Foothill Transit Agency Battery Electric Bus Progress Report

Data Period Focus: Jan. 2020 through June 2020

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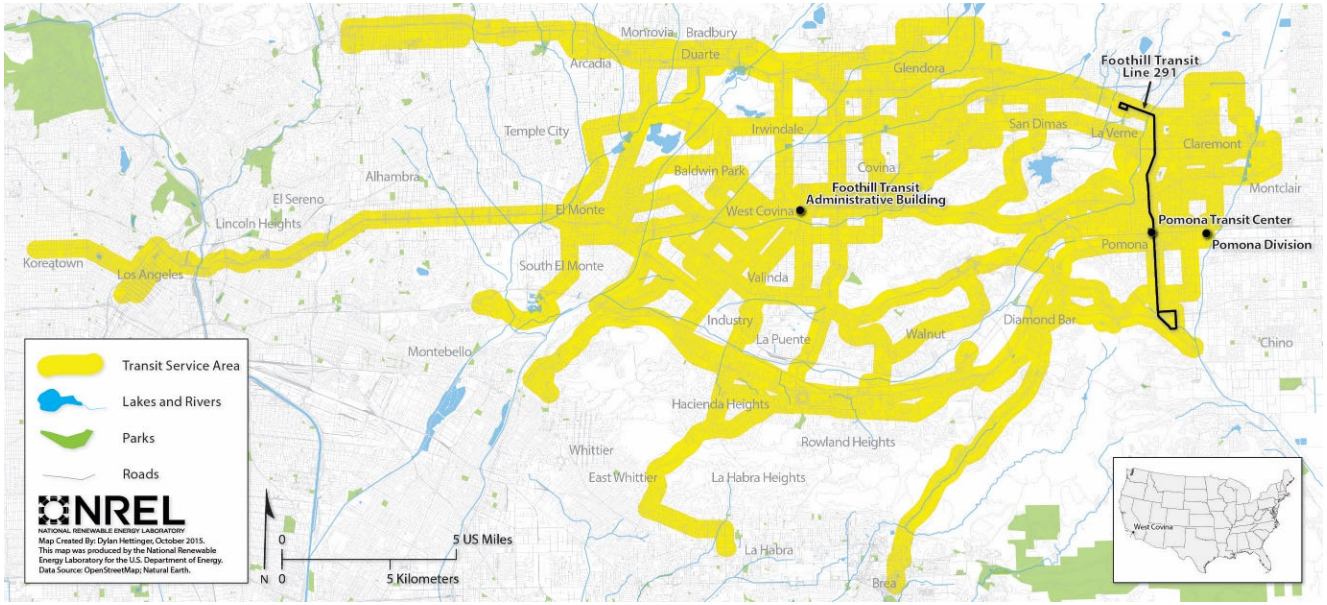
Introduction

This report summarizes results of a battery electric bus (BEB) evaluation at Foothill Transit, located in the San Gabriel Valley area of Los Angeles, California. Foothill Transit is collaborating with the California Air Resources Board and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) to evaluate the buses in revenue service. The focus of this evaluation is to compare the performance and the operating costs of the BEBs to that of conventional technology buses and to track progress over time. Previous reports documented results from April 2014 through December 2019 (report references). This report extends the previous data analysis through June 2020 and includes additional data analysis for a second fleet of BEBs operating at another depot. The data period focus of this report is January 2020–June 2020. This is the final planned progress report on the Foothill Transit fleet. NREL will publish a final technical report in early 2021 that incorporates data through December 2020.

Each NREL evaluation tracks data and performance results for a specific transit agency operating a specific manufacturer's technology design. Results from different original equipment manufacturer 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.

Fleet Profile

Foothill Transit serves a 327-square-mile area covering the San Gabriel and Pomona Valley region of Los Angeles County. Foothill Transit's administrative office is located in West Covina, California. Foothill Transit is governed by a joint powers authority of 22 member cities and the County of Los Angeles.



Foothill Transit operates 36 local and express routes, including commuter runs to downtown Los Angeles. The current bus fleet consists of 343 compressed natural gas (CNG) buses and 33 BEBs.

Report Structure

Foothill Transit operates BEB fleets at both its operation and maintenance facilities:

Operations & Maintenance Facility	BEB Fleet Description	NREL BEB Fleet ID	Number of Buses	Charging Strategy
Pomona	Proterra, 35-ft fast charge (original demonstration fleet)		2	On route, fast charge
	Proterra, 35-ft fast charge	BEB 35FC	12	On route, fast charge
	Proterra, 40-ft fast charge	BEB 40FC	2	On route, fast charge
Arcadia	Proterra, 40-ft Catalyst, extended range	BEB 40E2	14	Plug in at depot with supplemental fast charging on route
	Proterra, 35-ft Catalyst, extended range	BEB 35E2	3	Plug in at depot

NREL is collecting data on the four BEB fleets with assigned fleet IDs above and two CNG baseline fleets—one at each facility. The BEB 35E2 fleet at the Arcadia facility is not the focus of this report; however, NREL collects selected data to enable analysis of cost per mile for all BEBs at the Arcadia facility. This report is organized into two sections based on where the buses are operated. The first section focuses on the buses operated out of Pomona and the second section covers the buses operated out of Arcadia.

Pomona BEB Results

Proterra BEB 35FC

Proterra BEB 40FC

North American Bus Industries (NABI) CNG baseline

Results Summary

Bus fleets: Evaluation includes 12 Proterra 35-ft fast charge buses (BEB 35FC), 2 Proterra 40-ft Catalyst fast charge buses (BEB 40FC), and 8 NABI 42-ft CNG buses.

Bus use: The BEBs are operated on a 16-mile route (Line 291) that circles through the Pomona Transit Center (PTC) for charging. The average speed for this route is 10.6 miles per hour (mph). The CNG buses are randomly dispatched on all routes out of the operations facility, including higher-speed commuter routes. The average speed for the CNG buses is 17.6 mph. This difference in duty cycle influences the comparison of mileage, fuel economy, and costs per mile between fleets.

Reduced service: In April 2020, Foothill Transit reduced its service to 70% because of shutdowns for the COVID-19 pandemic. This resulted in significantly lower mileage accumulation on the BEBs, which has a noticeable effect on analyses that use mileage for calculations.

Availability: Availability in the first half of 2020 was 53% for the BEB 35FC buses, 70% for the BEB 40FC buses, and 90% for the CNG buses. Most unavailable time for the BEBs and CNG buses was due to general bus-related problems. Issues with the low-voltage batteries affected BEB availability. Other downtime resulted from issues with the energy storage system.

Results Summary (continued)

Fuel economy: From the beginning of the evaluation, NREL has collected miles and energy use from the Proterra data system on each bus. In 2018, Proterra transitioned its data system to a new system to increase capability. During the transition, some data were lost. In early 2018, Foothill Transit installed individual data loggers on each of its BEBs. NREL is using these data for calculating the fuel economy for the 35-ft buses. The data logger data for the BEB 40-ft buses were not available until May 2019. These data gaps are marked on the charts.

BEB energy efficiency in the first half of 2020 was 1.91 kWh/mi for the BEB 35FC fleet and 1.92 kWh/mi for the BEB 40FC. Fuel economy for the CNG bus fleet was 3.44 miles per gasoline gallon equivalent (mpgge). For comparison, diesel equivalent fuel economy was 19.69 miles per diesel gallon equivalent (mpdge) for the BEB 35FC, 19.61 mpdge for the BEB 40FC, and 3.94 mpdge for the CNG fleet. The BEB fuel economy is approximately five times that of the CNG buses as they are currently operated by Foothill Transit. Differences in duty cycle, such as number of stops and average speed, will impact the fuel economy of the fleets. Note that the 40-ft CNG buses are heavier than the 35-ft BEBs, which can also affect fuel economy.

Results Summary (continued)

Fuel cost: Since first placing its BEBs in service, Foothill Transit has been subject to three different electricity rate structures. The agency is currently on the TOU-EV-8 rate schedule with its utility provider, Southern California Edison. Based on energy purchased in the first half of 2020, the BEB fleet had a fuel cost of $0.44/mi (at $0.174/kWh) and the CNG fleet had a fuel cost of $0.31/mi (at $1.07/gge). The cost per unit of energy/fuel is the average for the data period of January 2020–June 2020.

Results Summary (continued)

Maintenance cost: Cost to maintain the buses in the first half of 2020 was $1.37/mi for the BEB 35FC buses, $0.84/mi for the BEB 40FC buses, and $0.51/mi for the CNG buses. This is a significant increase from what was reported in the last data period. Several factors contributed to the higher cost:

- Reduced service for the COVID-19 pandemic results in lower mileage accumulation for all three fleets. During this time, any maintenance cost is amplified by the low number of miles. Actual labor hours and parts costs were lower than the previous period for the BEB 35FC fleet, but the mileage was 2.6 times less, resulting in a cost per mile that is 1.6 times higher.
- On-site contractor staff handle all maintenance. For some work orders, increased labor hours were needed to troubleshoot and repair issues. During the data period, maintenance staff spent labor hours troubleshooting issues with the high-voltage batteries on several buses, although Proterra eventually handled the actual repair. Other issues resulting in higher labor hours were not due to advanced technology components. For one bus, the labor hours were high to replace a windshield wiper motor because the dash had to be removed to reach the motor.

Results Summary (continued)

- Foothill Transit continues to have issues with the low-voltage batteries. NREL updated the low-voltage battery data analysis for all three bus fleets. The BEBs averaged 11.6 replacements per bus at approximately 10,500 miles between replacement. The CNG buses averaged 2.6 replacements per bus at more than 121,000 miles between replacement. One issue is that the accessories (e.g., farebox, cameras) continually draw power from these batteries. The CNG buses are equipped with an auto shutoff for the accessories; the BEBs are not. Proterra reports that it has developed an auto-shutoff feature for its new designs. The manufacturer will provide a retrofit for BEBs currently in service. Because this issue is not related to the BEB technology, NREL has provided the costs with and without the low-voltage battery replacement costs.
    - Total maintenance cost without low-voltage battery costs was $1.18/mi for the BEB 35FC buses, $0.65/mi for the BEB 40FC buses, and $0.47/mi for the CNG buses.

Future analysis: NREL will continue to collect data on the two existing BEB fleets in comparison to the CNG baseline fleet through the end of 2020.

Evaluation Buses: Specifications

Vehicle System	BEB 35FC	BEB 40FC	CNG
Number of buses	12	2	8
Bus manufacturer/model	Proterra/BE35	Proterra/Catalyst Fast Charge	NABI/BRT-07.03
Model year	2014	2016	2014
Bus purchase cost[a]	$904,490	$879,845	$575,000
Length/width/height	35 ft/102 in./129 in.	42.5 ft/102 in./134 in.	42 ft/102 in./137 in.
GVWR[b]/curb weight	37,320 lb/27,680 lb	39,050 lb/27,000 lb	42,540 lb/33,880 lb
Wheelbase	237 in.	296 in.	308 in.
Passenger capacity	35 seats, 2 wheelchair positions, 18 standees	40 seats, 2 wheelchair positions, 18 standees	38 seats, 2 wheelchair positions, 10 standees
Motor or engine	Permanent magnet, UQM, PP220	Permanent magnet, UQM, PP220	CNG engine, Cummins, 8.9 ISL G
Rated power	220 kW peak (295 hp)	220 kW peak (295 hp)	280 hp @ 2,200 rpm
Energy storage (BEB) Fuel capacity (CNG)	Lithium-titanate batteries, Altairnano, TerraVolt 368 volts, 88 kWh total energy	Lithium-titanate batteries, Toshiba, TerraVolt 331 volts, 106 kWh total energy	7 Type IV cylinders, 22,204 scf[c] at 3,600 psi[d]
Accessories	Electric	Electric	Mechanical
Emissions equipment	N/A	N/A	3-way catalyst
Transmission/retarder	Regenerative braking	Regenerative braking	N/A

[a] Includes amenities such as painting of bus and livery, surveillance system, public address (PA) system, radio, and safety vision monitor
[b] Gross vehicle weight rating
[c] Standard cubic feet
[d] Pounds per square inch

Evaluation Buses

BEB 35FC

Photo by Leslie Eudy, NREL

BEB 40FC

Photo courtesy of Foothill Transit

CNG

Photo by Leslie Eudy, NREL

Infrastructure Description

Foothill worked with the City of Pomona to establish an on-route fast charging station at the PTC. The station features two Eaton 500-kW chargers in a climate-controlled building with charge heads (right photo) positioned on either side (left photo). The two chargers operate as separate units with a dedicated control system for each. A common communication network serves both units with sensors to detect which charge head a bus is approaching to enable proper bus-to-charger communication for docking. The system is designed to fully charge a bus in under 10 minutes. For Line 291, typical charge times are around 7 minutes, including docking time. Foothill Transit built a layover time into the schedule to allow enough time for charging. Software controls prevent charging from surpassing the kilowatt-hour limit that results in high demand charges.

Photos by Leslie Eudy, NREL

Data Summary: Total from Start of Service

Data Item	BEB 35FC	BEB 40FC	CNG
Number of buses	12	2	8
Data period	4/2014–6/2020	1/2017–6/2020	10/2014–6/2020
Number of months	75	42	69
Total mileage in data period	1,747,282	150,713	2,548,080
Average monthly mileage per bus	1,999	1,794	4,616
Availability (85% is target)	81.0%	79.8%	94.6%
Fuel consumption for BEBs (kWh/mile) or fuel economy for CNG buses (mpgge)	2.15	2.09	3.75
Fuel economy (mpdge)	17.47	17.99	4.30
Average speed, including stops (mph)	10.6	10.6	17.6
Miles between road call (MBRC[a])—bus	5,768	7,929	25,229
MBRC[a]—propulsion system only	14,142	18,831	36,929
MBRC[a]—energy storage system (ESS) only	194,142	137,003	—
Total maintenance cost ($/mile)[b]	0.476	0.511	0.305
Total maintenance cost without low-voltage battery costs ($/mile)[c]	*0.418*	*0.417*	*0.295*
Maintenance cost—propulsion system only ($/mile)	0.168	0.171	0.127
Propulsion system maintenance cost without low-voltage battery costs ($/mile)[c]	*0.110*	*0.077*	*0.117*

[a] MBRC data cumulative from the clean point of April 2014 through end of current data period
[b] Work order maintenance cost
[c] See issue with the low-voltage batteries explained on slide 56

Data Summary: Jan.–June 2020

Data Item	BEB 35FC	BEB 40FC	CNG
Number of buses	12	2	8
Data period	1/2020–6/2020	1/2020–6/2020	1/2020–6/2020
Number of months	6	6	6
Total mileage in data period	45,286	13,510	177,234
Average monthly mileage per bus	686	1,126	3,692
Availability (85% is target)	53.1%	69.7%	90.0%
Fuel consumption for BEBs (kWh/mile) or fuel economy for CNG buses (mpgge)	1.91	1.92	3.44
Fuel economy (mpdge)	19.69	19.61	3.94
Average speed, including stops (mph)	10.60	10.60	17.60
MBRC[a]—bus	5,768	7,929	25,229
MBRC[a]—propulsion system only	14,142	18,831	36,929
MBRC[a]—ESS only	194,142	137,003	—
Total maintenance cost ($/mile)[b]	1.372	0.835	0.507
Total maintenance cost without low-voltage battery costs ($/mile)[c]	*1.179*	*0.651*	*0.474*
Maintenance cost—propulsion system only ($/mile)	0.589	0.378	0.249
Propulsion system maintenance cost without low-voltage battery costs ($/mile)[c]	*0.396*	*0.194*	*0.216*

[a] MBRC data cumulative from the clean point of April 2014 through end of current data period
[b] Work order maintenance cost
[c] See issue with the low-voltage batteries explained on slide 56

Route Assignments

Foothill Transit uses the BEB 35FC buses to fully electrify Line 291, which requires seven buses during peak hours. Line 291 is a 16.1-mile route between La Verne and Pomona that loops through the PTC in both directions. The average speed for the route is 10.6 mph. The agency adjusted the schedule to accommodate time for charging the buses. The additional buses are used as spares to allow for maintenance downtime and as fill-in buses for other appropriate routes that go through the PTC, such as Line 855. The two 40-ft buses (BEB 40FC) are also used on these routes. In October 2017, Line 855 was eliminated. From that period on, the buses were operated only on Line 291.

The CNG buses are randomly dispatched on all routes out of Pomona Operations, including commuter routes. Average speed for Pomona Operations is 17.6 mph.

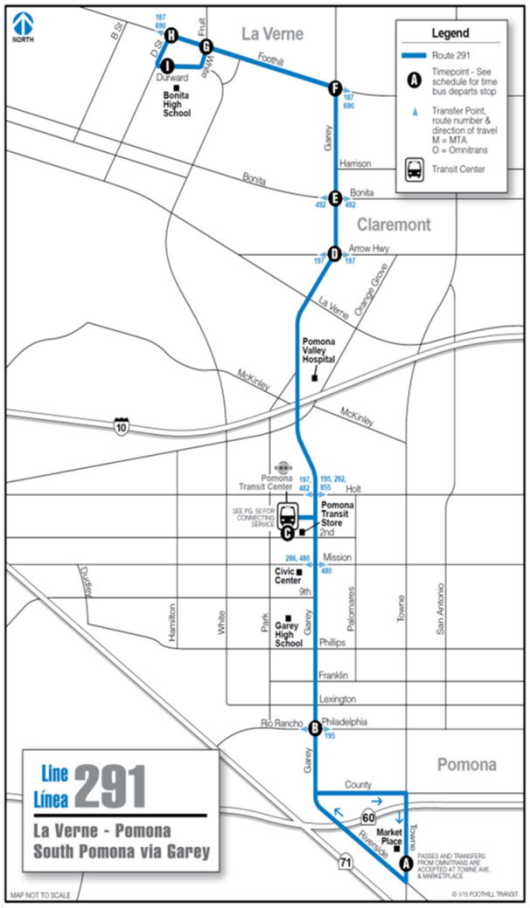
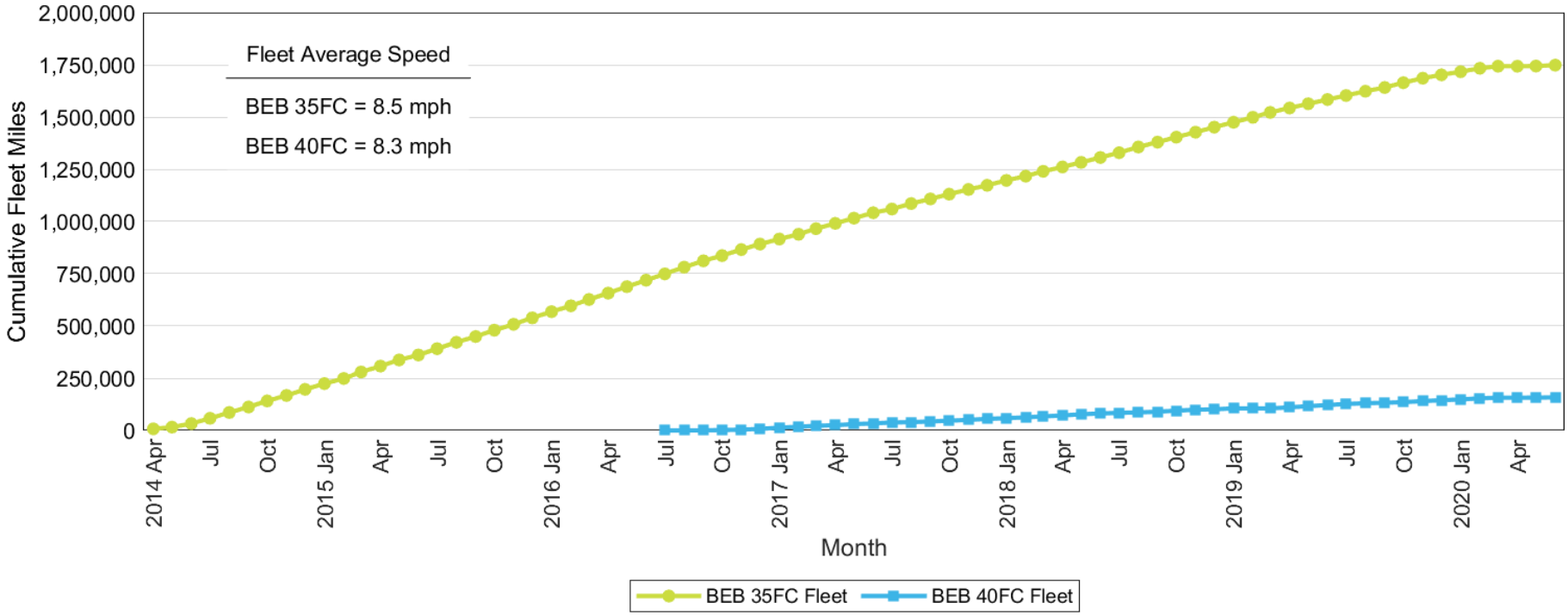


Image courtesy of Foothill Transit

BEB Fleet Total Miles



- Combined totals are shown for 12 BEB 35FC buses and 2 BEB 40FC buses.

Fleet Average Monthly Miles by Bus: Jan.–June 2020

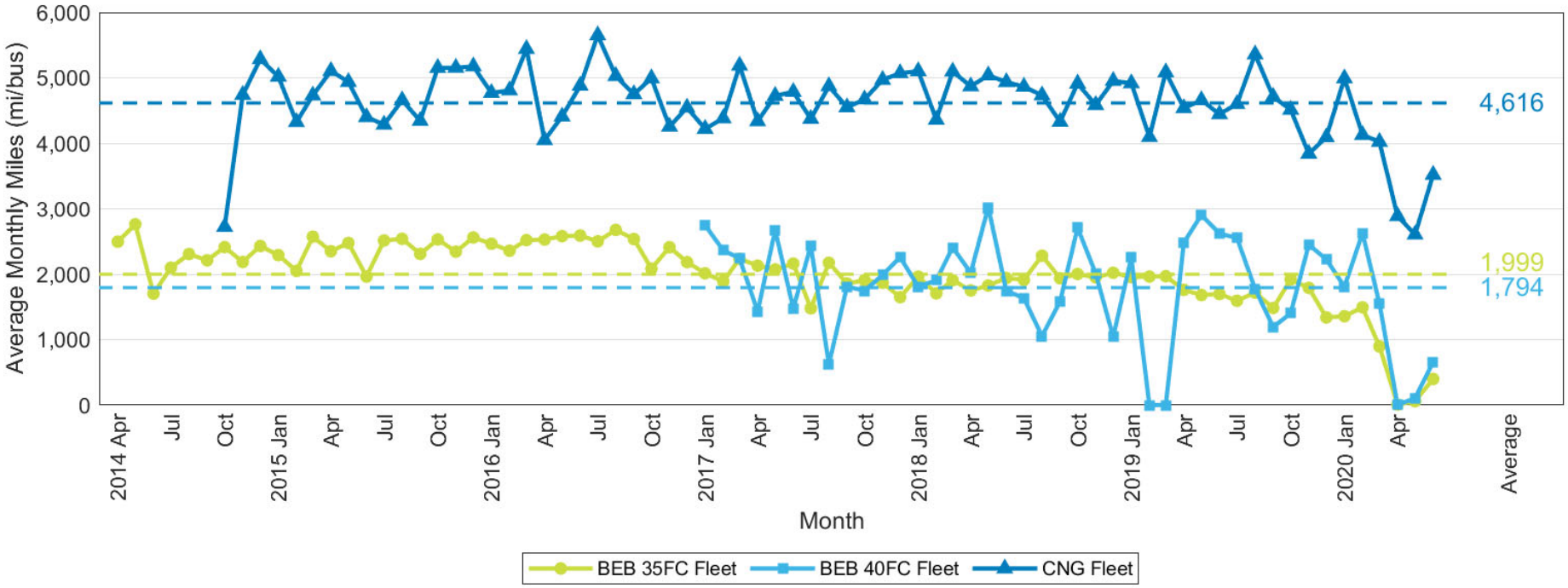
Bus ID	Miles	Bus Months	Average Monthly Mileage
2004	Bus removed from service Jan. 2020		
2005	4,870	6	812
2006	2,554	6	426
2007	5,606	6	934
2008	4,991	6	832
2009	5,741	6	957
2010	5,381	6	897
2011	1,768	6	295
2012	1,727	6	288
2013	1,885	6	314
2014	6,361	6	1,060
2015	4,403	6	734
BEB 35FC Fleet	**45,286**	**66**	**686**
2016	2,658	6	443
2017	10,851	6	1,809
BEB 40FC Fleet	**13,510**	**12**	**1,126**

Bus ID	Miles	Bus Months	Average Monthly Mileage
2200	25,962	6	4,327
2201	10,441	6	1,740
2202	23,956	6	3,993
2203	22,914	6	3,819
2204	21,571	6	3,595
2205	22,953	6	3,826
2206	24,813	6	4,136
2207	24,624	6	4,104
CNG Fleet	**177,234**	**48**	**3,692**

The average monthly operating mileage per bus for the CNG buses is 3–5 times that of the BEB fleets as operated by Foothill Transit. The mileage for the BEBs is much lower than the mileage accumulation from previous periods for several reasons:

- Reduced service due to the COVID-19 pandemic
- Issues with the BEBs.

Fleet Average Monthly Miles



- Service for all buses was reduced in April through June 2020 due to the COVID-19 pandemic
- Average miles listed for each fleet on the chart is for the entire data period
- Compared to the fleet averages, 2020 mileage was reduced by approximately 66% for BEB 35FC, 37% for BEB 40FC, and 20% for the CNG fleet.

Availability Analysis

Availability, which is a measure of reliability, is presented as the percentage of days the buses are 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 special events, or they may have been available but not used. Buses unavailable for service may have had issues with the propulsion system (energy storage system, electric drive system), general bus maintenance, or issues with the charging system. 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. The Foothill Transit buses are planned to operate every day, including weekends. For Foothill Transit, the source for availability data is garage activity sheets for Pomona Operations, which list each bus that is not available for morning pull-out and provide a general reason for unavailability. These activity sheets are for the facility as a whole and include the BEBs as well as the CNG buses. The garage activity sheets are typically available for weekdays.

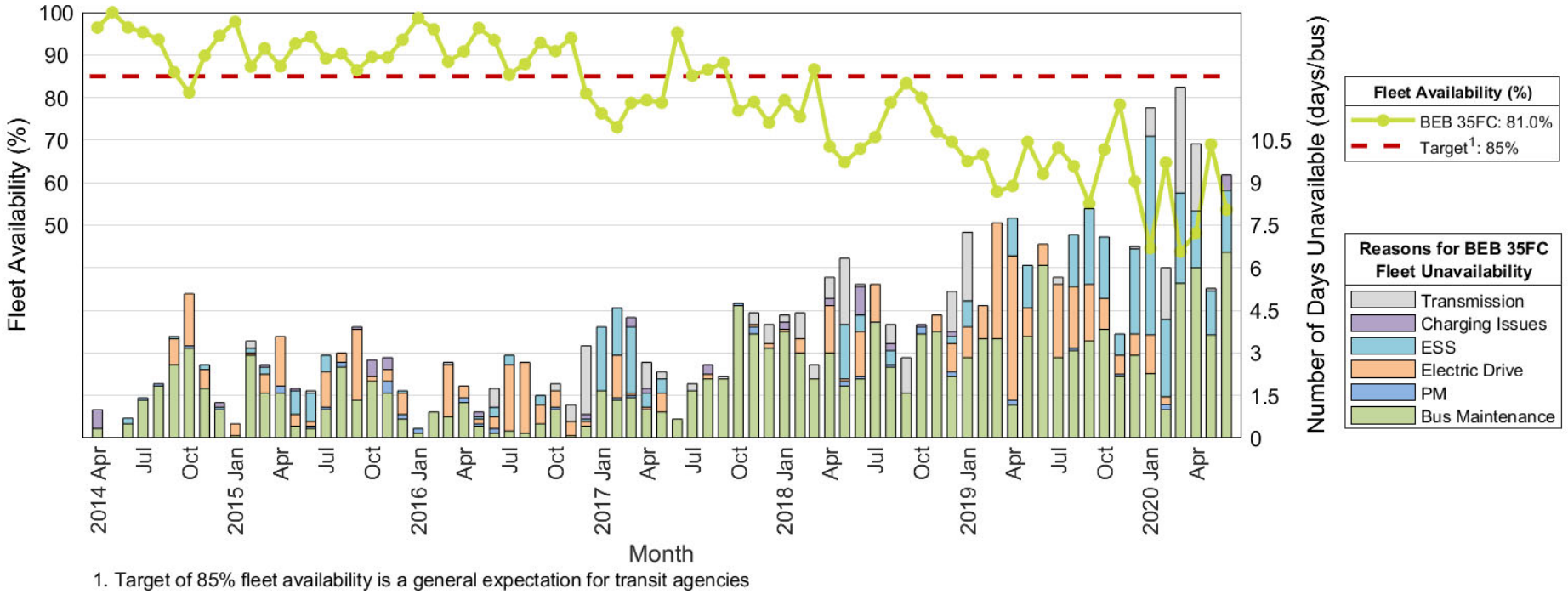
NREL presents availability as a monthly average trend and as overall availability. Unavailable time is separated into several categories to show the primary reason for downtime.

Availability Summary: Jan.–June 2020

Category	BEB 35FC (# days)	BEB 35FC (%)	BEB 40FC (# days)	BEB 40FC (%)	CNG (# days)	CNG (%)
Planned work days	1,287	—	234	—	930	—
Days available	683	53.1	163	69.7	837	90
Unavailable	604	46.9	71	30.3	93	10
ESS	205	15.9	21	9.0	—	—
CNG engine	—	—	—	—	4	0.4
Electric drive	18	1.4	0	0.0	—	—
Charging issues	6	0.5	0	0.0	—	—
Preventive maintenance (PM)	2	0.2	0	0.0	8	0.9
General bus maintenance	274	21.3	39	16.7	44	4.7
Transmission	99	7.7	11	4.7	37	4.0

- The per-bus availability for the BEBs ranged from a low of 15% to a high of 97% during the data period
- Bus 2004 was removed from service in early January and is not included in the analysis
- The BEBs experienced issues with the ESS during the data period, accounting for 15.9% of the time for the BEB 35FC and 9% of the time for the BEB 40FC buses
- General bus maintenance includes everything that doesn't fall into one of the other categories.

