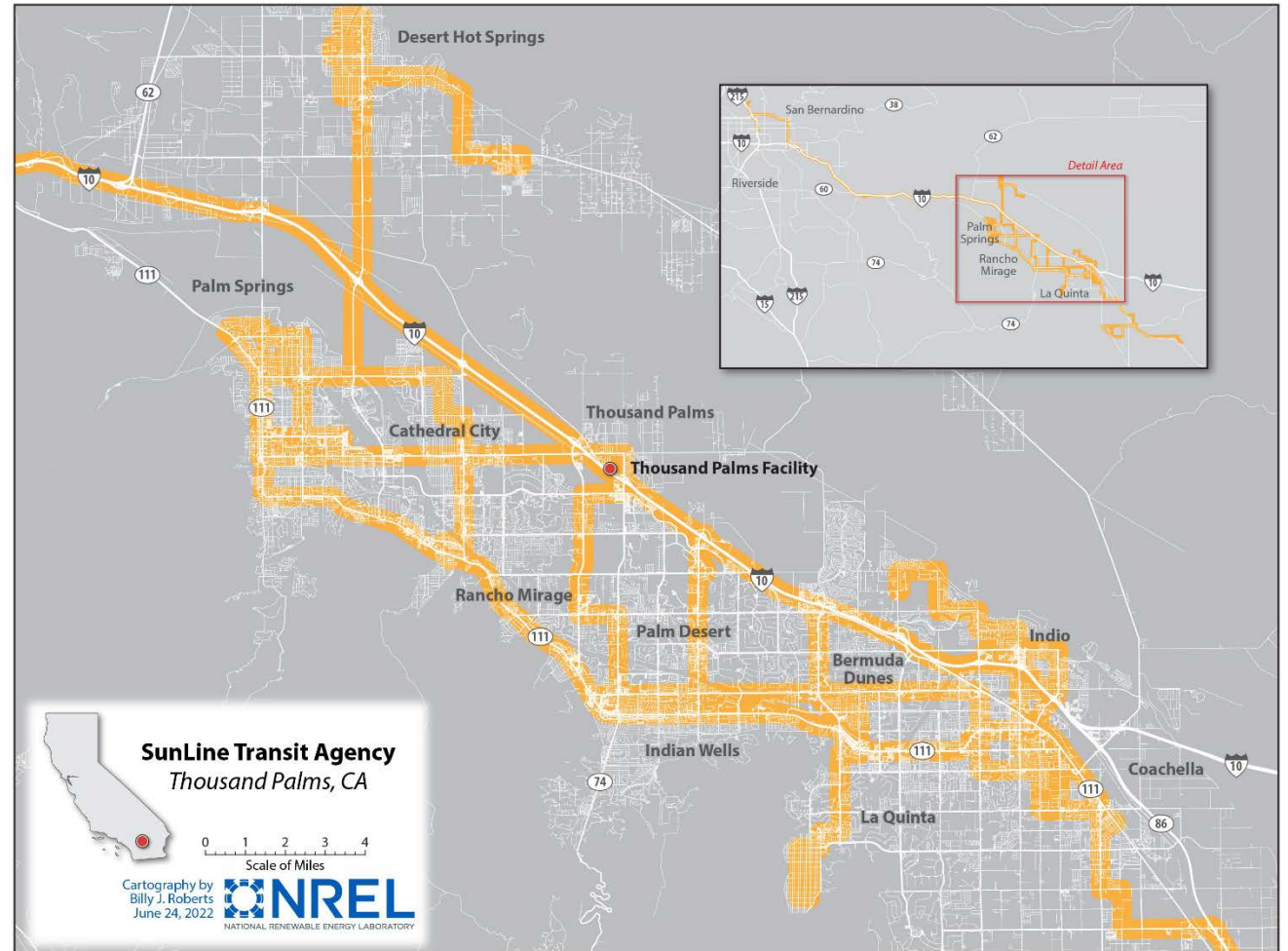
Note that both fleets of buses are under warranty and most repairs are covered by the OEM.

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 9 local bus routes, which were consolidated from 15 during this data period in January 2021. SunLine also operates one commuter route between Indio and San Bernardino as well as a 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 phased the remaining buses into the data as they were 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	1/20–12/21	4/20–12/21
Number of months	24	21
Total mileage in data period	404,413	499,081
Average odometer	86,427	102,535
Average monthly mileage per bus	3,118	5,145
Total FCPP ^a hours	31,016	—
Availability (85% is target)	72.5	72.8
Fuel economy (FCEB mi/kg or CNG mpgge ^b)	7.05	3.70
Fuel economy (mpdge ^c)	7.97	4.14
Miles between roadcalls (MBRC) – bus ^d	4,064	9,598
MBRC – propulsion system only ^d	6,346	31,193
MBRC – FC System only ^d	24,113	—
Total maintenance (\$/mile)	0.36	0.29
Maintenance – propulsion system only (\$/mile)	0.12	0.06

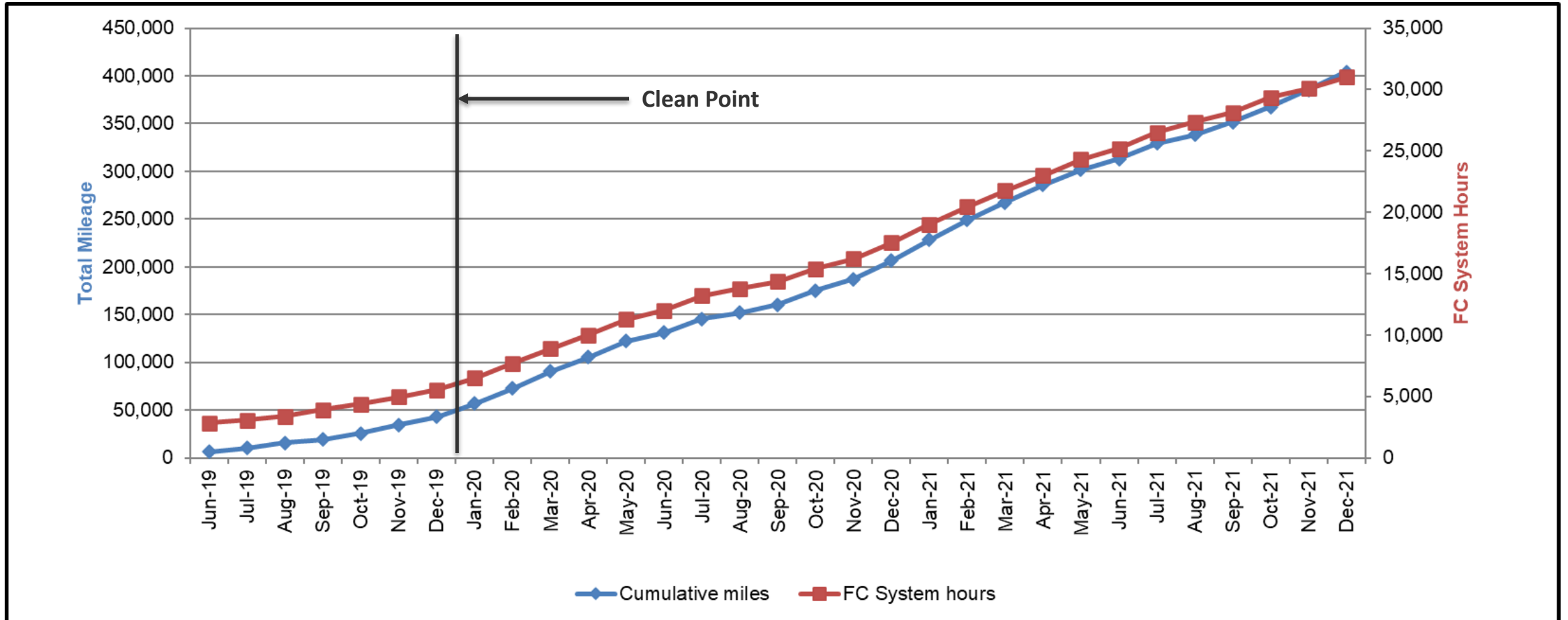
^a FCPP=fuel cell power plant

^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.

