



# Foothill Transit Agency Battery Electric Bus Progress Report

Data Period Focus: Jul. 2018 through Dec. 2018

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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. 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 June 2018.<sup>1,2,3,4</sup> This report extends the data analysis through the end of 2018. The data period focus of this report is July 2018–December 2018. NREL plans to publish progress reports on the Foothill Transit fleet every 6 months through 2020.

<sup>1</sup> Foothill Transit Battery Electric Bus Demonstration Results, NREL/TP-5400-65274, <https://www.nrel.gov/docs/fy16osti/65274.pdf>

<sup>2</sup> Foothill Transit Battery Electric Bus Demonstration Results: Second Report, NREL/TP-5400-67698, <https://www.nrel.gov/docs/fy17osti/67698.pdf>

<sup>3</sup> 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>

<sup>4</sup> 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>

# Results Summary

**Bus fleets:** This evaluation includes 12 Proterra 35-ft fast charge buses (BEB 35FC), two Proterra 40-ft Catalyst fast charge buses (BEB 40FC), and eight NABI 42-ft compressed natural gas (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 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 has an effect on the comparison of mileage, fuel economy, and costs per mile between fleets.

**Availability:** Availability in the second half of 2018 was 75.7% for the BEB 35FC buses, 75.0% for the BEB 40FC buses, and 90.1% for the CNG buses. The majority of unavailable time for the BEBs was due to general bus-related problems. Issues with the low-voltage batteries affected BEB availability. Other downtime resulted from issues with components such as transmission, air compressor, DC-DC converter, air conditioning, and the energy storage system (ESS).

# 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. Over the last year, Proterra has been transitioning its data system to a new system to increase capability. During this transition, some data have been unavailable. In early 2018, Foothill Transit installed individual data loggers on each of its BEBs. NREL is using this data for calculating the fuel economy for the 35-ft buses. The data logger data is not yet available for the BEB 40-ft buses.

BEB efficiency in the second half of 2018 was 2.18 kWh/mi (17.29 mpgge) for the BEB 35FC fleet and 3.63 mpgge (4.16 mpgde) for the CNG bus fleet. Because of the unavailable data for the BEB 40FC buses, no fuel economy can be calculated for the most recent 6-month data period. The BEB fuel economy is approximately 4 times higher than that of the CNG buses as they are currently operated by Foothill Transit. NREL collected data on CNG buses operating on Line 291 that showed an average fuel economy of 2.09 mpgde (see previous report for details<sup>5</sup>). The BEB fuel efficiency is 8 times higher than that of the CNG buses in the same service.

<sup>5</sup> Foothill Transit Battery Electric Bus Demonstration Results: Second Report, NREL/TP-5400-67698, <https://www.nrel.gov/docs/fy17osti/67698.pdf>

# Results Summary (continued)

**Fuel cost:** Based on energy purchased in the second half of 2018, the BEB fleet had a fuel cost of \$0.46/mi (at \$0.20/kWh) and the CNG fleet had a fuel cost of \$0.28/mi (at \$1.24/gge). The cost per unit of energy/fuel is the average for the data period of July 2018–December 2018. Because this 6-month data period includes more summer months when the electric rates are higher, the average cost per kWh is higher than the 6-month average from the previous report. For 2 out of the 6 months, the CNG cost increased due to disruptions in regional CNG supply, resulting in a higher average cost per gge than previously reported. To compare cost between buses in the same service, NREL estimated the cost per mile for the CNG buses if operated only on Line 291. An earlier analysis using data loggers to characterize the CNG bus operation on Line 291 resulted in a lower fuel economy of 2.09 mpdgc.<sup>6</sup> This lower fuel economy would increase the cost of the CNG buses to an overall average of \$0.66/mi, which is slightly higher than the cost of the BEB fleet.

<sup>6</sup> Foothill Transit Battery Electric Bus Demonstration Results: Second Report, NREL/TP-5400-67698, <https://www.nrel.gov/docs/fy17osti/67698.pdf>

# Results Summary (continued)

**Maintenance cost:** Cost to maintain the buses in the second half of 2018 was \$0.78/mi for the BEB 35FC buses, \$0.74/mi for the BEB 40FC buses, and \$0.46/mi for the CNG buses. The BEB 35FC bus cost has increased over what was reported previously. Several factors contributed to the high cost for the BEBs:

- The BEB 35FC buses are now past the warranty period for the majority of components, resulting in higher parts costs, such as a DC-DC converter at ~\$12,000 and a bus air compressor at ~\$8,000.
- All maintenance has been transitioned to on-site contractor staff, resulting in increased labor hours for training and troubleshooting as the staff become more familiar with systems and components. Total unscheduled labor on the BEBs has increased from 2017 to 2018. Unscheduled labor for the BEB 35FC buses increased from 72 hours per bus in 2017 to 130 hours per bus in 2018—a 45% increase. Unscheduled labor for the BEB 40FC buses increased by 60%, from 51 hours per bus in 2017 to 128 hours per bus in 2018. By comparison, the CNG buses' unscheduled labor increased by only 30%—79 hours per bus in 2017 to 113 hours per bus in 2018.

# Results Summary (continued)

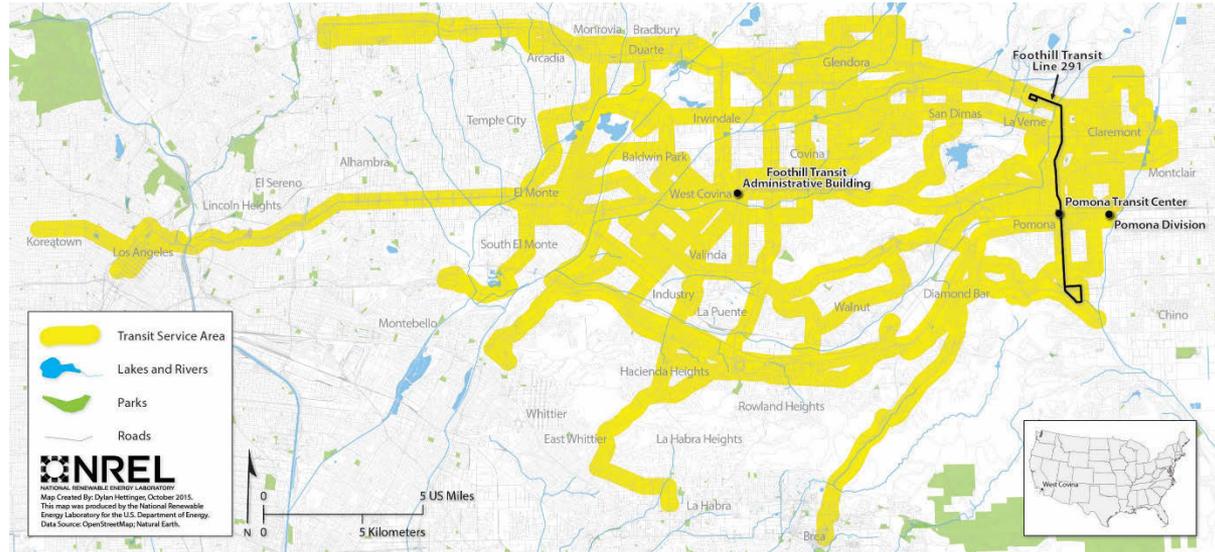
- Foothill Transit continues to have issues with the low-voltage batteries. NREL analyzed the data for low-voltage batteries for all three bus fleets. The BEBs averaged 7.8 changeouts per bus at approximately 12,000 miles between changeout. The CNG buses averaged 1.13 changeouts per bus at more than 214,000 miles between changeout. One issue is that the accessories (farebox, cameras, etc.) 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 is working on 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 \$0.70/mi for the BEB 35FC buses, \$0.63/mi for the BEB 40FC buses, and \$0.44/mi for the CNG buses.

# Results Summary (continued)

**Future analysis:** NREL will continue to collect data on the two existing BEB fleets in comparison to the CNG baseline fleet, and will add data from a fleet of 40-ft Proterra Catalyst E2 extended range buses. The new buses will be operated out of another depot and will be charged primarily through overnight depot charging. NREL will select another baseline fleet from this depot for comparison.

# 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 CNG buses and 16 BEBs.

# 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 <sup>a</sup>	\$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/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 at 3,600 psi
Accessories	Electric	Electric	Mechanical
Emissions equipment	N/A	N/A	3-way catalyst
Transmission/retarder	Regenerative braking	Regenerative braking	N/A

<sup>a</sup> Includes amenities such as painting of bus and livery, surveillance system, PA system, radio, safety vision monitor.

# Evaluation Buses

BEB 35FC



Photo by Leslie Eudy, NREL

BEB 40FC



Photo courtesy of Foothill Transit

CNG



Photo 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	4/14–12/18	1/17–12/18	10/14–12/18
Number of months	57	24	51
Total mileage in data period	1,449,320	93,418	1,932,057
Average odometer	110,825	38,067	217,943
Average monthly mileage per bus	2,183	1,946	4,735
Availability (85% is target)	86	80	96
Fuel economy (kWh/mile or mpgge <sup>a</sup> )	2.17	2.22	3.84
Fuel economy (mpdge <sup>b</sup> )	17.32	16.98	4.40
Average speed, including stops (mph)	10.60	10.60	17.60
Miles between roadcalls (MBRC <sup>c</sup> )—bus	5,706	6,673	26,834
MBRC <sup>c</sup> —propulsion system only	15,418	23,355	42,935
MBRC <sup>c</sup> —ESS <sup>d</sup> only	241,553	—	—
Total maintenance cost (\$/mile) <sup>e</sup>	0.39	0.44	0.26
<i>Total maintenance cost without low-voltage battery costs (\$/mile)<sup>f</sup></i>	<i>0.34</i>	<i>0.34</i>	<i>0.26</i>
Maintenance cost—propulsion system only (\$/mile)	0.11	0.16	0.10
<i>Propulsion system maintenance cost without low-voltage battery costs (\$/mile)<sup>f</sup></i>	<i>0.06</i>	<i>0.07</i>	<i>0.09</i>

<sup>a</sup> Miles per gasoline gallon equivalent

<sup>b</sup> Miles per diesel gallon equivalent

<sup>c</sup> MBRC data cumulative from the clean point of April 2014 through end of current data period

<sup>d</sup> Energy storage system

<sup>e</sup> Work order maintenance cost

<sup>f</sup> See issue with the low-voltage batteries explained on slide 50

# Data Summary: Jul.–Dec. 2018

Data Item	BEB 35FC	BEB 40FC	CNG
Number of buses	12	2	8
Data period	7/18–12/18	7/18–12/18	7/18–12/18
Number of months	6	6	6
Total mileage in data period	145,281	20,067	226,981
Average odometer	110,825	38,067	217,943
Average monthly mileage per bus	2,018	1,672	4,729
Availability (85% is target)	76	75	90
Fuel economy (kWh/mile or mpgge <sup>a</sup> )	2.18	—	3.63
Fuel economy (mpdge <sup>b</sup> )	17.29	—	4.16
Average speed, including stops (mph)	10.60	10.60	17.60
Miles between roadcalls (MBRC <sup>c</sup> )—bus	5,706	6,673	26,834
MBRC <sup>c</sup> —propulsion system only	15,418	23,355	42,935
MBRC <sup>c</sup> —ESS <sup>d</sup> only	241,553	—	—
Total maintenance cost (\$/mile) <sup>e</sup>	0.78	0.74	0.46
<i>Total maintenance cost without low-voltage battery costs (\$/mile)<sup>f</sup></i>	<i>0.70</i>	<i>0.63</i>	<i>0.44</i>
Maintenance cost—propulsion system only (\$/mile)	0.32	0.42	0.25
<i>Propulsion system maintenance cost without low-voltage battery costs (\$/mile)<sup>f</sup></i>	<i>0.24</i>	<i>0.30</i>	<i>0.23</i>

<sup>a</sup> Miles per gasoline gallon equivalent

<sup>b</sup> Miles per diesel gallon equivalent

<sup>c</sup> MBRC data cumulative from the clean point of April 2014 through end of current data period

<sup>d</sup> Energy storage system

<sup>e</sup> Work order maintenance cost

<sup>f</sup> See issue with the low-voltage batteries explained on slide 50

# 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 also 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 as a whole is 17.6 mph.