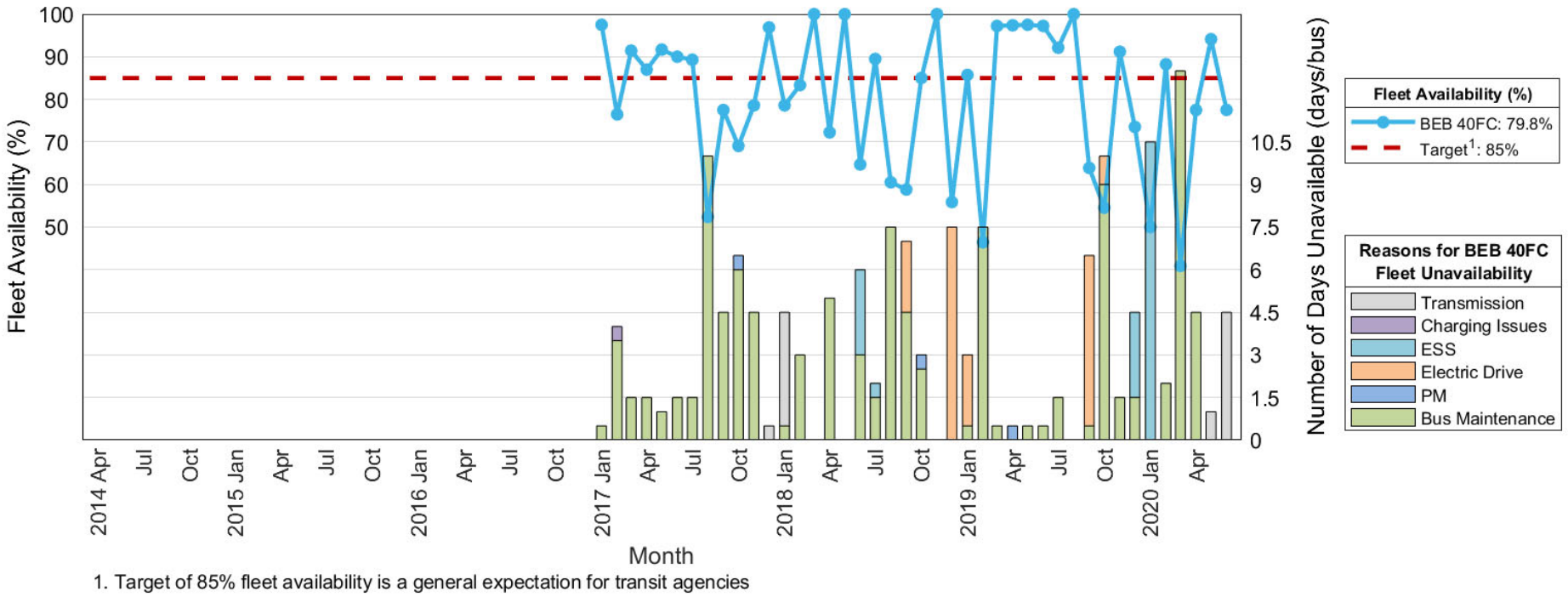
Monthly Availability: BEB 35FC Fleet



1. Target of 85% fleet availability is a general expectation for transit agencies

- The green line tracks the average monthly availability for the BEB 35FC fleet
- The stacked bars provide the number of unavailable days by bus each month, separated by six categories
- Downtime was attributed to low-voltage electrical, transmission, and traction motor
- ESS issues included time for troubleshooting high-voltage electrical.

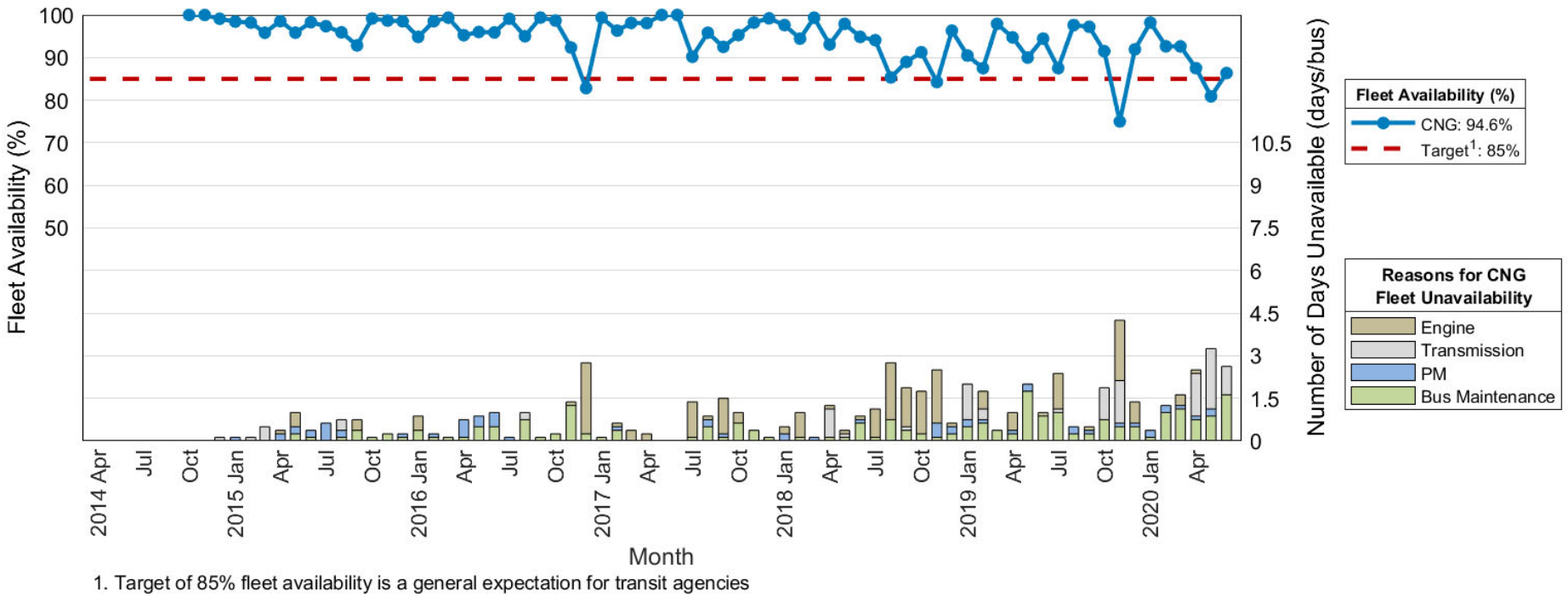
Monthly Availability: BEB 40FC Fleet



1. Target of 85% fleet availability is a general expectation for transit agencies

- The blue line tracks the average monthly availability for the BEB 40FC fleet
- The stacked bars provide the number of unavailable days by bus each month, separated by six categories
- ESS issues were primarily labor for troubleshooting high-voltage electrical
- Downtime included transmission issues and low-voltage electrical.

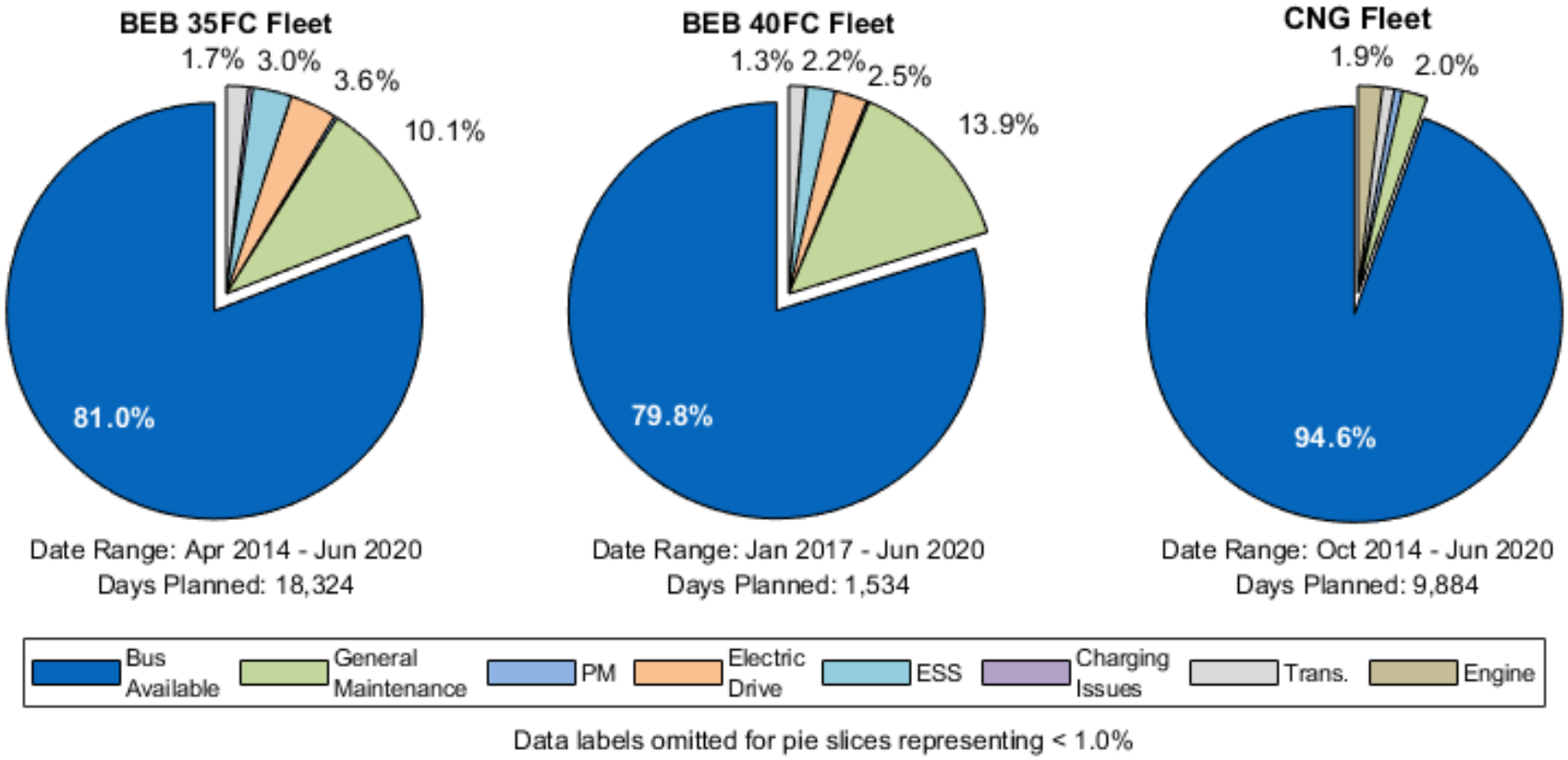
Monthly Availability: CNG Fleet



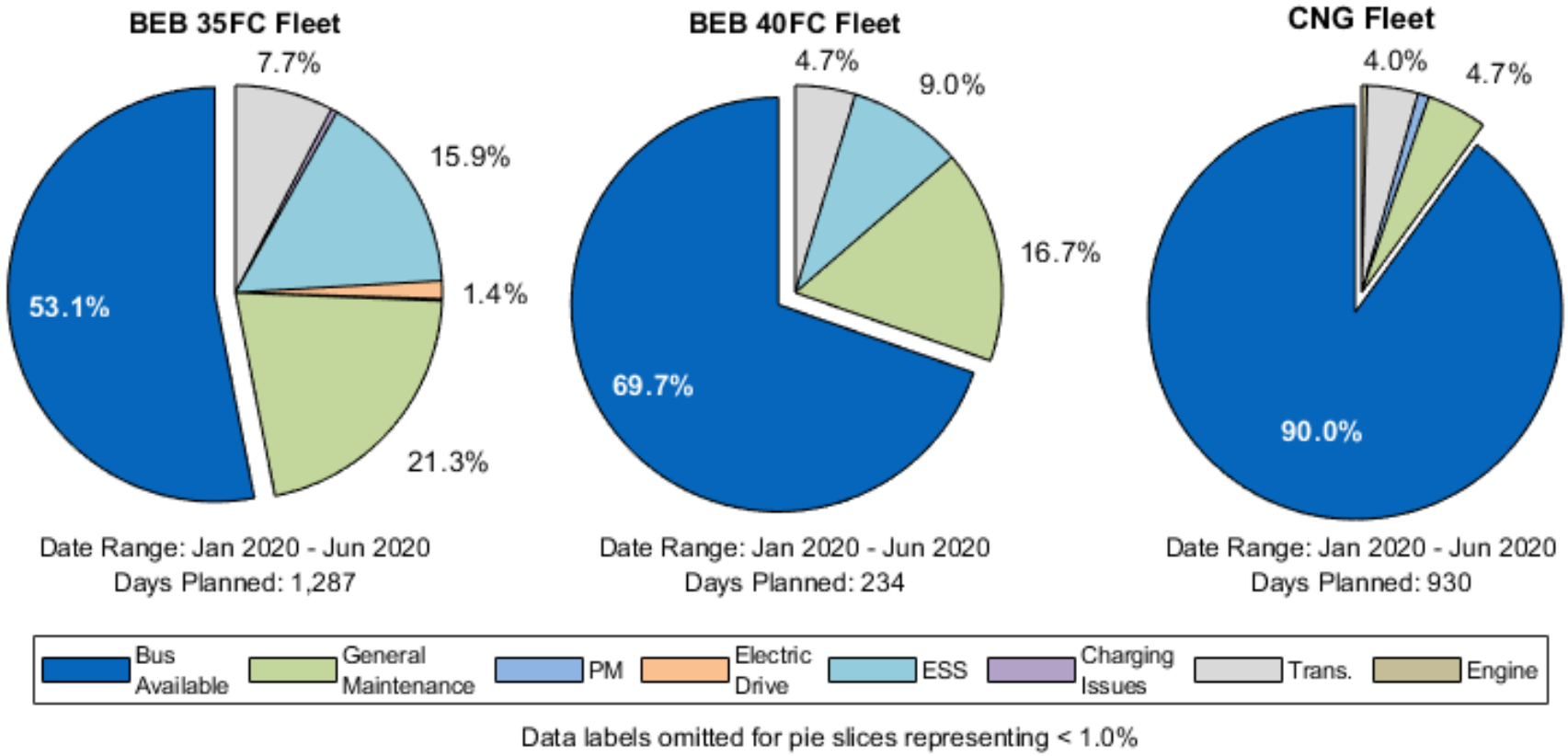
1. Target of 85% fleet availability is a general expectation for transit agencies

- The blue line tracks the average monthly availability for the CNG fleet
- The stacked bars provide the number of unavailable days by bus each month, separated by four categories
- One bus experienced transmission issues that kept it from service in May 2020.

Overall Fleet Availability: Full Data Period



Overall Fleet Availability: Jan.–June 2020



Energy Consumption/Fuel Economy Analysis

Proterra records and stores data—including total electrical energy consumed (kWh), number of charges, and miles driven—on each of the buses. These data were provided to NREL for calculating efficiency of the buses in kilowatt-hours per mile. Foothill Transit's CNG buses are typically fueled once each day. Foothill Transit provided individual fueling records for the CNG buses. CNG is typically dispensed in units of gasoline gallon equivalent (gge).

To compare the BEBs to the baseline buses, NREL converted the electrical energy from kWh to diesel gallon equivalent (dge) and converted the CNG fuel energy from gge to dge using the following conversion factors:

Energy content of fuel (Alternative Fuels Data Center: https://afdc.energy.gov/fuels/properties)

- Electricity: 3,414 Btu[a]/kWh
- CNG: 112,114 Btu/gge (LHV[b])
- Diesel: 128,488 Btu/dge (LHV)

Conversion factors

- Electrical energy to dge: 37.64 kWh/dge
- CNG fuel energy to dge: 1.146 gge/dge

[a] British thermal units

[b] Lower heating value

Fuel Consumption/Fuel Economy: Jan.–June 2020

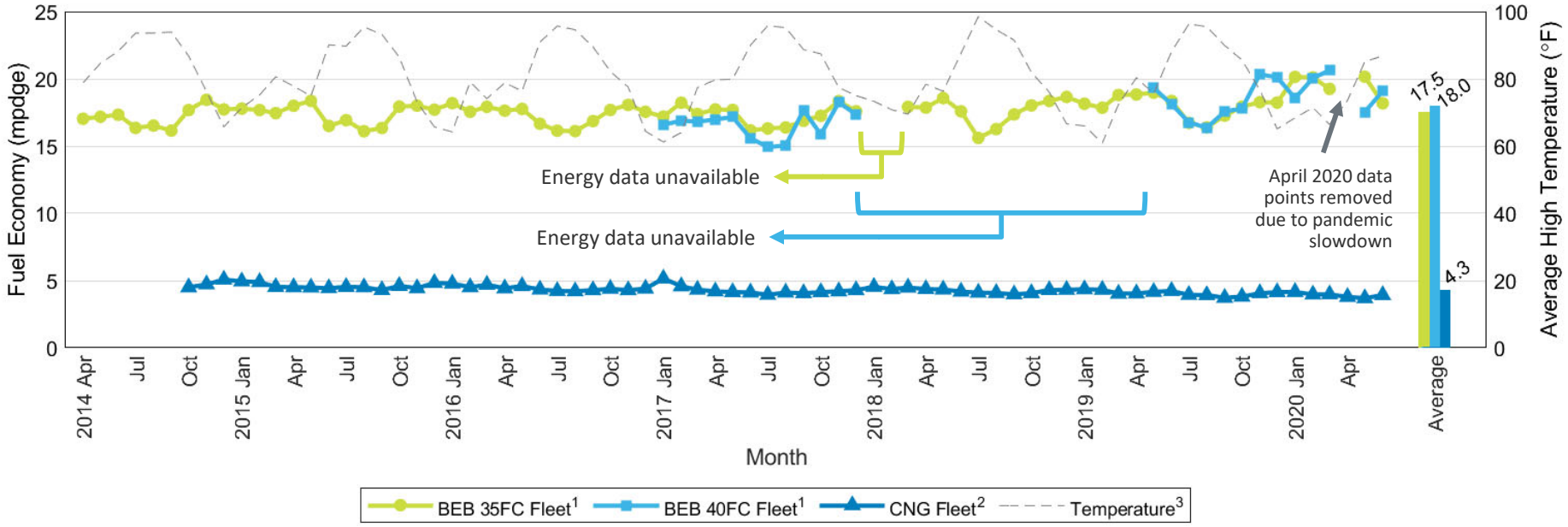
Bus ID	Miles	Energy[a] (kWh)	kWh/mi	Diesel Gallon Equiv.	Fuel economy (mpdge)
2004	Bus removed from service Jan. 2020				
2005	4,870	9,661.2	1.98	256.7	18.97
2006	2,554	5,320.0	2.08	141.4	18.07
2007	5,606	10,906.8	1.95	289.8	19.34
2008	4,991	10,049.9	2.01	267.0	18.69
2009	5,741	10,972.2	1.91	291.5	19.69
2010	5,381	9,860.4	1.83	262.0	20.54
2011	1,768	3,153.5	1.78	83.8	21.10
2012	1,727	3,192.6	1.85	84.8	20.36
2013	1,885	3,906.6	2.07	103.8	18.16
2014	6,361	11,511.6	1.81	305.9	20.80
2015	4,403	8,025.4	1.82	213.2	20.65
BEB 35FC Fleet	**45,286**	**86,560.3**	**1.91**	**2,300.0**	**19.69**
2016	2,658	5,106.6	1.92	135.7	19.59
2017	10,851	20,824.0	1.92	553.3	19.61
BEB 40FC Fleet	**13,510**	**25,930.6**	**1.92**	**689.0**	**19.61**

Bus ID	Miles	CNG (gge)	mpgge	Diesel Gallon Equiv.	Fuel economy (mpdge)
2200	25,237	7,433.1	3.40	6,485.8	3.89
2201	10,263	3,000.5	3.42	2,618.1	3.92
2202	22,399	6,177.3	3.63	5,390.1	4.16
2203	22,350	6,491.9	3.44	5,664.6	3.95
2204	21,052	6,300.4	3.34	5,497.5	3.83
2205	21,440	6,232.9	3.44	5,438.6	3.94
2206	23,822	6,940.9	3.43	6,056.3	3.93
2207	23,451	6,816.0	3.44	5,947.4	3.94
CNG Fleet	**170,014**	**49,392.9**	**3.44**	**43,098.4**	**3.94**

- The BEB fuel economy is approximately five times the CNG fuel economy, as operated on current routes
- Differences in duty cycle, such as number of stops and average speed, will impact the fuel economy of the fleets.

[a] Total energy consumed by the bus does not include losses during charging

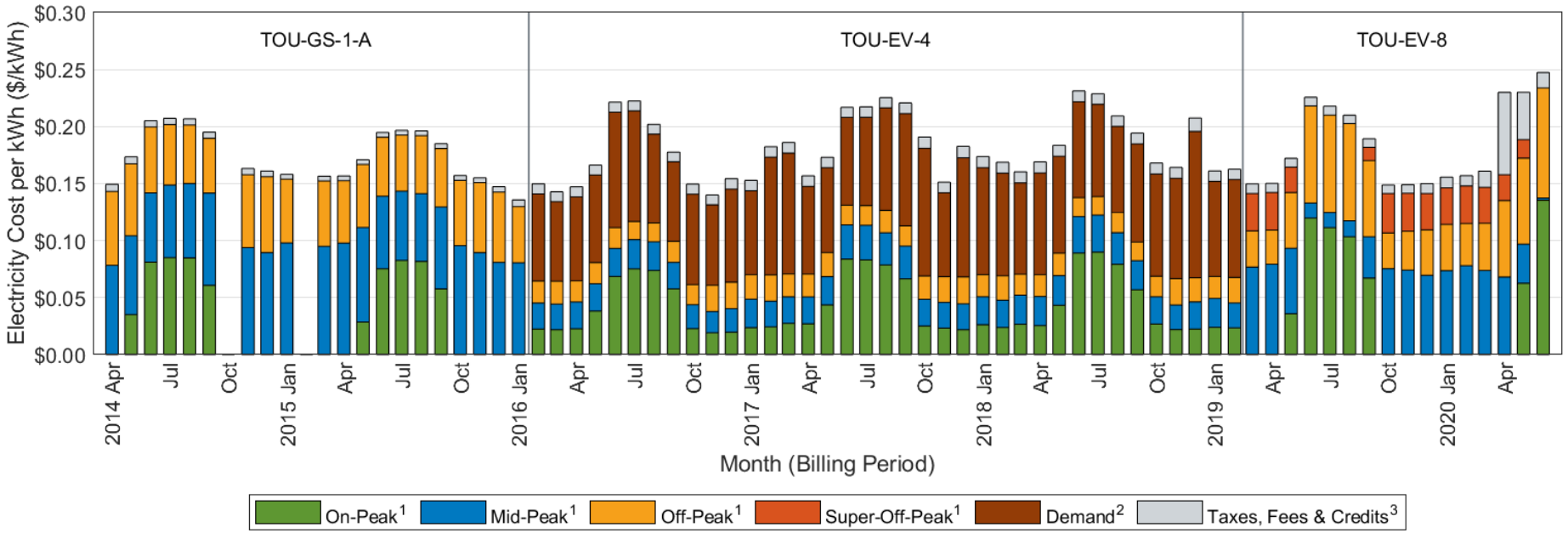
Fleet Average Monthly Fuel Economy



1. Electrical energy converted from kWh to diesel gallon equivalent (dge); conversion factor = 37.64 kWh/dge
2. CNG fuel energy converted from gasoline gallon eqivalent (gge) to diesel gallon equivalent (dge); conversion factor = 1.146 gge/dge
3. Average daily high temperatures at Ontario International Airport, CA; data acquired from: *https://www.ncdc.noaa.gov/*

	Overall		Jan.–June 2020	
Fleet	**kWh/mi, mpgge**	**mpdge**	**kWh/mi, mpgge**	**mpdge**
BEB 35FC	2.15	17.47	1.91	19.69
BEB 40FC	2.09	17.99	1.92	19.61
CNG	3.75	4.30	3.44	3.94

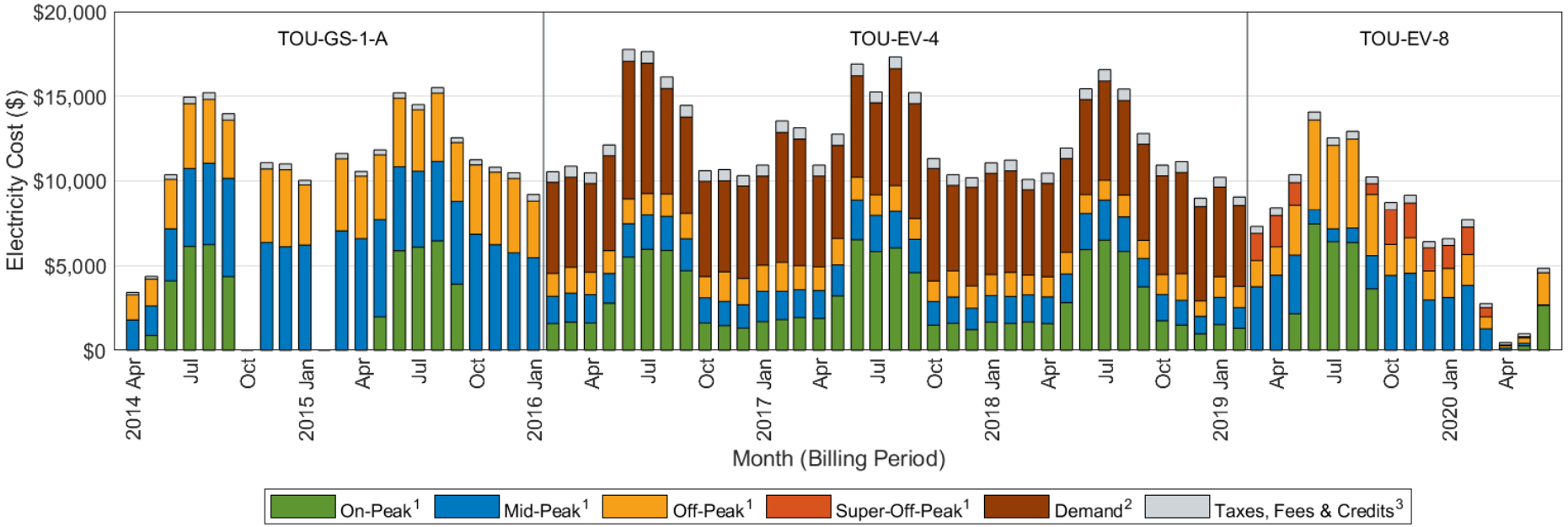
Monthly Electric Utility Costs



1. Time of use charge categories include respective costs for delivery and generation
2. Demand charges introduced in February 2016 with change to TOU-EV-4 rate structure and eliminated in March 2019 with change to TOU-EV-8 rate structure
3. Taxes, Fees & Credits category includes all remaining utility bill items (costs & credits)

	TOU-GS-1-A	TOU-EV-4	TOU-EV-8	Summer Avg (June–Sep.)	Winter Avg (Oct.–May)
$/kWh	0.17	0.18	0.18	0.21	0.16
$/dge	6.55	6.84	6.66	7.85	6.07

Monthly Electric Utility Costs



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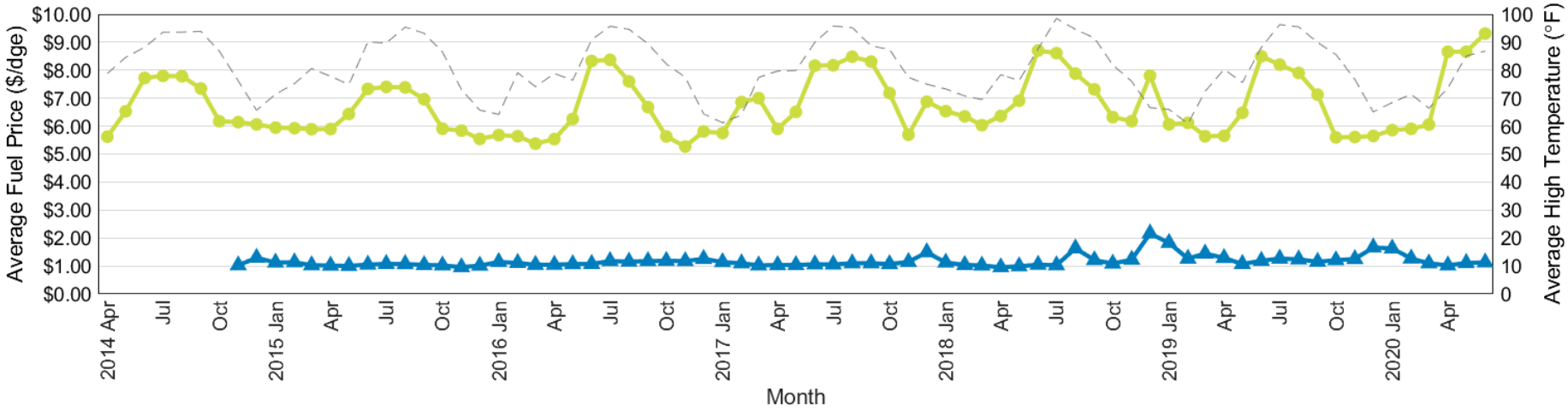
Monthly Average Fuel Price

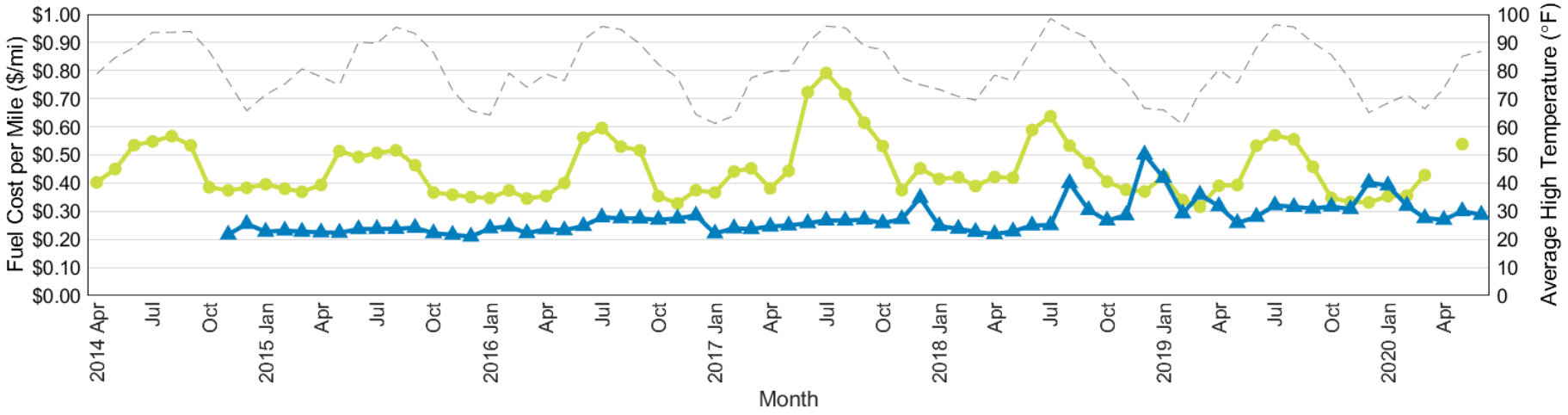


	Electricity Price (dge)[1]	CNG Price (dge)[2]
Overall average fuel price	$6.72/dge	$1.16/dge
Data period average fuel price	$6.53/dge	$1.22/dge

1. Electrical energy converted from kWh to diesel gallon equivalent (dge); conversion factor = 37.64 kWh/dge
2. CNG fuel energy converted from gasoline gallon eqivalent (gge) to diesel gallon equivalent (dge); conversion factor = 1.146 gge/dge
3. Average daily high temperatures at Ontario International Airport, CA; data acquired from: *https://www.ncdc.noaa.gov/*

- Electricity prices vary seasonally; CNG prices are consistent throughout the data period, but CNG prices increased in August 2018 and December 2018 due to temporary disruptions in regional CNG supply
- CNG cost includes price of fuel, transmission, and operations and maintenance cost for station
- On average, electricity cost is approximately six times the cost of CNG.