FCEB Total Miles and Hours



Fleet Average Monthly Miles by Bus

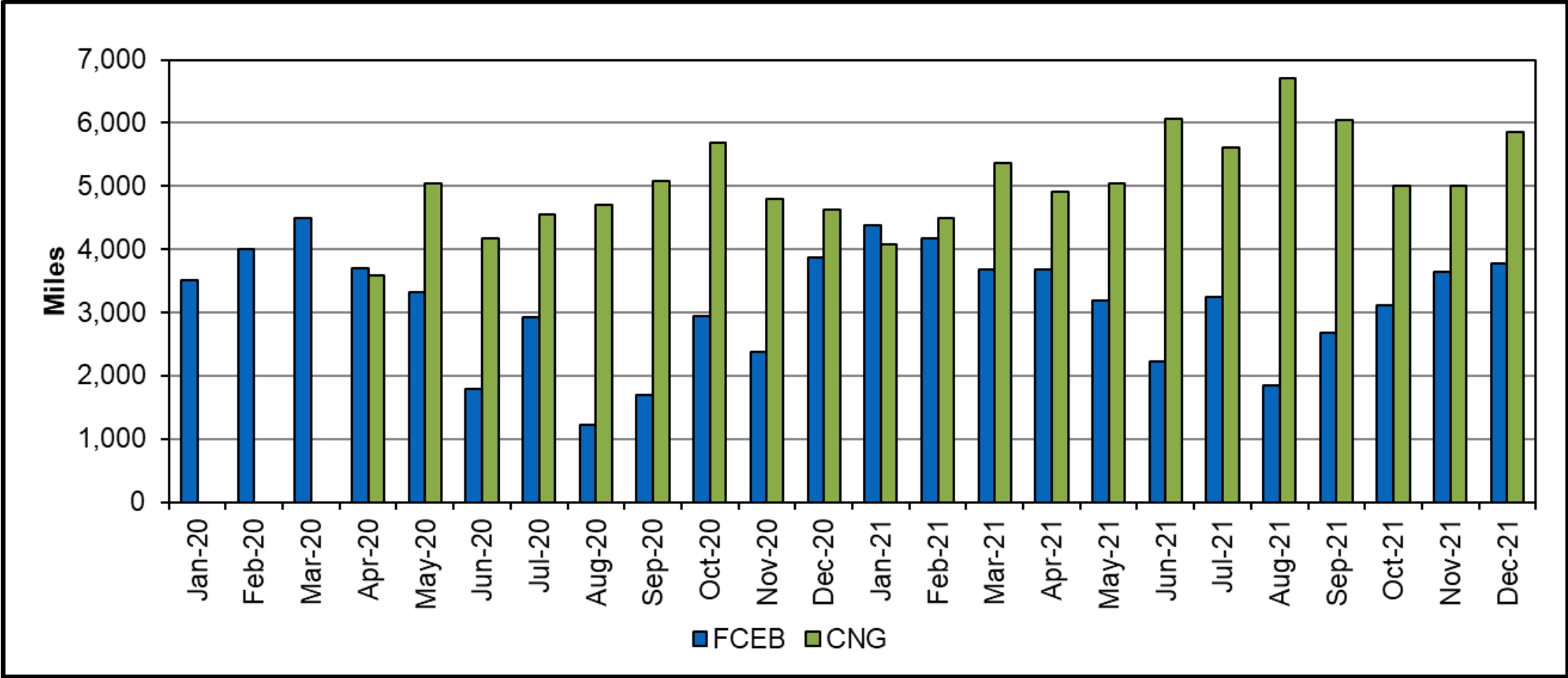
Bus	Miles	Bus Months	Average Monthly Mileage
FC14*	61,728	20	3,086
FC15	71,719	24	2,988
FC16	70,925	24	2,955
FC17	79,689	24	3,320
FC18	77,639	24	3,235
FCEB Fleet	361,700	116	3,118

Bus	Miles	Bus Months	Average Monthly Mileage
628	102,149	21	4,864
629^	75,186	17	4,423
630	112,231	20	5,612
631	113,449	20	5,672
632	96,066	19	5,056
CNG Fleet	499,081	97	5,145

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

^ bus 629 was phased in in August 2020

Average Monthly Miles



Clean Point Average: FCEB: 3,118 miles; CNG: 5,145 miles

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

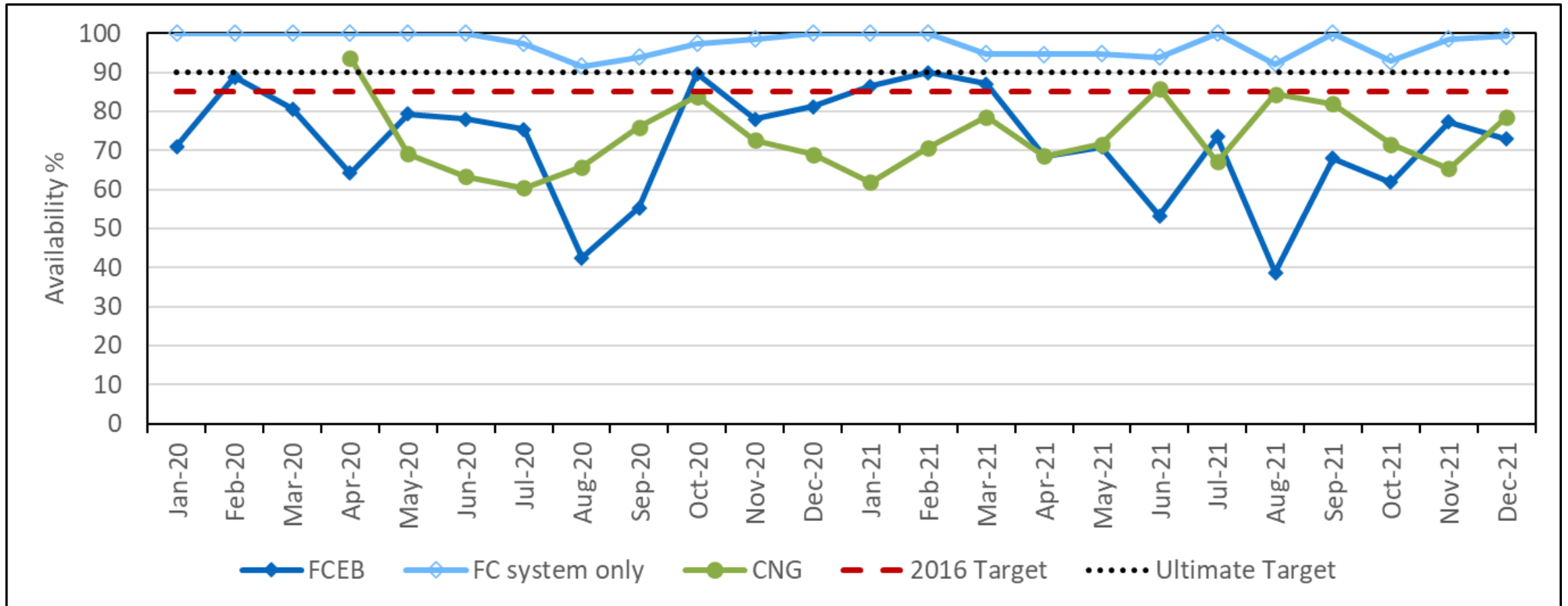
Category	FCEB # Days	FCEB %	CNG # Days	CNG %
Planned work days	3,492		2,941	
Days available	2,533	72.5	2,140	72.8
Days unavailable	959	27.5	801	27.2
Fuel cell system	91	3	N/A	—
Engine	N/A	—	59	2
Transmission	N/A	—	18	1
Electric drive	40	1	N/A	—
Batteries	50	1	N/A	—
Preventive maintenance	228	7	397	13
General bus maintenance	550	16	327	11

Monthly Availability by bus

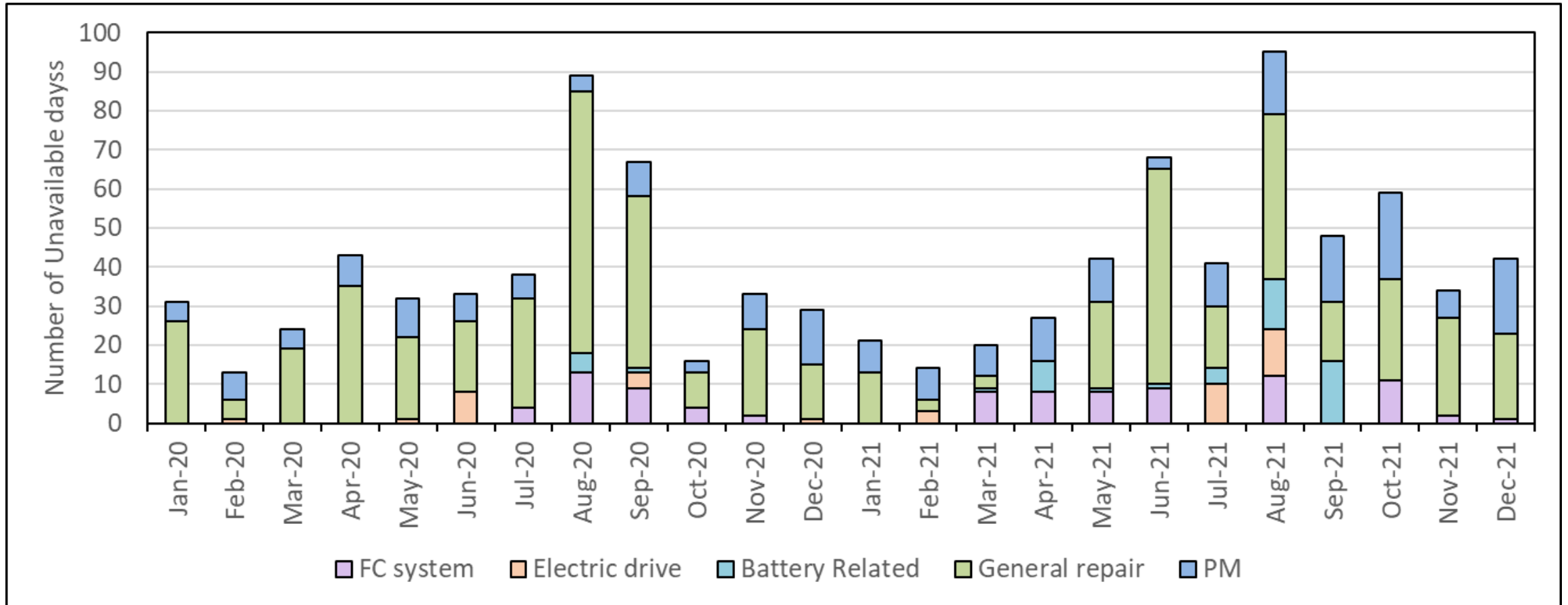
Bus	Planned Days	Available Days	% Availability
FC14	610	444	72.8
FC15	725	492	67.9
FC16	729	495	67.9
FC17	725	565	77.9
FC18	728	537	73.8
FCEB Fleet	3,517	2,533	72.0