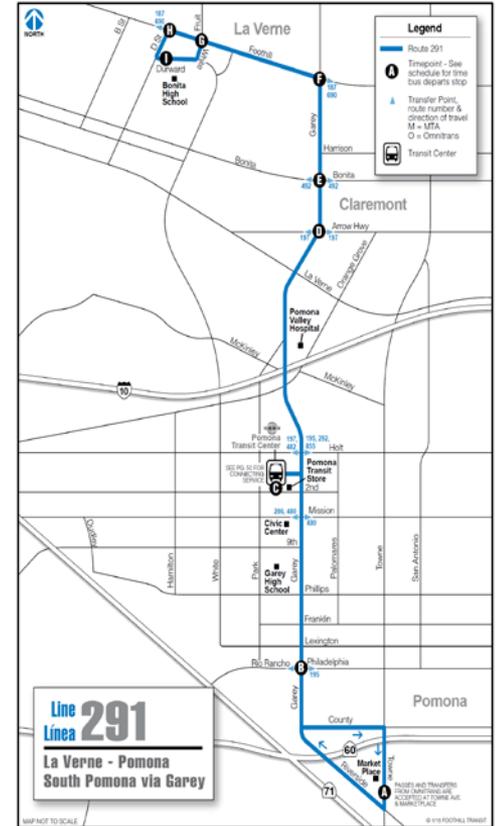
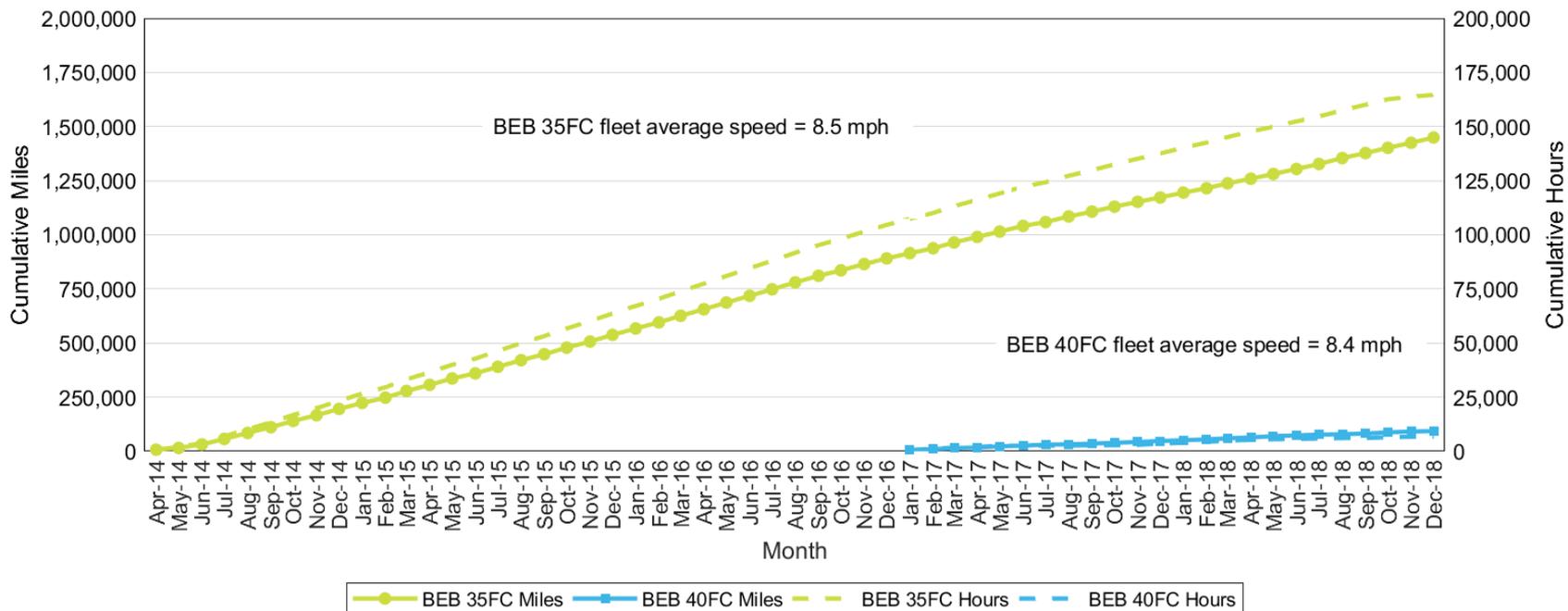


Image courtesy of Foothill Transit

# BEB Fleet Total Miles



- Combined totals for 12 BEB 35FC buses and two BEB 40FC buses

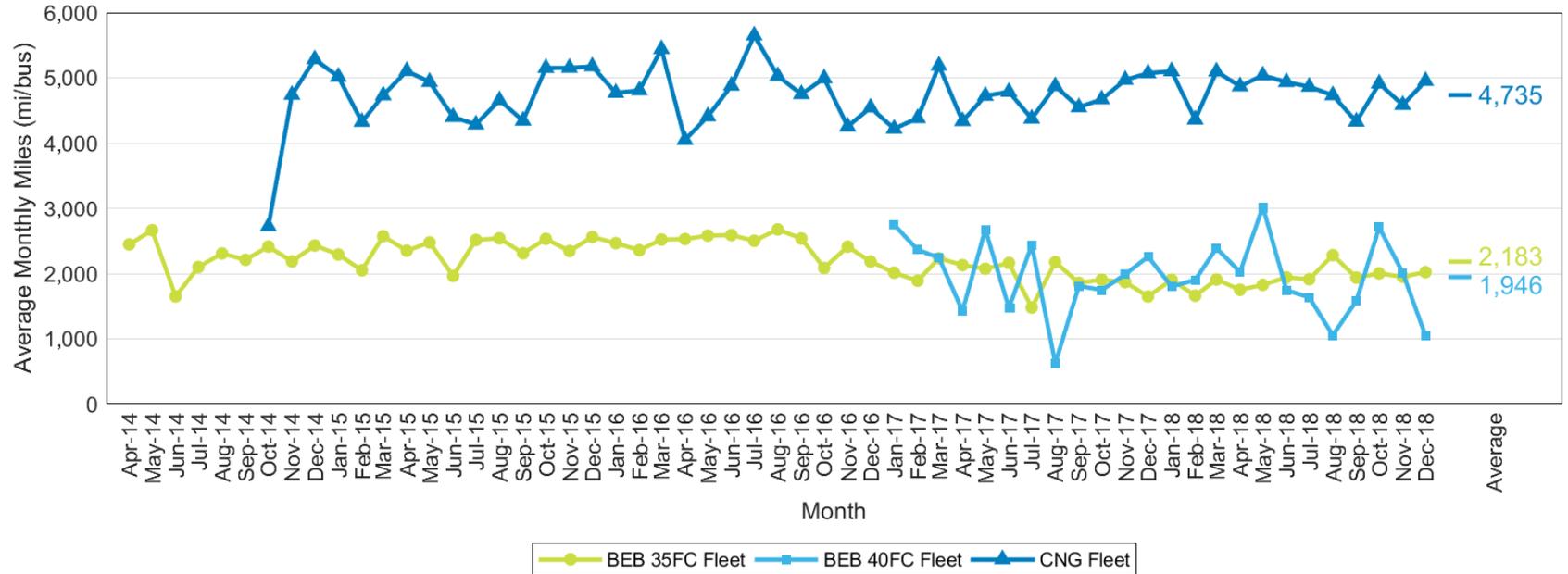
# Fleet Average Monthly Miles by Bus: Jul.–Dec. 2018

Bus ID	Miles	Months	Average Monthly Mileage
2004	13,962	6	2,327
2005	9,853	6	1,642
2006	10,715	6	1,786
2007	11,889	6	1,981
2008	14,021	6	2,337
2009	13,395	6	2,233
2010	11,505	6	1,917
2011	14,006	6	2,334
2012	11,299	6	1,883
2013	8,542	6	1,424
2014	13,595	6	2,266
2015	12,498	6	2,083
<b>BEB 35FC Total</b>	<b>145,281</b>	<b>72</b>	<b>2,018</b>
2016	8,616	6	1,436
2017	11,451	6	1,909
<b>BEB 40FC Total</b>	<b>20,067</b>	<b>12</b>	<b>1,672</b>

Bus ID	Miles	Months	Average Monthly Mileage
2200	25,733	6	4,289
2201	23,389	6	3,898
2202	31,071	6	5,179
2203	25,457	6	4,243
2204	28,932	6	4,822
2205	31,614	6	5,269
2206	31,353	6	5,226
2207	29,432	6	4,905
<b>CNG Total</b>	<b>226,981</b>	<b>48</b>	<b>4,729</b>

The average monthly operating mileage per bus for the BEBs is less than half that of the CNG buses. This is a result of the planned operation of the buses, in which the CNG buses accumulate miles faster than the BEBs do, and does not indicate a specific limitation of the technology.

# Fleet Average Monthly Miles



# Availability Analysis

Availability, which is a measure of reliability, is presented as the percentage of days the buses are actually available out of days that the buses are planned for passenger service. Buses available for service may have been used in passenger service, training, or special events, or they may have been available but just 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. For the Foothill Transit fleet, the buses are planned to operate every day, including weekends. For Foothill Transit, the source for availability data is garage activity sheets for the 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.

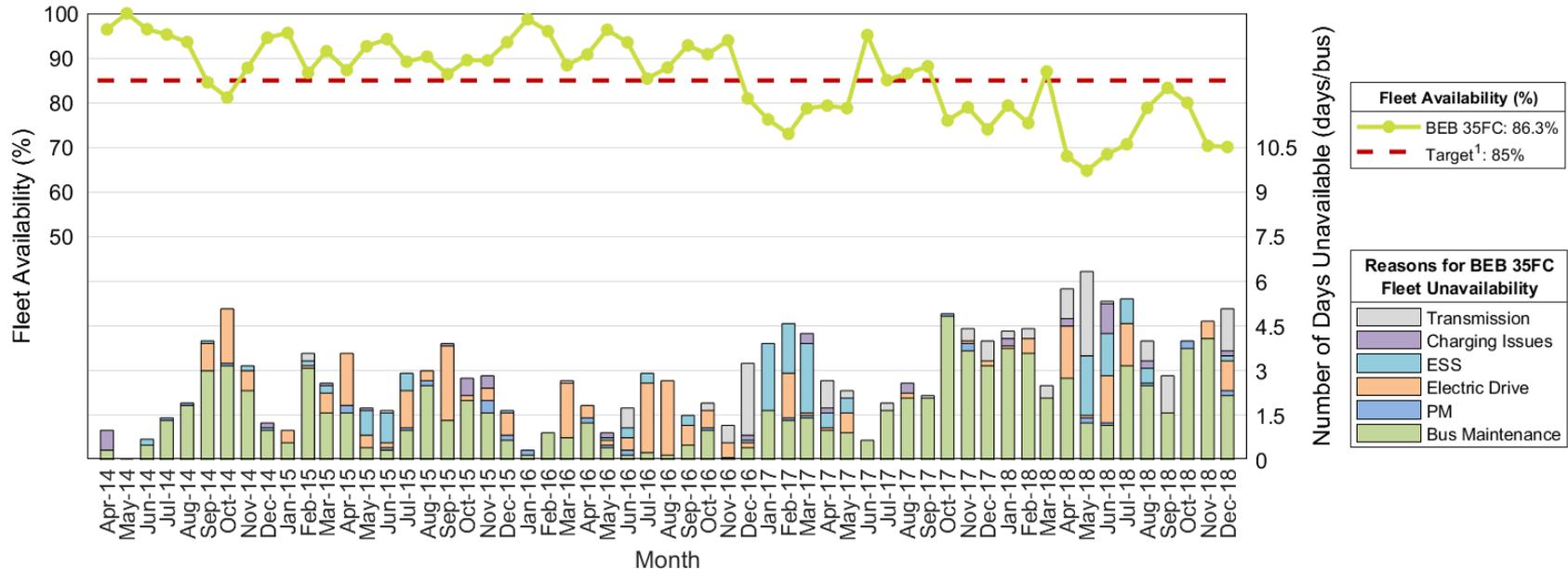
NREL presents availability as a monthly average trend and as overall availability. Unavailable time is separated into several categories to show the primary reason for downtime.