Monthly Average Fuel Cost Per Mile



	BEB Fleet[1]	CNG Fleet
Overall average fuel cost/mi	$0.45/mi	$0.27/mi
Data period average fuel cost/mi	$0.44/mi	$0.31/mi

1. BEB Fleet includes all battery buses using fast charger (BEB 35FC & BEB 40FC fleets)
2. Average daily high temperatures at Ontario Intenational Airport, CA; data acquired from: *https://www.ncdc.noaa.gov/*

- Fuel cost per mile for the BEBs tracks with the ambient temperature when summer electric rates are higher and efficiency is lower due to air-conditioning use
- Baseline CNG bus cost per mile spikes when the CNG cost is higher
- Fleet mileage for April 2020 and June 2020 was insufficient to display fuel cost/mi.

Fuel Cost Per Mile

During the first half of 2020, Foothill Transit paid an average of $1.07/gge ($1.22/dge) for CNG. The average cost of electricity during the first half of 2020 was $0.173/kWh ($6.53/dge). The table provides the cost per mile for the BEBs and CNG buses as operated by the fleet, for both the current data period and since the start of service. Overall, the average CNG fuel cost was $0.27/mi and average fuel cost for the BEBs was $0.45/mi.

The operating duty cycle of a bus has a significant effect on fuel economy and therefore cost. The BEB and CNG fleets are currently operated on different routes with different average speeds, which should be considered when comparing fuel costs.

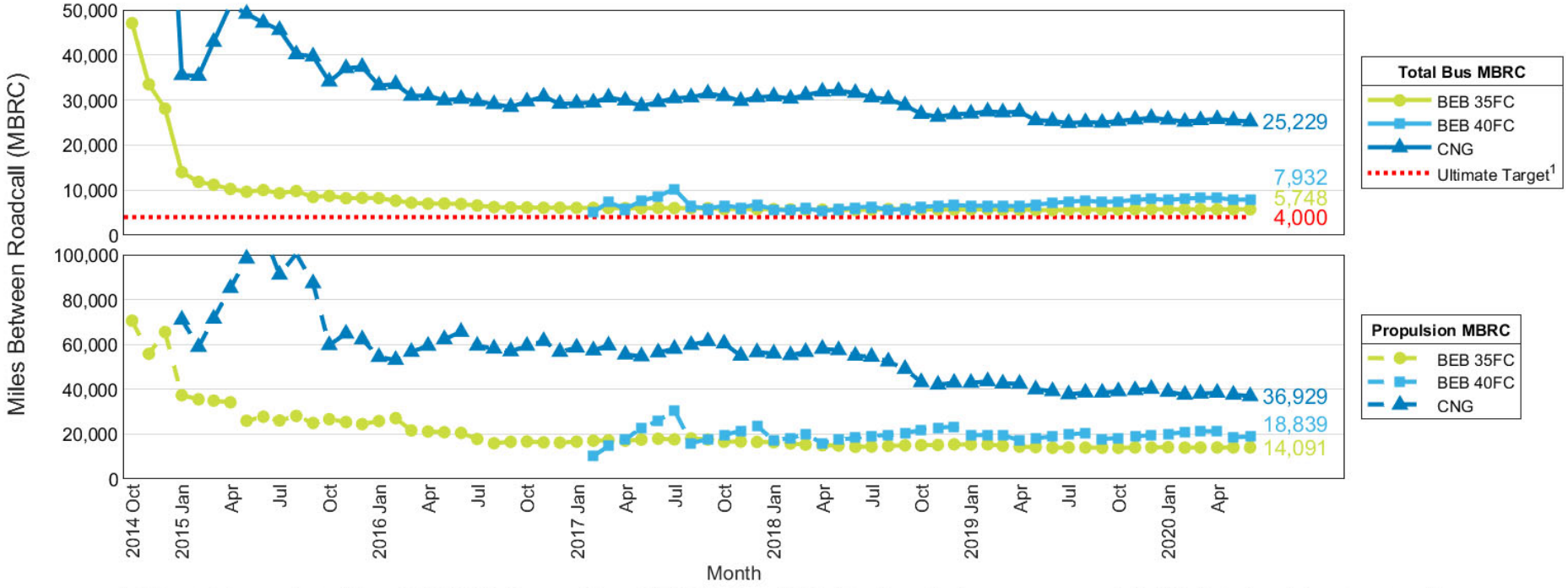
	Average Service Speed (mph)	Fuel Economy (mpdge)	Total from 4/2014 Fuel $/mi	2020 Data Period Fuel $/mi
BEB 35FC	10.6	17.47	0.45	0.44
BEB 40FC	10.6	17.89	0.45	0.44
CNG	17.6	4.30	0.27	0.31

Road Call Analysis

A road call, 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, it is not considered a road call. The analysis described here includes only road calls that were caused by "chargeable" failures. Chargeable road calls 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 road calls 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 bus road calls, propulsion-related road calls, and ESS-related road calls (for electric buses). Total bus road calls include all chargeable road calls. Propulsion-related road calls are a subset of total road calls and include all road calls due to propulsion-related systems including the battery system (or engine for a conventional bus), electric drive, fuel, exhaust, air intake, cooling, non-lighting electrical, and transmission systems. The ESS-related road calls—a subset of the propulsion-related road calls—and MBRC are included for the BEBs.

Cumulative MBRC



1. Ultimate Target adopted from: DOE FCTO Program Record #12012, Sept. 2012, *http://www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf*

- The upper chart shows cumulative MBRC for all chargeable road calls
- The lower chart shows MBRC for propulsion-related road calls
- The ESS-related MBRC for the BEB 35FC fleet is 194,142
- The ESS-related MBRC for the BEB 40FC fleet is 150,713.

Maintenance Analysis

NREL collects all work orders for the evaluation buses to calculate 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 labor rate of $50 per hour. This does not reflect an average rate for Foothill Transit. Cost per mile is calculated as follows:

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

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 what systems have the most costs for each technology. The work orders are coded using Vehicle Maintenance Reporting Standards (VMRS) developed by the American Trucking Association to aid the industry in tracking equipment and maintenance using a common standard.

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

Maintenance Analysis Results: Jan.–June 2020

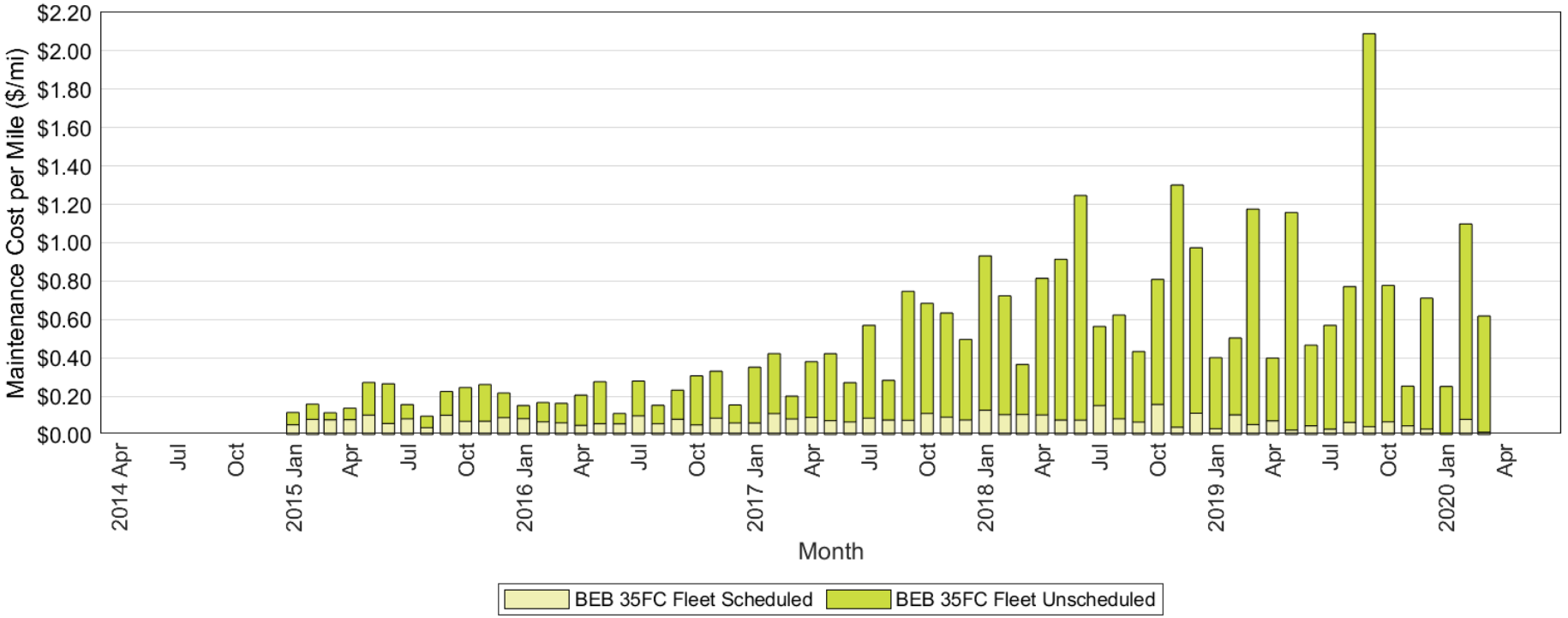
Bus ID	Mileage	Parts ($)	Labor Hours	Scheduled Cost ($/mi)	Unscheduled Cost ($/mi)	Total Cost ($/mi)
2004	Bus removed from service Jan. 2020					
2005	4,870	782.72	55.57	0.06	0.67	0.73
2006	2,554	1,789.89	86.47	0.07	2.33	2.39
2007	5,606	1,440.85	43.02	0.02	0.62	0.64
2008	4,991	2,234.62	156.13	0.06	1.96	2.01
2009	5,741	702.78	100.58	0.04	0.96	1.00
2010	5,381	3,351.16	84.24	0.04	1.36	1.41
2011	1,768	857.16	28.53	0.15	1.14	1.29
2012	1,727	1,606.10	34.79	0.00	1.94	1.94
2013	1,885	1,852.64	102.72	0.08	3.62	3.71
2014	6,361	3,733.34	80.94	0.10	1.12	1.22
2015	4,403	34.42	101.99	0.05	1.12	1.17
BEB 35FC Fleet	**45,286**	**18,385.68**	**875.0**	**0.06**	**1.31**	**1.37**
2016	2,658	1,506.56	122.26	0.10	2.77	2.87
2017	10,851	1,901.10	35.2	0.02	0.32	0.34
BEB 40FC Fleet	**13,510**	**3,407.66**	**157.46**	**0.04**	**0.80**	**0.84**

Bus ID	Mileage	Parts ($)	Labor Hours	Scheduled Cost ($/mi)	Unscheduled Cost ($/mi)	Total Cost ($/mi)
2200	25,962	4,792.73	87.39	0.10	0.25	0.35
2201	10,441	9,933.58	125.69	0.16	1.39	1.55
2202	23,956	3,723.36	100.92	0.12	0.25	0.37
2203	22,914	6,357.87	91.29	0.13	0.35	0.48
2204	21,571	7,016.72	100.68	0.10	0.46	0.56
2205	22,953	2,662.29	122.20	0.09	0.30	0.38
2206	24,813	5,311.48	107.50	0.12	0.31	0.43
2207	24,624	9,234.72	79.20	0.12	0.41	0.54
CNG Fleet	**177,234**	**49,032.75**	**814.87**	**0.11**	**0.39**	**0.51**

BEB issues included:

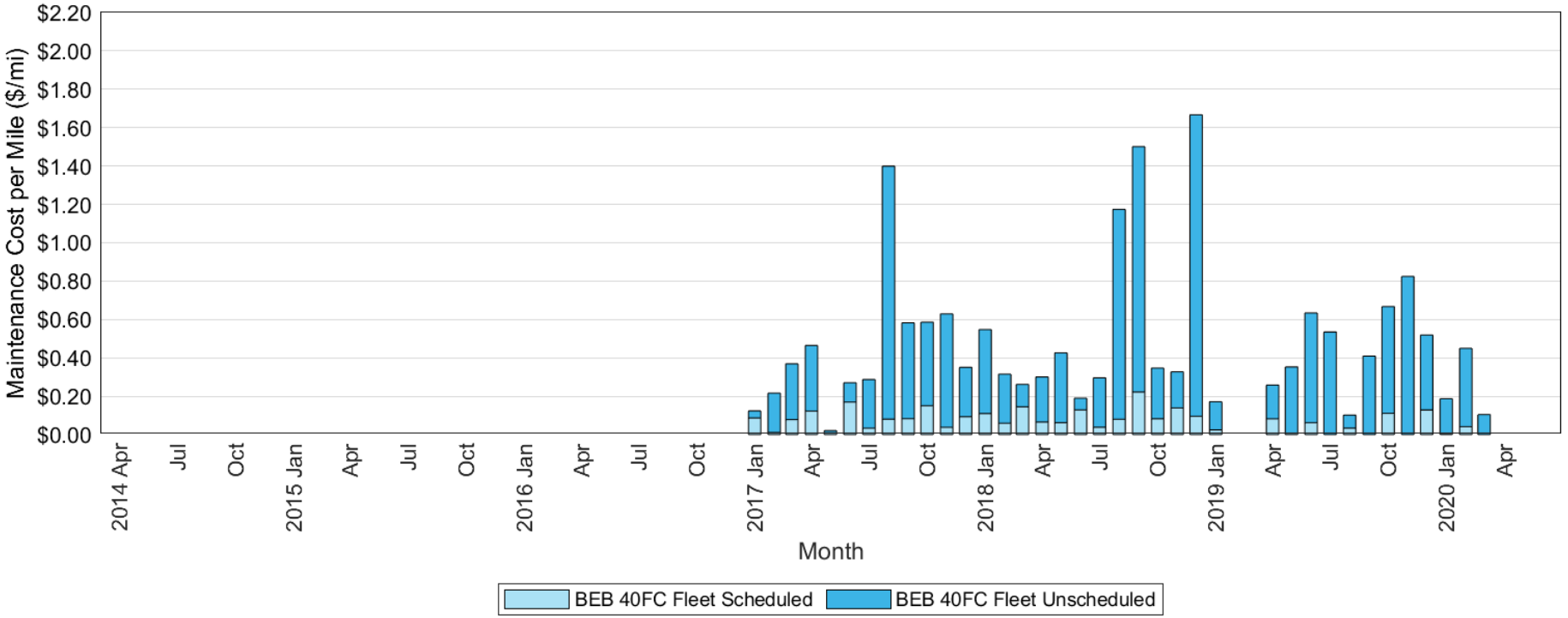
- Low-voltage battery replacement
- High-voltage batteries
- Traction motor replaced
- Transmission
- Wiper motor
- Air system

Monthly Scheduled and Unscheduled Maintenance Cost: BEB 35FC Fleet



- The warranty period has ended, and transit staff are handling all the maintenance work
- Issues with the low-voltage batteries continue to result in increasing costs
- Cost per mile for April, May, and June 2020 are artificially high due to low mileage accumulation during reduced service. These costs are not representative of the overall costs and have been removed from the chart. The data are included in the analysis totals.

Monthly Scheduled and Unscheduled Maintenance Cost: BEB 40FC Fleet



- Issues with the low-voltage batteries resulted in costs that were higher than expected
- Because the fleet consists of only two buses, the monthly cost per mile is more sensitive to cost increases
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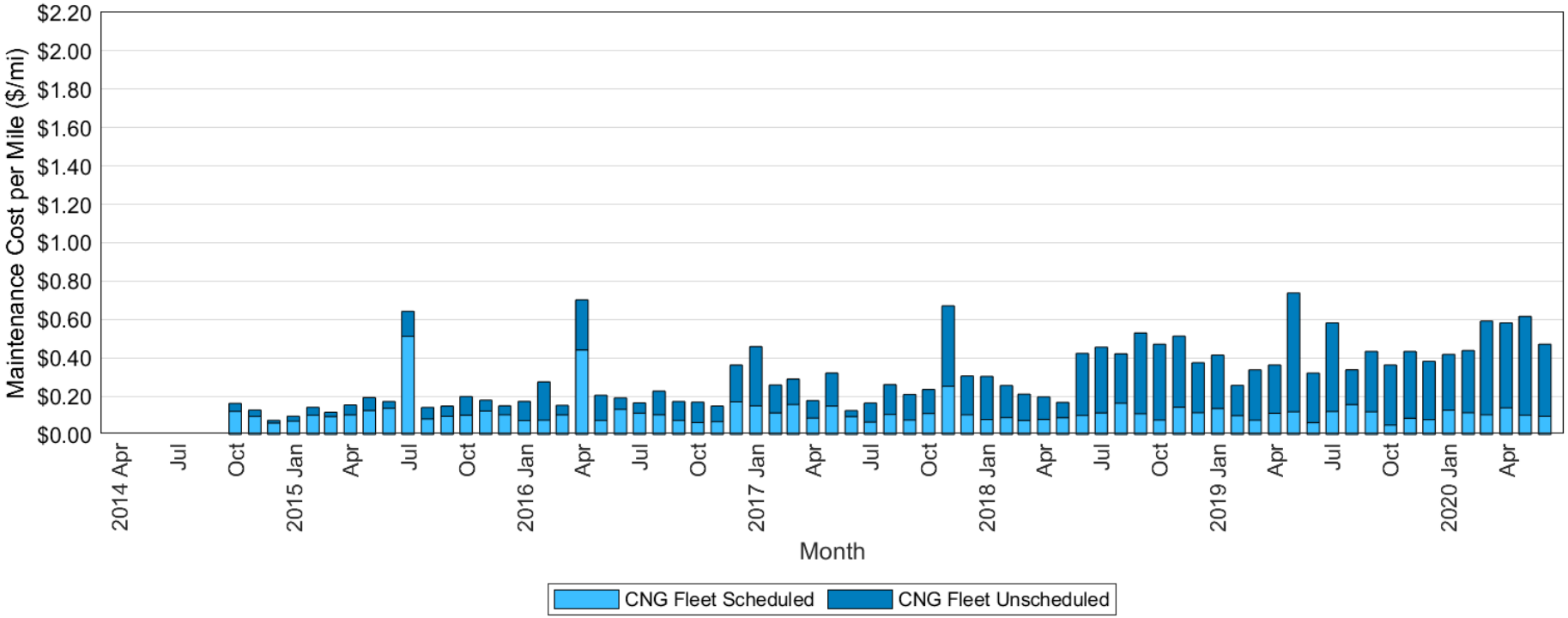
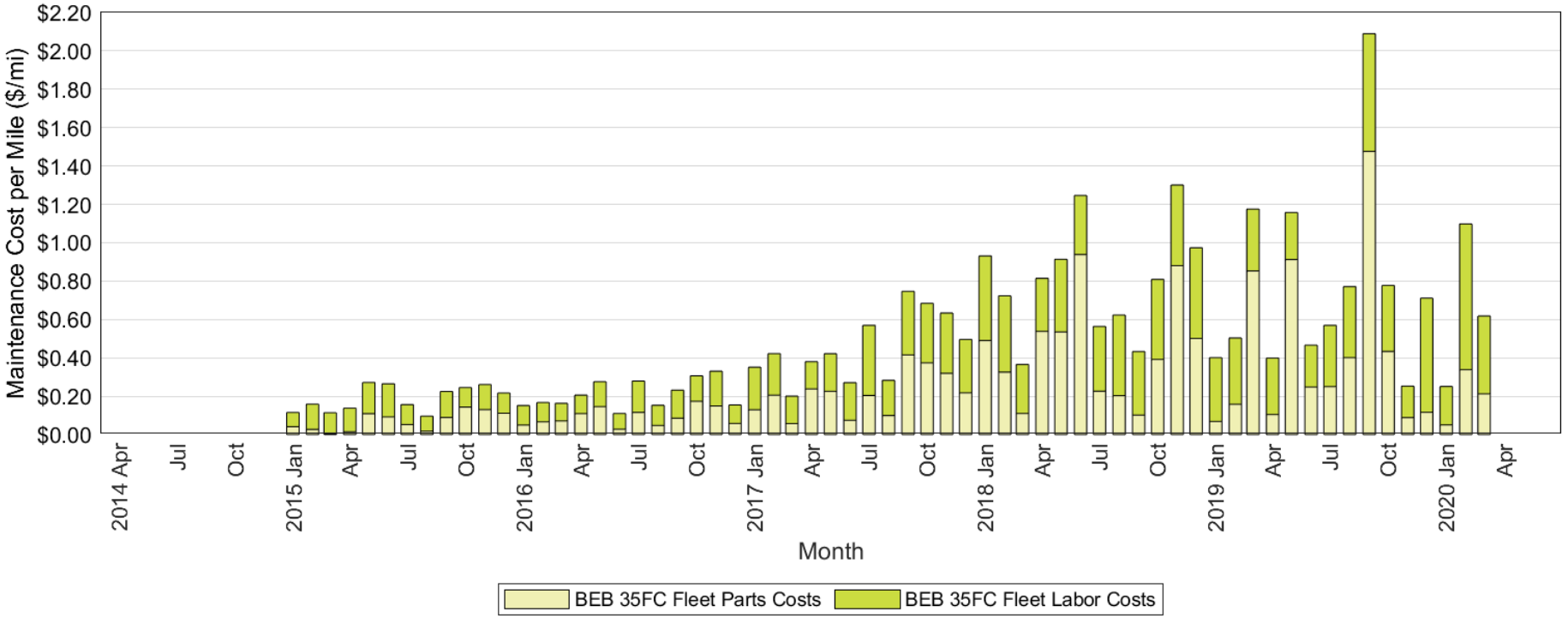


- Spikes in costs for some months are caused by multiple buses reaching the mileage target for a major preventive maintenance (PM) during the same month
- Unscheduled costs in the last year have risen primarily due to engine issues.

Monthly Parts and Labor Maintenance Cost: BEB 35FC Fleet



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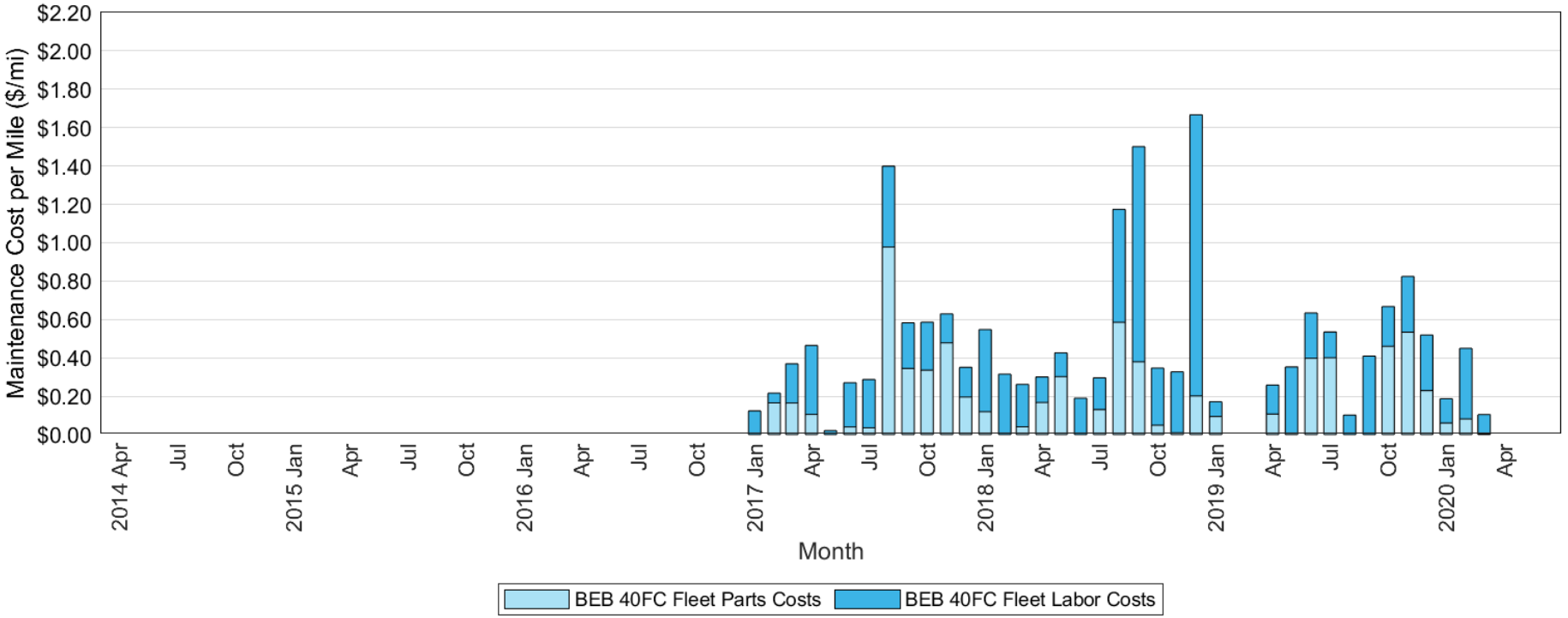

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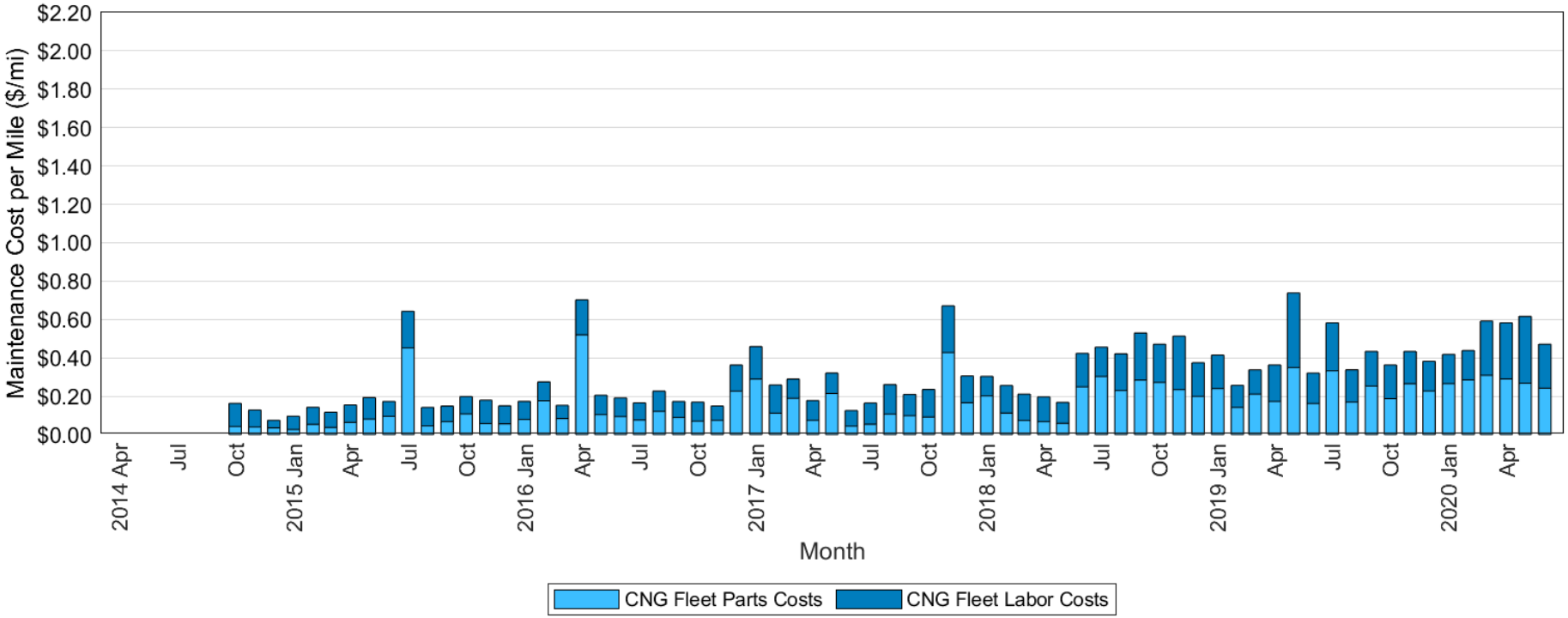

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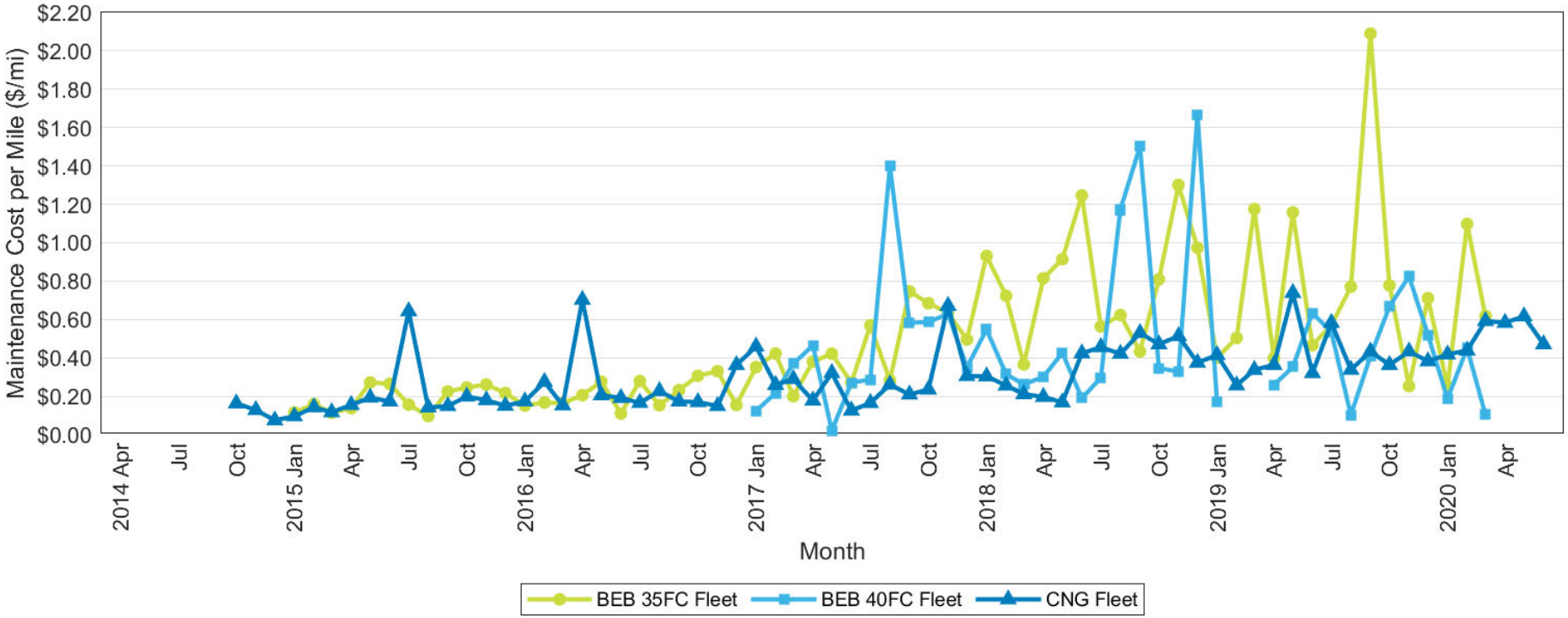
Monthly Maintenance Cost per Mile



- The trend lines in this chart match the stacked columns from the three previous charts, shown here for comparison.