Bus	Planned Days	Available Days	% Availability
628	626	449	71.7
629	518	325	62.7
630	610	481	78.9
631	608	476	78.3
632	579	409	70.6
CNG Fleet	2,941	2,140	72.8

Monthly Availability

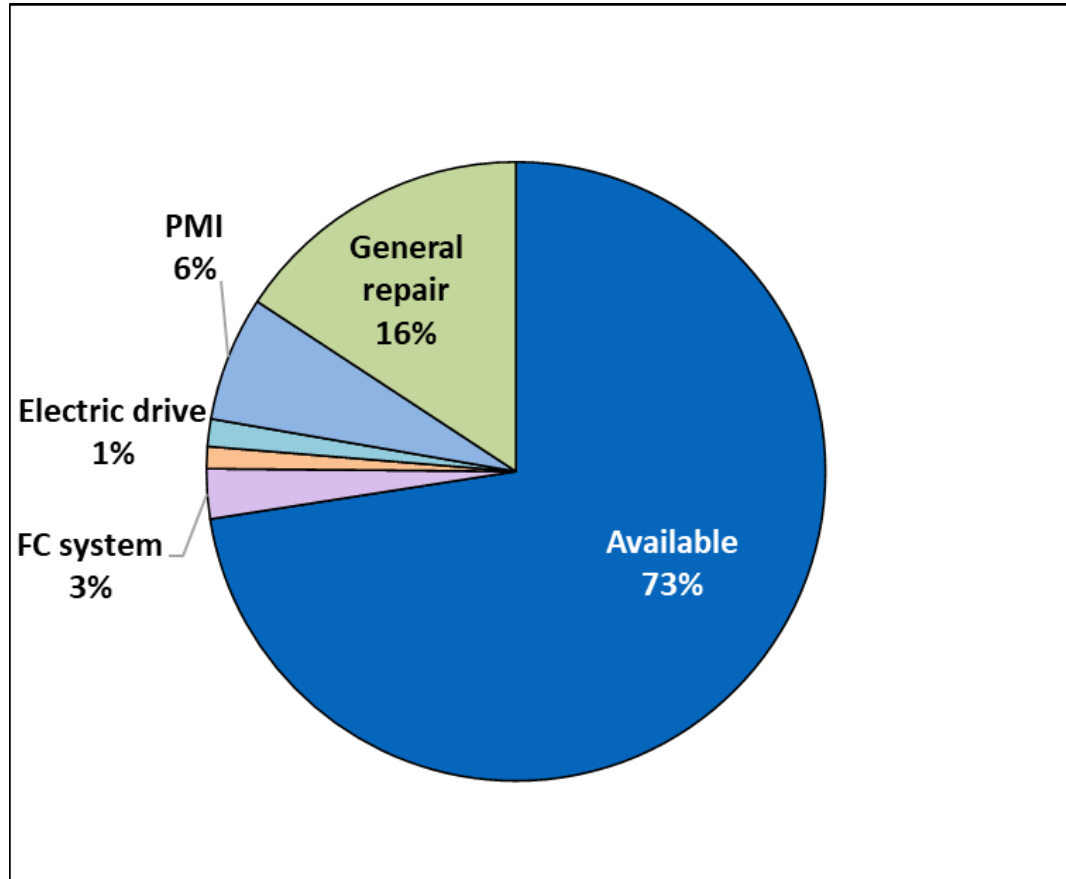


FCEB Monthly Unavailability Reasons

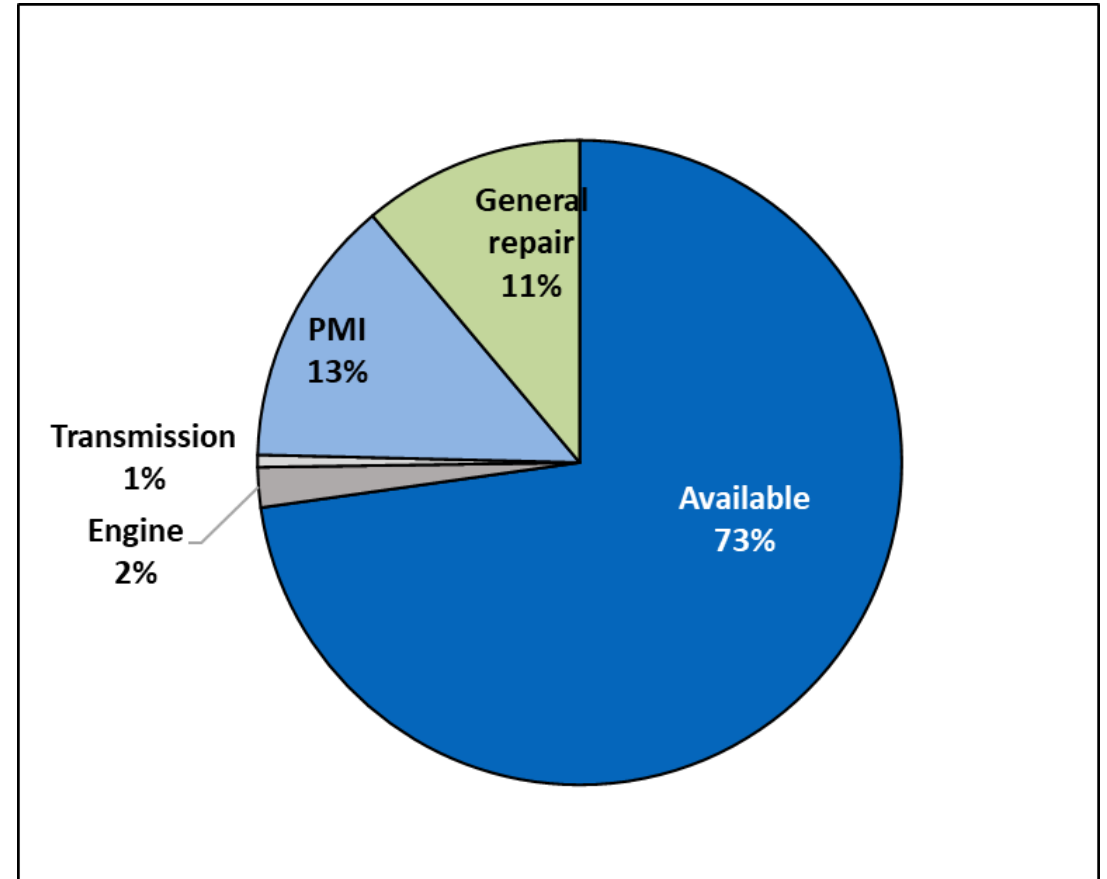


Overall Availability

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 \$21.04/kg. The average cost of hydrogen during the evaluation period was \$13.79/kg. The CNG fuel cost for the data period was \$1.27 per gge.