# Availability Summary: Jul.–Dec. 2018

Category	BEB 35FC (# Days)	BEB 35FC (%)	BEB 40FC (# Days)	BEB 40FC (%)	CNG (# Days)	CNG (%)
Planned work days	1,286		216		861	
Days available	974	75.7	162	75.0	776	90.1
Unavailable	312	24.3	54	25.0	85	9.9
ESS	18	1.4	1	0.5	—	—
CNG engine	—	—	—	—	65	7.5
Electric drive	36	2.8	20	9.3	—	—
Charging issues	5	0.4	0	0.0	—	—
Preventive maintenance	6	0.5	1	0.5	6	0.7
General bus maintenance	207	16.1	32	14.8	13	1.5
Transmission	40	3.1	0	0.0	1	0.1

- The per-bus availability for the BEBs ranged from a low of 57% to a high of 91%.
- The majority of unavailable time for the BEBs was attributed to general bus maintenance.
- Issues with the low-voltage batteries lowered availability for the BEBs (29% of general bus maintenance days for the 35FC BEBs and 47% of general bus maintenance days for the 40FC BEBs).
- The majority of unavailable time for the CNG buses was attributed to engine issues.
- General bus maintenance includes everything that doesn't fall into one of the other categories.

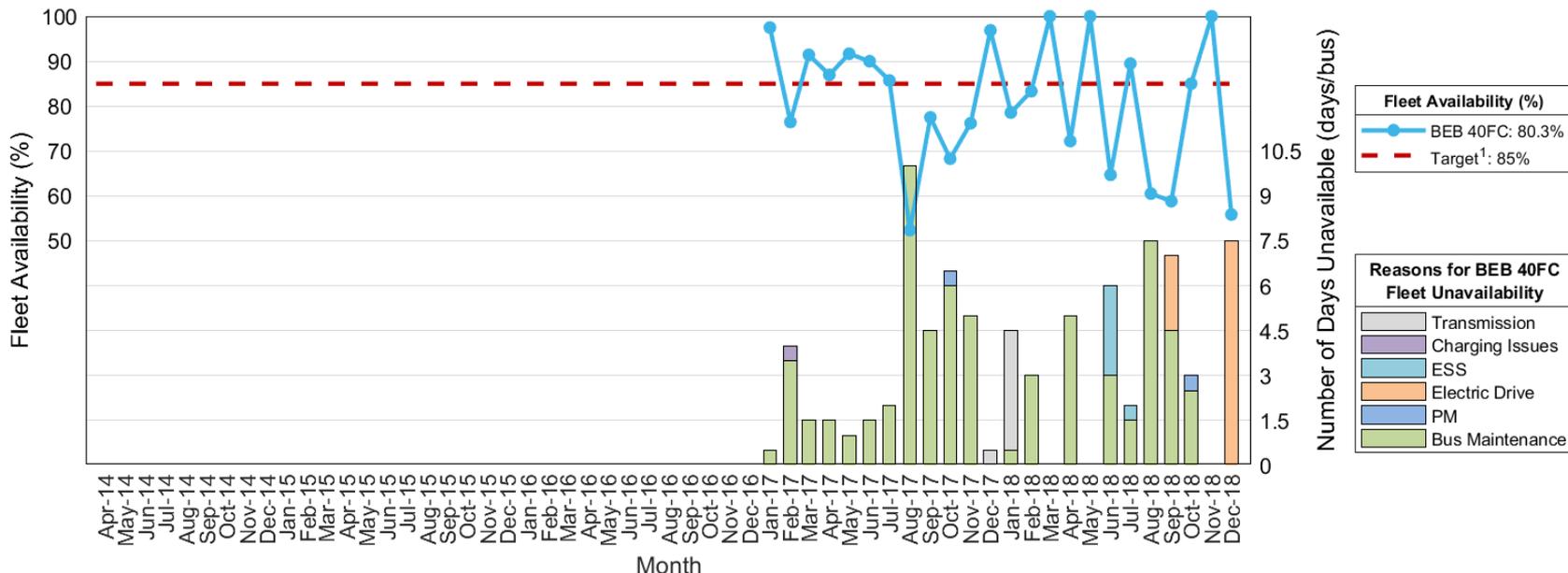
# Monthly Availability: BEB 35FC Fleet



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.
- Low-voltage batteries fall into the general Bus Maintenance category (green bars) and make up 29% of general bus maintenance unavailable days.

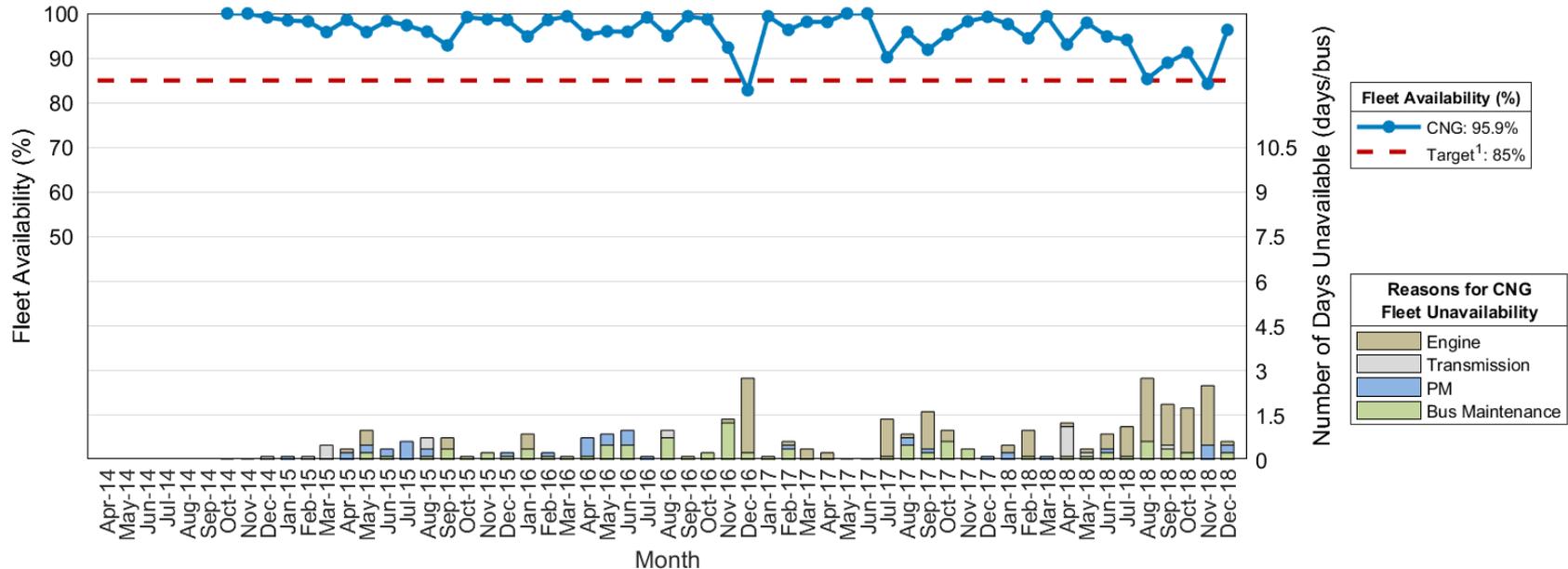
# Monthly Availability: BEB 40FC Fleet



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.
- Issues with the low-voltage battery during August 2017 lowered the availability (47% of general bus maintenance unavailable days). December availability issues were due to a traction motor inverter failure.

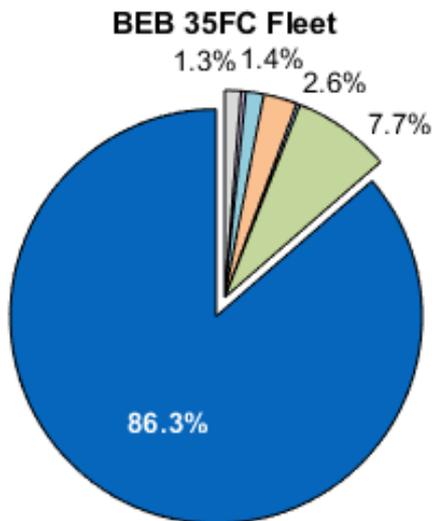
# Monthly Availability: CNG Fleet



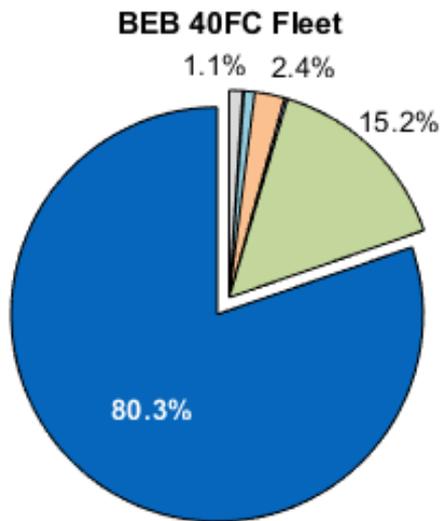
1. Target of 85% fleet availability is a general expectation for transit agencies

- 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.

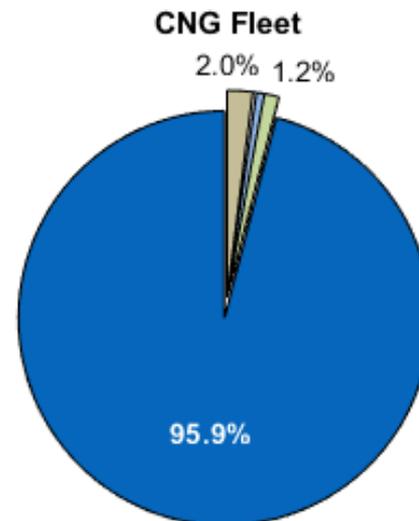
# Overall Fleet Availability: Full Data Period



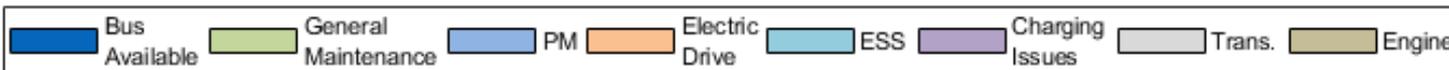
Date Range: Apr 2014 - Dec 2018  
Days Planned: 14,401



Date Range: Jan 2017 - Dec 2018  
Days Planned: 851



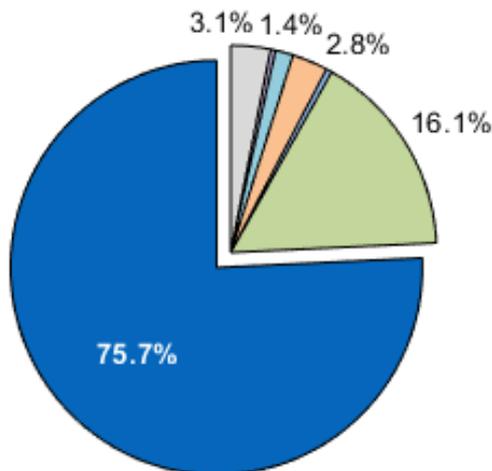
Date Range: Oct 2014 - Dec 2018  
Days Planned: 7,162



Data labels omitted for pie slices representing < 1.0%

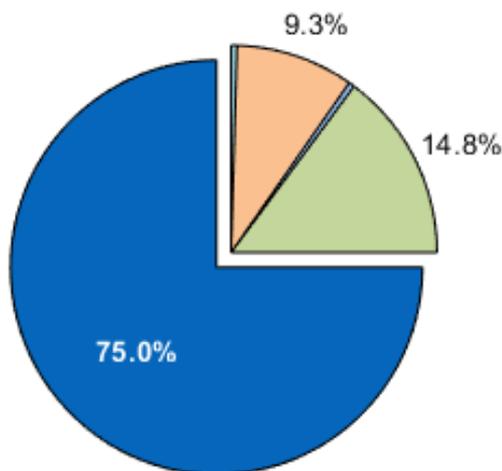
# Overall Fleet Availability: Jul.–Dec. 2018

### BEB 35FC Fleet



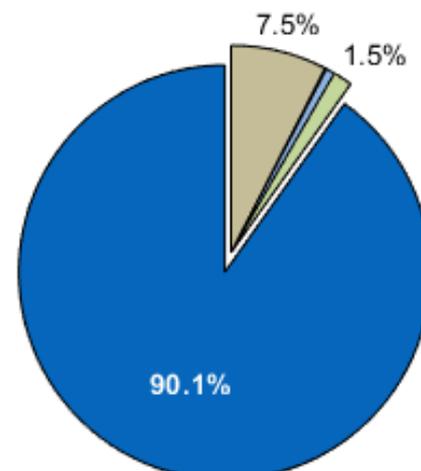
Date Range: Jul 2018 - Dec 2018  
Days Planned: 1,286