Maintenance Cost per Mile by System: Jan.–June 2020

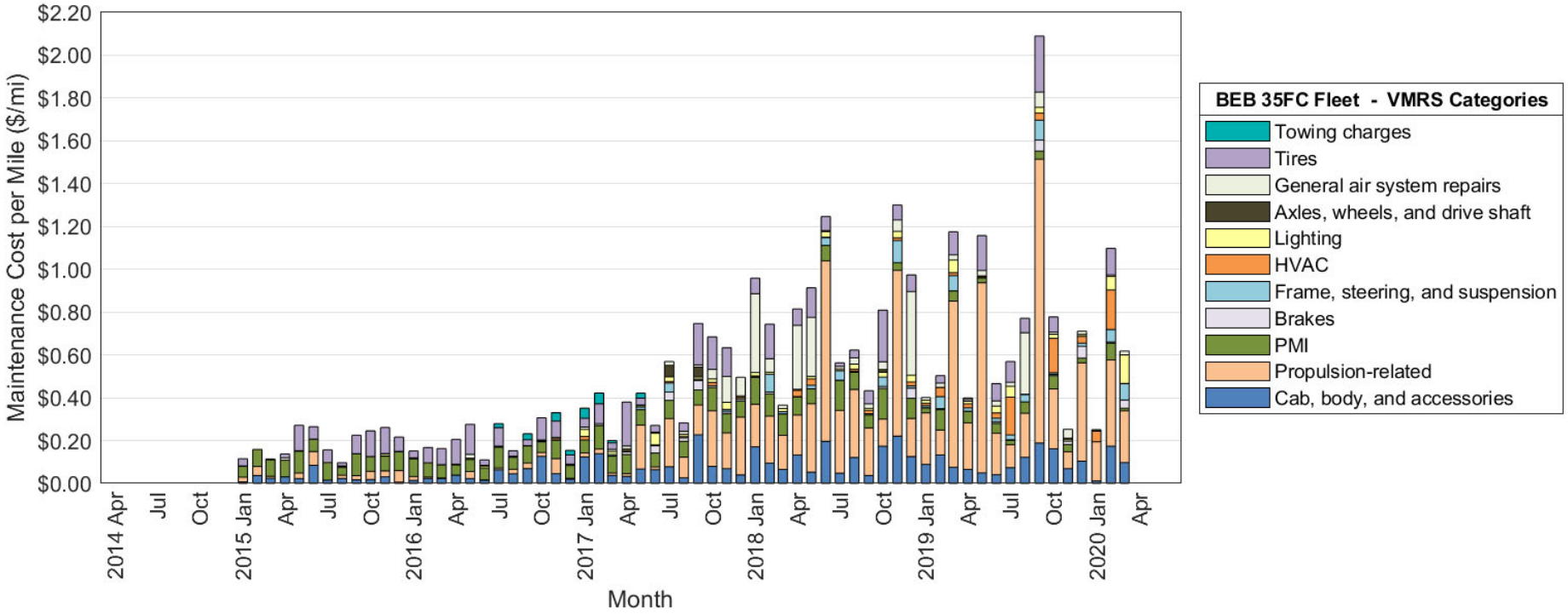
System	BEB 35FC		BEB 40FC		CNG	
	Cost per Mile ($)	Percent of Total (%)	Cost per Mile ($)	Percent of Total (%)	Cost per Mile ($)	Percent of Total (%)
Cab, body, and accessories	0.589	42.9	0.378	45.3	0.249	49.2
Propulsion-related	0.224	16.3	0.251	30.1	0.101	19.9
Preventative maintenance inspection (PMI)	0.037	2.7	0.016	1.9	0.037	7.4
Brakes	0.117	8.5	0.004	0.5	0.026	5.2
Frame, steering, and suspension	0.040	2.9	0.000	0.0	0.013	2.7
Heating, ventilation, and air conditioning (HVAC)	0.180	13.1	0.040	4.8	0.010	2.0
Lighting	0.064	4.7	0.001	0.2	0.009	1.7
General air-system repairs	0.014	1.0	0.078	9.3	0.010	2.1
Axles, wheels, and drive shaft	0.022	1.6	0.000	0.0	0.006	1.1
Tires	0.085	6.2	0.066	7.9	0.045	8.8
Towing charges	0.000	0.0	0.000	0.0	0.000	0.0
Total	***1.372***	***100***	***0.835***	*100*	***0.507***	*100*
Total w/o low-voltage battery costs	***1.179***		***0.651***		***0.474***	

Color coding:

- Highest cost
- Second-highest cost
- Third-highest cost

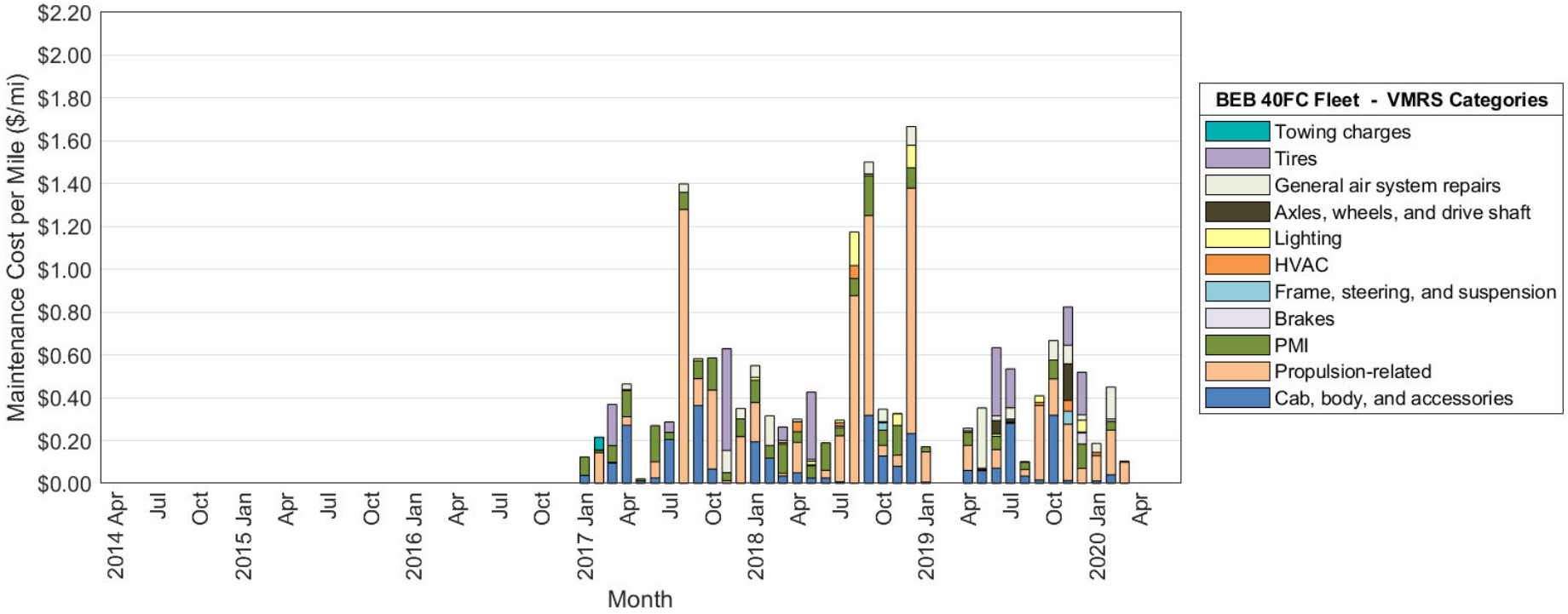
- Propulsion-related repairs for the BEBs were for low-voltage batteries, high-voltage electrical, traction motor, and transmission
- Cost per mile are artificially high due to low mileage accumulation during reduced service. These costs are not representative of the overall costs.

Maintenance Cost by System: BEB 35FC Fleet



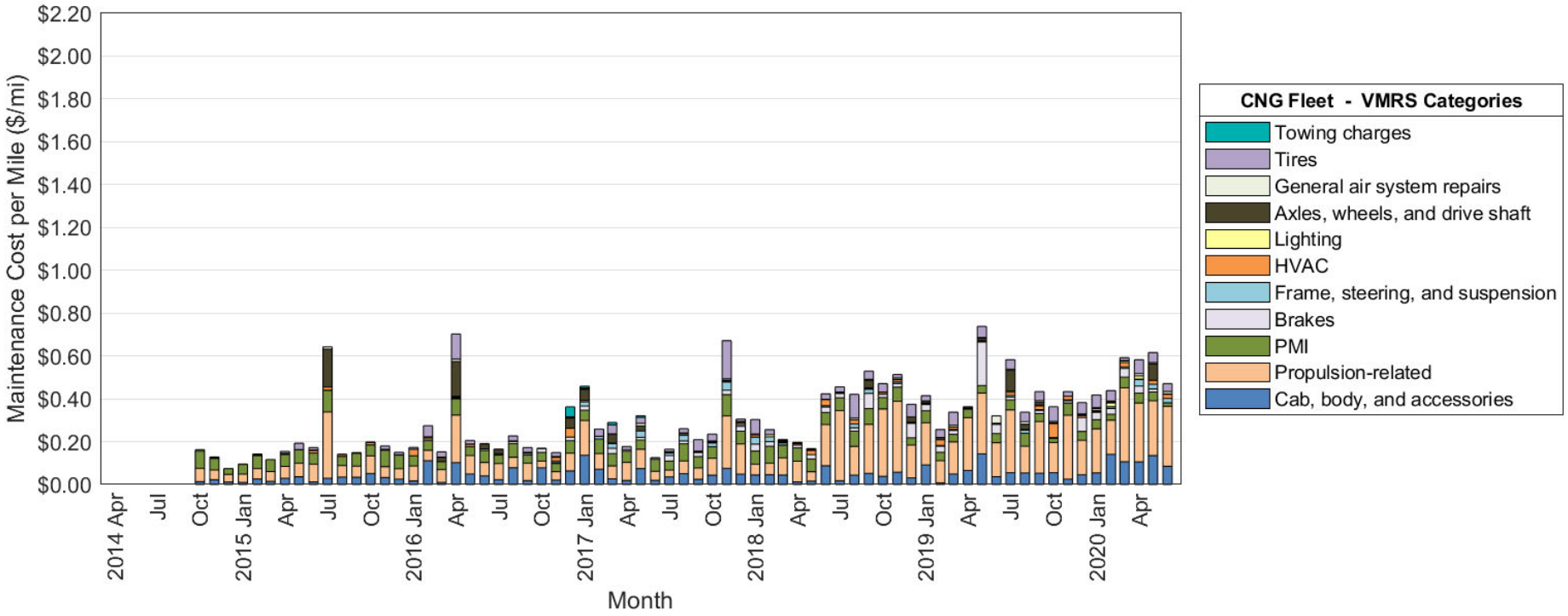
- The primary driver for the higher propulsion-related cost was issues with the low-voltage batteries (see Low-Voltage Battery Maintenance Analysis)
- Cost per mile for April, May, and June 2020 are artificially high due to low mileage accumulation during reduced service. These costs are not representative of the overall costs and have been removed from the chart. The data are included in the analysis totals.

Maintenance Cost by System: BEB 40FC Fleet



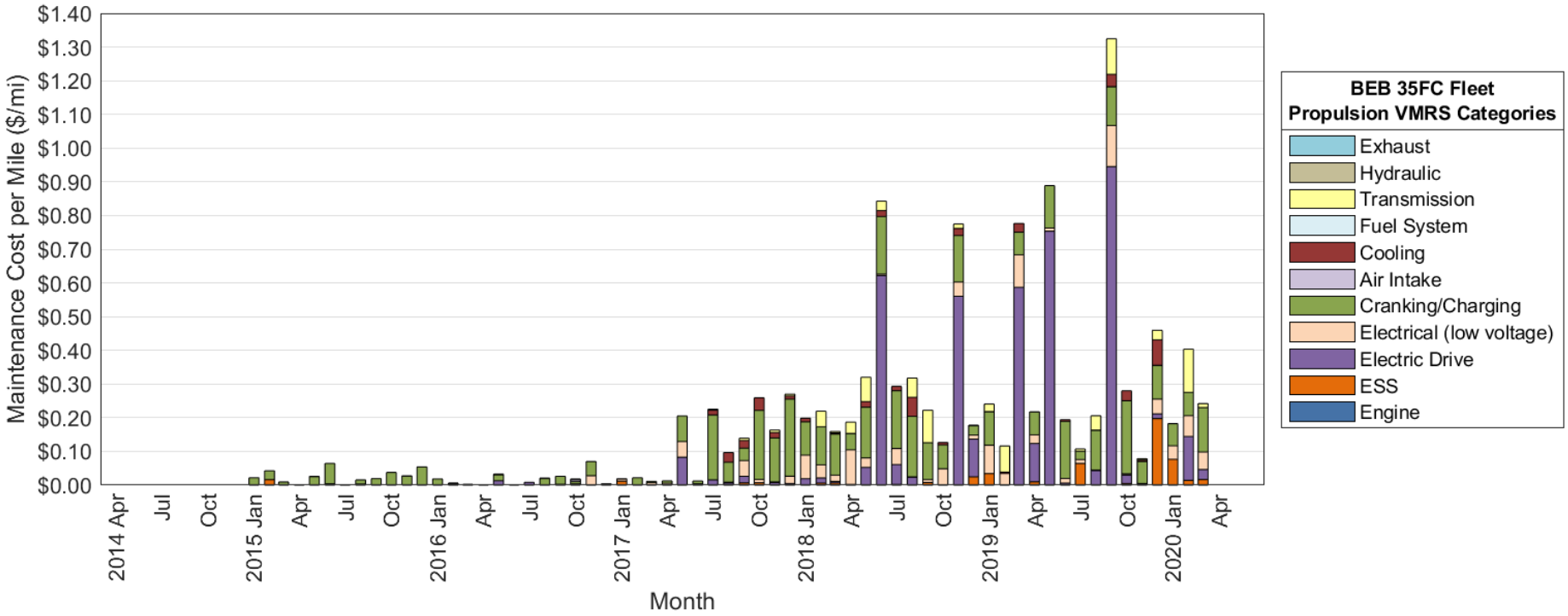
- Because the BEB 40FC fleet consists of only two buses, the monthly cost per mile is more sensitive to cost increases
- The buses still experience issues with the low-voltage batteries (see Low-Voltage Battery Maintenance Analysis)
- Cost per mile for April, May, and June 2020 are artificially high due to low mileage accumulation during reduced service. These costs are not representative of the overall costs and have been removed from the chart. The data are included in the analysis totals.

Maintenance Cost by System: CNG Fleet



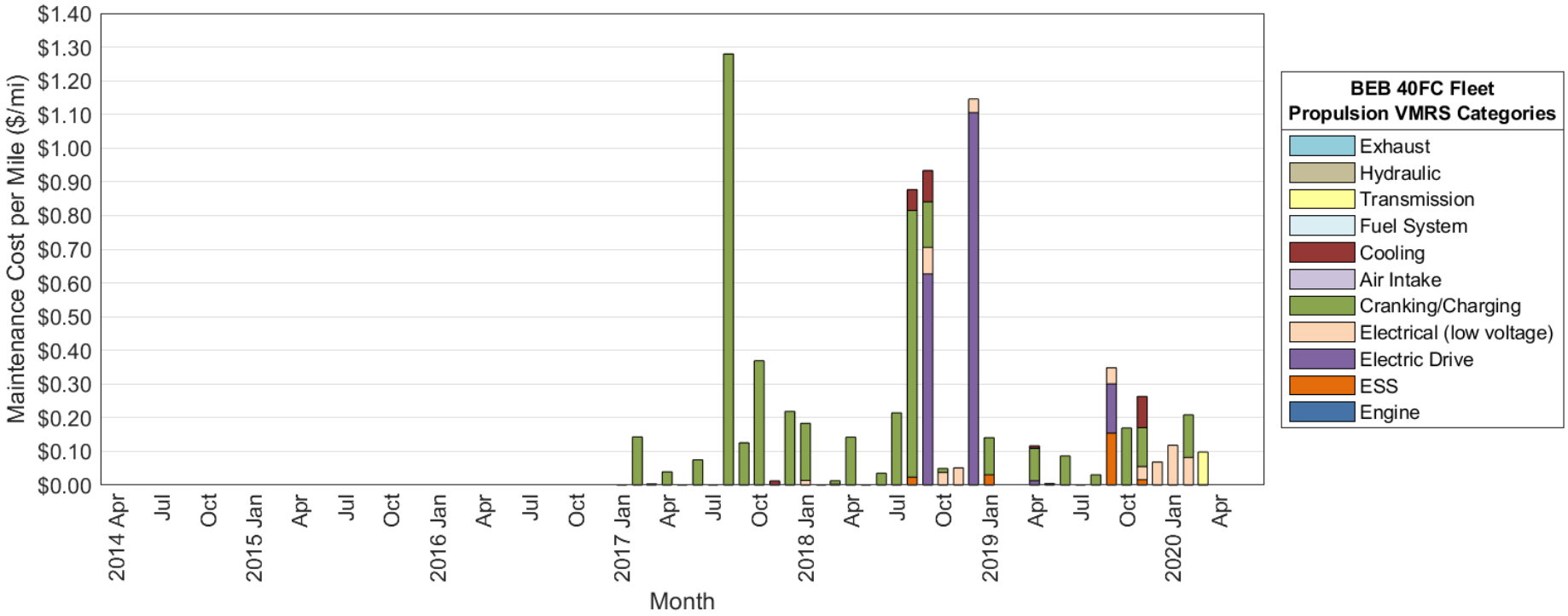
- CNG bus maintenance cost shows an increase over time as the buses age and pass the warranty period
- During the high-cost months, multiple buses reached the mileage for a major PM.

Propulsion System Maintenance Cost by Subsystem: BEB 35FC Fleet



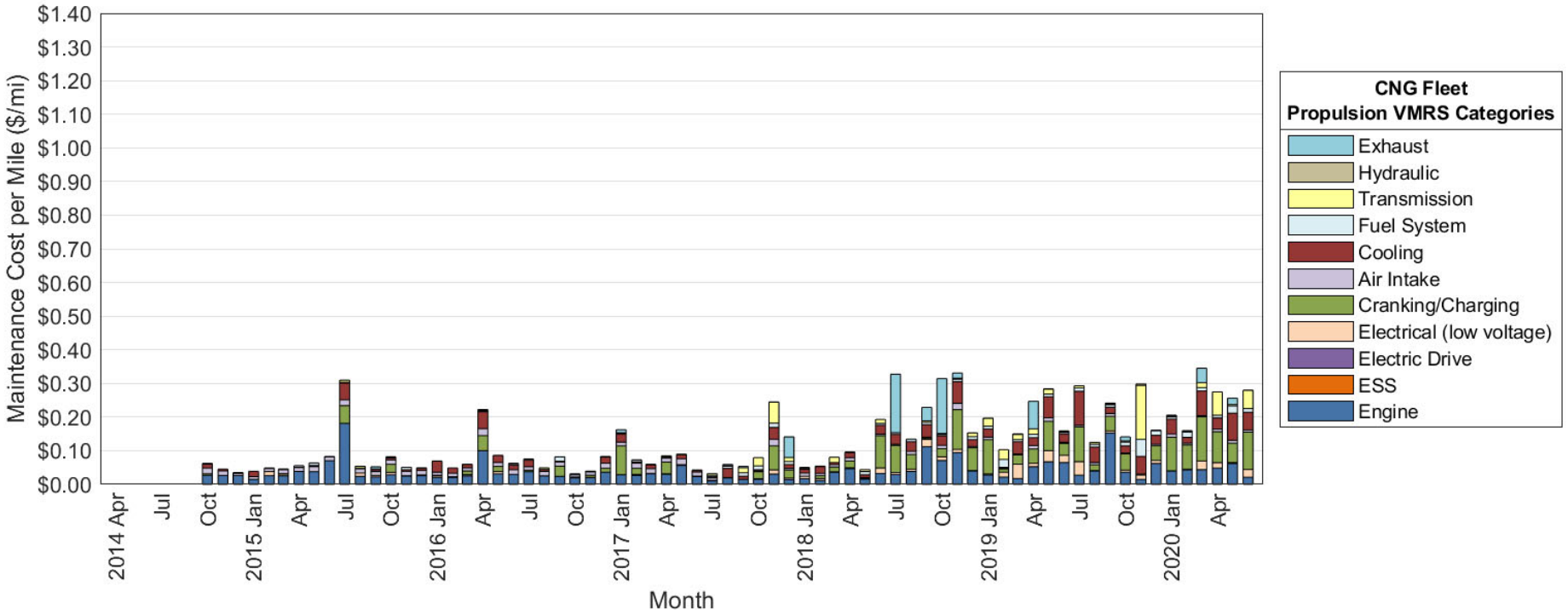
- Low-voltage battery replacements fall into the cranking/charging category
- Cost per mile for April, May, and June 2020 are artificially high due to low mileage accumulation during reduced service. These costs are not representative of the overall costs and have been removed from the chart. The data are included in the analysis totals.

Propulsion System Maintenance Cost by Subsystem: BEB 40FC Fleet



- Both buses in the BEB 40FC fleet had low-voltage battery changeouts and issues with controllers
- Cost per mile for April, May, and June 2020 are artificially high due to low mileage accumulation during reduced service. These costs are not representative of the overall costs and have been removed from the chart. The data are included in the analysis totals.

Propulsion System Maintenance Cost by Subsystem: CNG Fleet



- Increased costs in the first half of 2020 fall into several categories:
  - Cranking/charging—low-voltage batteries
  - Cooling
  - Engine—control module failures.

Propulsion-Related Maintenance Costs by Subsystem: Jan.–June 2020

Maintenance System		BEB 35FC	BEB 40FC	CNG
Mileage		45,286	13,510	177,234
Total Propulsion-Related Systems (Roll-Up of All Systems)	Parts cost ($)	7,085.73	2,575.02	28,098.14
	Labor hours	391.4	50.7	321.1
	Total cost ($)	26,656.73	5,111.02	44,154.14
	Total cost ($) per mile *Without battery changeouts*	**0.589** ***0.396***	**0.378** ***0.184***	**0.249** ***0.033***
Exhaust System Repairs	Parts cost ($)	0.00	0.00	1,401.10
	Labor hours	0.0	0.0	10.0
	Total cost ($)	0.00	0.00	1,900.60
	Total cost ($) per mile	**0.000**	**0.000**	**0.011**
Fuel System Repairs	Parts cost ($)	0.00	0.00	991.20
	Labor hours	0.0	0.0	21.7
	Total cost ($)	0.00	0.00	2,074.70
	Total cost ($) per mile	**0.000**	**0.000**	**0.012**
Powerplant System Repairs (ESS for BEBs)	Parts cost ($)	0.00	0.00	2,816.99
	Labor hours	90.5	0.0	91.6
	Total cost ($)	90.54	0.00	91.58
	Total cost ($) per mile	**0.100**	**0.000**	**0.042**
Electric Propulsion System Repairs	Parts cost ($)	0.00	0.00	0.00
	Labor hours	70.9	4.8	0.0
	Total cost ($)	3,547.00	241.50	0.00
	Total cost ($) per mile	**0.078**	**0.018**	**0.000**

Propulsion-Related Maintenance Costs by Subsystem: Jan.–June 2020

Maintenance System		BEB 35FC	BEB 40FC	CNG
Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)	Parts cost ($)	6,762.12	2,575.02	16,220.27
	Labor hours	122.4	36.1	57.1
	Total cost ($)	12,880.12	4,381.02	19,074.77
	Total cost ($) per mile	**0.284**	**0.324**	**0.108**
Air Intake System Repairs	Parts cost ($)	0.00	0.00	1,087.08
	Labor hours	0.0	0.0	1.9
	Total cost ($)	0.00	0.00	1,180.58
	Total cost ($) per mile	**0.000**	**0.000**	**0.007**
Cooling System Repairs	Parts cost ($)	0.00	0.00	3,524.68
	Labor hours	0.0	0.0	101.9
	Total cost ($)	0.00	0.00	8,618.18
	Total cost ($) per mile	**0.000**	**0.000**	**0.049**
Transmission System Repairs	Parts cost ($)	323.61	0.00	2,056.82
	Labor hours	107.6	9.8	37.1
	Total cost ($)	5,702.61	488.50	3,909.32
	Total cost ($) per mile	**0.126**	**0.036**	**0.022**
Hydraulic System Repairs	Parts cost ($)	0.00	0.00	0.00
	Labor hours	0.0	0.0	0.0
	Total cost ($)	0.00	0.00	0.00
	Total cost ($) per mile	**0.000**	**0.000**	**0.000**

Low-Voltage Battery Maintenance Analysis

Foothill Transit continues to have issues with the low-voltage batteries. The tables summarize the low-voltage battery changeout data from the BEB and CNG buses. The BEBs are averaging 11.6 changeouts per bus at approximately 10,500 miles between changeout. The CNG buses average 2.6 changeouts per bus at more than 121,000 miles between changeouts. One issue is that the accessories (e.g., farebox, cameras) continually draw power from these batteries. If the BEB master switch is not turned off at the end of operation, the accessories continue to draw power from the low-voltage batteries. The CNG buses are equipped with an auto shutoff for the accessories; the BEBs are not.

BEB	Low-Voltage Battery Changeouts	Accumulated Miles	Miles between Changeout	Data Period
2004	7	120,103	17,158	0
2005	13	133,494	10,269	1
2006	12	133,440	11,120	2
2007	9	130,295	14,477	0
2008	13	128,249	9,865	2
2009	10	145,365	14,537	0
2010	6	129,779	21,630	0
2011	12	129,648	10,804	2
2012	9	128,418	14,269	1
2013	11	107,184	9,744	3
2014	11	143,582	13,053	1
2015	20	120,941	6,047	0
2016	17	69,411	4,083	3
2017	12	81,238	6,770	2
Overall	**162**	**1,701,148**	**10,501**	**17**

Proterra is aware of the issue and has developed an auto shutoff to address the problem. New designs include this feature.

CNG Bus	Low-Voltage Battery Changeouts	Accumulated Miles	Miles between Changeout
2200	3	318,359	106,120
2201	1	301,659	301,659
2202	2	320,434	160,217
2203	3	321,826	107,275
2204	3	304,385	101,462
2205	2	320,811	160,406
2206	1	332,962	332,962
2207	6	327,644	54,607
Overall	**21**	**2,548,080**	**121,337**

Arcadia BEB Results

Proterra BEB 40E2

Proterra BEB 35E2 (selected data)

New Flyer CNG baseline

Results Summary

Bus fleets: This evaluation includes 14 Proterra 40-ft E2 buses (BEB 40E2) and 14 New Flyer 40-ft CNG buses. Although Foothill Transit's 35-ft E2 buses (BEB 35E2) are not a focus of this report, NREL collects mileage and energy from these buses. This is necessary to calculate cost per mile for Arcadia because all 17 BEBs are charged at the facility. The utility data are not separated by bus, so the data from all buses are required for the calculation.

Bus use: The BEB 40E2s are operated primarily on Line 280, which circles through the Azusa Intermodal Transit Center (AITC) for supplemental charging. The CNG buses are randomly dispatched on all routes out of the operations facility, including higher-speed commuter routes. The average speed for the CNG buses is around 17 mph. This difference in duty cycle influences the comparison of mileage, fuel economy, and costs per mile between fleets.

Availability: Availability in the first half of 2020 was 84% for the BEB 40E2 buses and 94% for the CNG buses. Most unavailable time for the BEBs was due to general bus-related problems. Issues with the low-voltage batteries as well as problems with bus bodies affected BEB availability. Other downtime resulted from issues with components such as high-voltage electrical, cooling, suspension, air compressor, and traction motor.

Results Summary (continued)

Fuel economy: NREL collects miles and energy use from individual data loggers installed on each of the E2 BEBs. NREL is using these data to calculate the fuel economy for the buses.

BEB efficiency in the first half of 2020 was 1.89 kWh/mi for the BEB 40E2 fleet and 1.82 kWh/mi for the BEB 35E2 fleet. Fuel economy for the CNG bus fleet was 3.4 mpgge. For comparison, diesel equivalent fuel economy was 19.89 mpdge for the BEB 40E2, 20.70 mpdge for the BEB 35E2, and 3.90 mpdge for the CNG fleet. The BEB E2 fuel economy is approximately five times that of the CNG buses as they are currently operated by Foothill Transit.

Fuel cost: Because the BEB 40E2 fleet (14 BEBs) and the BEB 35E2 fleet (3 BEBs) are collectively charging at both the Arcadia depot and AITC, the electricity costs for charging at both locations must be combined and the total fleet mileage for both fleets must be combined to calculate an average fuel cost per mile.