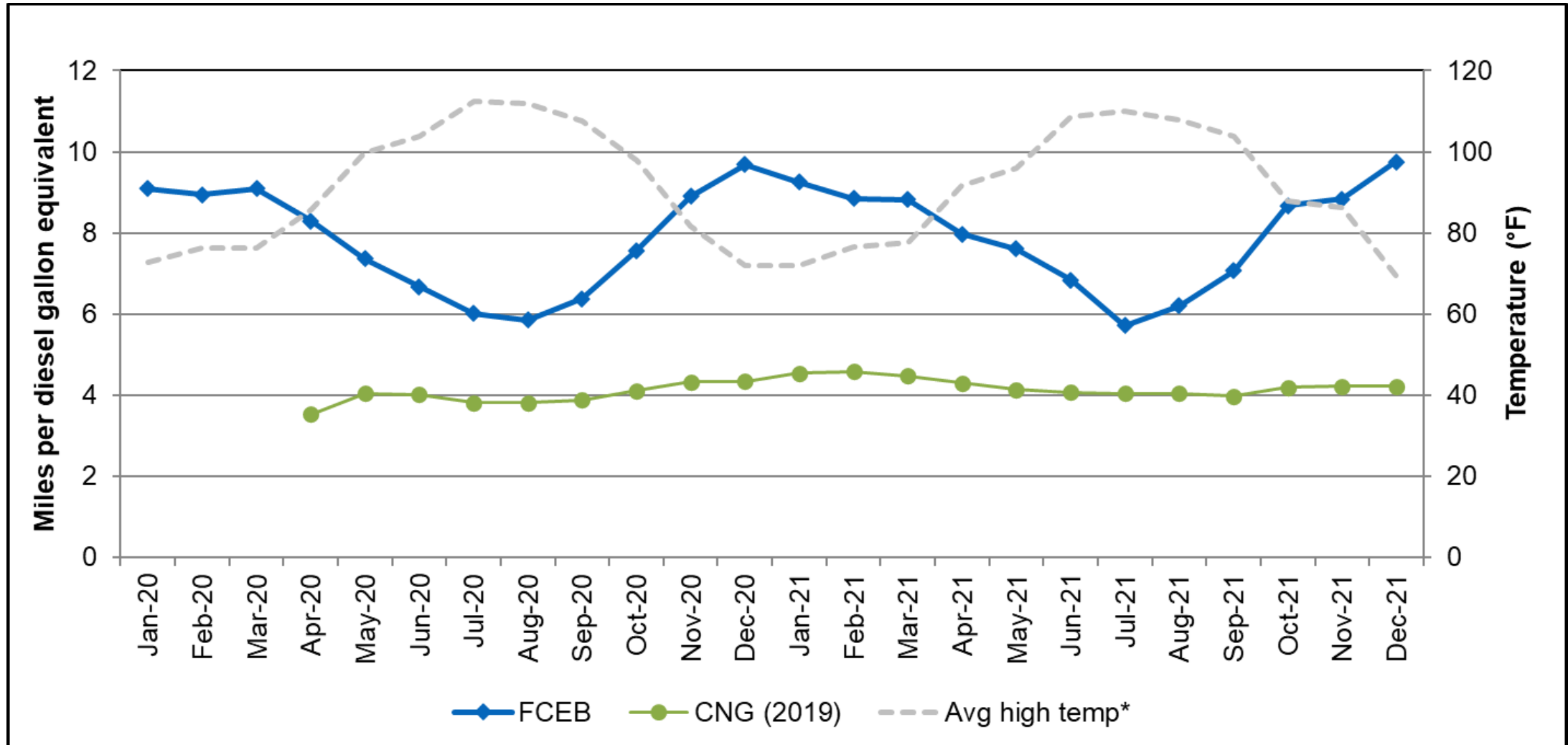
Fuel Economy by Bus

Bus	Miles	Hydrogen (kg)	mi/kg	Hydrogen (dge)	Fuel economy (mpdge)
FC14	54,032	7,740.9	6.98	6,850.4	7.89
FC15	62,735	9,000.5	6.97	7,965.0	7.88
FC16	64,261	9,165.1	7.01	8,110.7	7.92
FC17	69,898	9,820.1	7.12	8,690.3	8.04
FC18	67,644	9,450.0	7.16	8,362.9	8.09
FCEB Fleet	318,570	45,176.6	7.05	39,979.3	7.97

Bus	Miles	CNG (gge)	Miles/gge	CNG (dge)	Fuel Economy (mpdge)
628	96,194	25,850.7	3.72	23,136.4	4.16
629	69,867	19,401.3	3.60	17,364.1	4.02
630	104,843	28,438.0	3.69	25,452.0	4.12
631	105,905	27,997.4	3.78	25,057.6	4.23
632	89,937	24,391.8	3.69	21,830.7	4.12
CNG Total	466,746	126,079.1	3.70	112,840.8	4.14

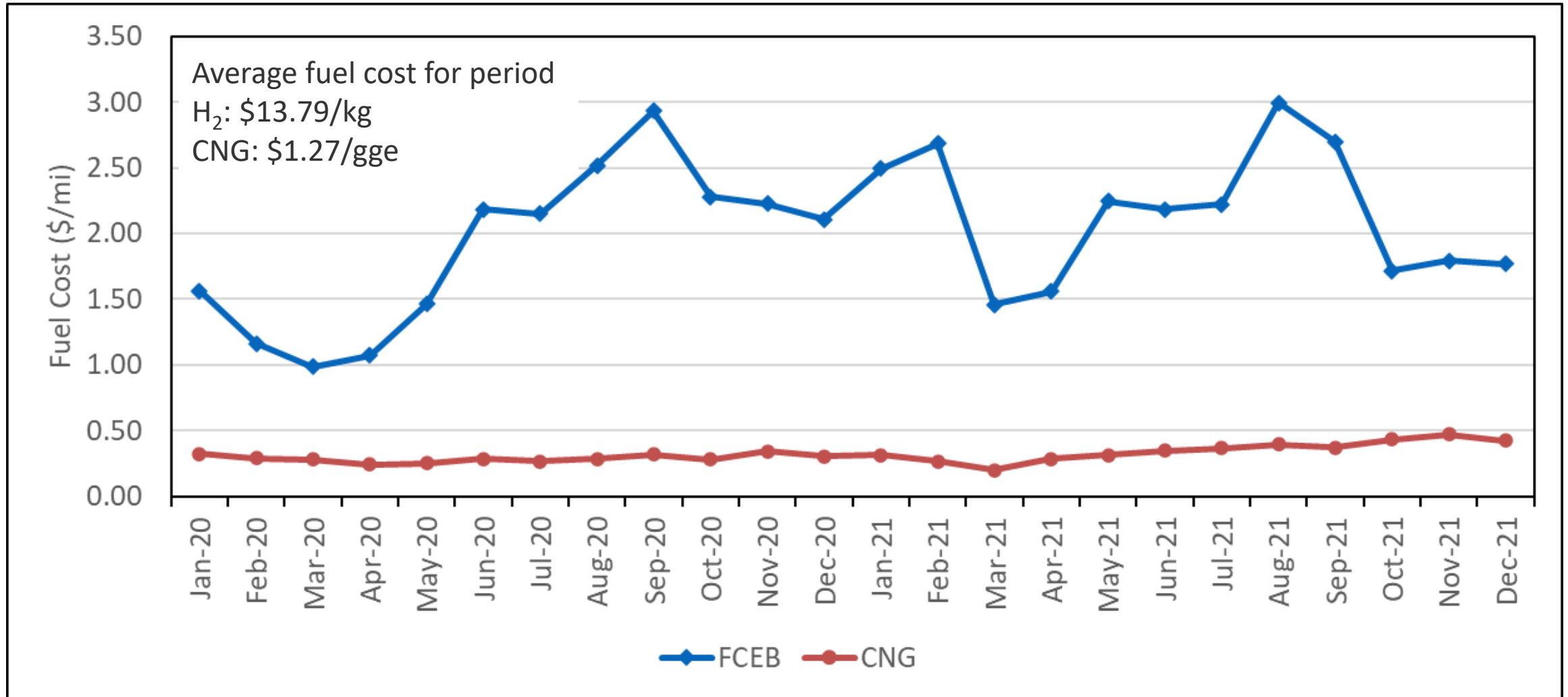
- FCEB fuel economy is almost 2 times that of the CNG buses.

Monthly Average Fuel Economy

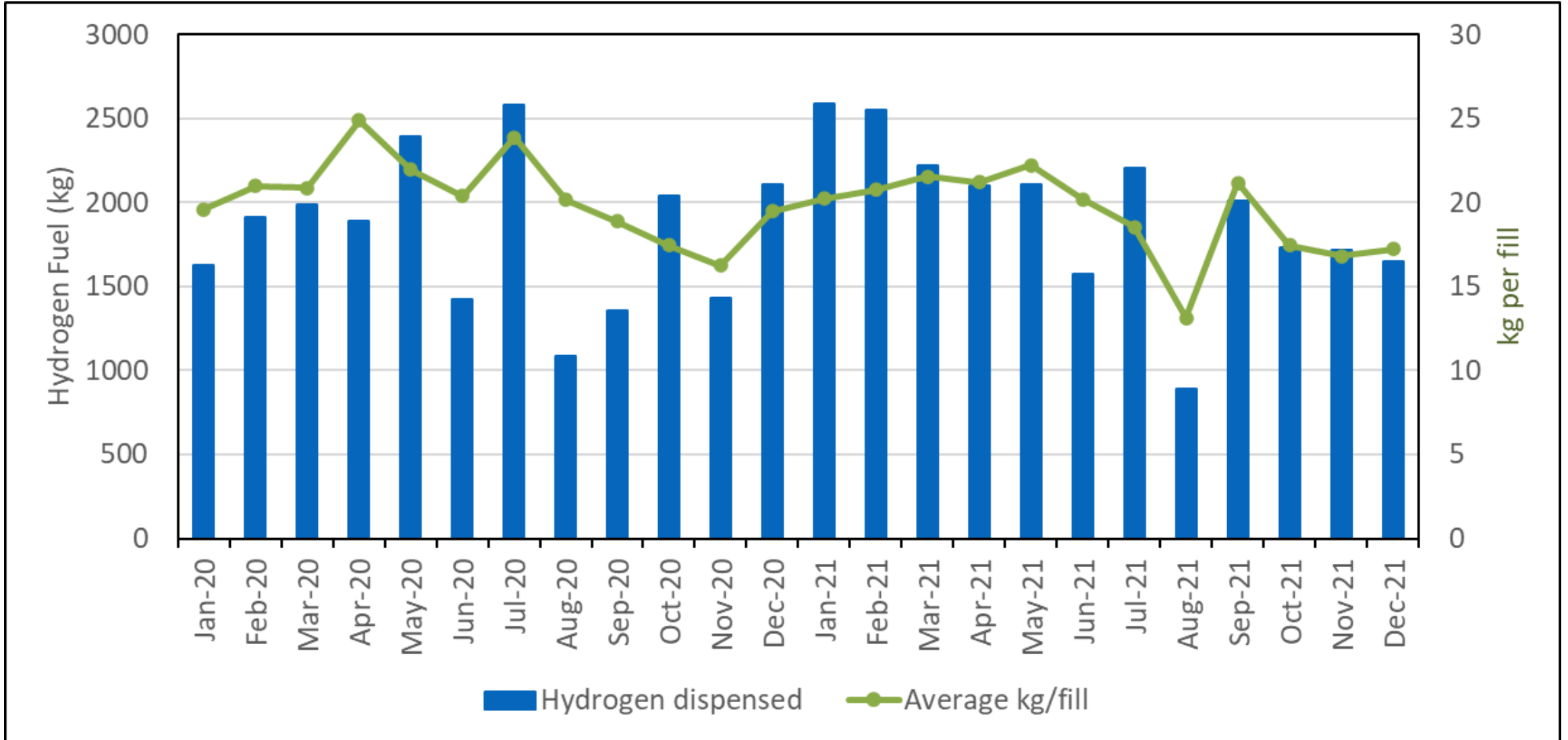


*Average monthly high temperatures at Palm Springs, CA airport. Data acquired from www.ncdn.noaa.gov