### BEB 40FC Fleet

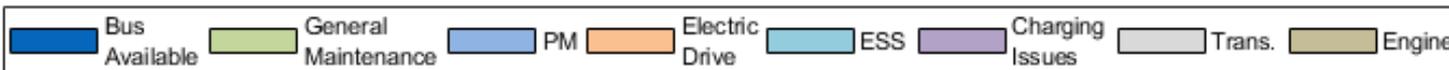


Date Range: Jul 2018 - Dec 2018  
Days Planned: 216

### CNG Fleet



Date Range: Jul 2018 - Dec 2018  
Days Planned: 861



Data labels omitted for pie slices representing < 1.0%

# Fuel Economy Analysis

Proterra records and stores data—including total electrical energy used (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 kWh 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 tracked 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 (DOE Alternative Fuels Data Center: <https://afdc.energy.gov/fuels/properties>)

- Electricity: 3,414 Btu/kWh
- CNG: 112,114 Btu/gge (LHV)
- 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

# Fuel Economy by Bus: Jul.–Dec. 2018

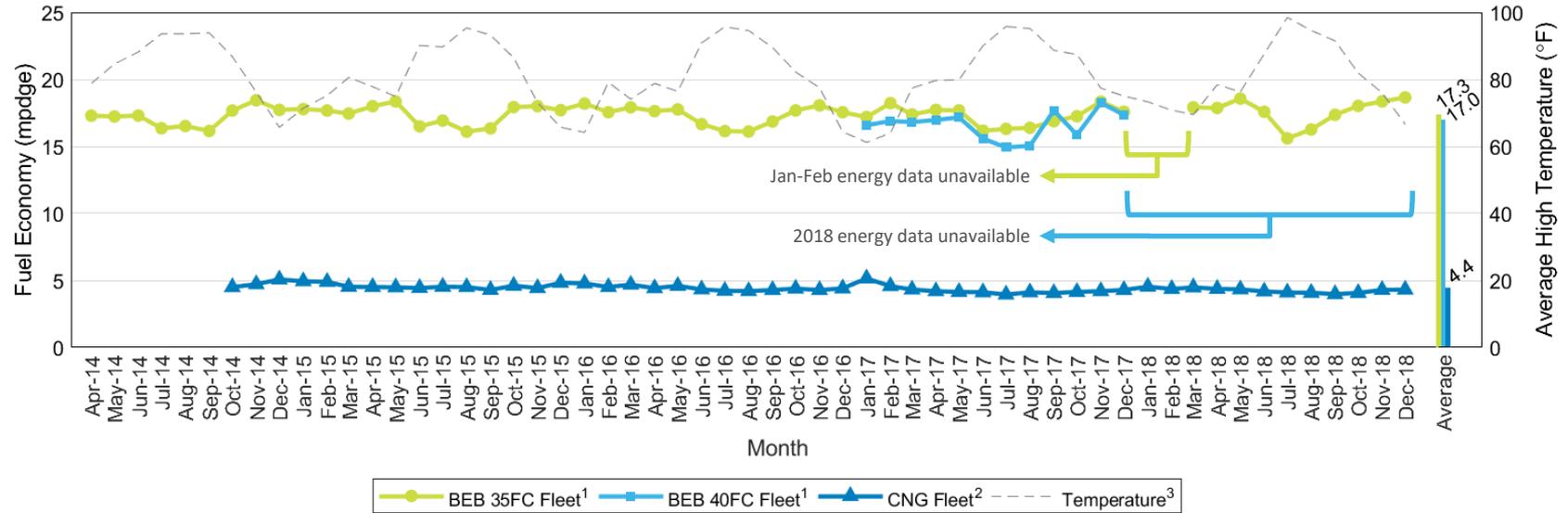
Bus ID	Miles	Energy <sup>a</sup> (kWh)	kWh/mi	Diesel Gallon Equiv.	Fuel economy (mpdge)
2004	13,962	27,990.2	2.00	743.6	18.78
2005	9,853	21,026.4	2.13	558.6	17.64
2006	10,715	24,361.8	2.27	647.2	16.55
2007	11,889	26,838.6	2.26	713.0	16.67
2008	14,021	31,271.8	2.23	830.8	16.88
2009	13,395	29,301.3	2.19	778.5	17.21
2010	11,505	25,761.1	2.24	684.4	16.81
2011	14,006	28,856.5	2.06	766.6	18.27
2012	11,299	24,795.9	2.19	658.8	17.15
2013	8,542	17,706.1	2.07	470.4	18.16
2014	13,595	29,098.6	2.14	773.1	17.59
2015	12,498	29,267.6	2.34	777.6	16.07
<b>BEB 35FC Total</b>	<b>145,281</b>	<b>316,276.0</b>	<b>2.18</b>	<b>8,402.7</b>	<b>17.29</b>
2016	—	—	—	—	—
2017	—	—	—	—	—
<b>BEB 40FC Total</b>	—	—	—	—	—

Bus ID	Miles	CNG (gge)	mpgge	Diesel Gallon Equiv.	Fuel economy (mpdge)
2200	24,701	7,048.0	3.50	6,149.8	4.02
2201	20,665	6,169.9	3.35	5,383.7	3.84
2202	25,510	6,674.2	3.82	5,823.7	4.38
2203	20,145	5,332.4	3.78	4,652.9	4.33
2204	22,887	6,256.7	3.66	5,459.4	4.19
2205	25,585	7,018.0	3.65	6,123.7	4.18
2206	25,645	6,967.5	3.68	6,079.6	4.22
2207	22,640	6,307.3	3.59	5,503.5	4.11
<b>CNG Total</b>	<b>187,778</b>	<b>51,774.0</b>	<b>3.63</b>	<b>45,176.1</b>	<b>4.16</b>

- The BEB fuel economy is 4 times higher than that of the CNG buses, as operated on current routes.
- Previous testing showed the CNG buses had a fuel economy around 2.09 mpdge on Line 291, which is 8 times lower than that of the BEBs.
- Insufficient energy data was received for the BEB 40FC fleet to calculate 2018 fuel economy.

<sup>a</sup> Total energy consumed by the bus, does not include losses during charging

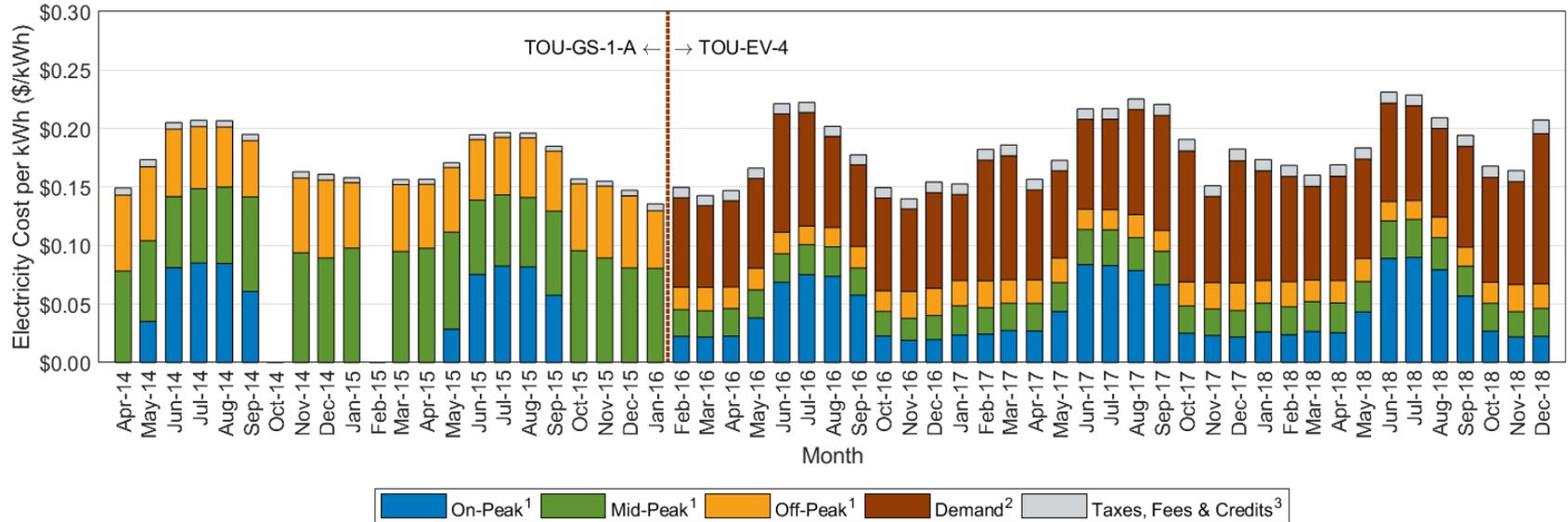
# Fleet Average Monthly Fuel Economy



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 equivalent (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/>

Fleet	Overall		Jul.–Dec. 2018	
	kWh/mi, mpgge	mpdge	kWh/mi, mpgge	mpdge
BEB 35FC	2.17	17.32	2.18	17.29
BEB 40FC	2.22	16.98	—	—
CNG	3.84	4.40	3.63	4.16

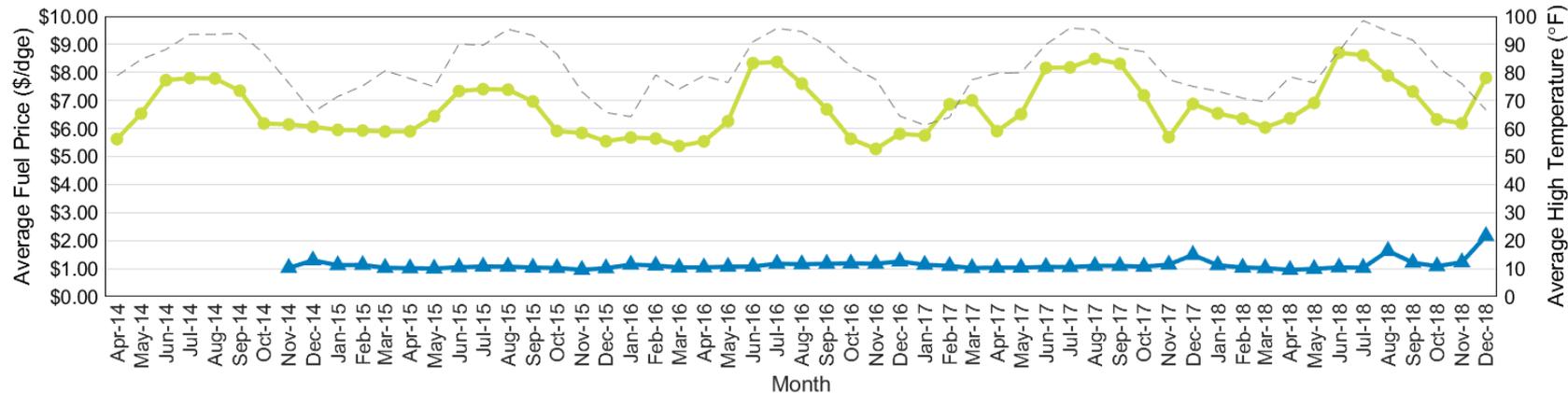
# Monthly Electric Utility Costs



1. On-Peak, Mid-Peak, and Off-Peak charge categories include respective costs for delivery and generation
2. Rate structure changed from TOU-GS-1-A to TOU-EV-4 February 2016, introducing demand charges
3. 'Taxes, Fees & Credits' category includes all remaining utility bill items (positive & negative charges)

- Data are based on utility billing periods, not calendar months
- Seasonal rates apply: average summer rate (Jun–Sep): \$0.21/kWh; average winter rate (Oct–May): \$0.16/kWh
- Average rate under TOU-GS-1-A rate structure: \$0.17/kWh; average rate under TOU-EV-4 rate structure: \$0.18/kWh
- Average rate for 2018 full calendar year: \$0.19/kWh

# Monthly Average Fuel Price



	Electricity Price (dge) <sup>1</sup>	CNG Price (dge) <sup>2</sup>	Temperature <sup>3</sup>
Overall average fuel price	\$6.76/dge	\$1.12/dge	
Data period average fuel price	\$7.35/dge	\$1.42/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 equivalent (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 more than 6 times the cost of CNG.