For the first half of 2020, the total electricity cost was $116,369 (by calendar month) and the total accumulated mileage for all 17 BEBs was 543,889 miles. The average fuel cost for both the BEBs and CNG buses was $0.36/mi.

Results Summary (continued)

Maintenance cost: Cost to maintain the buses in the first half of 2020 was $0.40/mi for the BEB 40E2s and $0.34/mi for the CNG buses.

- On-site contractor staff handle most of the maintenance. For some work orders, increased labor hours were needed to troubleshoot and repair the issue. During the first half of 2020, scheduled costs were $0.07/mi for the BEB 40E2 buses. Unscheduled costs were $0.33/mi. The scheduled maintenance costs for the CNG buses were higher than for the BEBs at $0.12/mi. The unscheduled costs for the CNG buses at $0.22/mi were 33% lower than that of the BEB 40E2 fleet.
- Propulsion system costs for the BEB 40E2 and CNG buses were the same, at $0.12/mi. Propulsion system issues for the BEB 40E2 fleet were for the cooling system, non-lighting electrical, and transmission. The CNG buses experienced issues with the engine, cooling system, and non-lighting electrical.

Future analysis: NREL will continue to collect data on the BEB E2 fleet in comparison to the CNG baseline fleet through the end of 2020.

Evaluation Buses: Specifications

Vehicle System	BEB 40E2	CNG
Number of buses	14	14
Bus manufacturer/model	Proterra/Catalyst E2	New Flyer/Xcelsior XN40
Model year	2017	2017
Bus purchase cost[a]	$898,854	$575,000
Length/width/height	42 ft/102 in./133 in.	40 ft/102 in./133 in.
GVWR/curb weight	42,000 lb/31,360 lb	43,720 lb/32,270 lb
Wheelbase	296 in.	283 in.
Passenger capacity	40 seats, 2 wheelchair positions	35 seats, 2 wheelchair positions
Motor or engine	Permanent magnet	CNG engine, Cummins, 8.9 ISL G
Rated power	220 kW peak	280 hp @ 2,000 rpm
Energy storage (BEB) Fuel capacity (CNG)	440 kWh	7 all carbon fiber cylinders, Hexagon 23,065 scf[b] at 3,600 psi[c]
Accessories	Electric	Mechanical
Emissions equipment	N/A	3-way catalyst
Transmission/retarder	Regenerative braking	N/A

[a] Includes amenities such as painting of bus and livery, surveillance system, public address (PA) system, radio, and safety vision monitor
[b] Standard cubic feet
[c] Pounds per square inch

Infrastructure Description

The primary means of charging for the BEB E2s is plug-in chargers installed at the Arcadia facility. Foothill Transit installed 13 60-kW chargers and a 125-kW charger to accommodate its 17 BEBs. The system, which has a capacity for up to 40 chargers, was designed for gantry-style charging with cables that drop down from the charger support structure. The support structure design will allow for adding photovoltaic panels in the future. The system was commissioned in December 2019. Foothill Transit is not currently using software to manage charging; instead, staff do not plug in the buses between 4–9 p.m. to avoid peak electric charges.

Foothill Transit installed a second on-route fast charging station at the AITC. The station is similar to the one at the PTC, with two charge heads. The buses can be charged at this transit center to extend the range of the buses. The schedule for the BEB E2 buses typically includes a 10-minute stop at Azusa, but this time can be longer if the driver is at a break period. The BEBs are not charged every time they stop at the transit center. (Note: the BEB 35E2 fleet does not charge at the AITC.)

Data Summary: Jan.–June 2020

Data Item	BEB 40E2	BEB 35E2	CNG
Number of buses	14	3	14
Data period	1/2020–6/2020	1/2020–6/2020	1/2020–6/2020
Number of months	6	6	6
Total mileage in data period	271,944	52,345	373,030
Average monthly mileage per bus	3,237	2,908	4,441
Availability (85% is target)	84.0	—	94.1
Fuel consumption for BEBs (kWh/mile) or fuel economy for CNG buses (mpgge)	1.89	1.82	3.40
Fuel economy (mpdge)	19.89	20.70	3.90
Average speed, including stops (mph)	—	—	—
MBRC[a]—bus	27,194	—	17,763
MBRC[a]—propulsion system only	54,389	—	24,869
MBRC[a]—ESS only[b]	—	—	—
Total maintenance cost ($/mile)[c]	0.401	—	0.340
Maintenance cost—propulsion system only ($/mile)	0.120	—	0.119

[a] MBRC data cumulative from the clean point of Jan. 2020 through end of current data period
[b] To date, the BEB E2 fleet has not had an ESS-related road call
[c] Work order maintenance cost

Route Assignments

Foothill Transit uses the BEB 40E2 buses primarily on Line 280, which cycles through the Azusa Intermodal Transit Center, allowing for supplemental charging at the fast-charge station to increase range.

The CNG buses are randomly dispatched on all routes out of Arcadia Operations, including commuter routes. Average speed for Arcadia Operations is approximately 17 mph.

Foothill Transit operates the BEB 35E2 fleet on a shuttle route for the City of Duarte. This route runs through the city and residential areas with narrow streets and parked cars, which requires shorter buses.

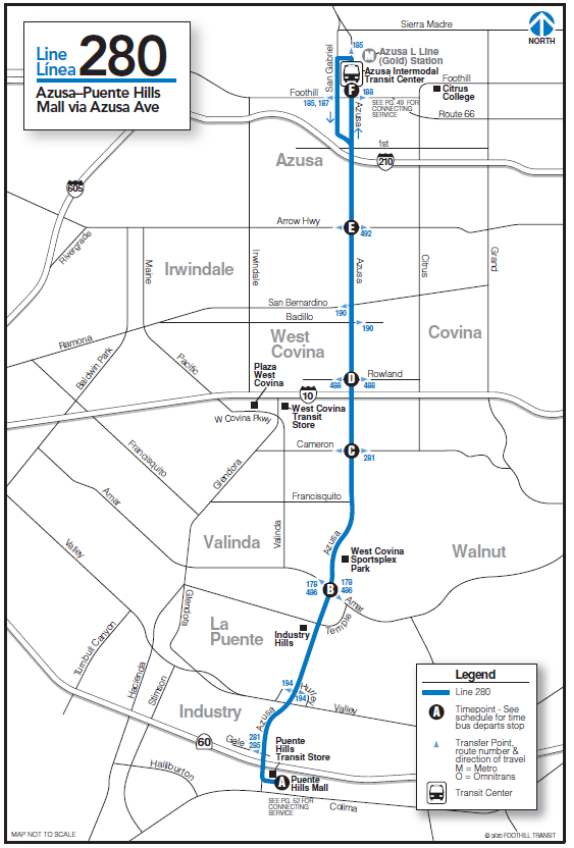
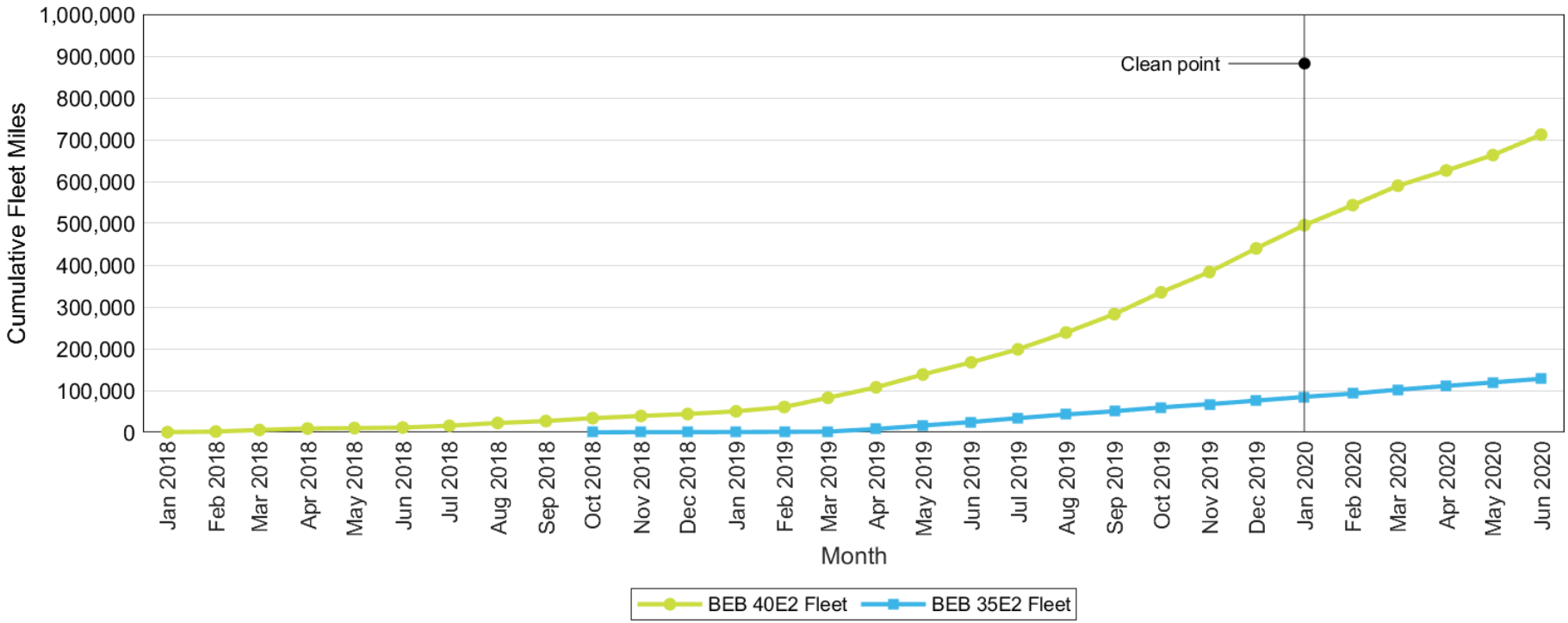


Image courtesy of Foothill Transit

BEB Fleet Total Miles



- Combined totals are shown for 14 BEB 40E2 buses and 3 BEB 35E2 buses.

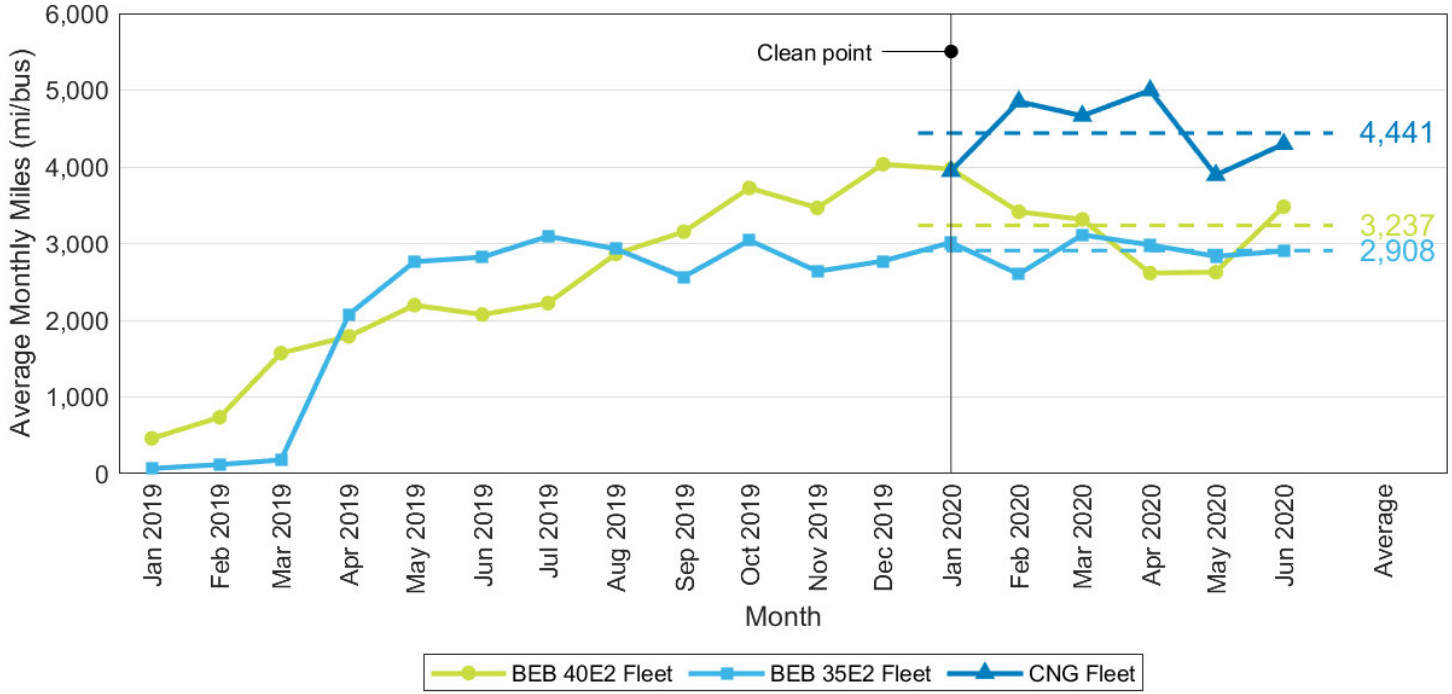
Fleet Average Monthly Miles by Bus: Jan.–June 2020

Bus ID	Miles	Bus Months	Average Monthly Mileage
2600	20,379	6	3,396
2601	20,783	6	3,464
2602	21,168	6	3,528
2603	19,230	6	3,205
2604	20,657	6	3,443
2605	18,719	6	3,120
2606	21,258	6	3,543
2607	23,367	6	3,894
2608	6,029	6	1,005
2609	21,992	6	3,665
2610	24,049	6	4,008
2611	14,061	6	2,343
2612	21,002	6	3,500
2613	19,252	6	3,209
BEB 40E2 Fleet	**271,944**	**84**	**3,237**

Bus ID	Miles	Bus Months	Average Monthly Mileage
2516	27,235	6	4,539
2517	28,191	6	4,699
2518	26,556	6	4,426
2519	22,519	6	3,753
2520	28,861	6	4,810
2521	26,824	6	4,471
2522	27,337	6	4,556
2523	28,659	6	4,777
2524	27,226	6	4,538
2525	29,129	6	4,855
2526	21,600	6	3,600
2527	26,484	6	4,414
2528	28,627	6	4,771
2529	23,782	6	3,964
CNG Fleet	**373,030**	**84**	**4,441**

The average monthly operating mileage per bus for the BEB 40E2 fleet is 27% lower than that of the CNG buses as operated by Foothill Transit.

Fleet Average Monthly Miles



- The BEB 40E2 fleet was delivered in early 2018, but not placed into active service until January 2020, when the plug-in charging infrastructure installation was completed and commissioned. Prior to that time, the buses were used for training and testing on selected routes. The clean point was set for January 2020 to coincide with the start of service.

Availability Analysis

Availability, which is a measure of reliability, is presented as the percentage of days the buses are 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 special events, or they may have been available but not used. Buses unavailable for service may have had issues with the propulsion system (energy storage system, electric drive system), general bus maintenance, or issues with the charging system. 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. The Foothill Transit buses are planned to operate every day, including weekends. For Foothill Transit, the source for availability data is garage activity sheets for Arcadia Operations, which list each bus that is not available for morning pull-out and provide a general reason for unavailability. These activity sheets are for the facility as a whole and include the BEBs as well as the CNG buses. The garage activity sheets are typically available for weekdays.

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.

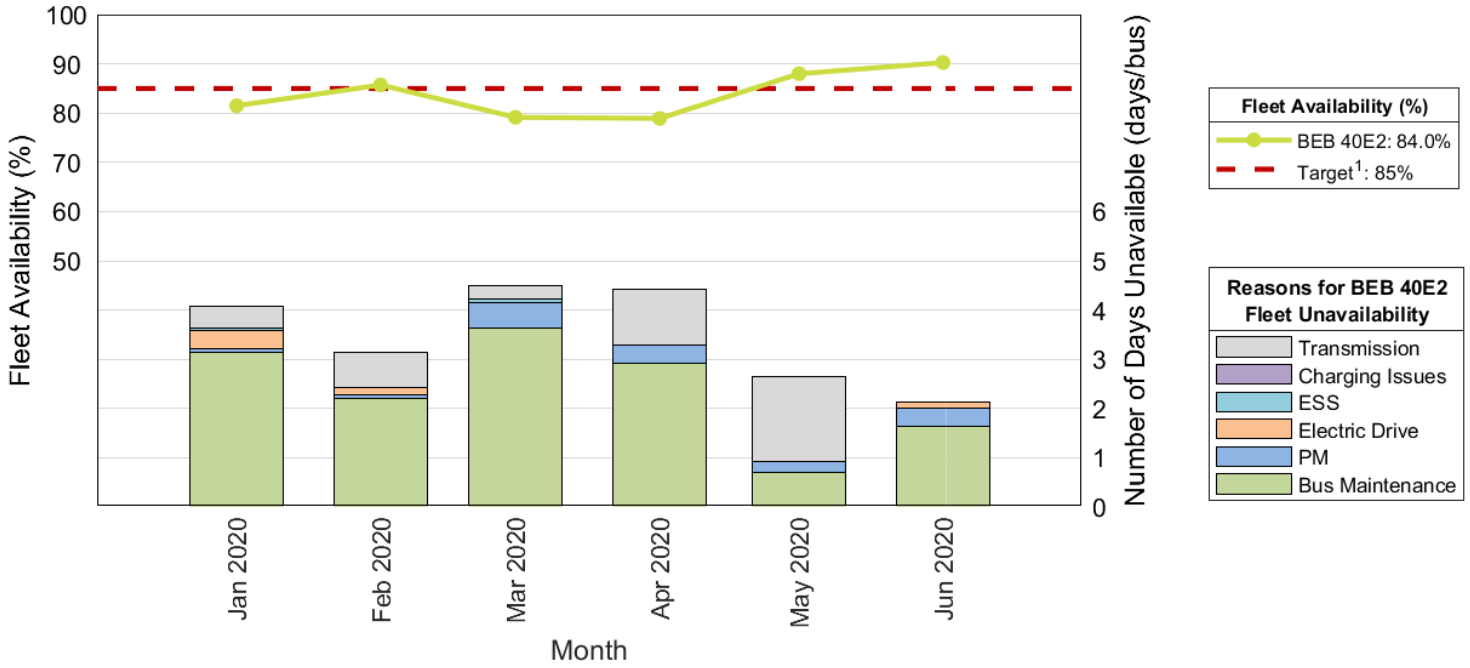
Availability Summary: Jan.–June 2020

Category	BEB 40E2 (# days)[a]	BEB 40E2 (%)	CNG (# days)[a]	CNG (%)
Planned work days	1,828	—	1,823	—
Days available	1,535	84.0	1,716	94.1
Unavailable	293	16.0	107	5.9
ESS	2	0.1	—	—
CNG engine	—	—	48	2.6
Electric drive	9	0.5	—	—
Charging issues	0	0.0	—	—
Preventive maintenance	22	1.2	17	0.9
General bus maintenance	200	10.9	42	2.3
Transmission	60	3.3	0	0.0

[a] Sum of days for all buses in a fleet

- The per-bus availability for the BEBs ranged from a low of 25% to a high of 98% during the data period.
- Most unavailable time for the BEBs was attributed to general bus maintenance. Most unavailable time for the CNG buses was attributed to engine issues and general bus maintenance.
- General bus maintenance includes everything that doesn't fall into one of the other categories.

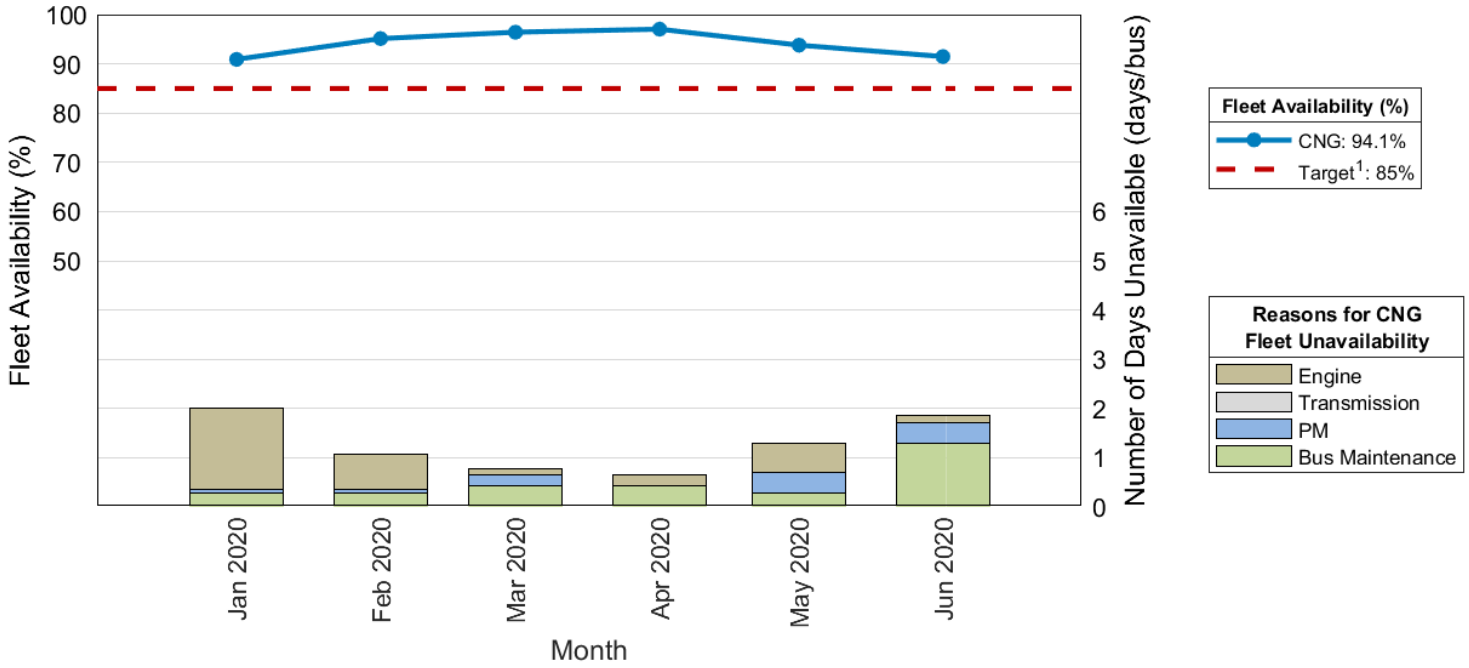
Monthly Availability: BEB 40E2 Fleet



1. Target of 85% fleet availability is a general expectation for transit agencies

- The green line tracks the average monthly availability for the BEB 40E2 fleet
- The stacked bars provide the number of unavailable days by bus each month, separated by six categories
- Most downtime was attributed to general bus issues such as coolant pumps, air compressors, and information technology (IT) equipment.

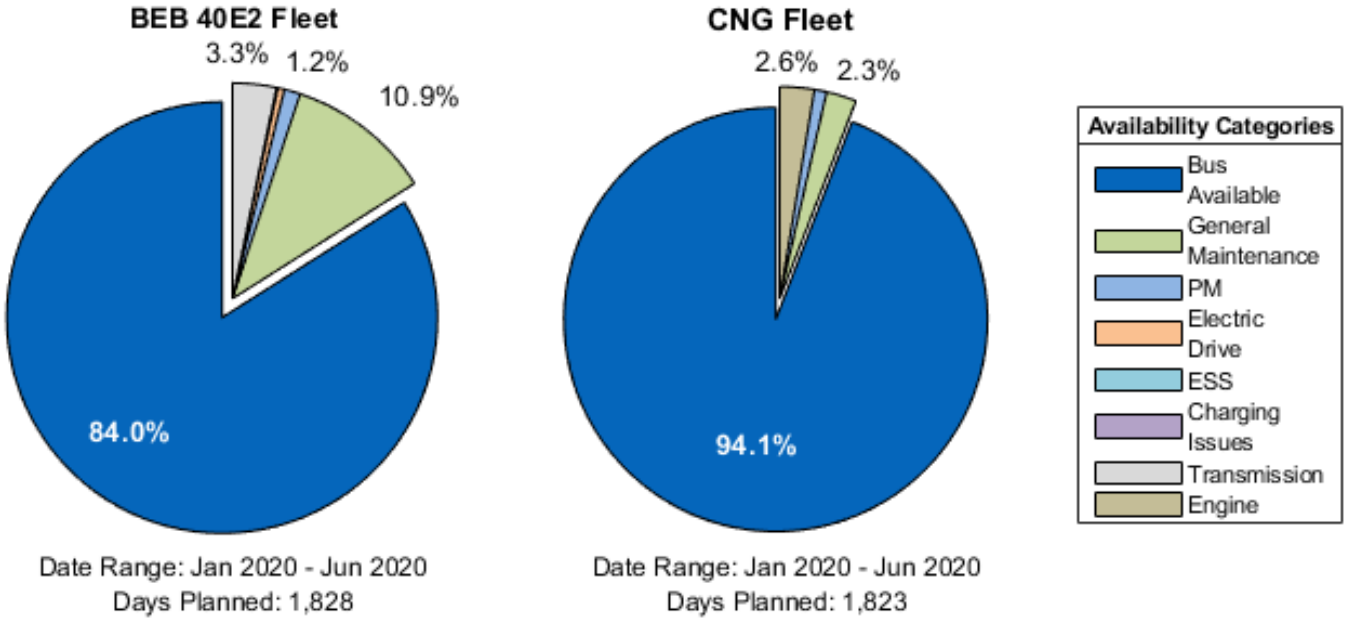
Monthly Availability: CNG Fleet



1. Target of 85% fleet availability is a general expectation for transit agencies

- The blue line tracks the average monthly availability for the CNG fleet
- The stacked bars provide the number of unavailable days by bus each month, separated by four categories.

Overall Fleet Availability: Jan.–June 2020



Fuel Consumption/Fuel Economy: Jan.–June 2020

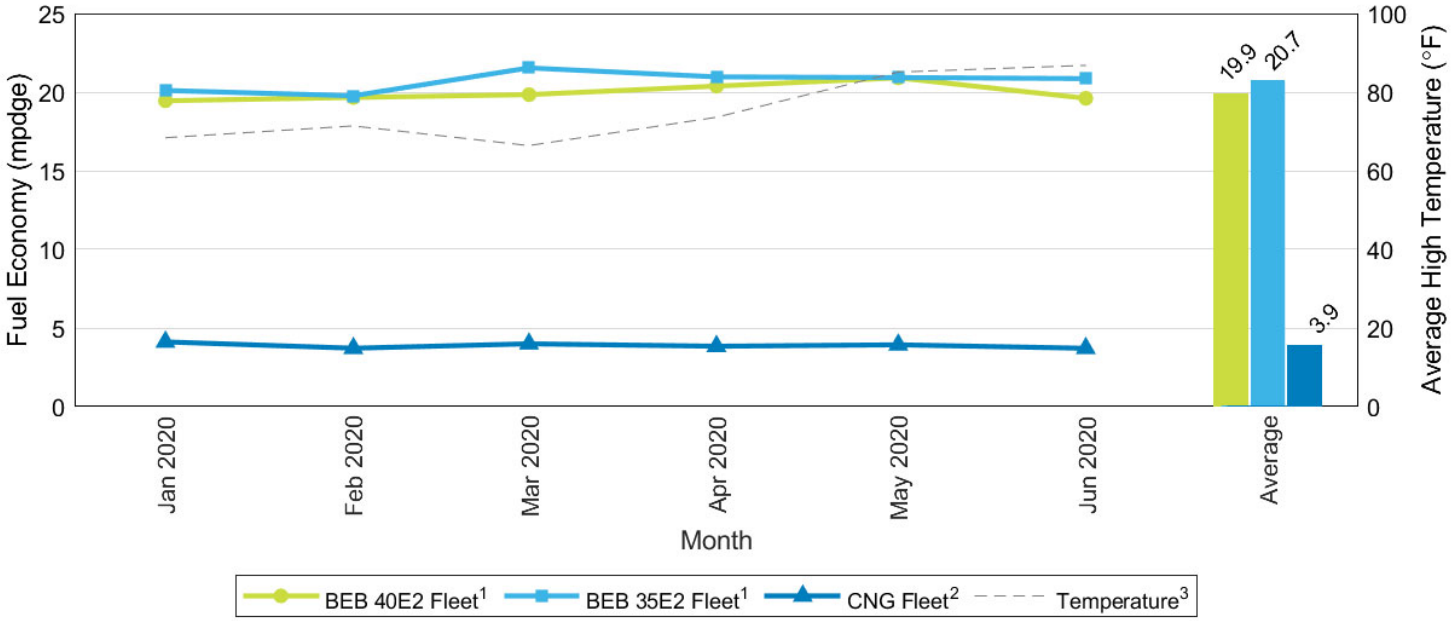
Bus ID	Miles	Energy[a] (kWh)	kWh/mi	Diesel Gallon Equiv.	Fuel economy (mpdge)
2600	20,379	39,555.3	1.94	1,051.0	19.39
2601	20,783	40,654.7	1.96	1,080.2	19.24
2602	21,168	40,086.8	1.89	1,065.1	19.87
2603	19,230	35,069.6	1.82	931.8	20.64
2604	20,657	39,701.7	1.92	1,054.9	19.58
2605	18,719	36,595.5	1.95	972.4	19.25
2606	21,258	40,075.3	1.89	1,064.8	19.96
2607	23,367	42,927.9	1.84	1,140.6	20.49
2608	6,029	11,114.8	1.84	295.3	20.41
2609	21,992	42,658.2	1.94	1,133.5	19.40
2610	24,049	45,087.7	1.87	1,198.0	20.07
2611	14,061	26,360.4	1.87	700.4	20.07
2612	21,002	38,888.0	1.85	1,033.3	20.33
2613	19,252	35,726.2	1.86	949.3	20.28
BEB 40E2 Fleet	**271,944**	**514,502.1**	**1.89**	**13,670.6**	**19.89**

Bus ID	Miles	CNG (gge)	mpgge	Diesel Gallon Equiv.	Fuel economy (mpdge)
2516	2,841	744.4	3.82	649.5	4.37
2517	1,525	409.8	3.72	357.6	4.26
2518	2,134	613.5	3.48	535.3	3.99
2519	922	227.5	4.05	198.5	4.65
2520	2,958	865.2	3.42	754.9	3.92
2521	440	127.9	3.44	111.6	3.94
2522	1,729	548.5	3.15	478.6	3.61
2523	1,309	414.6	3.16	361.7	3.62
2524	2,123	686.3	3.09	598.8	3.55
2525	3,062	898.8	3.41	784.2	3.90
2526	972	296.1	3.28	258.4	3.76
2527	1,619	513.8	3.15	448.3	3.61
2528	872	292.9	2.98	255.6	3.41
2529	2,485	709.7	3.50	619.3	4.01
CNG Fleet	**24,991**	**7,348.9**	**3.40**	**6,412.4**	**3.90**

[a] Total energy consumed by the bus does not include losses during charging

- The BEB fuel economy is approximately five times the CNG fuel economy, as operated on current routes.