Monthly Average Fuel Cost Per Mile



Fleet Hydrogen Use

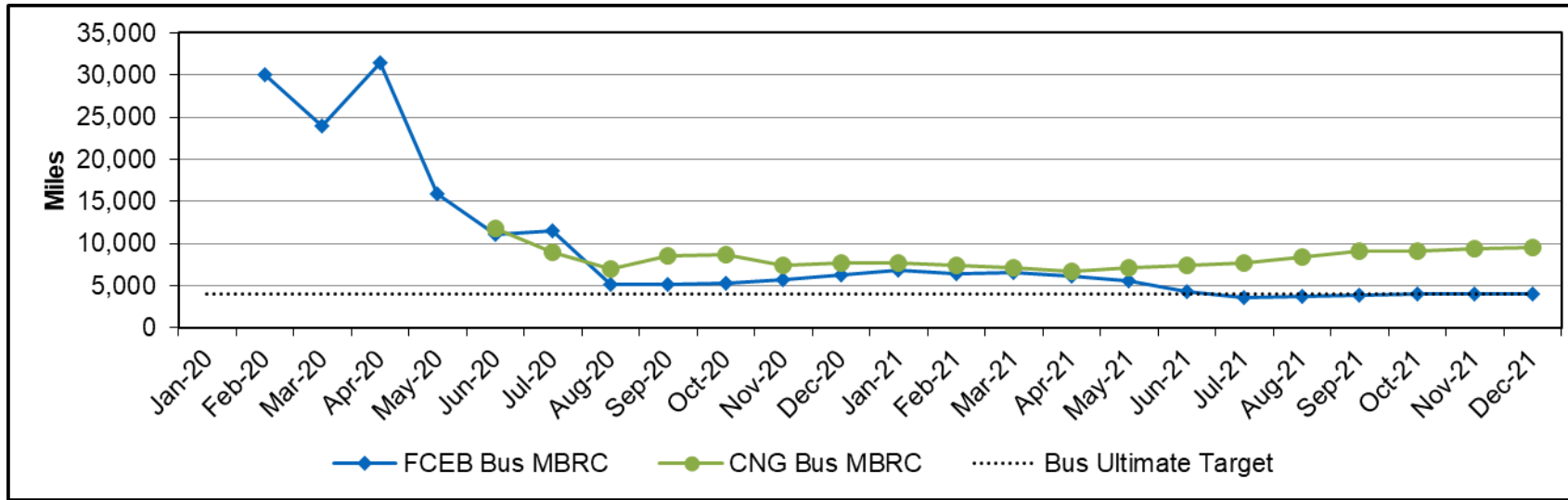


Roadcall Analysis

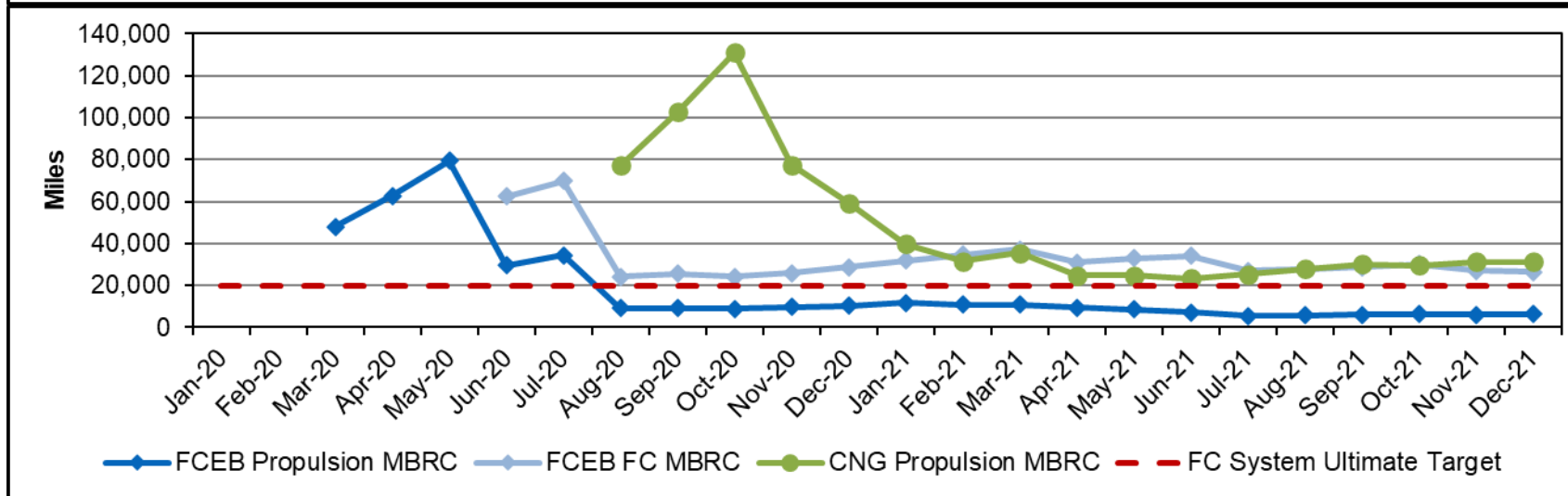
A roadcall or revenue vehicle system failure is defined as a failure of an in-service bus that causes the bus to be replaced on route or causes a significant delay in schedule. If the problem with the bus can be repaired during a layover and the schedule is kept, this is not considered a roadcall. The 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	4,281	9,598
Propulsion MBRC	6,346	31,193
FC System MBRC	24,113	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 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.

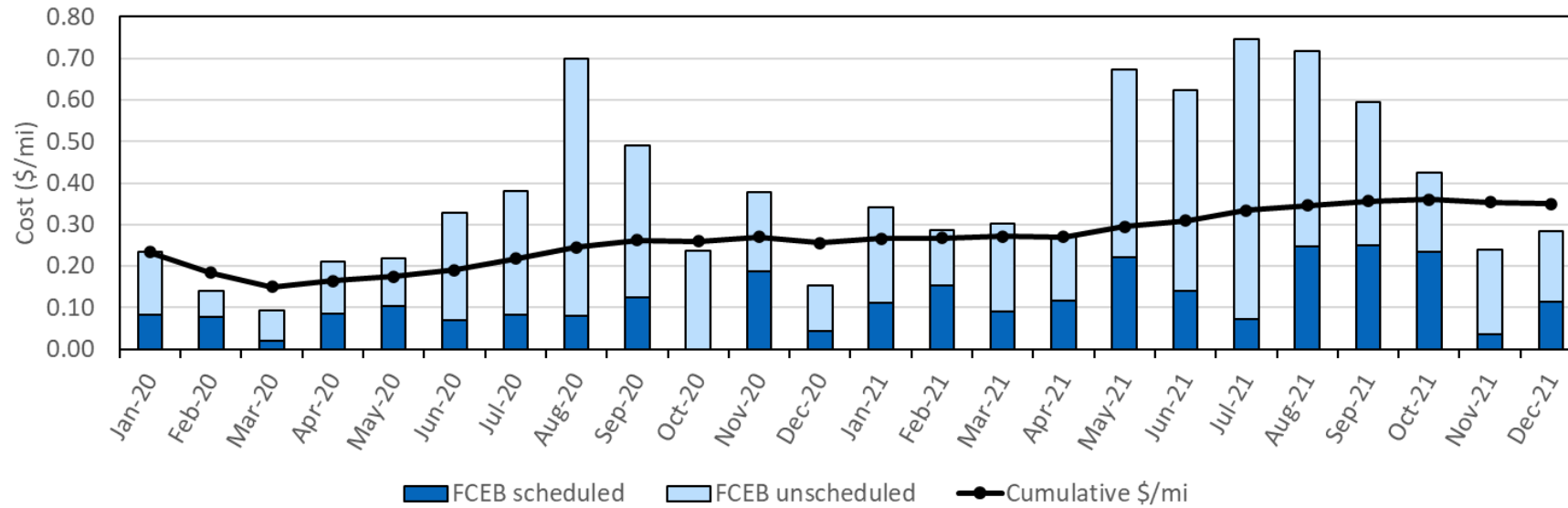
Maintenance Analysis Results

Bus	Mileage	Parts (\$)	Labor hours	Scheduled Cost (\$/mi)	Unscheduled Cost (\$/mi)	Total Cost per Mile (\$)
FC14	61,728	5,846.37	281.0	0.10	0.22	0.32
FC15	71,719	13,094.53	425.8	0.12	0.35	0.48
FC16	70,925	5,334.89	399.8	0.11	0.25	0.36
FC17	79,689	4,981.57	373.8	0.10	0.20	0.30
FC18	77,639	4,053.11	384.3	0.11	0.19	0.30
FCEB Fleet	361,700	33,310.47	1,864.5	0.11	0.24	0.35