# Fuel Cost Per Mile

The operating duty cycle of a bus has a significant effect on fuel economy and therefore cost. Earlier in the evaluation, NREL collected drive cycle data on a selection of CNG buses that were operated on a variety of Foothill Transit routes including Line 291. On Line 291, the average fuel economy for the CNG buses was 2.09 mpdge.

During the second half of 2018, Foothill Transit paid an average of \$1.24/gge (\$1.42/dge) for CNG. The average cost of electricity during the second half of 2018 was \$0.20/kWh (\$7.35/dge). The table provides the cost per mile for the BEBs and CNG buses as used by the fleet and estimates the cost per mile of the CNG buses if they were only operated on Line 291. The lower fuel economy would increase the CNG fuel cost to an average of \$0.52/mi, which is slightly higher than that of the BEBs.

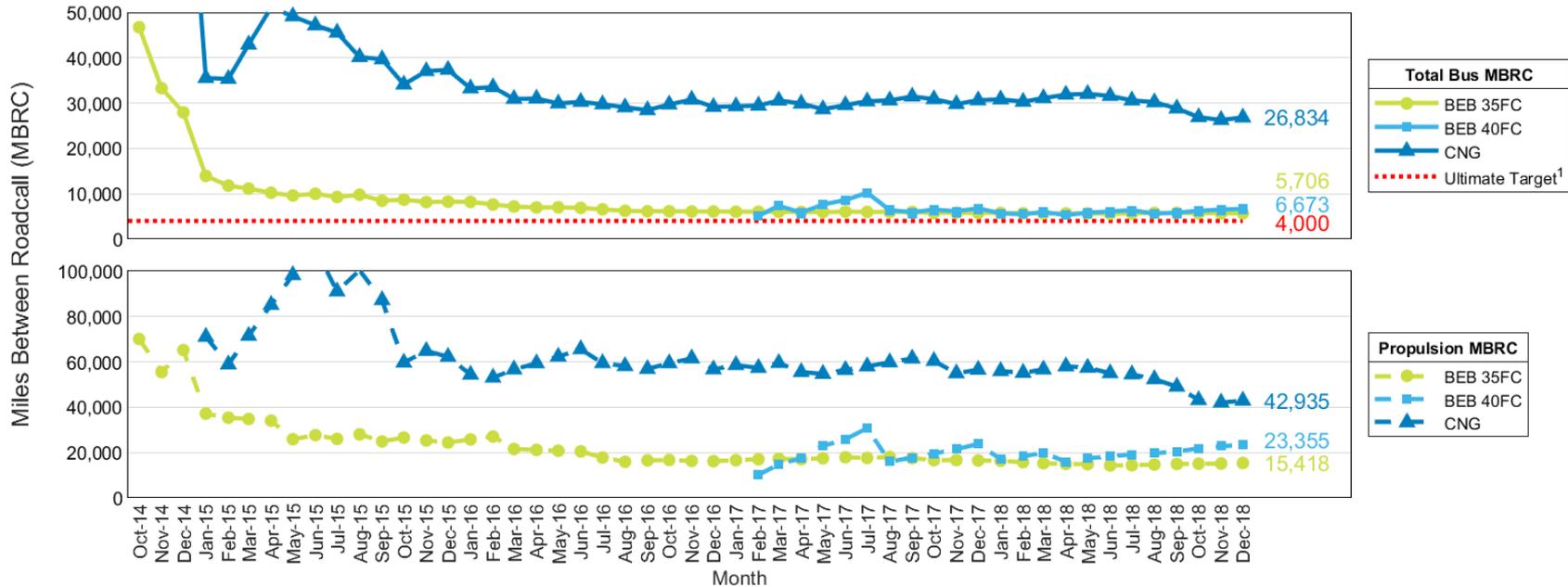
	Average Service Speed (mph)	Fuel Economy (mpdge)	Overall \$/mi	Data Period \$/mi
BEB 35FC	10.6	17.32	0.45	0.46
BEB 40FC	10.6	16.98	0.45	0.46
CNG	17.6	4.40	0.23	0.28
CNG on Line 291	10.6	2.09	0.52	0.66

# Roadcall Analysis

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

The transit industry measures reliability as mean distance between failures, also documented as MBRC. NREL tracks MBRC by total bus roadcalls, propulsion-related roadcalls, and ESS-related roadcalls (for electric buses). Total bus roadcalls include all chargeable roadcalls. Propulsion-related roadcalls is a subset of total roadcalls and includes all roadcalls 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 roadcalls—a subset of the propulsion-related roadcalls—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](http://www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf)

- The upper chart shows cumulative MBRC for all chargeable roadcalls.
- The lower chart shows MBRC for propulsion-related roadcalls.
- The ESS-related MBRC for the BEB 35FC fleet is 241,553.
- No ESS-related roadcalls have been recorded for the BEB 40FC fleet.

# Maintenance Analysis

NREL collects all work orders for the evaluation buses to calculate a maintenance cost per mile. Costs for accident-related repair, 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:

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

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: Jul.–Dec. 2018

Bus ID	Mileage	Parts (\$)	Labor Hours	Scheduled Cost (\$/mi)	Unscheduled Cost (\$/mi)	Total Cost (\$/mi)
2004	13,962	\$2,440.28	108.4	\$0.12	\$0.44	\$0.56
2005	9,853	\$897.43	50.4	\$0.09	\$0.26	\$0.35
2006	10,715	\$3,522.45	158.5	\$0.07	\$1.00	\$1.07
2007	11,889	\$2,894.48	89.4	\$0.08	\$0.54	\$0.62
2008	14,021	\$3,174.09	90.5	\$0.11	\$0.44	\$0.55
2009	13,395	\$3,713.20	145.9	\$0.09	\$0.73	\$0.82
2010	11,505	\$2,930.04	86.6	\$0.09	\$0.55	\$0.63
2011	14,006	\$3,555.98	67.8	\$0.11	\$0.39	\$0.50
2012	11,299	\$15,847.70	87.6	\$0.10	\$1.69	\$1.79
2013	8,542	\$2,573.98	76.3	\$0.08	\$0.67	\$0.75
2014	13,595	\$1,967.96	90.8	\$0.08	\$0.40	\$0.48
2015	12,498	\$11,764.02	113.3	\$0.11	\$1.28	\$1.39
<b>BEB 35FC Fleet</b>	<b>145,281</b>	<b>\$55,281.61</b>	<b>1,165.7</b>	<b>\$0.09</b>	<b>\$0.69</b>	<b>\$0.78</b>
2016	8,616	\$1,157.84	164.05	\$0.11	\$0.98	\$1.09
2017	11,451	\$2,423.66	61.68	\$0.09	\$0.39	\$0.48
<b>BEB 40FC Fleet</b>	<b>20,067</b>	<b>\$3,581.50</b>	<b>225.7</b>	<b>\$0.10</b>	<b>\$0.64</b>	<b>\$0.74</b>

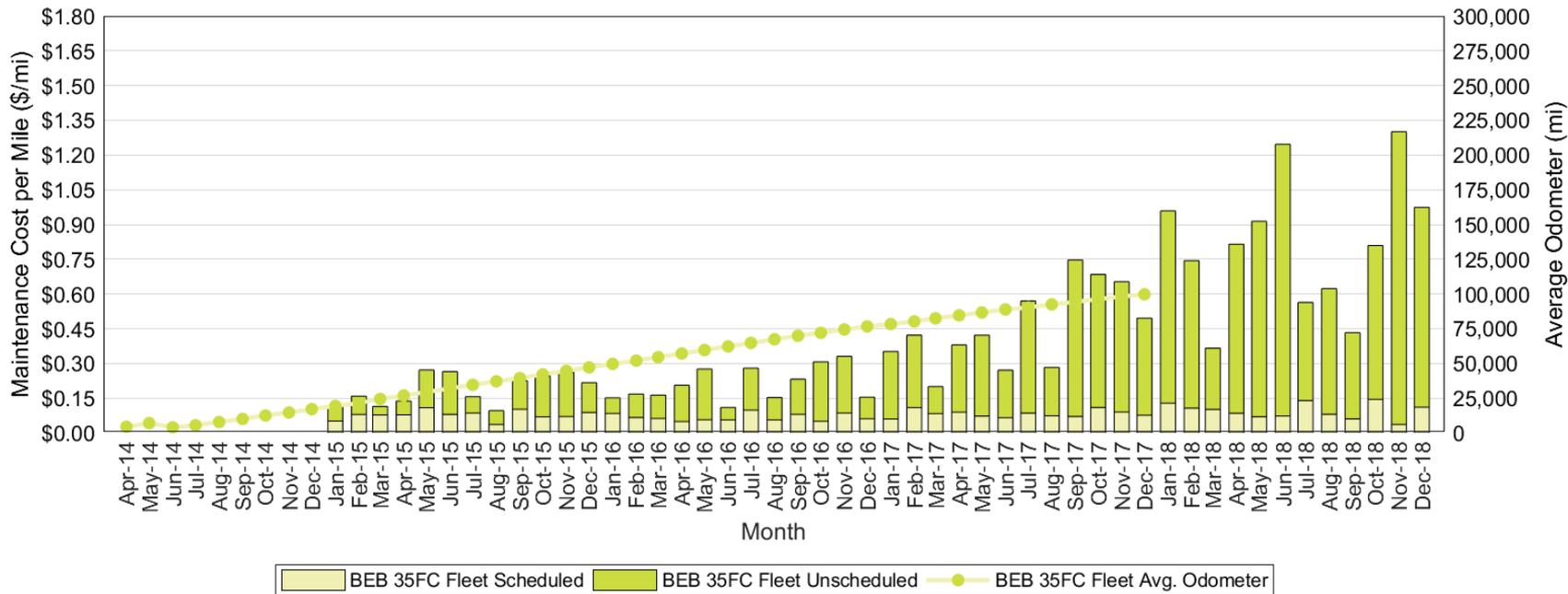
OEM: original equipment manufacturer

Bus ID	Mileage	Parts (\$)	Labor Hours	Scheduled Cost (\$/mi)	Unscheduled Cost (\$/mi)	Total Cost (\$/mi)
2200	25,733	\$6,737.04	115.1	\$0.15	\$0.34	\$0.49
2201	23,389	\$9,497.79	119.2	\$0.11	\$0.55	\$0.66
2202	31,071	\$4,523.21	92.7	\$0.12	\$0.18	\$0.29
2203	25,457	\$13,945.13	179.1	\$0.08	\$0.82	\$0.90
2204	28,932	\$6,477.17	107.5	\$0.12	\$0.29	\$0.41
2205	31,614	\$4,143.41	73.1	\$0.13	\$0.11	\$0.25
2206	31,353	\$5,420.07	126.2	\$0.12	\$0.25	\$0.37
2207	29,432	\$6,747.83	120.5	\$0.12	\$0.31	\$0.43
<b>CNG Fleet</b>	<b>226,981</b>	<b>\$57,491.65</b>	<b>933.4</b>	<b>\$0.12</b>	<b>\$0.34</b>	<b>\$0.46</b>

Reasons for cost increase over previous report (BEB 35FC: \$0.71/mi, BEB 40FC: \$0.29/mi):