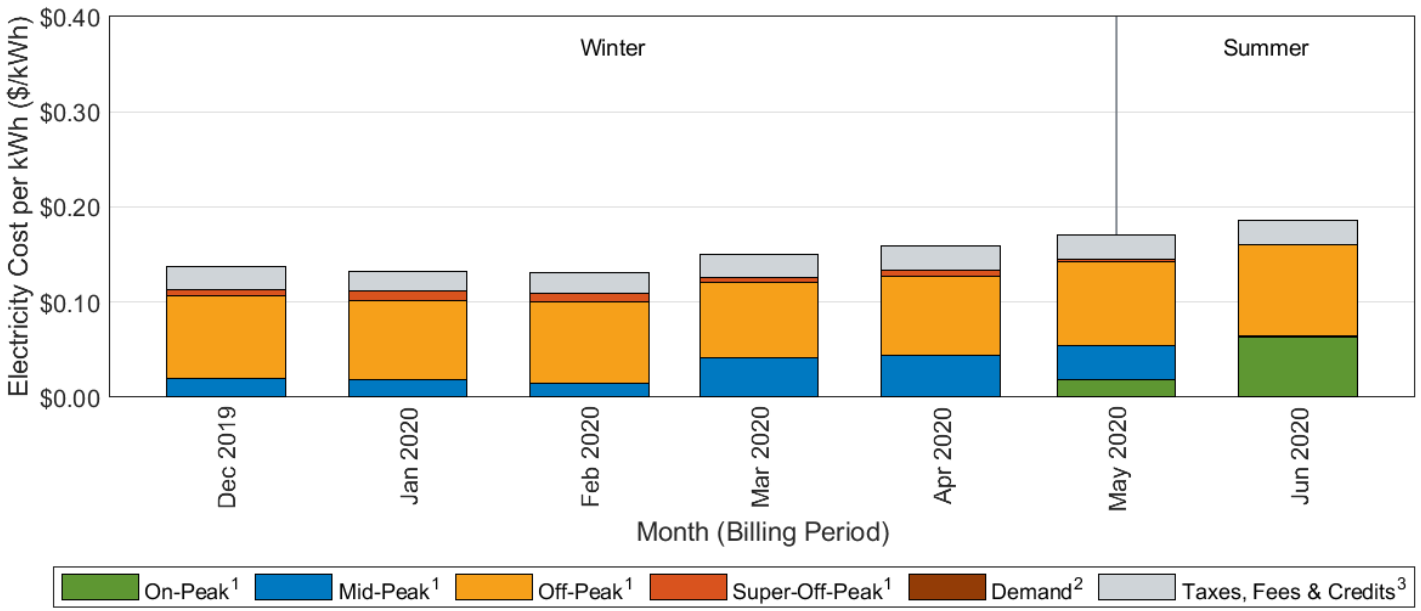
Fleet Average Monthly Fuel Economy



1. Electrical energy converted from kWh to diesel gallon equivalent (dge); conversion factor = 37.64 kWh/dge
2. CNG fuel energy converted from gasoline gallon eqivalent (gge) to diesel gallon equivalent (dge); conversion factor = 1.146 gge/dge
3. Average daily high temperatures at Ontario International Airport, CA; data acquired from: *https://www.ncdc.noaa.gov/*

	Jan.–June 2020	
Fleet	**kWh/mi, mpgge**	**mpdge**
BEB 40E2	1.89	19.89
BEB 35E2	1.82	20.70
CNG	3.40	3.90

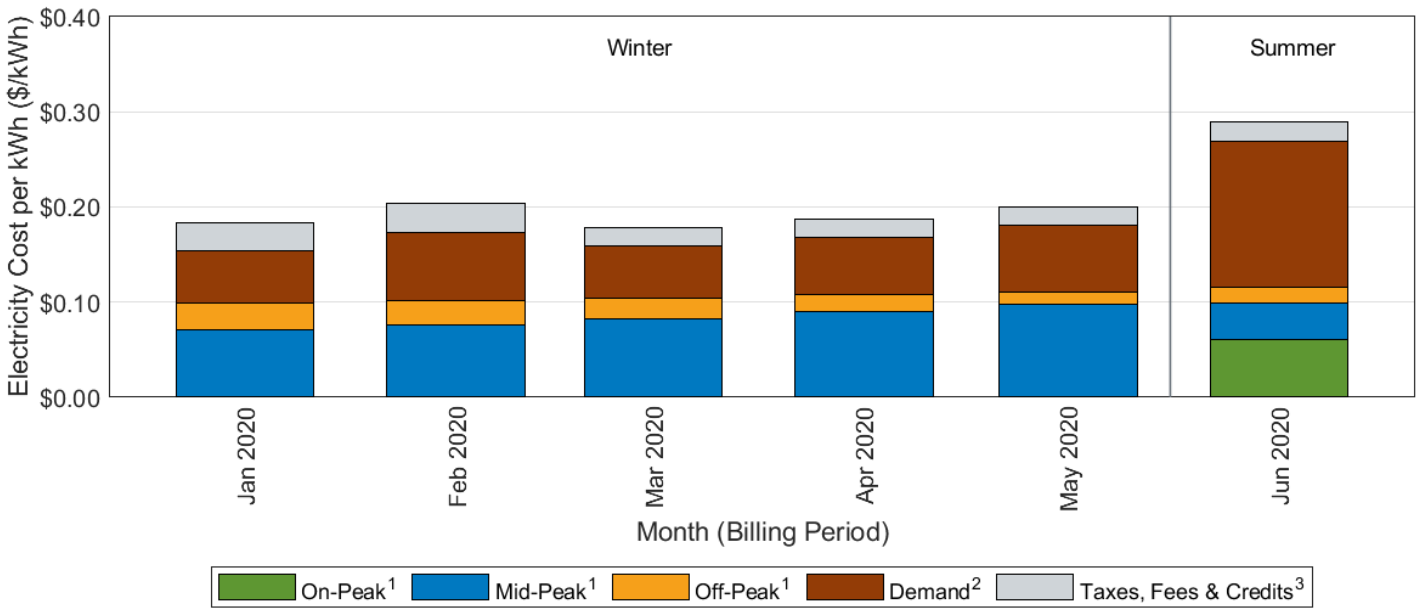
Monthly Electric Utility Costs – Arcadia Depot



1. Time of use charge categories include respective costs for delivery and generation
2. Demand charges currently waived under TOU-EV-9 rate structure
3. Taxes, Fees & Credits category includes all remaining utility bill items (costs & credits)

- Overnight charging at the Arcadia Depot occurs primarily during off-peak hours and averages $0.154/kWh, with prices rising slightly from winter into summer months.

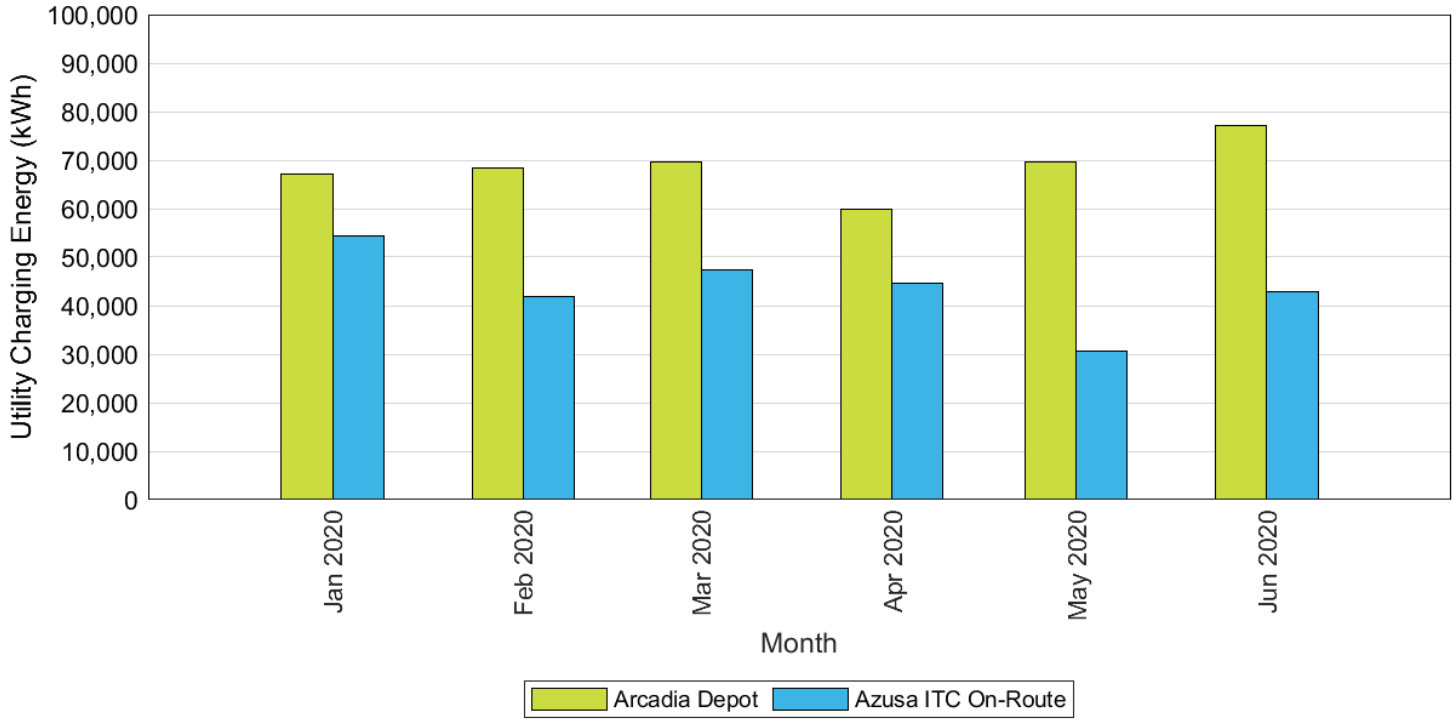
Monthly Electric Utility Costs – AITC



1. Time of use charge categories include On-Peak, Mid-Peak and Off-Peak time periods
2. Demand charges include power factor demand charges
3. Taxes, Fees & Credits category includes all remaining utility bill items (costs & credits)

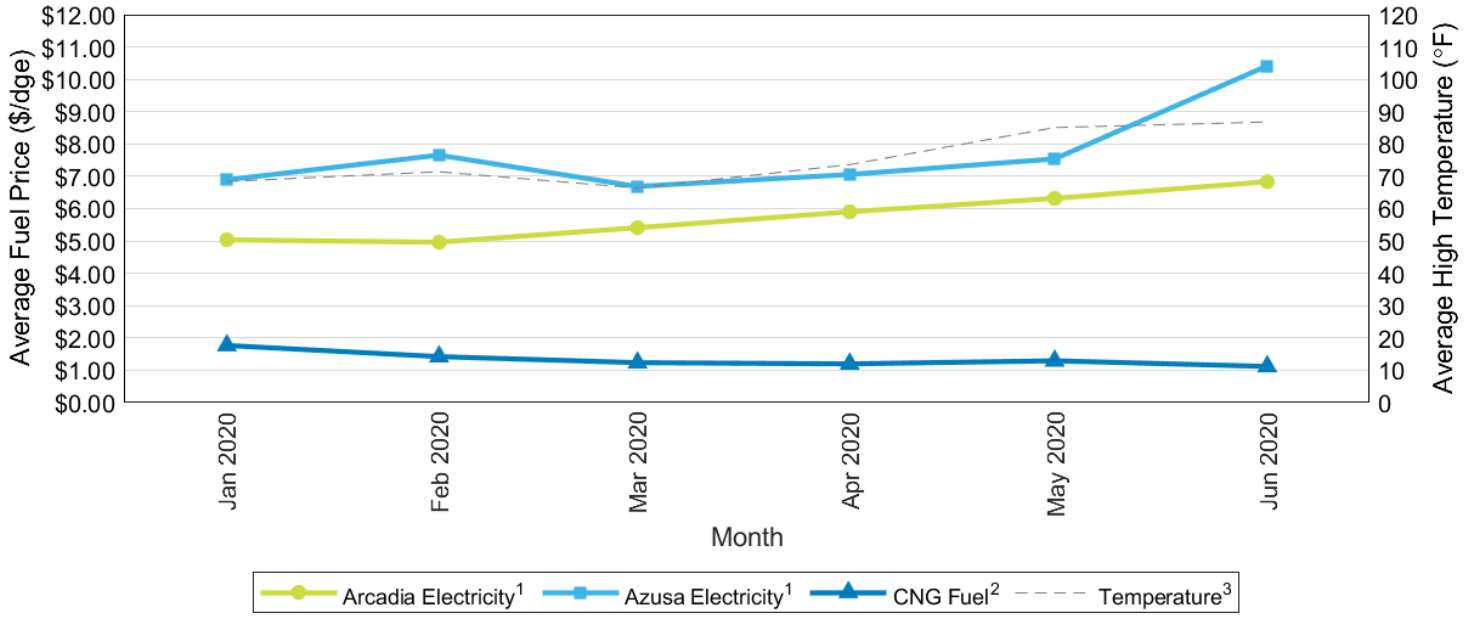
- Supplemental on-route charging at the Azusa Intermodal Transit Center is subject to significant demand charges
- Average electricity cost during winter months was $0.189/kWh; June 2020 cost was $0.289/kWh.

Monthly Electric Utility Consumption



- The majority of energy for the BEBs is provided during overnight charging. Overall, the BEB 40E2 and BEB 35E2 fleets receive 61% of energy from plug-in charging at the Arcadia depot.

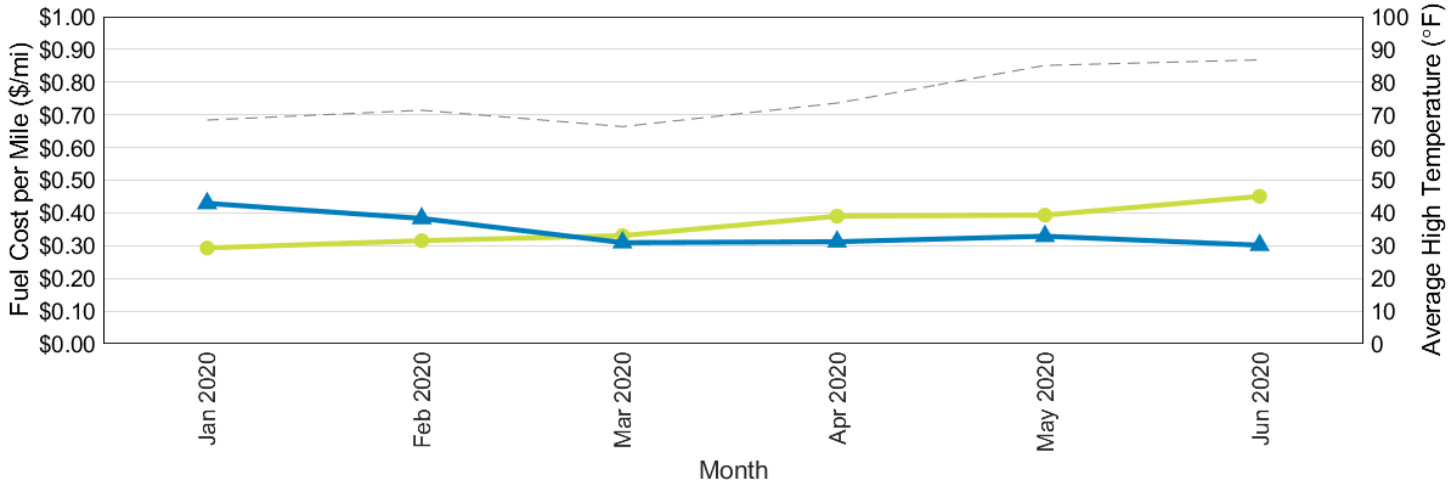
Monthly Average Fuel Price



1. Electrical energy converted from kWh to diesel gallon equivalent (dge); conversion factor = 37.64 kWh/dge
2. CNG fuel energy converted from gasoline gallon eqivalent (gge) to diesel gallon equivalent (dge); conversion factor = 1.146 gge/dge
3. Average daily high temperatures at Ontario International Airport, CA; data acquired from: *https://www.ncdc.noaa.gov/*

- Average fuel price, on a diesel-gallon-equivalent basis, is higher for electricity than for CNG fuel and is expected to increase in the summer months for the Arcadia Depot and AITC on-route charging.

Monthly Average Fuel Cost Per Mile



	BEB Fleet[1]	CNG Fleet
Overall average fuel cost/mi	$0.36/mi	$0.36/mi

1. BEB Fleet includes all battery buses at Arcadia (BEB 40E2 & BEB 35E2 fleets)
2. Average daily high temperatures at Ontario Intenational Airport, CA; data acquired from: *https://www.ncdc.noaa.gov/*

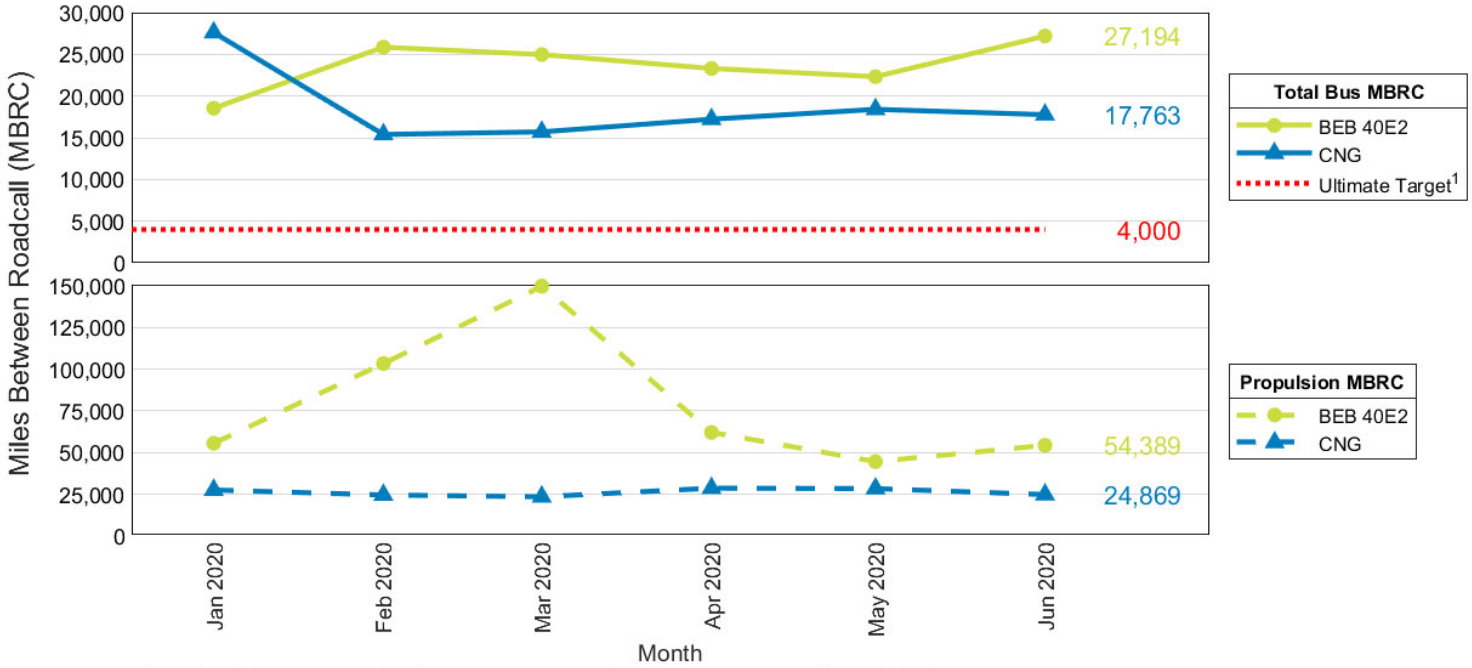
- BEB cost per mile values include charging costs from the Arcadia Depot and Azusa on-route charging, as well as combined mileage from BEB 40E2 and BEB 35E2 fleets, which are using both charging methods
- Higher energy efficiency of the BEBs compared to CNG buses is offset by higher per-unit energy costs for electricity compared to CNG fuel, resulting in similar per-mile fuel cost for BEBs.

Road Call Analysis

A road call, 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, it is not considered a road call. The analysis described here includes only road calls that were caused by "chargeable" failures. Chargeable road calls 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 road calls 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 bus road calls, propulsion-related road calls, and ESS-related road calls (for electric buses). Total bus road calls include all chargeable road calls. Propulsion-related road calls is a subset of total road calls and includes all road calls due to propulsion-related systems including the battery system (or engine for a conventional bus), electric drive, fuel, exhaust, air intake, cooling, non-lighting electrical, and transmission systems. The ESS-related road calls—a subset of the propulsion-related road calls—and ESS-related MBRC are included for the BEBs.

Cumulative MBRC



1. Ultimate Target adopted from: DOE FCTO Program Record #12012, Sept. 2012, *http://www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf*

- The upper chart shows cumulative MBRC for all chargeable road calls
- The lower chart shows MBRC for propulsion-related road calls
- To date, the BEB 40E2 fleet has not experienced any ESS-related road calls

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 labor rate. This does not reflect an average rate for Foothill Transit. Cost per mile is calculated as follows:

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

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 what systems have the most costs for each technology. The work orders are coded using Vehicle Maintenance Reporting Standards (VMRS) developed by the American Trucking Association to aid the industry in tracking equipment and maintenance using a common standard.

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

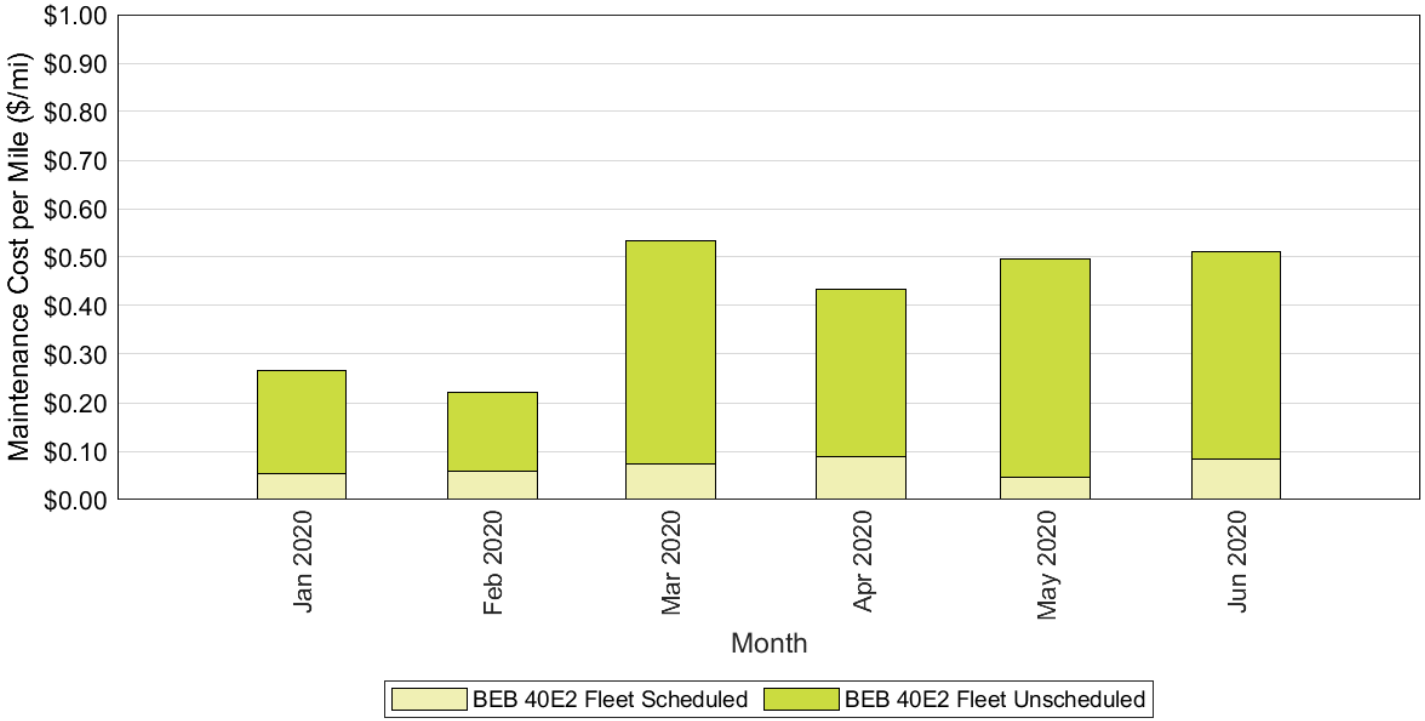
Maintenance Analysis Results: Jan.–June 2020

Bus ID	Mileage	Parts ($)	Labor Hours	Scheduled Cost ($/mi)	Unscheduled Cost ($/mi)	Total Cost ($/mi)
2600	20,379	2,219.68	65.6	0.04	0.23	0.27
2601	20,783	2,263.06	71.2	0.05	0.23	0.28
2602	21,168	1,896.78	101.8	0.08	0.25	0.33
2603	19,230	1,013.34	73.4	0.06	0.18	0.24
2604	20,657	984.07	93.1	0.04	0.23	0.27
2605	18,719	8,948.51	157.2	0.10	0.80	0.90
2606	21,258	2,468.45	91.8	0.07	0.27	0.33
2607	23,367	1,532.37	64.7	0.09	0.11	0.20
2608	6,029	3,811.96	123.4	0.08	1.58	1.66
2609	21,992	3,894.49	93.0	0.08	0.31	0.39
2610	24,049	2,447.11	65.5	0.05	0.18	0.24
2611	14,061	2,421.45	144.2	0.05	0.63	0.68
2612	21,002	4,182.71	83.0	0.05	0.35	0.40
2613	19,252	3,757.92	117.5	0.09	0.41	0.50
BEB 40E2 Fleet	**271,944**	**41,841.90**	**1,345.3**	**0.07**	**0.33**	**0.40**

Bus ID	Mileage	Parts ($)	Labor Hours	Scheduled Cost ($/mi)	Unscheduled Cost ($/mi)	Total Cost ($/mi)
2516	27,235	2,735.34	125.9	0.13	0.20	0.33
2517	28,191	4,013.87	131.3	0.11	0.26	0.38
2518	26,556	6,603.89	139.1	0.12	0.39	0.51
2519	22,519	3,589.48	94.2	0.16	0.21	0.37
2520	28,861	3,436.29	116.3	0.12	0.20	0.32
2521	26,824	3,697.59	94.7	0.10	0.21	0.31
2522	27,337	3,009.71	132.1	0.10	0.25	0.35
2523	28,659	5,287.15	98.3	0.11	0.24	0.36
2524	27,226	2,418.25	92.5	0.12	0.14	0.26
2525	29,129	2,442.92	104.0	0.13	0.14	0.26
2526	21,600	4,392.92	116.7	0.14	0.33	0.47
2527	26,484	3,985.81	131.8	0.10	0.30	0.40
2528	28,627	1,762.52	98.5	0.15	0.09	0.23
2529	23,782	1,462.62	81.5	0.12	0.11	0.23
CNG Fleet	**373,030**	**48,838.37**	**1,557**	**0.12**	**0.22**	**0.34**

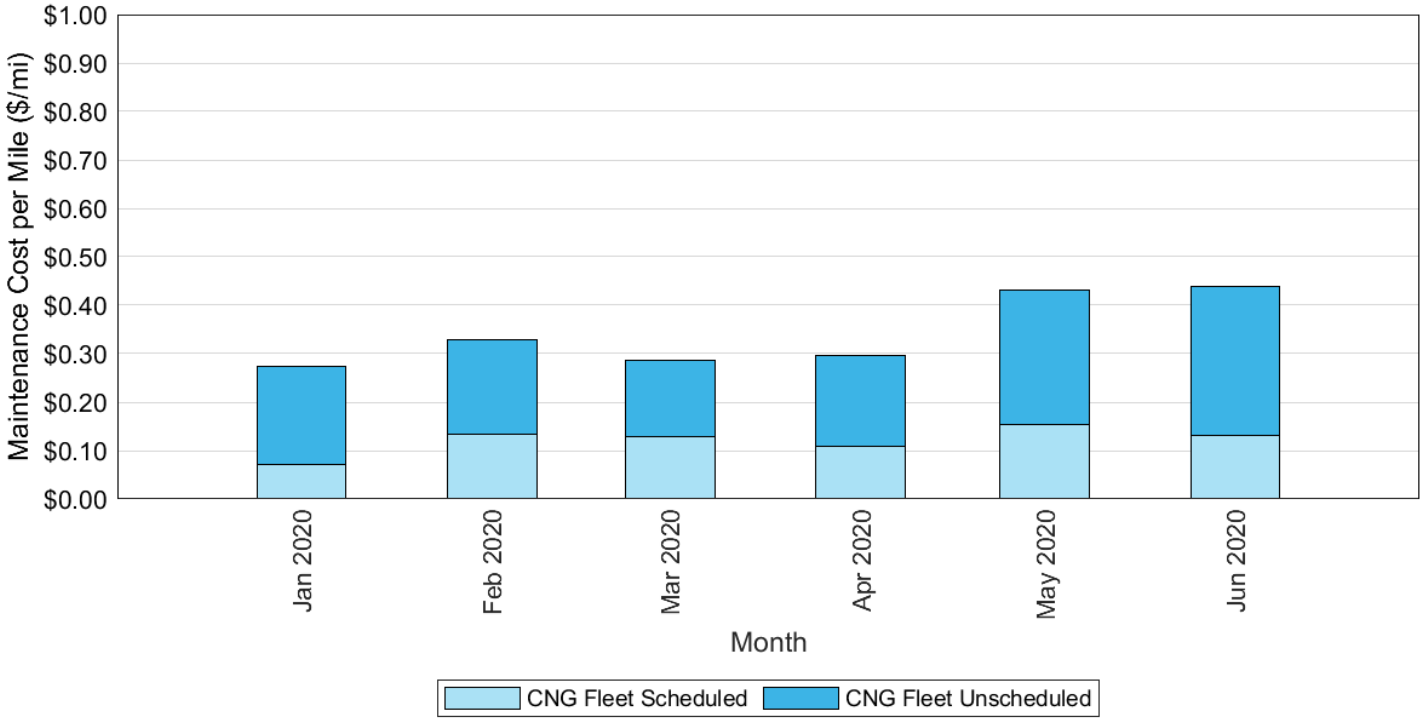
- BEB issues included coolant pumps, transmission, tires, and air compressors.