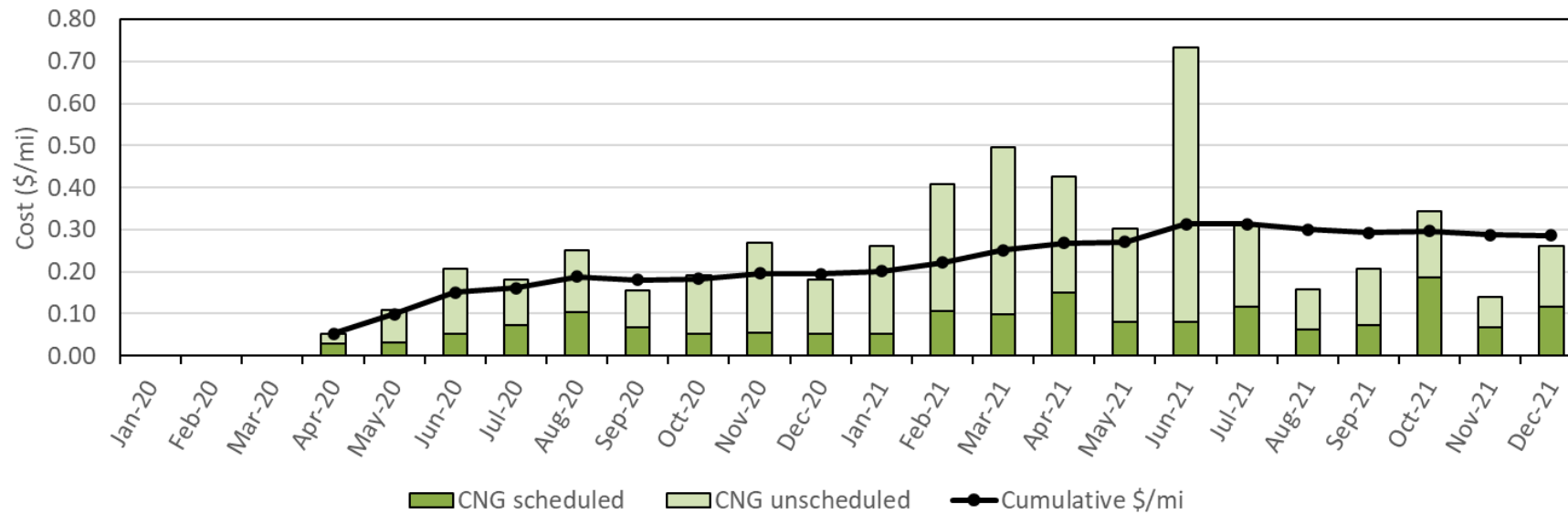
Bus	Mileage	Parts (\$)	Labor hours	Scheduled Cost (\$/mi)	Unscheduled Cost (\$/mi)	Total Cost per Mile (\$)
628	102,149	11,349.24	349.0	0.09	0.20	0.28
629	75,186	5,856.46	359.3	0.08	0.23	0.32
630	112,231	8,833.75	391.8	0.08	0.17	0.25
631	113,449	6,471.81	674.3	0.09	0.27	0.35
632	96,066	5,661.23	317.3	0.09	0.14	0.22
CNG Fleet	499,081	38,172.49	2,091.5	0.09	0.20	0.29

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

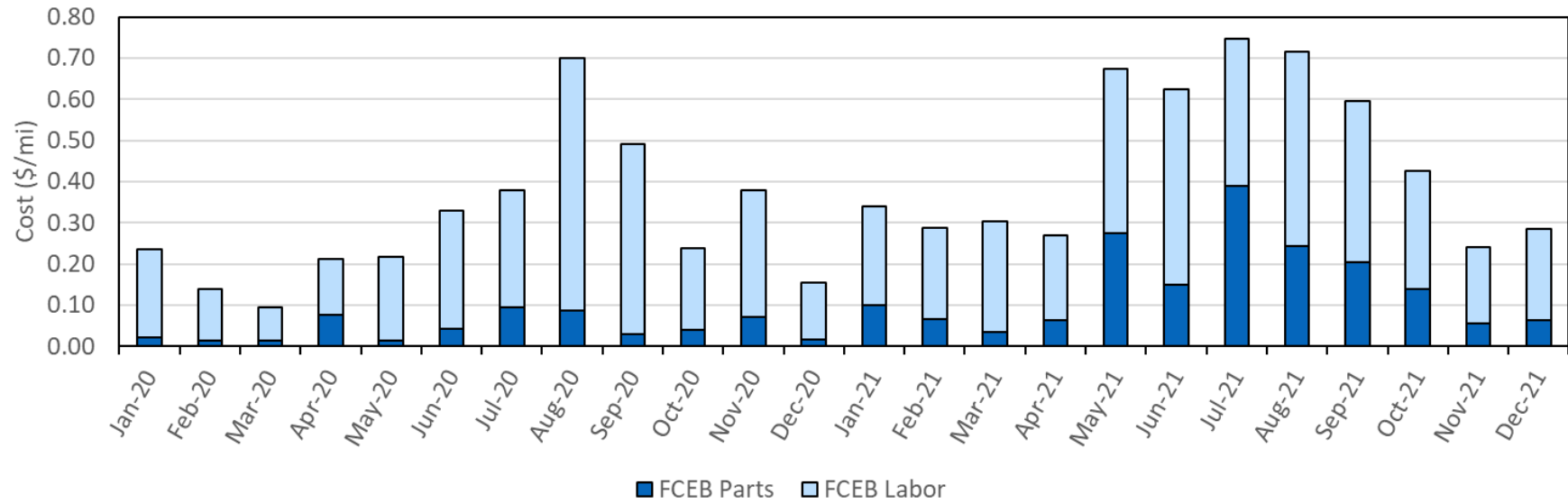
Scheduled and Unscheduled Maintenance Cost



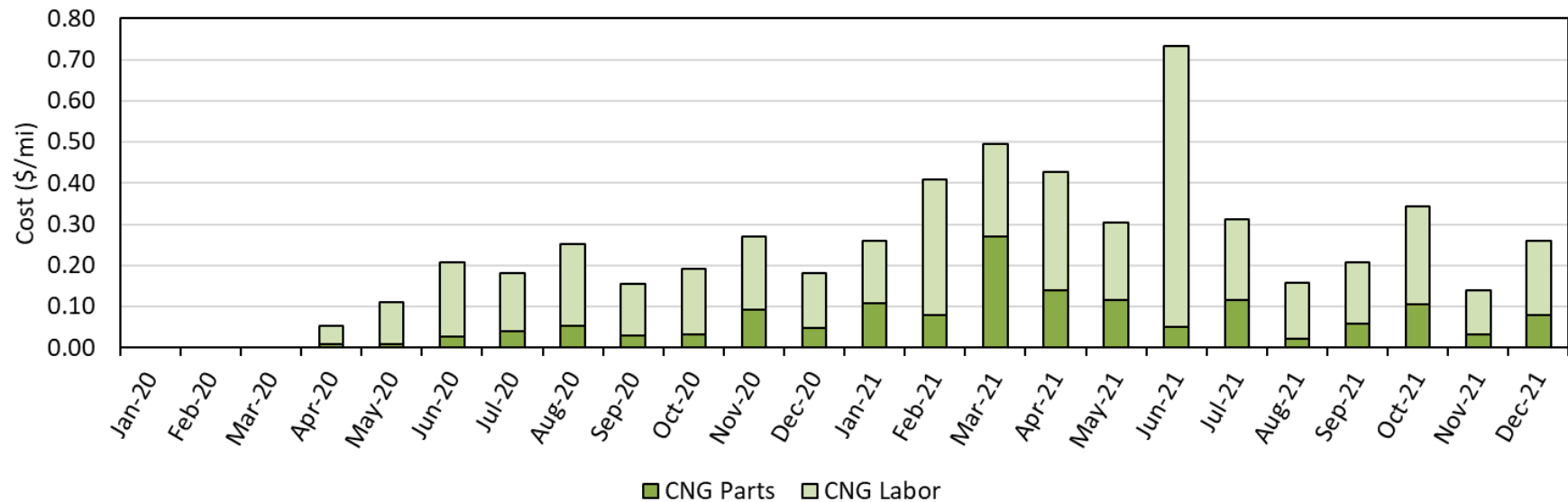
- Scheduled costs make up 32% of the FCEB fleet cost and 30% of the CNG bus fleet cost



Parts and Labor Maintenance Cost



- Most costs for both fleets are for labor: 74% for the FCEBs and 73% for the CNG buses



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	0.122	33.5	0.059	20.7
Cab, body, and accessories	0.086	23.7	0.087	30.4
PMI	0.094	25.8	0.100	35.1
Brakes	0.011	3.0	0.010	3.4
Frame, steering, and suspension	0.010	2.9	0.004	1.6
HVAC	0.017	4.7	0.005	1.7
Lighting	0.006	1.7	0.008	2.9
General air system repairs	0.009	2.5	0.007	2.4
Axles, wheels, and drive shaft	0.001	0.2	0.000	0.0
Tires	0.008	2.1	0.005	1.7
Total	0.363	100	0.286	100

Color coding:

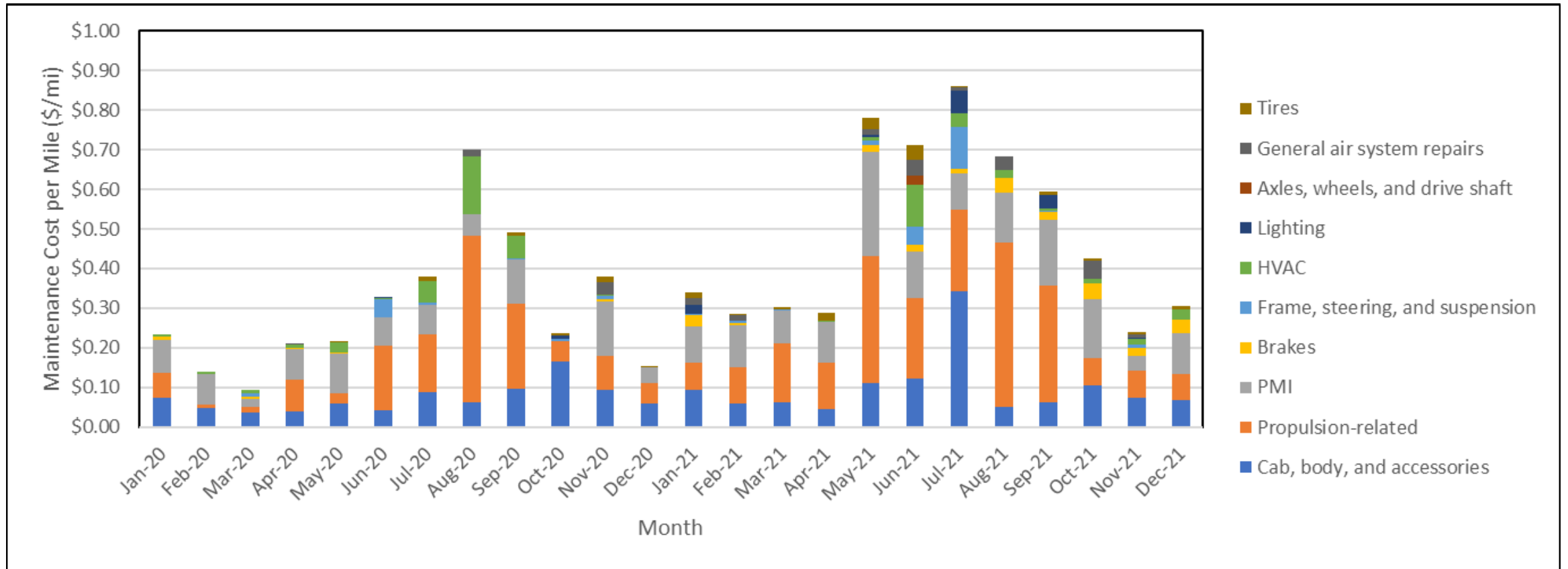
 Highest cost

 Second highest cost

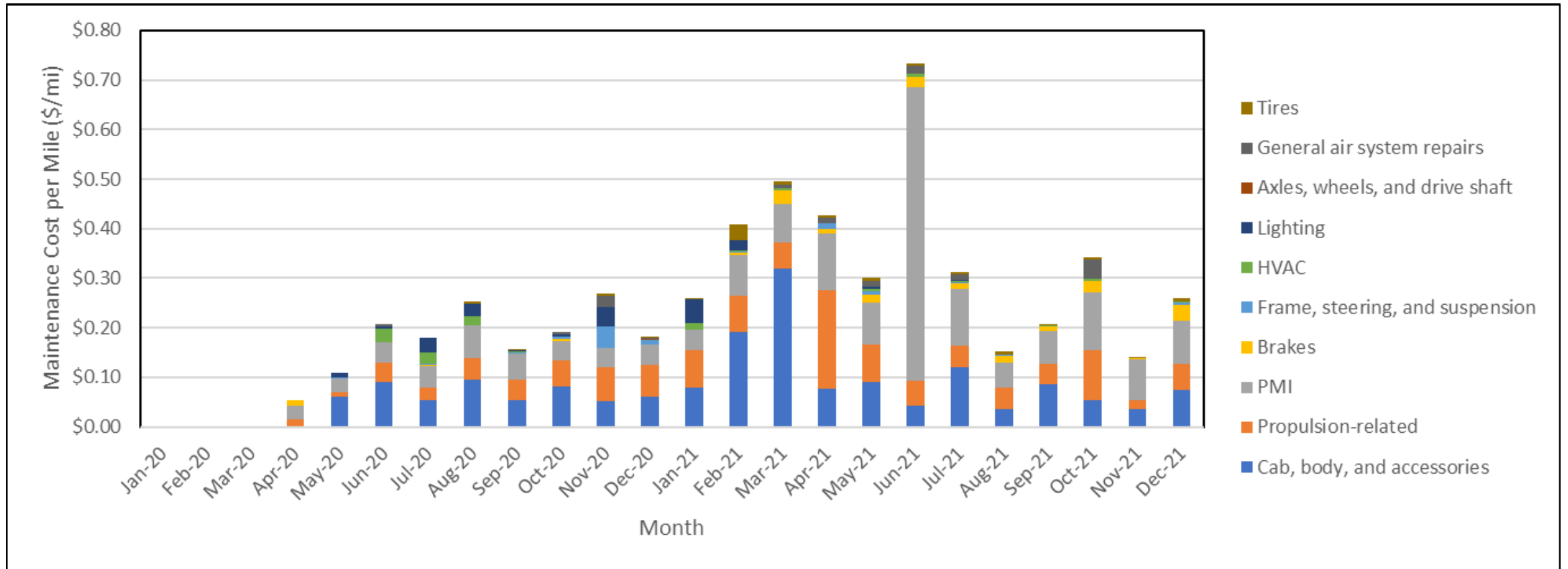
 Third highest cost

- 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		361,700	499,081	Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)	Parts cost (\$)	2,561.49	4,428.78
Total Propulsion-Related Systems (Roll-Up of All Systems)	Parts cost (\$)	14,384.22	14,368.43		Labor hours	71.3	39.0
	Labor hours	593.0	303.0		Total cost (\$)	6,123.99	6,378.78
	Total cost (\$)	44,034.22	29,518.43		Total cost (\$) per mile	0.017	0.013
	Total cost (\$) per mile	0.122	0.059	Air Intake System Repairs	Parts cost (\$)	874.09	295.70
Exhaust System Repairs	Parts cost (\$)	0.00	5.75		Labor hours	9.0	0.0
	Labor hours	0.0	0.0		Total cost (\$)	1,324.09	295.70
	Total cost (\$)	0.00	5.75		Total cost (\$) per mile	0.004	0.001
	Total cost (\$) per mile	0.000	0.000	Cooling System Repairs	Parts cost (\$)	698.03	642.88
Fuel System Repairs	Parts cost (\$)	2,824.30	753.80		Labor hours	52.3	16.0
	Labor hours	6.8	0.0		Total cost (\$)	3,310.53	1,442.88
	Total cost (\$)	3,161.80	753.80		Total cost (\$) per mile	0.009	0.003
	Total cost (\$) per mile	0.009	0.002	Transmission System Repairs	Parts cost (\$)	298.74	172.55
Powerplant System Repairs (Fuel Cell System for FCEBs)	Parts cost (\$)	6,315.53	8,068.97		Labor hours	0.5	37.3
	Labor hours	257.8	210.0		Total cost (\$)	323.74	2,035.05
	Total cost (\$)	19,203.03	18,568.97		Total cost (\$) per mile	0.001	0.004
	Total cost (\$) per mile	0.053	0.037	Hydraulic System Repairs	Parts cost (\$)	12.08	0.00
Electric Propulsion System Repairs	Parts cost (\$)	799.96	0.00		Labor hours	0.0	0.0
	Labor hours	195.5	0.8		Total cost (\$)	12.08	0.00
	Total cost (\$)	10,574.96	37.50		Total cost (\$) per mile	0.000	0.000
	Total cost (\$) per mile	0.029	0.000				

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	5	5
Period used for fuel and oil analysis	1/20–12/20	4/20–12/20
Total number of months in period	24	21
Fuel and oil analysis base fleet mileage	318,570	466,746
Period used for maintenance analysis	1/20–12/20	4/20–12/20
Total number of months in period	24	21
Maintenance analysis base fleet mileage	361,700	499,081
Average monthly mileage per vehicle	5,652	15,596
Availability	72.5	72.8
Fleet fuel usage in kg hydrogen or gge CNG	45,176.6	126,079.1
Roadcalls	93	89
Total MBRC	3,889	5,608
Propulsion roadcalls	59	57
Propulsion MBRC	6,131	8,756
Fleet mi/kg hydrogen (FCEB), mi/gge (CNG)	7.05	3.70
Representative fleet mpg (energy equiv.)	7.97	4.14
Fuel cost per kg hydrogen or gge CNG	13.79	1.27
Fuel cost per mile	1.960	0.330
Total scheduled repair cost per mile	0.110	0.085
Total unscheduled repair cost per mile	0.239	0.201
Total maintenance cost per mile	0.350	0.286
Total operating cost per mile	2.310	0.616

Maintenance Cost Summary

Maintenance Cost Summary

	FCEB	CNG
Fleet mileage	361,700	499,081
Total parts cost	\$34,914.66	\$38,172.49
Total labor hours	1931.3	2087.8
Average labor cost (@ \$50.00 per hour)	\$96,562.50	\$104,387.50
Total maintenance cost	\$131,477.16	\$142,559.99
Total maintenance cost per bus	\$26,295.43	\$28,512.00
Total maintenance cost per mile	\$0.363	\$0.286

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	\$14,384.22	\$14,368.43
Labor hours	593.0	303.0
Average labor cost	\$29,650.00	\$15,150.00
Total cost (for system)	\$44,034.22	\$29,518.43
Total cost (for system) per bus	\$8,806.84	\$5,903.69
Total cost (for system) per mile	\$0.122	\$0.059