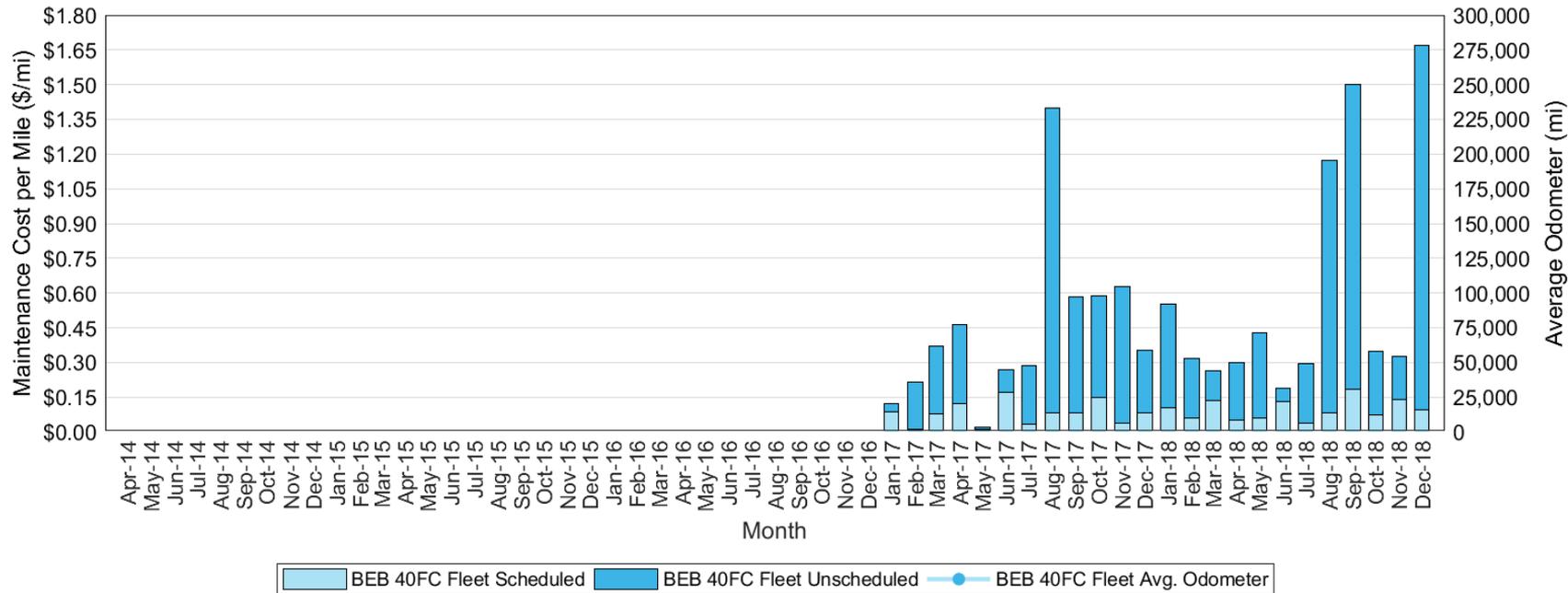
- Continued issues with the low-voltage batteries
- Issues with the bus air compressor
- Replacement of one DC-DC converter
- Maintenance being transferred from OEM to contractor, which results in more labor hours
- Warranty ended for some systems.

# Monthly Scheduled and Unscheduled Maintenance Cost: BEB 35FC Fleet



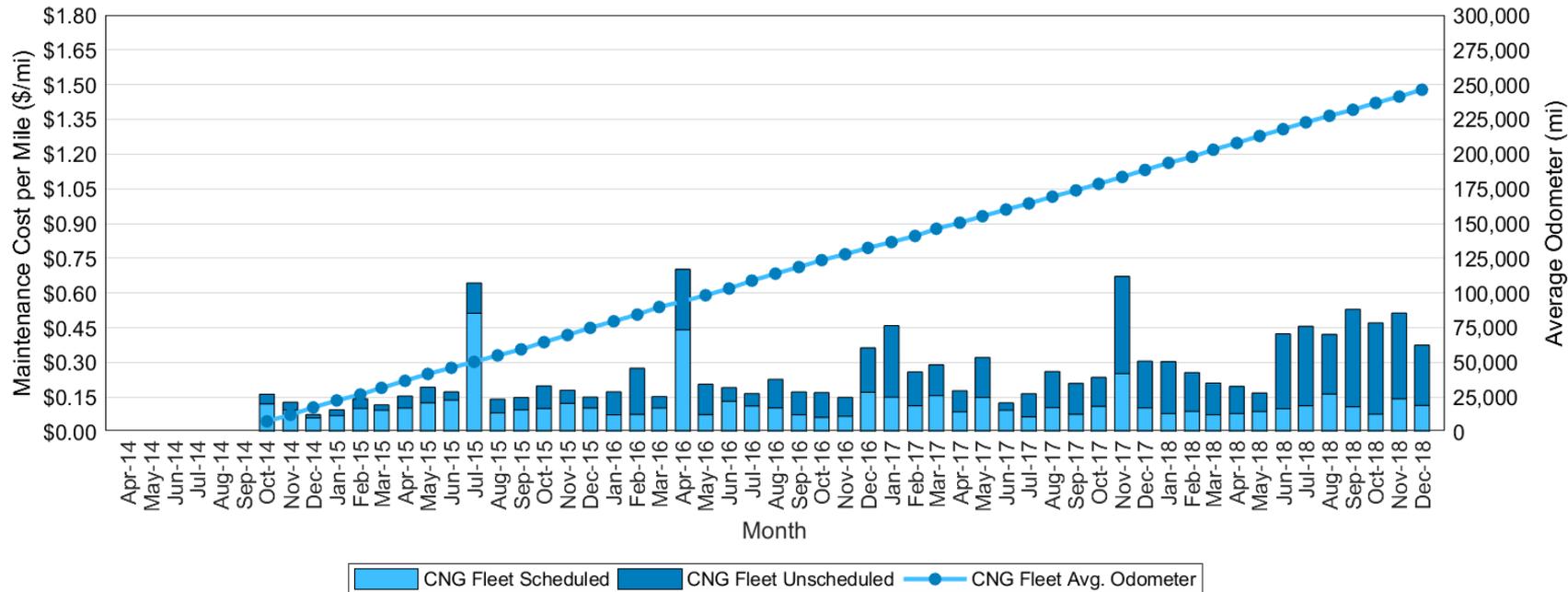
- The warranty period has ended and transit staff are handling most of the maintenance work.
- Issues with the low-voltage batteries continue to result in increasing costs.
- DC-DC converter replacement (part cost >\$12,000) increased November 2018 costs.
- Air compressor replacement (part cost >\$8,000) increased December 2018 costs.

# 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 cost per mile is more sensitive to cost increases.
- The average odometer trend for the BEB 40FC fleet is not included at this time.

# Monthly Scheduled and Unscheduled Maintenance Cost: CNG Fleet



- Higher scheduled costs during July 2015, April 2016, and November 2017 are caused by multiple buses reaching the mileage target for a major preventive maintenance (PM).
- Unscheduled costs in the last 8 months have risen primarily due to engine issues.

# Maintenance Cost per Mile by System: Jul.–Dec. 2018

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	0.317	41	0.417	56	0.248	54
Propulsion-related	0.121	16	0.126	17	0.039	9
PMI	0.092	12	0.101	14	0.059	13
Brakes	0.010	1	0.001	0	0.034	7
Frame, steering, and suspension	0.034	4	0.009	1	0.008	2
HVAC	0.009	1	0.009	1	0.008	2
Lighting	0.021	3	0.043	6	0.001	0
Axles, wheels, and drive shaft	0.002	0	0.034	5	0.010	2
Air, general	0.091	12	0.000	0	0.004	1
Tires	0.084	11	0.000	0	0.048	10
Towing charges	0.000	0	0.000	0	0.000	0
<b>Total</b>	<b>0.782</b>	<b>100</b>	<b>0.741</b>	<b>100</b>	<b>0.459</b>	<b>100</b>
<b>Total w/o low voltage battery costs</b>	<b>0.70</b>		<b>0.63</b>		<b>0.44</b>	

Color coding:



Highest cost



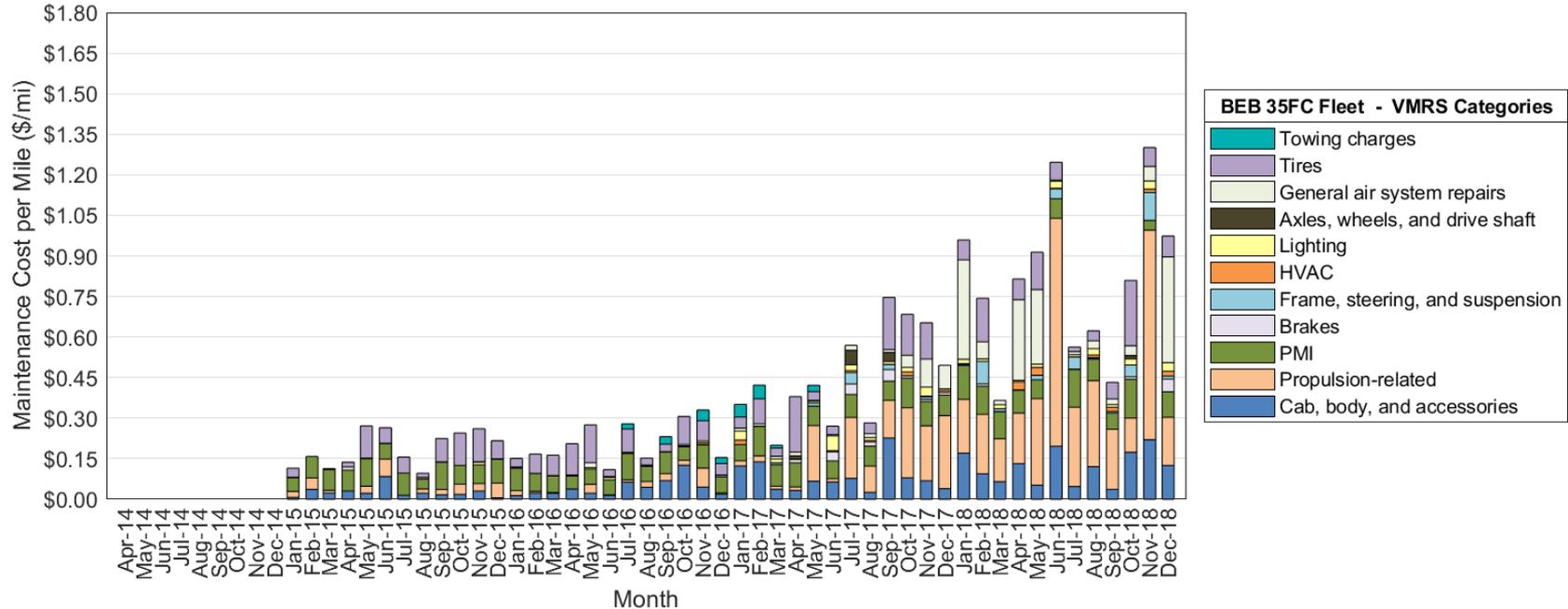
Second highest cost



Third highest cost

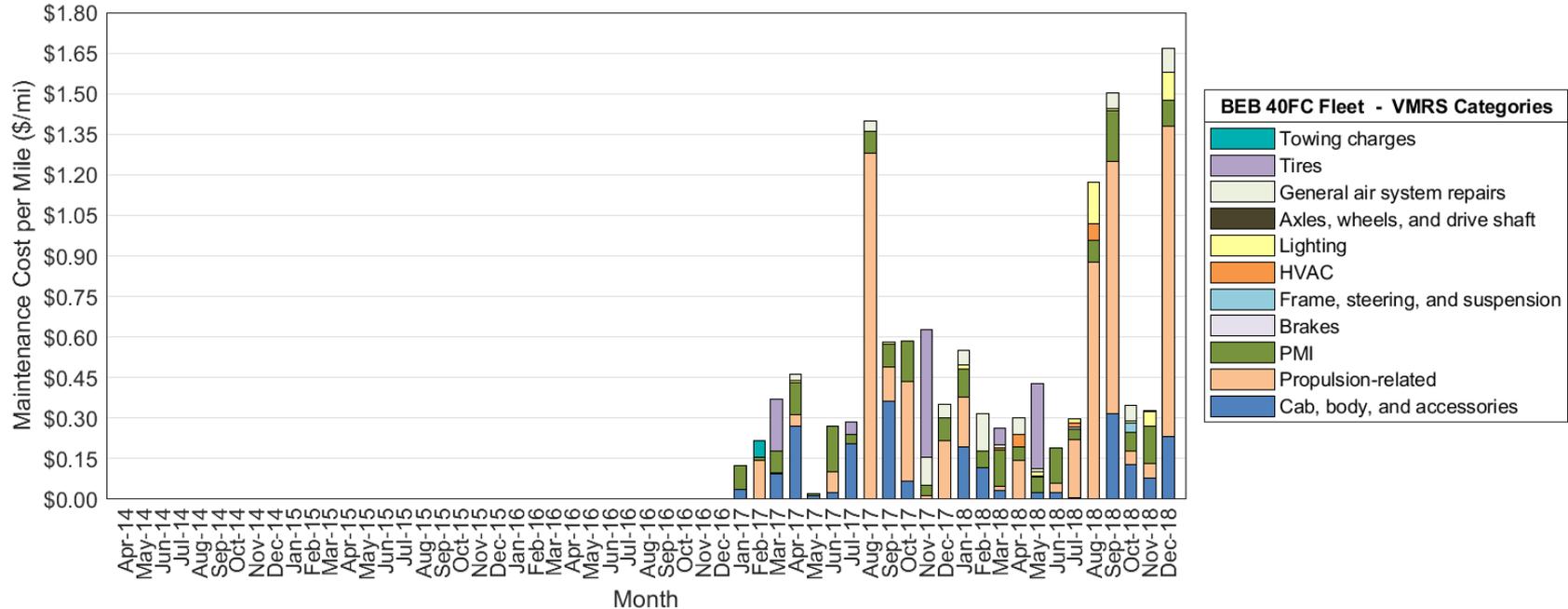
- Propulsion-related repairs for the BEBs: low-voltage batteries, battery equalizer, cooling system, DC-DC converter
- Overall cost per mile without low-voltage battery costs for the BEB 35FC buses was 1.6 times higher than the CNG bus cost; cost for the BEB 40FC buses was 1.4 times higher than the CNG bus cost.