Monthly Scheduled and Unscheduled Maintenance Cost: BEB 40E2 Fleet



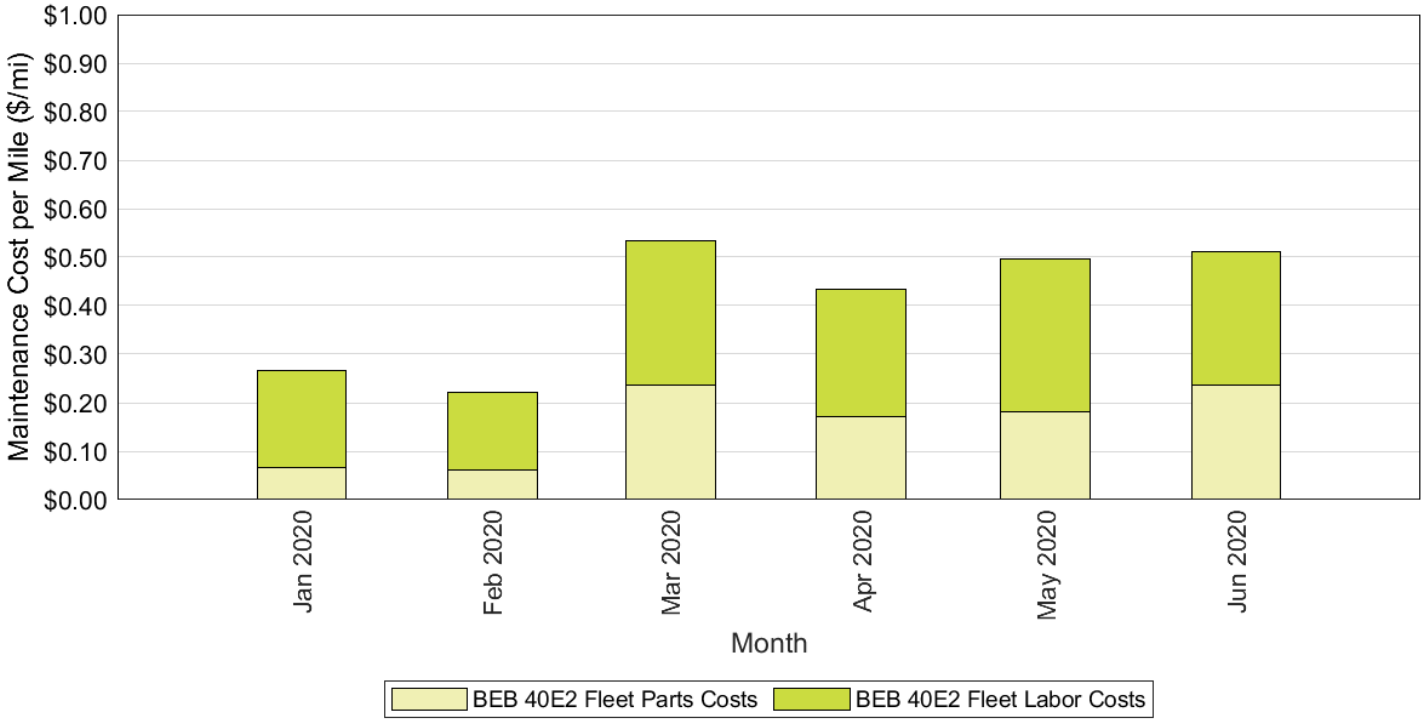
- Most unscheduled costs involve labor for troubleshooting issues.

Monthly Scheduled and Unscheduled Maintenance Cost: CNG Fleet



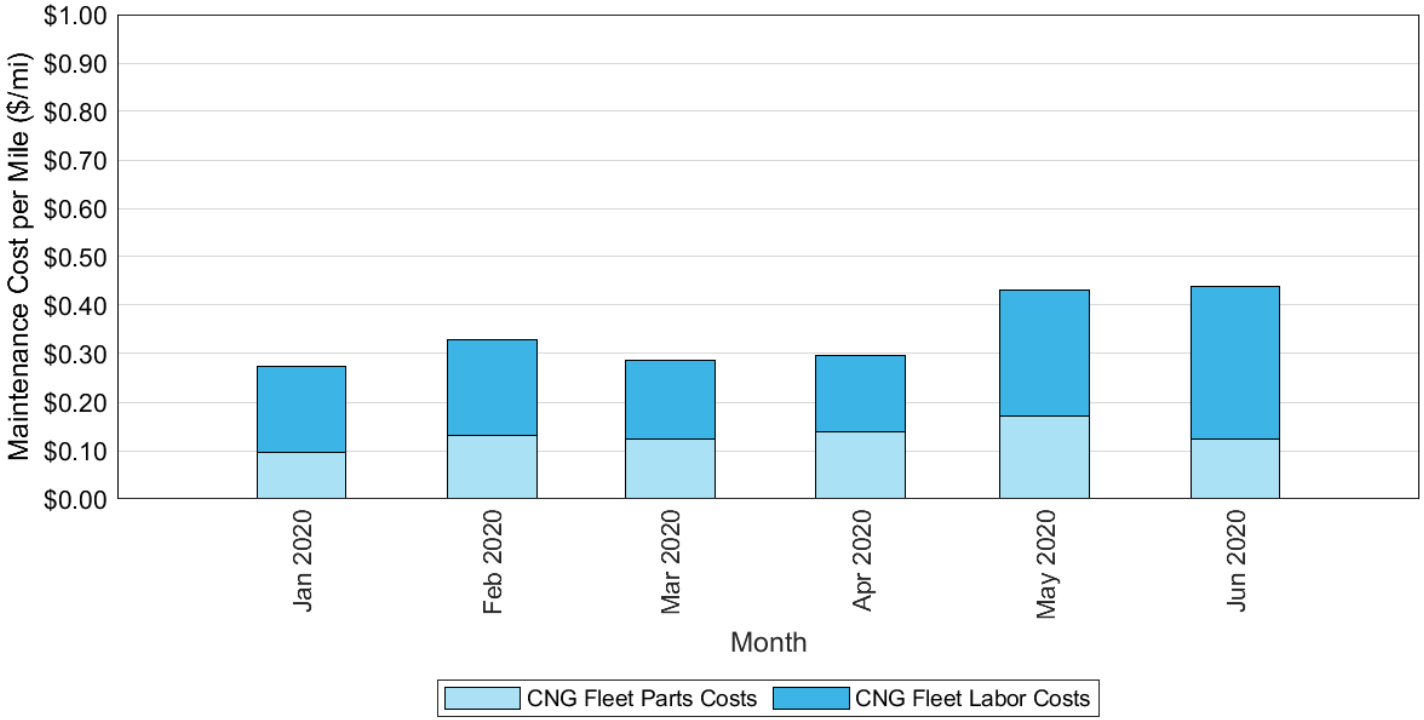
- Unscheduled costs included issues with water pumps, exhaust gas recirculation, gas sensors, tires, and air bags.

Monthly Parts and Labor Maintenance Cost: BEB 40E2 Fleet



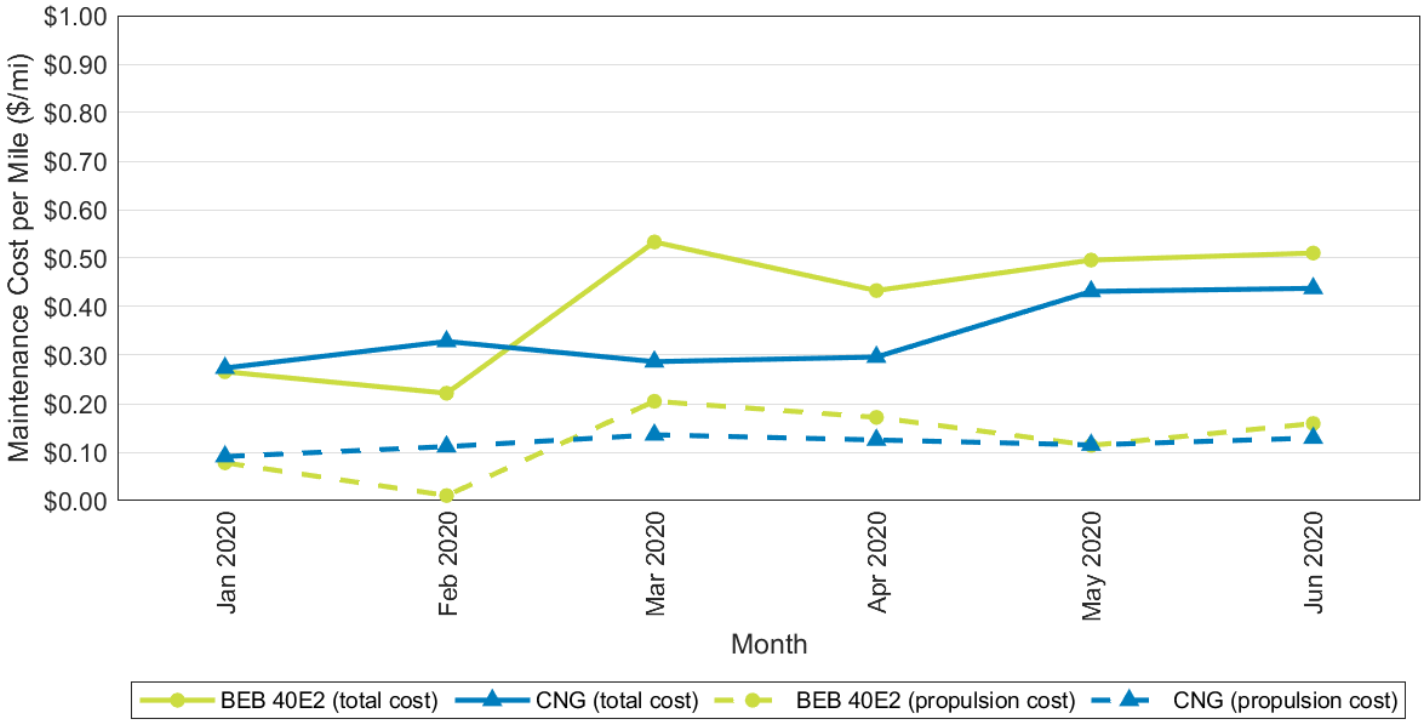
- Labor costs include time to troubleshoot issues
- Parts costs include low-voltage batteries, water pumps, air compressor, tires, and electrical.

Monthly Parts and Labor Maintenance Cost: CNG Fleet



- Unscheduled parts costs include air bags, tires, high-pressure regulator, and low-voltage batteries.

Monthly Maintenance Cost per Mile



- The solid trend lines in this chart match the stacked columns from the two previous charts, shown here for comparison
- The dashed trend lines match the stacked columns in the propulsion system charts that follow.

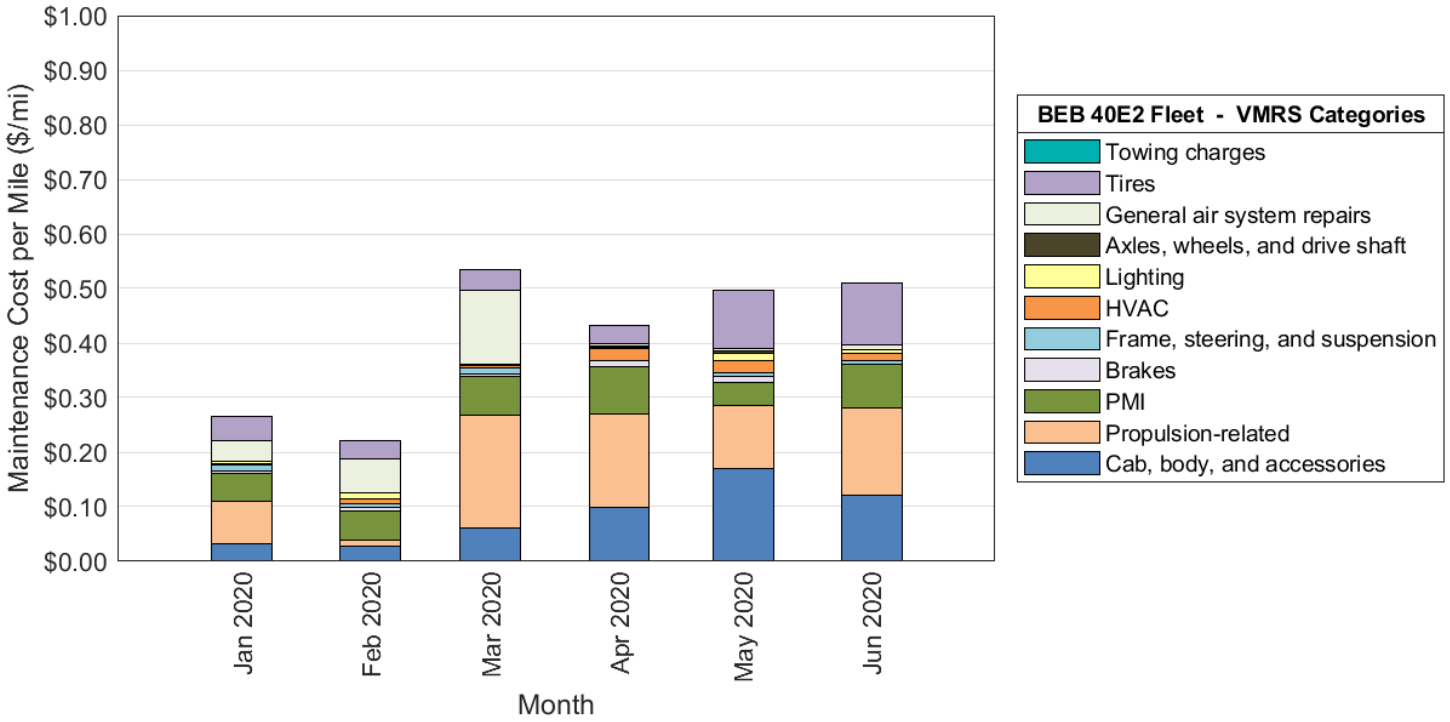
Maintenance Cost per Mile by System: Jan.–June 2020

System	BEB 40E2		CNG	
	Cost per Mile ($)	Percent of Total (%)	Cost per Mile ($)	Percent of Total (%)
Propulsion-related	0.120	29.9	0.119	35.0
Cab, body, and accessories	0.080	20.0	0.049	14.4
PMI	0.063	15.8	0.061	18.1
Brakes	0.006	1.6	0.019	5.7
Frame, steering, and suspension	0.007	1.8	0.027	7.9
HVAC	0.011	2.7	0.021	6.3
Lighting	0.007	1.6	0.003	1.0
General air system repairs	0.001	0.3	0.002	0.5
Axles, wheels, and drive shaft	0.044	11.1	0.004	1.1
Tires	0.061	15.2	0.034	10.0
Towing charges	0.000	0.0	0.000	0.0
Total	***0.401***	*100*	***0.340***	*100*

Color coding:
- Highest cost
- Second-highest cost
- Third-highest cost

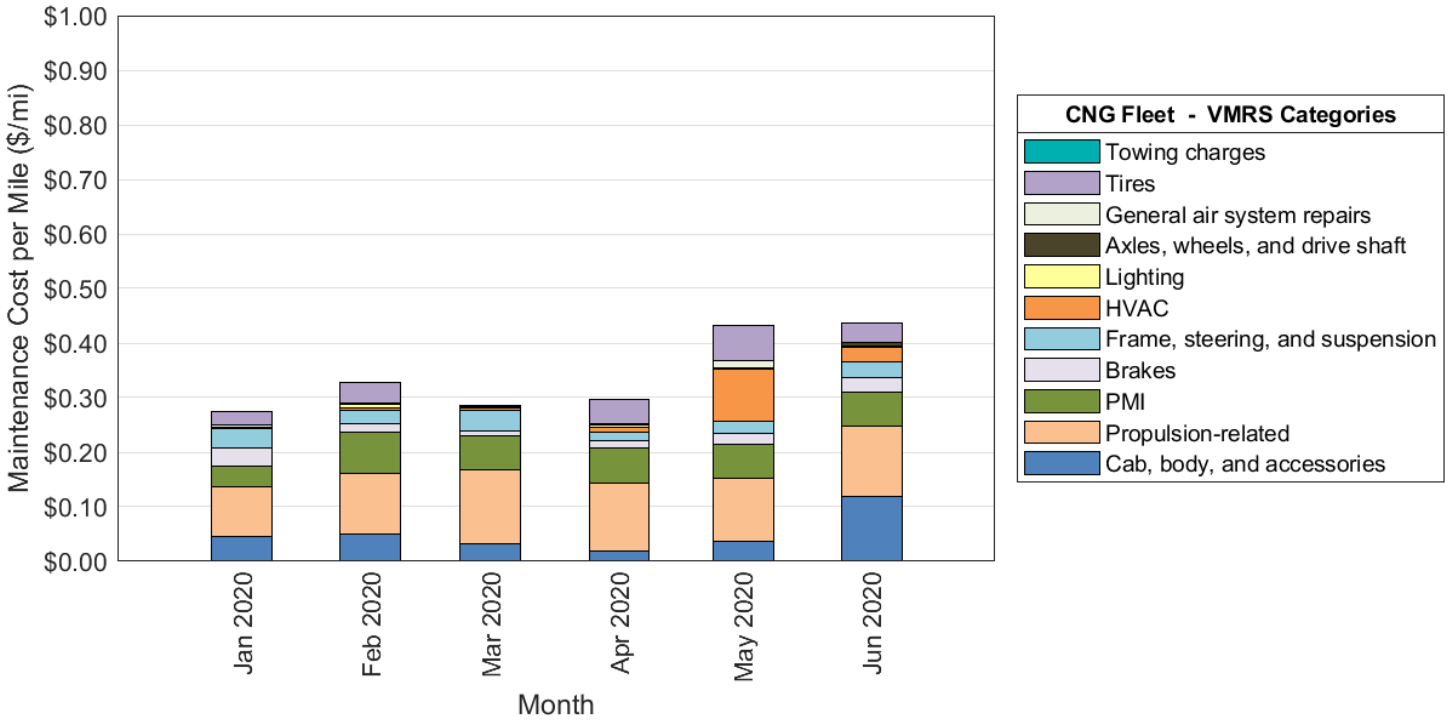
- Propulsion-related repairs for the BEB 40E2 fleet were for low-voltage batteries, high-voltage electrical, cooling system, and transmission
- Overall cost per mile for the BEB 40E2 fleet was 18% higher than that of the CNG bus fleet.

Maintenance Cost by System: BEB 40E2 Fleet



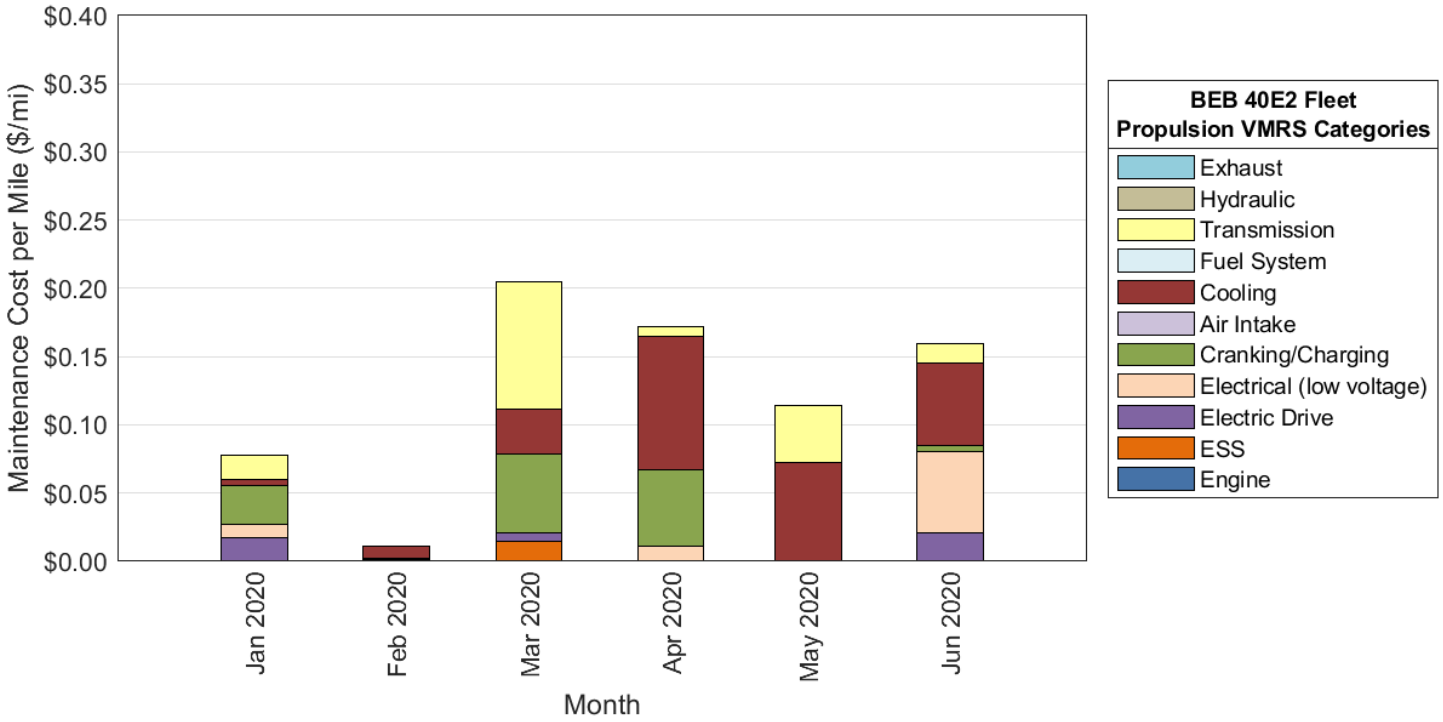
- High propulsion costs in March through June were due to issues with cooling systems, low-voltage electrical, and high-voltage electrical
- Several buses needed tires in May and June.

Maintenance Cost by System: CNG Fleet



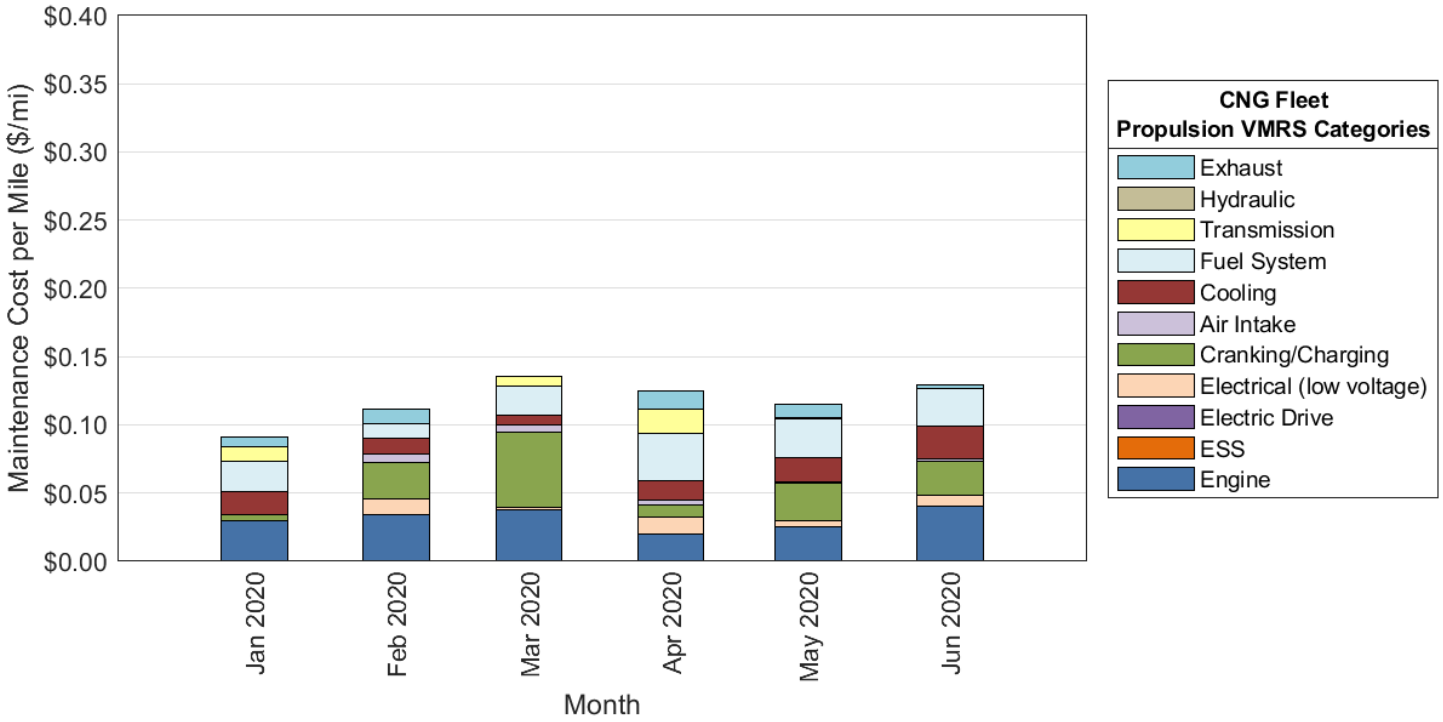
- Propulsion system costs included issues with cooling system, engine exhaust gas recirculation, and spark plug replacements
- Body work for one bus drove up costs in June.

Propulsion System Maintenance Cost by Subsystem: BEB 40E2 Fleet



- High hours for troubleshooting transmission issues on one bus resulted in high costs in March
- Several buses experienced issues with the cooling system from April through June. Water pumps on six buses were replaced.

Propulsion System Maintenance Cost by Subsystem: CNG Fleet



- Fuel system issues were primarily for gas sensors
- Cranking/charging issues included spark plug replacement and batteries.