Maintenance Cost by Vehicle System

	FCEB	CNG
Exhaust System Repairs (ATA VMRS 43)		
Parts cost	0.00	5.75
Labor hours	0	0
Average labor cost	\$0.00	\$0.00
Total cost (for system)	\$0.00	\$5.75
Total cost (for system) per bus	\$0.00	\$1.15
Total cost (for system) per mile	\$0.000	\$0.000
Fuel System Repairs (ATA VMRS 44)		
Parts cost	2,824.30	753.80
Labor hours	6.75	0
Average labor cost	\$337.50	\$0.00
Total cost (for system)	\$3,161.80	\$753.80
Total cost (for system) per bus	\$632.36	\$150.76
Total cost (for system) per mile	\$0.009	\$0.002
Power Plant (Engine) Repairs (ATA VMRS 45)		
Parts cost	6,315.53	8,068.97
Labor hours	257.75	210
Average labor cost	\$12,887.50	\$10,500.00
Total cost (for system)	\$19,203.03	\$18,568.97
Total cost (for system) per bus	\$3,840.61	\$3,713.79
Total cost (for system) per mile	\$0.053	\$0.037

Maintenance Cost by Vehicle System

	FCEB	CNG
Electric Propulsion Repairs (ATA VMRS 46)		
Parts cost	799.96	0.00
Labor hours	195.5	0.75
Average labor cost	\$9,775.00	\$37.50
Total cost (for system)	\$10,574.96	\$37.50
Total cost (for system) per bus	\$2,114.99	\$7.50
Total cost (for system) per mile	\$0.029	\$0.000
Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)		
Parts cost	2,561.49	4,428.78
Labor hours	71.25	39
Average labor cost	\$3,562.50	\$1,950.00
Total cost (for system)	\$6,123.99	\$6,378.78
Total cost (for system) per bus	\$1,224.80	\$1,275.76
Total cost (for system) per mile	\$0.017	\$0.013
Air Intake System Repairs (ATA VMRS 41)		
Parts cost	874.09	295.70
Labor hours	9	0
Average labor cost	\$450.00	\$0.00
Total cost (for system)	\$1,324.09	\$295.70
Total cost (for system) per bus	\$264.82	\$59.14
Total cost (for system) per mile	\$0.004	\$0.001

Maintenance Cost by Vehicle System

	FCEB	CNG
Cooling System Repairs (ATA VMRS 42)		
Parts cost	698.03	642.88
Labor hours	52.25	16
Average labor cost	\$2,612.50	\$800.00
Total cost (for system)	\$3,310.53	\$1,442.88
Total cost (for system) per bus	\$662.11	\$288.58
Total cost (for system) per mile	\$0.009	\$0.003
Hydraulic System Repairs (ATA VMRS 65)		
Parts cost	12.08	0.00
Labor hours	0	0
Average labor cost	\$0.00	\$0.00
Total cost (for system)	\$12.08	\$0.00
Total cost (for system) per bus	\$2.42	\$0.00
Total cost (for system) per mile	\$0.000	\$0.000
General Air System Repairs (ATA VMRS 10)		
Parts cost	2,359.29	2,248.79
Labor hours	18.75	24.5
Average labor cost	\$937.50	\$1,225.00
Total cost (for system)	\$3,296.79	\$3,473.79
Total cost (for system) per bus	\$659.36	\$694.76
Total cost (for system) per mile	\$0.009	\$0.007

Maintenance Cost by Vehicle System

	FCEB	CNG
Brake System Repairs (ATA VMRS 13)		
Parts cost	1,696.20	1,951.34
Labor hours	44.25	58
Average labor cost	\$2,212.50	\$2,900.00
Total cost (for system)	\$3,908.70	\$4,851.34
Total cost (for system) per bus	\$781.74	\$970.27
Total cost (for system) per mile	\$0.011	\$0.010
Transmission Repairs (ATA VMRS 27)		
Parts cost	298.74	172.55
Labor hours	0.5	37.25
Average labor cost	\$25.00	\$1,862.50
Total cost (for system)	\$323.74	\$2,035.05
Total cost (for system) per bus	\$64.75	\$407.01
Total cost (for system) per mile	\$0.001	\$0.004
Inspections Only - No Parts Replacements (101)		
Parts cost	753.50	500.04
Labor hours	662.75	991
Average labor cost	\$33,137.50	\$49,550.00
Total cost (for system)	\$33,891.00	\$50,050.04
Total cost (for system) per bus	\$6,778.20	\$10,010.01
Total cost (for system) per mile	\$0.094	\$0.100

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	12,146.53	14,696.92
Labor hours	380	573.75
Average labor cost	\$19,000.00	\$28,687.50
Total cost (for system)	\$31,146.53	\$43,384.42
Total cost (for system) per bus	\$6,229.31	\$8,676.88
Total cost (for system) per mile	\$0.086	\$0.087
HVAC System Repairs (ATA VMRS 01)		
Parts cost	120.54	416.21
Labor hours	121.25	41
Average labor cost	\$6,062.50	\$2,050.00
Total cost (for system)	\$6,183.04	\$2,466.21
Total cost (for system) per bus	\$1,236.61	\$493.24
Total cost (for system) per mile	\$0.017	\$0.005
Lighting System Repairs (ATA VMRS 34)		
Parts cost	1,923.94	3,195.32
Labor hours	5.5	20
Average labor cost	\$275.00	\$1,000.00
Total cost (for system)	\$2,198.94	\$4,195.32
Total cost (for system) per bus	\$439.79	\$839.06
Total cost (for system) per mile	\$0.006	\$0.008

Maintenance Cost by Vehicle System

	FCEB	CNG
Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)		
Parts cost	1,530.44	781.30
Labor hours	44.75	28.75
Average labor cost	\$2,237.50	\$1,437.50
Total cost (for system)	\$3,767.94	\$2,218.80
Total cost (for system) per bus	\$753.59	\$443.76
Total cost (for system) per mile	\$0.010	\$0.004
Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)		
Parts cost	0.00	14.14
Labor hours	5	0.5
Average labor cost	\$250.00	\$25.00
Total cost (for system)	\$250.00	\$39.14
Total cost (for system) per bus	\$50.00	\$7.83
Total cost (for system) per mile	\$0.001	\$0.000
Tire Repairs (ATA VMRS 17)		
Parts cost	0.00	0.00
Labor hours	56	47.25
Average labor cost	\$2,800.00	\$2,362.50
Total cost (for system)	\$2,800.00	\$2,362.50
Total cost (for system) per bus	\$560.00	\$472.50
Total cost (for system) per mile	\$0.008	\$0.005

Fleet Summary Statistics: SI Units

	FCEB	CNG
Number of vehicles	5	5
Period used for fuel and oil analysis	1/20–12/20	4/20–12/20
Total number of months in period	24	21
Fuel and oil analysis base fleet kilometers	512,675	751,134
Period used for maintenance analysis	1/20–12/20	4/20–12/20
Total number of months in period	24	21
Maintenance analysis base fleet kilometers	582,084	803,171
Average monthly kilometers per vehicle	5,058	13,959
Availability	72.5	72.8
Fleet fuel usage in H ₂ kg/liter equiv	45,176.6	477,261.3
Roadcalls	93	89
Total KMBRC	6,259	9,024
Propulsion roadcalls	59	57
Propulsion KMBRC	9,866	14,091
Fleet kg hydrogen/100 km (1.13 kg H ₂ /gal diesel fuel)	8.81	
Rep. fleet fuel consumption (L/100 km)	29.52	63.54
Hydrogen cost per kg/ CNG cost/liter	13.79	0.34
Fuel cost per kilometer	1.215	0.213
Total scheduled repair cost per kilometer	0.069	0.053
Total unscheduled repair cost per kilometer	0.149	0.125
Total maintenance cost per kilometer	0.217	0.178
Total operating cost per kilometer	1.433	0.391

Maintenance Cost Summary: SI Units

Maintenance Cost Summary

	FCEB	CNG
Fleet mileage	461,042	572,813
Total parts cost	25,637.34	29,880.51
Total labor hours	1,498	1,631
Average labor cost (@ \$50.00 per hour)	74,900.00	81,537.50
Total maintenance cost	100,537	111,418
Total maintenance cost per bus	20,107.47	22,283.60
Total maintenance cost per kilometer	0.218	0.195

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	582,084	803,171
Labor hours	\$34,914.66	\$38,172.49
Average labor cost	1931.3	2087.8
Total cost (for system)	\$96,562.50	\$104,387.50
Total cost (for system) per bus	\$131,477.16	\$142,559.99
Total cost (for system) per kilometer	\$26,295.43	\$28,512.00

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	1
Fuel System (ATA VMRS 44)	2	7
Power Plant (Engine) (ATA VMRS 45)	48	195
Electric Propulsion (ATA VMRS 46)	15	0
Electrical System (ATA VMRS 30, 31, 32, 33)	15	20
Air Intake System (ATA VMRS 41)	34	1
Cooling System (ATA VMRS 42)	1	11
Hydraulic System (ATA VMRS 65)	2	2
General Air System (ATA VMRS 10)	11	8
Brake System (ATA VMRS 13)	10	25
Transmission (ATA VMRS 27)	6	4
Cab, Body, and Accessories (ATA VMRS 02, 50, 71)	164	171
HVAC System (ATA VMRS 01)	6	6
Lighting System (ATA VMRS 34)	9	7
Frame, Steering, and Suspension (VRMS 14, 15, 16)	8	17
Axle, Wheel, and Drive Shaft (ATA VMRS 11, 18, 22, 24)	0	2
Tire (ATA VMRS 17)	0	0

FCEB Total Miles =
361,700
 CNG Total Miles =
499,081

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