# Maintenance Cost by System: BEB 35FC Fleet



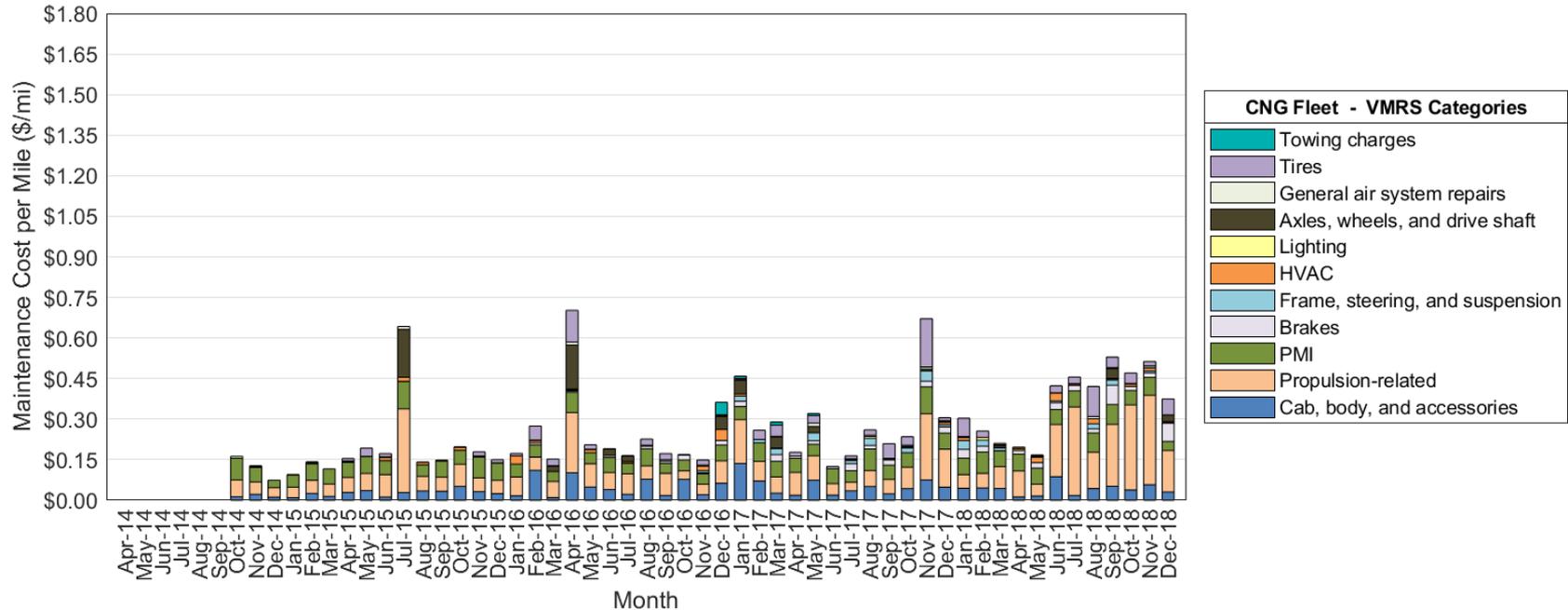
- Costs for the BEB 35FC fleet continue to increase since the warranty ended and transit staff are learning to repair all systems.
- The primary driver for the higher propulsion-related cost was issues with the low-voltage batteries (see cost per mile by propulsion subsystem chart on slide 44).
- Replacement of a DC-DC converter in November 2018 resulted in high costs.

# Maintenance Cost by System: BEB 40FC Fleet



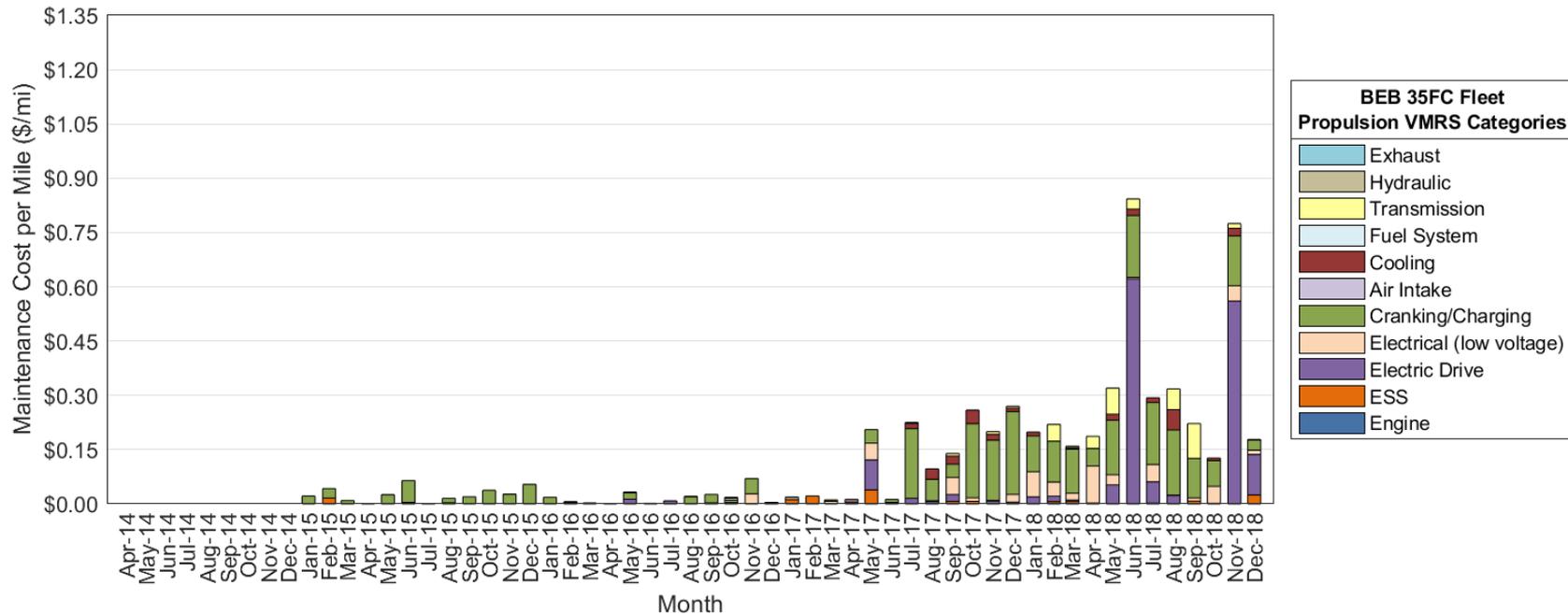
- Because the BEB 40FC fleet consists of only two buses, the cost per mile is more sensitive to cost increases.
- The high propulsion cost during August 2017 and August 2018 was primarily due to the low-voltage battery issue (see cost per mile by propulsion subsystem chart on slide 45).

# Maintenance Cost by System: CNG Fleet



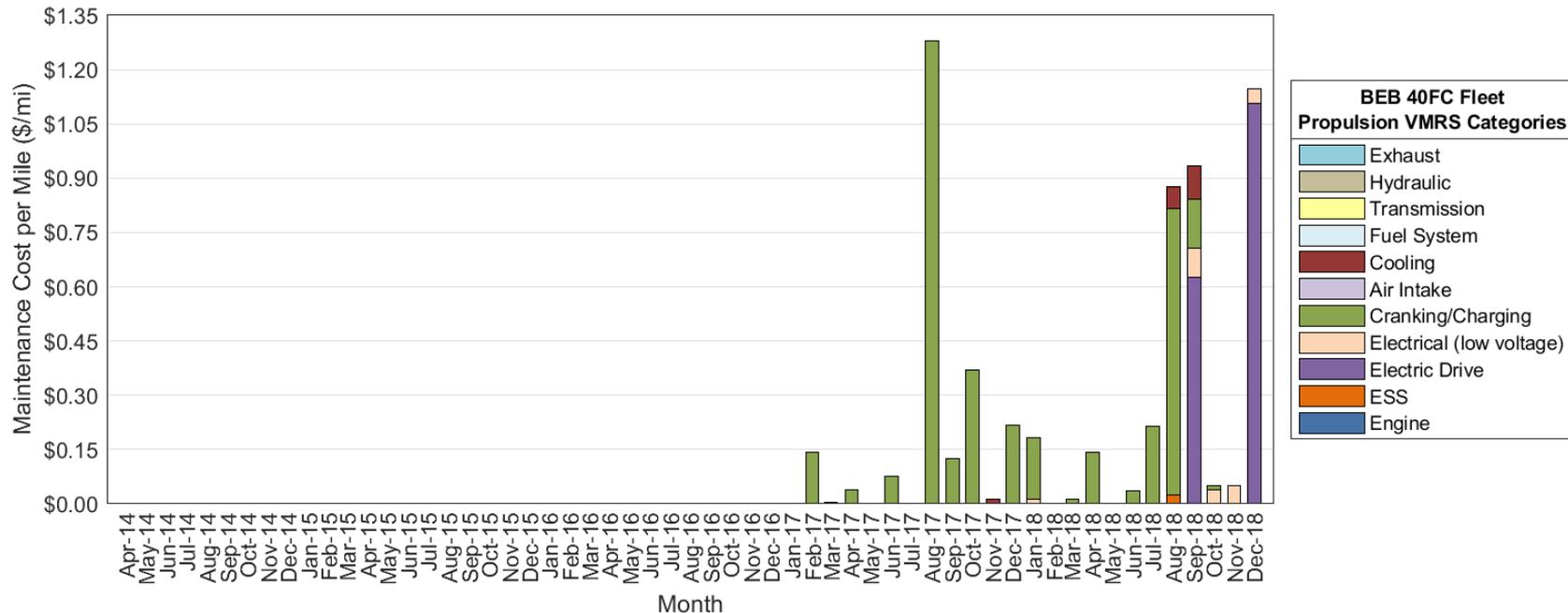
- CNG bus maintenance cost shows an increase over time as the buses age and pass the warranty period.
- During the high-cost months, multiple buses reached the mileage for a major PM.
- Higher propulsion system costs in the last half of 2018 were due to tune-ups on multiple buses, exhaust issues, oil leaks, and engine control module failures.