Propulsion-Related Maintenance Costs by Subsystem: Jan.–June 2020

Maintenance System		BEB 40E2	CNG
Mileage		271,944	373,030
Total Propulsion-Related Systems (Roll-Up of All Systems)	Parts cost ($)	15,088.02	23,592.41
	Labor hours	350.5	413.8
	Total cost ($)	32,610.52	44,280.91
	Total cost ($) per mile	**0.120**	**0.119**
Exhaust System Repairs	Parts cost ($)	0.00	1,686.01
	Labor hours	0.0	21.3
	Total cost ($)	0.00	2,749.51
	Total cost ($) per mile	**0.000**	**0.007**
Fuel System Repairs	Parts cost ($)	0.00	5,867.45
	Labor hours	0.0	61.0
	Total cost ($)	0.00	8,917.95
	Total cost ($) per mile	**0.000**	**0.024**
Powerplant System Repairs (ESS for BEBs)	Parts cost ($)	0.00	5,678.41
	Labor hours	13.9	118.9
	Total cost ($)	695.50	11,625.41
	Total cost ($) per mile	**0.003**	**0.031**
Electric Propulsion System Repairs	Parts cost ($)	0.00	0.00
	Labor hours	46.6	0.0
	Total cost ($)	2,331.50	0.00
	Total cost ($) per mile	**0.009**	**0.000**

Propulsion-Related Maintenance Costs by Subsystem: Jan.–June 2020

Maintenance System		BEB 40E2	CNG
Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)	Parts cost ($)	7,611.25	7,102.28
	Labor hours	56.1	95.6
	Total cost ($)	10,416.25	11,882.78
	Total cost ($) per mile	**0.038**	**0.032**
Air Intake System Repairs	Parts cost ($)	0.00	1,092.47
	Labor hours	0.0	0.0
	Total cost ($)	0.00	1,092.47
	Total cost ($) per mile	**0.000**	**0.003**
Cooling System Repairs	Parts cost ($)	7,476.77	803.63
	Labor hours	78.0	96.5
	Total cost ($)	11,376.27	5,630.63
	Total cost ($) per mile	**0.042**	**0.015**
Transmission System Repairs	Parts cost ($)	155.82	20.40
	Labor hours	7,791.0	2,377.7
	Total cost ($)	0.03	0.01
	Total cost ($) per mile	**0.000**	**4.420**
Hydraulic System Repairs	Parts cost ($)	0.00	0.00
	Labor hours	0.0	4.4
	Total cost ($)	0.00	0.00
	Total cost ($) per mile	**0.000**	**0.000**

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Acronyms and Abbreviations

AITC	Azusa Intermodal Transit Center
BEB	battery electric bus
Btu	British thermal unit
CNG	compressed natural gas
dge	diesel gallon equivalent
ESS	energy storage system
gge	gasoline gallon equivalent
GVWR	gross vehicle weight rating
hp	horsepower
HVAC	heating, ventilation, and air conditioning
KBRC	kilometers between road calls
LHV	lower heating value
MBRC	miles between road calls
mpdge	miles per diesel gallon equivalent
mpgge	miles per gasoline gallon equivalent
mph	miles per hour
NABI	North American Bus Industries
NREL	National Renewable Energy Laboratory
PM	preventive maintenance
PMI	preventive maintenance inspection
PTC	Pomona Transit Center
rpm	rotations per minute
VMRS	Vehicle Maintenance Reporting Standards

Previous Foothill Transit Evaluation Reports

1. Foothill Transit Battery Electric Bus Demonstration Results, NREL/TP-5400-65274, https://www.nrel.gov/docs/fy16osti/65274.pdf
2. Foothill Transit Battery Electric Bus Demonstration Results: Second Report, NREL/TP-5400-67698, https://www.nrel.gov/docs/fy17osti/67698.pdf
3. Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2017 through Dec. 2017, NREL/PR-5400-71292, https://www.nrel.gov/docs/fy18osti/71292.pdf
4. Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2018 through Jun. 2018, NREL/PR-5400-72207, https://www.nrel.gov/docs/fy19osti/72207.pdf
5. Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jul. 2018 through Dec. 2018, NREL/PR-5400-72209, https://www.nrel.gov/docs/fy19osti/72209.pdf
6. Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, https://www.nrel.gov/docs/fy20osti/73516.pdf
7. Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jul. 2019 through Dec. 2019, NREL/PR-5400-75581, https://www.nrel.gov/docs/fy20osti/75581.pdf

Acknowledgments

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Appendix A:
Fleet Summary Statistics, Pomona

Fleet Summary Statistics, Pomona

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Number of vehicles	12	12	2	2	8	8
Period used for fuel and oil analysis	4/14–6/20	1/20–6/20	1/17–6/20	1/20–6/20	10/14–6/20	1/20–6/20
Total number of months in period	75	6	42	6	69	6
Fuel and oil analysis base fleet mileage	1,703,235	45,286	77,626	13,510	2,293,627	170,014
Period used for maintenance analysis	1/15–6/20	1/20–6/20	1/17–6/20	1/20–6/20	10/14–6/20	1/20–6/20
Total number of months in period	66	6	42	6	69	6
Maintenance analysis base fleet mileage	1,550,704	45,286	150,713	13,510	2,548,080	177,234
Availability (%)	81	53	80	70	95	90
Fleet fuel/energy usage in kWh (BEB) or gge (CNG)	3,669,692	86,560	162,429	25,931	611,888	49,393
Road calls	304	9	19	2	101	10
Total MBRC	5,748	5,032	7,932	6,755	25,229	17,723
Propulsion road calls	124	3	8	1	69	10
Propulsion MBRC	14,091	15,095	18,839	13,510	36,929	17,723
Fleet kWh/mile (BEB) or mpgge (CNG)	2.15	1.91	2.09	1.92	3.75	3.44
Representative fleet mpg (energy equiv.)	17.47	19.69	17.99	19.61	4.30	3.94
Energy cost ($) per kWh or CNG cost ($) per gge	0.179	0.174	0.179	0.174	1.012	1.068
Fuel cost ($) per mile	0.447	0.437	0.447	0.437	0.271	0.314
Total scheduled repair cost ($) per mile	0.074	0.057	0.069	0.036	0.115	0.114
Total unscheduled repair cost ($) per mile	0.402	1.315	0.442	0.799	0.190	0.393
Total maintenance cost ($) per mile	0.476	1.372	0.511	0.835	0.305	0.507
Total operating cost ($) per mile	***0.923***	***1.809***	***0.958***	***1.272***	***0.576***	***0.821***

Maintenance Cost Summary, Pomona

Maintenance Cost Summary

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Fleet mileage	1,550,498	46,328	150,649	13,510	2,548,080	177,234
Total parts cost ($)	357,578.39	18,385.68	30,536.97	3,407.66	414,826.56	49,032.75
Total labor hours	7,618.2	875.0	930.9	157.5	7,225.4	814.9
Average labor cost ($) (at $50.00 per hour)	380,911.00	43,749.00	46,544.00	7,873.00	361,269.00	40,743.50
Total maintenance cost ($)	738,489.39	62,134.68	77,080.97	11,280.66	776,095.56	89,776.25
Total maintenance cost ($) per bus	61,540.78	5,177.89	38,540.49	5,640.33	97,011.95	11,222.03
Total maintenance cost ($) per mile	**0.476**	**1.372**	**0.511**	**0.835**	**0.305**	**0.507**
without low-voltage battery cost	***0.418***	***1.179***	***0.417***	***0.651***	***0.295***	***0.474***

Propulsion System Maintenance Cost Summary

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Total Engine/Fuel-Related Systems (ATA VMRS 27, 30, 31, 32, 33, 41, 42, 43, 44, 45, 46, 65)						
Parts cost ($)	150,032.37	7,085.73	12,818.17	2,575.02	222,598.35	28,098.14
Labor hours	2,223.39	391.42	260.48	50.72	2,013.73	321.12
Average labor cost ($)	111,169.50	19,571.00	13,024.00	2,536.00	100,686.50	16,056.00
Total cost ($) (for system)	261,201.87	26,656.73	25,842.17	5,111.02	323,284.85	44,154.14
Total cost ($) (for system) per bus	21,766.82	2,221.39	12,921.09	2,555.51	40,410.61	5,519.27
Total cost ($) (for system) per mile	**0.168**	**0.589**	**0.112**	**0.378**	**0.127**	**0.249**
without low-voltage battery cost	***0.110***	***0.396***	***0.077***	***0.194***	***0.117***	***0.216***

Maintenance Cost by Vehicle System, Pomona

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Exhaust System Repairs (ATA VMRS 43)						
Parts cost ($)	0.00	0.00	0.00	0.00	20,273.34	1,401.10
Labor hours	0.0	0.0	0.0	0.0	76.5	10.0
Average labor cost ($)	0.00	0.00	0.00	0.00	3,825.00	499.50
Total cost ($) (for system)	0.00	0.00	0.00	0.00	24,098.34	1,900.60
Total cost ($) (for system) per bus	0.00	0.00	0.00	0.00	3,012.29	237.58
Total cost ($) (for system) per mile	**0.000**	**0.000**	**0.000**	**0.000**	**0.009**	**0.011**
Fuel System Repairs (ATA VMRS 44)						
Parts cost ($)	0.00	0.00	0.00	0.00	8,081.99	991.20
Labor hours	0.0	0.0	0.0	0.0	137.6	21.7
Average labor cost ($)	0.00	0.00	0.00	0.00	6,877.50	1,083.50
Total cost ($) (for system)	0.00	0.00	0.00	0.00	14,959.49	2,074.70
Total cost ($) (for system) per bus	0.00	0.00	0.00	0.00	1,869.94	259.34
Total cost ($) (for system) per mile	**0.000**	**0.000**	**0.000**	**0.000**	**0.006**	**0.012**
Power Plant (Engine) Repairs (ATA VMRS 45)						
Parts cost ($)	56.34	0.00	0.00	0.00	66,633.13	2,816.99
Labor hours	247.2	90.5	12.7	0.0	605.2	91.6
Average labor cost ($)	12,362.00	4,527.00	635.00	0.00	30,258.00	4,579.00
Total cost ($) (for system)	12,418.34	4,527.00	635.00	0.00	96,891.13	7,395.99
Total cost ($) (for system) per bus	1,034.86	377.25	317.50	0.00	12,111.39	924.50
Total cost ($) (for system) per mile	**0.008**	**0.100**	**0.004**	**0.000**	**0.038**	**0.042**

Maintenance Cost by Vehicle System, Pomona

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Electric Propulsion Repairs (ATA VMRS 46)						
Parts cost ($)	71,772.66	0.00	0.00	0.00	0.00	0.00
Labor hours	415.3	70.9	100.3	4.8	0.0	0.0
Average labor cost ($)	20,763.00	3,547.00	5,014.00	241.50	0.00	0.00
Total cost ($) (for system)	92,535.66	3,547.00	5,014.00	241.50	0.00	0.00
Total cost ($) (for system) per bus	7,711.31	295.58	2,507.00	120.75	0.00	0.00
Total cost ($) (for system) per mile	**0.060**	**0.078**	**0.033**	**0.018**	**0.000**	**0.000**
Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)						
Parts cost ($)	71,659.79	6,762.12	12,326.89	2,575.02	63,766.80	16,220.27
Labor hours	1078.9	122.4	121.6	36.1	517.4	57.1
Average labor cost ($)	53,947.00	6,118.00	6,081.50	1,806.00	25,869.00	2,854.50
Total cost ($) (for system)	125,606.79	12,880.12	18,408.39	4,381.02	89,635.80	19,074.77
Total cost ($) (for system) per bus	10,467.23	1,073.34	9,204.20	2,190.51	11,204.48	2,384.35
Total cost ($) (for system) per mile	**0.081**	**0.284**	**0.122**	**0.324**	**0.035**	**0.108**
Air Intake System Repairs (ATA VMRS 41)						
Parts cost ($)	108.20	0.00	6.20	0.00	22,744.64	1,087.08
Labor hours	3.9	0.0	0.0	0.0	11.7	1.9
Average labor cost ($)	195.00	0.00	0.00	0.00	582.50	93.50
Total cost ($) (for system)	303.20	0.00	6.20	0.00	23,327.14	1,180.58
Total cost ($) (for system) per bus	25.27	0.00	3.10	0.00	2,915.89	147.57
Total cost ($) (for system) per mile	**0.000**	**0.000**	**0.000**	**0.000**	**0.009**	**0.007**

Maintenance Cost by Vehicle System, Pomona

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Cooling System Repairs (ATA VMRS 42)						
Parts cost ($)	4,307.51	0.00	485.08	0.00	26,378.26	3,524.68
Labor hours	116.5	0.0	16.1	0.0	523.6	101.9
Average labor cost ($)	5,827.00	0.00	805.00	0.00	26,179.50	5,093.50
Total cost ($) (for system)	10,134.51	0.00	1,290.08	0.00	52,557.76	8,618.18
Total cost ($) (for system) per bus	844.54	0.00	645.04	0.00	6,569.72	1,077.27
Total cost ($) (for system) per mile	**0.007**	**0.000**	**0.009**	**0.000**	**0.021**	**0.049**
Hydraulic System Repairs (ATA VMRS 65)						
Parts cost ($)	0.00	0.00	0.00	0.00	126.03	0.00
Labor hours	2.0	0.0	0.0	0.0	1.0	0.0
Average labor cost ($)	97.50	0.00	0.00	0.00	50.00	0.00
Total cost ($) (for system)	97.50	0.00	0.00	0.00	176.03	0.00
Total cost ($) (for system) per bus	8.13	0.00	0.00	0.00	22.00	0.00
Total cost ($) (for system) per mile	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
General Air System Repairs (ATA VMRS 10)						
Parts cost ($)	38,534.86	308.33	1,288.77	28.41	4,706.21	610.42
Labor hours	368.9	13.7	135.2	20.4	75.8	7.8
Average labor cost ($)	18,444.00	682.50	6,761.50	1,021.00	3,787.50	390.50
Total cost ($) (for system)	56,978.86	990.83	8,050.27	1,049.41	8,493.71	1,000.92
Total cost ($) (for system) per bus	4,748.24	82.57	4,025.14	524.71	1,061.71	125.12
Total cost ($) (for system) per mile	**0.037**	**0.022**	**0.053**	**0.078**	**0.003**	**0.006**

Maintenance Cost by Vehicle System, Pomona

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Brake System Repairs (ATA VMRS 13)						
Parts cost ($)	5,371.52	2,328.48	0.00	0.00	22,356.24	2,505.75
Labor hours	169.6	59.1	14.4	1.2	383.7	42.6
Average labor cost ($)	8,481.00	2,957.00	717.50	58.50	19,184.50	2,130.50
Total cost ($) (for system)	13,852.52	5,285.48	717.50	58.50	41,540.74	4,636.25
Total cost ($) (for system) per bus	1,154.38	440.46	358.75	29.25	5,192.59	579.53
Total cost ($) (for system) per mile	**0.009**	**0.117**	**0.005**	**0.004**	**0.016**	**0.026**
Transmission Repairs (ATA VMRS 27)						
Parts cost ($)	2,127.87	323.61	0.00	0.00	14,594.17	2,056.82
Labor hours	359.6	107.6	9.8	9.8	140.9	37.1
Average labor cost ($)	17,978.00	5,379.00	488.50	488.50	7,045.00	1,852.50
Total cost ($) (for system)	20,105.87	5,702.61	488.50	488.50	21,639.17	3,909.32
Total cost ($) (for system) per bus	1,675.49	475.22	244.25	244.25	2,704.90	488.67
Total cost ($) (for system) per mile	**0.013**	**0.126**	**0.003**	**0.036**	**0.008**	**0.022**
Inspections Only—No Parts Replacements (101)						
Parts cost ($)	0.00	0.00	0.00	0.00	0.00	0.00
Labor hours	2203.1	33.8	189.8	4.4	2699.2	132.5
Average labor cost ($)	110,155.00	1,690.00	9,489.50	217.50	134,959.00	6,627.00
Total cost ($) (for system)	110,155.00	1,690.00	9,489.50	217.50	134,959.00	6,627.00
Total cost ($) (for system) per bus	9,179.58	140.83	4,744.75	108.75	16,869.88	828.38
Total cost ($) (for system) per mile	**0.071**	**0.037**	**0.063**	**0.016**	**0.053**	**0.037**

Maintenance Cost by Vehicle System, Pomona

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)						
Parts cost ($)	35,135.42	1,876.95	4,209.32	0.00	52,081.17	7,337.99
Labor hours	1563.8	165.2	249.8	67.8	1398.1	209.9
Average labor cost ($)	78,189.50	8,261.00	12,488.50	3,391.50	69,904.50	10,494.00
Total cost ($) (for system)	113,324.92	10,137.95	16,697.82	3,391.50	121,985.67	17,831.99
Total cost ($) (for system) per bus	9,443.74	844.83	8,348.91	1,695.75	15,248.21	2,229.00
Total cost ($) (for system) per mile	**0.073**	**0.224**	**0.111**	**0.251**	**0.048**	**0.101**
HVAC System Repairs (ATA VMRS 01)						
Parts cost ($)	9,597.75	2,031.24	166.29	7.50	13,495.96	1,028.08
Labor hours	279.3	122.8	23.6	10.7	127.9	15.7
Average labor cost ($)	13,963.00	6,138.50	1,179.50	532.50	6,397.00	783.00
Total cost ($) (for system)	23,560.75	8,169.74	1,345.79	540.00	19,892.96	1,811.08
Total cost ($) (for system) per bus	1,963.40	680.81	672.90	270.00	2,486.62	226.39
Total cost ($) (for system) per mile	**0.015**	**0.180**	**0.009**	**0.040**	**0.008**	**0.010**
Lighting System Repairs (ATA VMRS 34)						
Parts cost ($)	4,762.95	194.77	369.30	6.73	1,010.32	388.10
Labor hours	289.2	54.0	23.7	0.3	80.7	23.1
Average labor cost ($)	14,458.50	2,701.50	1,184.50	12.50	4,032.50	1,156.00
Total cost ($) (for system)	19,221.45	2,896.27	1,553.80	19.23	5,042.82	1,544.10
Total cost ($) (for system) per bus	1,601.79	241.36	776.90	9.62	630.35	193.01
Total cost ($) (for system) per mile	**0.012**	**0.064**	**0.010**	**0.001**	**0.002**	**0.009**

Maintenance Cost by Vehicle System, Pomona

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)						
Parts cost ($)	7,450.73	1,082.28	331.52	0.00	10,148.63	1,145.49
Labor hours	226.1	14.9	3.1	0.0	123.3	24.9
Average labor cost ($)	11,303.50	743.00	155.50	0.00	6,164.00	1,246.50
Total cost ($) (for system)	18,754.23	1,825.28	487.02	0.00	16,312.63	2,391.99
Total cost ($) (for system) per bus	1,562.85	152.11	243.51	0.00	2,039.08	299.00
Total cost ($) (for system) per mile	**0.012**	**0.040**	**0.003**	**0.000**	**0.006**	**0.013**
Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)						
Parts cost ($)	2,210.80	317.90	799.69	0.00	26,776.74	1,200.23
Labor hours	22.8	6.3	10.1	0.0	94.3	13.0
Average labor cost ($)	1,142.00	314.50	503.50	0.00	4,712.50	650.00
Total cost ($) (for system)	3,352.80	632.40	1,303.19	0.00	31,489.24	1,850.23
Total cost ($) (for system) per bus	279.40	52.70	651.60	0.00	3,936.16	231.28
Total cost ($) (for system) per mile	**0.002**	**0.014**	**0.009**	**0.000**	**0.012**	**0.010**
Tire Repairs (ATA VMRS 17)						
Parts cost ($)	98,196.99	3,160.00	10,268.91	790.00	58,951.74	6,718.55
Labor hours	272.1	13.8	20.8	2.1	227.8	24.2
Average labor cost ($)	13,605.00	690.00	1,040.00	103.50	11,391.00	1,210.00
Total cost ($) (for system)	111,801.99	3,850.00	11,308.91	893.50	70,342.74	7,928.55
Total cost ($) (for system) per bus	9,316.83	320.83	5,654.46	446.75	8,792.84	991.07
Total cost ($) (for system) per mile	**0.072**	**0.085**	**0.075**	**0.066**	**0.028**	**0.045**

Maintenance Cost by Vehicle System, Pomona

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Towing Charges						
Charge ($)	6,285.00	0.00	285.00	0.00	2,701.20	0.00
Labor hours	0.00	0.00	0.00	0.00	1.00	0.00
Average labor cost ($)	0.00	0.00	0.00	0.00	50.00	0.00
Total cost ($) (for system)	6,285.00	0.00	285.00	0.00	2,751.20	0.00
Total cost ($) (for system) per bus	523.75	0.00	142.50	0.00	343.90	0.00
Total cost ($) (for system) per mile	**0.004**	**0.000**	**0.002**	**0.000**	**0.001**	**0.000**

Fleet Summary Statistics, Pomona: SI Units

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Number of vehicles	12	12	2	2	8	8
Period used for fuel and oil analysis	4/14–6/20	1/20–6/20	1/17–6/20	1/20–6/20	10/14–6/20	1/20–6/20
Total number of months in period	75	6	42	6	69	6
Fuel and oil analysis base fleet kilometers	2,741,016	72,879	124,924	21,741	3,691,134	273,604
Period used for maintenance analysis	1/15–6/20	1/20–6/20	1/17–6/20	1/20–6/20	10/14–6/20	1/20–6/20
Total number of months in period	66	6	42	6	69	6
Maintenance analysis base fleet kilometers	2,495,548	72,879	242,543	21,741	4,100,625	285,223
Average monthly kilometers per vehicle	3,217	1,104	2,887	1,812	7,429	5,942
Availability (%)	81.0	53.1	79.8	69.7	94.6	90.0
Fleet fuel/energy usage in kWh (BEB) or liter (CNG)	3,669,692	86,560	162,429	25,931	2,316,250	186,973
Road calls	304	9	19	2	101	10
Total kilometers between road calls (KBRC)	9,250	8,098	12,765	10,870	40,600	28,522
Propulsion road calls	124	3	8	1	69	10
Propulsion KBRC	22,677	24,293	30,318	21,741	59,429	28,522
Representative fleet L/100 km (energy equiv.)	13.44	11.92	13.05	11.97	56.16	61.16
Energy cost per kWh or CNG cost per liter	0.179	0.174	0.179	0.174	0.267	0.282
Fuel cost ($) per kilometer	0.277	0.272	0.277	0.272	0.168	0.193
Total scheduled repair cost ($) per km	0.046	0.036	0.043	0.023	0.071	0.071
Total unscheduled repair cost ($) per km	0.250	0.817	0.275	0.496	0.118	0.244
Total maintenance cost ($) per km	0.296	0.853	0.318	0.519	0.189	0.315
Total operating cost ($) per km	***0.573***	***1.124***	***0.595***	***0.791***	***0.357***	***0.508***

Maintenance Cost Summary, Pomona: SI Units

Maintenance Cost Summary

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Fleet kilometers	2,495,548	72,879	242,543	21,741	4,100,625	285,223
Total parts cost ($)	357,578.39	18,385.68	30,536.97	3,407.66	414,826.56	49,032.75
Total labor hours	7,618.2	875.0	930.9	157.5	7,225.4	814.9
Average labor cost ($) (at $50.00 per hour)	380,911.00	43,749.00	46,544.00	7,873.00	361,269.00	40,743.50
Total maintenance cost ($)	738,489.39	62,134.68	77,080.97	11,280.66	776,095.56	89,776.25
Total maintenance cost ($) per bus	61,540.78	5,177.89	38,540.49	5,640.33	97,011.95	11,222.03
Total maintenance cost ($) per km	**0.296**	**0.853**	**0.318**	**0.519**	**0.189**	**0.315**
without low-voltage battery cost	***0.259***	***0.733***	***0.259***	***0.404***	***0.183***	***0.294***

Appendix B:
Fleet Summary Statistics, Arcadia

Fleet Summary Statistics, Arcadia

	BEB 40E2	CNG
Number of vehicles	14	14
Period used for fuel and oil analysis	1/20–6/20	1/20–6/20
Total number of months in period	6	6
Fuel and oil analysis base fleet mileage	271,944	24,991
Period used for maintenance analysis	1/20–6/20	1/20–6/20
Total number of months in period	6	6
Maintenance analysis base fleet mileage	271,944	373,030
Availability (%)	83	95
Fleet fuel/energy usage in kWh (BEB) or gge (CNG)	3,582,903	7,349
Road calls	10	21
Total MBRC	27,194	17,763
Propulsion road calls	5	15
Propulsion MBRC	54,389	24,869
Fleet kWh/mile (BEB) or mpgge (CNG)	1.89	3.40
Representative fleet mpg (energy equiv.)	19.89	3.90
Energy cost ($) per kWh or CNG cost ($) per gge	0.156	1.176
Fuel cost ($) per mile	0.359	0.357
Total scheduled repair cost ($) per mile	0.067	0.122
Total unscheduled repair cost ($) per mile	0.334	0.218
Total maintenance cost ($) per mile	0.401	0.339
Total operating cost ($) per mile	***0.760***	***0.696***

Maintenance Cost Summary, Arcadia

Maintenance Cost Summary

	BEB 40E2	CNG
Fleet mileage	271,944	373,030
Total parts cost ($)	41,841.90	48,838.37
Total labor hours	1,345.3	1,556.8
Average labor cost ($) (at $50.00 per hour)	67,267.00	77,840.00
Total maintenance cost ($)	109,108.90	126,678.37
Total maintenance cost ($) per bus	7,793.49	9,048.45
Total maintenance cost ($) per mile	***0.401***	***0.340***

Propulsion System Maintenance Cost Summary

	BEB 40E2	CNG
Total Engine/Fuel-Related Systems (ATA VMRS 27, 30, 31, 32, 33, 41, 42, 43, 44, 45, 46, 65)		
Parts cost ($)	15,088.02	23,592.41
Labor hours	350.45	413.77
Average labor cost ($)	17,522.50	20,688.50
Total cost ($) (for system)	32,610.52	44,280.91
Total cost ($) (for system) per bus	2,329.32	3,162.92
Total cost ($) (for system) per mile	**0.120**	**0.119**

Maintenance Cost by Vehicle System, Arcadia

	BEB 40E2	CNG
Exhaust System Repairs (ATA VMRS 43)		
Parts cost ($)	0.00	1,686.01
Labor hours	0.0	21.3
Average labor cost ($)	0.00	1,063.50
Total cost ($) (for system)	0.00	2,749.51
Total cost ($) (for system) per bus	0.00	196.39
Total cost ($) (for system) per mile	**0.000**	**0.007**
Fuel System Repairs (ATA VMRS 44)		
Parts cost ($)	0.00	5,867.45
Labor hours	0.0	61.0
Average labor cost ($)	0.00	3,050.50
Total cost ($) (for system)	0.00	8,917.95
Total cost ($) (for system) per bus	0.00	637.00
Total cost ($) (for system) per mile	**0.000**	**0.024**
Power Plant (Engine) Repairs (ATA VMRS 45)		
Parts cost ($)	0.00	5,678.41
Labor hours	13.9	118.9
Average labor cost ($)	695.50	5,947.00
Total cost ($) (for system)	695.50	11,625.41
Total cost ($) (for system) per bus	49.68	830.39
Total cost ($) (for system) per mile	**0.003**	**0.031**

Maintenance Cost by Vehicle System, Arcadia

	BEB 40E2	CNG
Electric Propulsion Repairs (ATA VMRS 46)		
Parts cost ($)	0.00	0.00
Labor hours	46.6	0.0
Average labor cost ($)	2,331.50	0.00
Total cost ($) (for system)	2,331.50	0.00
Total cost ($) (for system) per bus	166.54	0.00
Total cost ($) (for system) per mile	**0.009**	**0.000**
Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)		
Parts cost ($)	7,611.25	7,102.28
Labor hours	56.1	95.6
Average labor cost ($)	2,805.00	4,780.50
Total cost ($) (for system)	10,416.25	11,882.78
Total cost ($) (for system) per bus	744.02	848.77
Total cost ($) (for system) per mile	**0.038**	**0.032**
Air Intake System Repairs (ATA VMRS 41)		
Parts cost ($)	0.00	1,092.47
Labor hours	0.0	0.0
Average labor cost ($)	0.00	0.00
Total cost ($) (for system)	0.00	1,092.47
Total cost ($) (for system) per bus	0.00	78.03
Total cost ($) (for system) per mile	**0.000**	**0.003**

Maintenance Cost by Vehicle System, Arcadia

	BEB 40E2	CNG
Cooling System Repairs (ATA VMRS 42)		
Parts cost ($)	7,476.77	803.63
Labor hours	78.0	96.5
Average labor cost ($)	3,899.50	4,827.00
Total cost ($) (for system)	11,376.27	5,630.63
Total cost ($) (for system) per bus	812.59	402.19
Total cost ($) (for system) per mile	**0.042**	**0.015**
Hydraulic System Repairs (ATA VMRS 65)		
Parts cost ($)	0.00	4.42
Labor hours	0.0	0.0
Average labor cost ($)	0.00	0.00
Total cost ($) (for system)	0.00	4.42
Total cost ($) (for system) per bus	0.00	0.32
Total cost ($) (for system) per mile	**0.000**	**0.000**
General Air System Repairs (ATA VMRS 10)		
Parts cost ($)	6,888.67	41.53
Labor hours	104.2	27.2
Average labor cost ($)	5,209.50	1,361.50
Total cost ($) (for system)	12,098.17	1,403.03
Total cost ($) (for system) per bus	864.16	100.22
Total cost ($) (for system) per mile	**0.044**	**0.004**

Maintenance Cost by Vehicle System, Arcadia

	BEB 40E2	CNG
Brake System Repairs (ATA VMRS 13)		
Parts cost ($)	0.00	2,273.39
Labor hours	34.9	99.7
Average labor cost ($)	1,746.50	4,984.00
Total cost ($) (for system)	1,746.50	7,257.39
Total cost ($) (for system) per bus	124.75	518.39
Total cost ($) (for system) per mile	**0.006**	**0.019**
Transmission Repairs (ATA VMRS 27)		
Parts cost ($)	0.00	1,357.74
Labor hours	155.8	20.4
Average labor cost ($)	7,791.00	1,020.00
Total cost ($) (for system)	7,791.00	2,377.74
Total cost ($) (for system) per bus	556.50	169.84
Total cost ($) (for system) per mile	**0.029**	**0.006**
Inspections Only—No Parts Replacements (101)		
Parts cost ($)	0.00	0.00
Labor hours	345.4	458.7
Average labor cost ($)	17,267.50	22,936.00
Total cost ($) (for system)	17,267.50	22,936.00
Total cost ($) (for system) per bus	1,233.39	1,638.29
Total cost ($) (for system) per mile	**0.063**	**0.061**

Maintenance Cost by Vehicle System, Arcadia

	BEB 40E2	CNG
Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)		
Parts cost ($)	4,111.58	3,455.09
Labor hours	353.9	296.6
Average labor cost ($)	17,693.00	14,831.50
Total cost ($) (for system)	21,804.58	18,286.59
Total cost ($) (for system) per bus	1,557.47	1,306.19
Total cost ($) (for system) per mile	**0.080**	**0.049**
HVAC System Repairs (ATA VMRS 01)		
Parts cost ($)	112.38	4,098.62
Labor hours	56.6	78.3
Average labor cost ($)	2,830.00	3,912.50
Total cost ($) (for system)	2,942.38	8,011.12
Total cost ($) (for system) per bus	210.17	572.22
Total cost ($) (for system) per mile	**0.011**	**0.021**
Lighting System Repairs (ATA VMRS 34)		
Parts cost ($)	824.52	522.50
Labor hours	19.1	14.2
Average labor cost ($)	954.50	711.00
Total cost ($) (for system)	1,779.02	1,233.50
Total cost ($) (for system) per bus	127.07	88.11
Total cost ($) (for system) per mile	**0.007**	**0.003**

Maintenance Cost by Vehicle System, Arcadia

	BEB 40E2	CNG
Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)		
Parts cost ($)	0.00	4,935.13
Labor hours	40.3	102.4
Average labor cost ($)	2,014.50	5,118.50
Total cost ($) (for system)	2,014.50	10,053.63
Total cost ($) (for system) per bus	143.89	718.12
Total cost ($) (for system) per mile	**0.007**	**0.027**
Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)		
Parts cost ($)	0.00	12.31
Labor hours	6.2	11.6
Average labor cost ($)	310.50	579.00
Total cost ($) (for system)	310.50	591.31
Total cost ($) (for system) per bus	22.18	42.24
Total cost ($) (for system) per mile	**0.001**	**0.002**
Tire Repairs (ATA VMRS 17)		
Parts cost ($)	14,816.73	9,907.39
Labor hours	34.4	54.4
Average labor cost ($)	1,718.50	2,717.50
Total cost ($) (for system)	16,535.23	12,624.89
Total cost ($) (for system) per bus	1,181.09	901.78
Total cost ($) (for system) per mile	**0.061**	**0.034**

Maintenance Cost by Vehicle System, Arcadia

	BEB 40E2	CNG
Towing Charges		
Charge ($)	0.00	0.00
Labor hours	0.00	0.00
Average labor cost ($)	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**

Fleet Summary Statistics, Arcadia: SI Units

	BEB 40E2	CNG
Number of vehicles	14	14
Period used for fuel and oil analysis	1/20–6/20	1/20–6/20
Total number of months in period	6	6
Fuel and oil analysis base fleet kilometers	437,640	40,218
Period used for maintenance analysis	1/20–6/20	1/20–6/20
Total number of months in period	6	6
Maintenance analysis base fleet kilometers	437,640	600,317
Average monthly kilometers per vehicle	5,210	7,147
Availability (%)	84.0	94.1
Fleet fuel/energy usage in kWh (BEB) or liter (CNG)	3,582,903	27,819
Road calls	10	21
Total KBRC	43,764	28,587
Propulsion road calls	5	15
Propulsion KBRC	87,528	40,021
Representative fleet L/100 km (energy equiv.)	11.80	61.91
Energy cost ($) per kWh or CNG cost ($) per liter	0.156	0.311
Fuel cost ($) per kilometer	0.223	0.215
Total scheduled repair cost ($) per km	0.042	0.076
Total unscheduled repair cost ($) per km	0.208	0.135
Total maintenance cost ($) per km	0.249	0.211
Total operating cost ($) per km	***0.472***	***0.426***

Maintenance Cost Summary, Arcadia: SI Units

Maintenance Cost Summary

	BEB 40E2	CNG
Fleet kilometers	437,640	600,317
Total parts cost ($)	41,841.90	48,838.37
Total labor hours	1,345.3	1,556.8
Average labor cost ($) (at $50.00 per hour)	67,267.00	77,840.00
Total maintenance cost ($)	109,108.90	126,678.37
Total maintenance cost ($) per bus	7,793.49	9,048.45
Total maintenance cost ($) per km	***0.249***	***0.211***

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