# Propulsion System Maintenance Cost by Subsystem: BEB 35FC Fleet



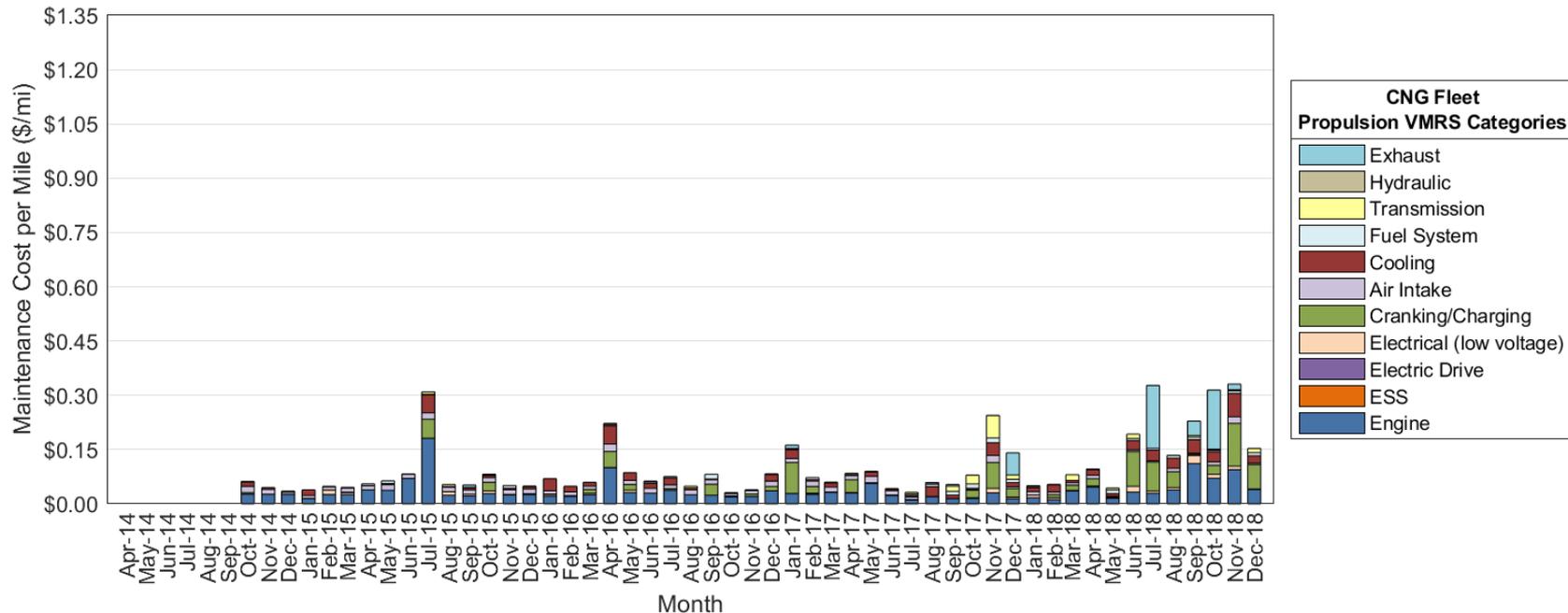
- Low-voltage battery replacements fall into the cranking/charging category.
- Replacement of a DC-DC converter in June 2018 and November 2018 resulted in high costs in the electric drive category.

# Propulsion System Maintenance Cost by Subsystem: BEB 40FC Fleet



- Both buses in the BEB 40FC fleet had low-voltage battery changeouts in August 2017 and August 2018.
- High costs in September 2018 were due to labor to troubleshoot issues with a DC-DC converter.
- High costs in December 2018 were due to labor to replace the traction motor inverter; the part cost was covered under warranty.

# Propulsion System Maintenance Cost by Subsystem: CNG Fleet



- Increased costs in the last half of 2018 fall into several categories:
  - Exhaust system—exhaust gas recirculation, turbocharger, catalyst
  - Cranking/charging—low-voltage batteries
  - Engine—oil leak, tune-ups, and electronic control module failures.

# Propulsion-Related Maintenance Costs by Subsystem: Jul.–Dec. 2018

Maintenance System		BEB 35FC	BEB 40FC	CNG
Mileage		145,281	20,067	235,197
Total Propulsion-Related Systems (Roll-Up of All Systems)	Parts cost (\$)	25,439.54	2,204.80	37,496.19
	Labor hours	413.0	123.4	376.1
	Total cost (\$)	46,089.54	8,373.30	56,300.19
	Total cost (\$) per mile	<b>0.317</b>	<b>0.417</b>	<b>0.239</b>
	Without battery changeouts	<b>0.235</b>	<b>0.303</b>	<b>0.219</b>
Exhaust System Repairs	Parts cost (\$)	0.00	0.00	13,704.36
	Labor hours	0.0	0.0	28.8
	Total cost (\$)	0.00	0.00	15,142.36
	Total cost (\$) per mile	<b>0.000</b>	<b>0.000</b>	<b>0.064</b>
Fuel System Repairs	Parts cost (\$)	0.00	0.00	1,138.12
	Labor hours	0.0	0.0	7.2
	Total cost (\$)	0.00	0.00	1,499.12
	Total cost (\$) per mile	<b>0.000</b>	<b>0.000</b>	<b>0.006</b>
Powerplant System Repairs (ESS for BEBs)	Parts cost (\$)	0.00	0.00	5,581.21
	Labor hours	17.4	1.0	173.8
	Total cost (\$)	869.00	50.00	14,269.71
	Total cost (\$) per mile	<b>0.006</b>	<b>0.002</b>	<b>0.061</b>
Electric Propulsion System Repairs	Parts cost (\$)	12,644.00	0.00	0.00
	Labor hours	103.6	85.9	0.0
	Total cost (\$)	17,825.00	4,293.00	0.00
	Total cost (\$) per mile	<b>0.123</b>	<b>0.214</b>	<b>0.000</b>

# Propulsion-Related Maintenance Costs by Subsystem: Jul.–Dec. 2018

Maintenance System		BEB 35FC	BEB 40FC	CNG
Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)	Parts cost (\$)	10,518.44	2,174.72	10,196.45
	Labor hours	204.4	28.6	95.6
	Total cost (\$)	20,738.94	3,606.22	14,975.95
	Total cost (\$) per mile	<b>0.143</b>	<b>0.180</b>	<b>0.064</b>
Air Intake System Repairs	Parts cost (\$)	16.53	0.00	1,506.60
	Labor hours	0.0	0.0	5.7
	Total cost (\$)	16.53	0.00	1,791.60
	Total cost (\$) per mile	<b>0.000</b>	<b>0.000</b>	<b>0.008</b>
Cooling System Repairs	Parts cost (\$)	1,563.80	30.08	4,857.21
	Labor hours	19.2	7.9	58.4
	Total cost (\$)	2,523.30	424.08	7,777.71
	Total cost (\$) per mile	<b>0.017</b>	<b>0.021</b>	<b>0.033</b>
Transmission System Repairs	Parts cost (\$)	696.77	0.00	512.24
	Labor hours	68.4	0.0	6.6
	Total cost (\$)	4,116.77	0.00	843.74
	Total cost (\$) per mile	<b>0.028</b>	<b>0.000</b>	<b>0.004</b>
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	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>

# Brake Maintenance Analysis

NREL has been tracking the Foothill Transit BEBs for sufficient time to analyze the differences in brake system costs between the BEBs and CNG buses. The duty cycle of the buses can have a significant effect on how components wear, including brake system components. The best comparison would be between bus fleets operated in the same service. While the bus fleets in this evaluation are operated in very different duty cycles, some general observations can be made. The tables below summarize the cost for each bus type. The majority of brake system costs for the CNG buses were for relines at 87% of the total costs. Brake relines accounted for only 55% of the total cost for the BEBs. The “other” category includes items such as labor for brake inspections and work on parking brakes.

CNG	Labor (h)	Parts (\$)	Cost (\$/mi)	% of total
Reline	131.79	11,883.84	0.0096	87%
Rotor	14.62	293.20	0.0005	5%
Other	20.22	810.31	0.0009	9%
<b>Overall</b>	<b>166.63</b>	<b>12,987.35</b>	<b>0.0110</b>	

BEB	Labor (h)	Parts (\$)	Cost (\$/mi)	% of total
Reline	28.12	1,218.71	0.0021	55%
Rotor	0.00	0.00	0.0000	0%
Other	35.38	387.18	0.0017	45%
<b>Overall</b>	<b>63.50</b>	<b>1,605.89</b>	<b>0.0038</b>	

- All eight of the CNG buses have had brake relines
- Of the 14 BEBs, 10 have had brake relines
- The majority of relines on the BEBs were front brakes only
- Average distance traveled before the first reline:
  - BEB = 92,500 miles (for BEBs that have had relines)
  - CNG = 125,700 miles
- Average distance between relines by fleet:
  - BEB = 147,700 miles
  - CNG = 58,500 miles (rear); 83,900 miles (rear)
- The brake cost for the BEBs is 65% less than that of the CNG buses

# Low-Voltage Battery Maintenance Analysis

Foothill Transit continues to have issues with the low-voltage (LV) batteries. The tables summarize the low-voltage battery changeout data from the BEB and CNG buses. The BEBs are averaging 7.8 changeouts per bus at approximately 12,000 miles between changeout. The CNG buses average 1.13 changeouts per bus at more than 214,000 miles. One issue is that the accessories (farebox, cameras, etc.) continually draw power from these batteries. If the 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	LV Battery Changeouts	Accumulated Miles	Miles between Changeout	Data Period
2004	5	94,684	18,937	0
2005	6	107,151	17,858	1
2006	6	114,980	19,163	1
2007	5	112,538	22,508	1
2008	8	110,000	13,750	1
2009	8	116,702	14,588	2
2010	5	100,541	20,108	1
2011	8	110,668	13,834	1
2012	7	108,239	15,463	2
2013	7	76,044	10,863	2
2014	8	109,808	13,726	1
2015	19	92,361	4,861	2
2016	9	45,892	5,099	2
2017	8	47,527	5,941	3
<b>Total</b>	<b>109</b>	<b>1,347,134</b>	<b>12,359</b>	<b>20</b>
<b>Per Bus</b>	<b>7.8</b>			<b>1.4</b>

Proterra is aware of the issue and is developing an auto shutoff to address the problem. New designs will include this feature. Proterra is also working on a retrofit for buses already in service.

CNG Bus	LV Battery Changeouts	Accumulated Miles	Miles between Changeout
2200	2	230,335	115,168
2201	0	237,749	
2202	0	240,518	
2203	3	240,174	80,058
2204	2	234,459	117,230
2205	0	248,993	
2206	0	250,921	
2207	2	248,908	124,454
<b>Total</b>	<b>9</b>	<b>1,932,057</b>	<b>214,673</b>
<b>Per Bus</b>	<b>1.13</b>		

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# Acronyms and Abbreviations

BEB	battery electric bus	LHV	lower heating value
Btu	British thermal unit	LV	low voltage
CNG	compressed natural gas	MBRC	miles between roadcalls
dge	diesel gallon equivalent	mi	miles
ESS	energy storage system	mpdge	miles per diesel gallon equivalent
FC	fast charge	mpgge	miles per gasoline gallon equivalent
ft	feet	mph	miles per hour
gge	gasoline gallon equivalent	NREL	National Renewable Energy Laboratory
GVWR	gross vehicle weight rating	OEM	original equipment manufacturer
hp	horsepower	PM	preventive maintenance
HVAC	heating, ventilation, and air conditioning	PMI	preventive maintenance inspection
in.	inches	psi	pounds per square inch
kW	kilowatts	PTC	Pomona Transit Center
kWh	kilowatt hours	scf	standard cubic feet
lb	pounds	VMRS	Vehicle Maintenance Reporting Standards

# Acknowledgments

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# Appendix: Fleet Summary Statistics

# Fleet Summary Statistics

	BEB 35FC All Data	BEB 35F 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	4/14–12/18	7/18–12/18	1/17–12/18	7/18–12/18	10/14–12/18	7/18–12/18
Total number of months in period	57	6	24	6	51	6
Fuel and oil analysis base fleet mileage	1,406,520	145,281	29,863	—	1,724,299	187,778
Period used for maintenance analysis	1/15–12/18	7/18–12/18	1/17–12/18	7/18–12/18	10/14–12/18	7/18–12/18
Total number of months in period	48	6	24	6	51	6
Maintenance analysis base fleet mileage	1,253,716	145,281	93,418	20,067	1,932,057	226,981
Availability	86	76	80	75	96	90
Fleet fuel/energy usage in kWh (BEB) or gge (CNG)	3,056,096.9	316,276.0	66,206.3	—	449,421.4	51,774.0
Roadcalls	254	21	14	2	72	18
Total MBRC	5,706	6,918	6,673	10,033	26,834	12,610
Propulsion roadcalls	94	3	4	0	45	14
Propulsion MBRC	15,418	48,427	23,355	—	42,935	16,213
Fleet kWh/mile (BEB) or mpggge (CNG)	2.17	2.18	2.22	—	3.84	3.63
Representative fleet mpg (energy equiv.)	17.32	17.29	16.98	—	4.40	4.16
Energy cost per kWh or CNG cost per gge	0.18	0.20	0.18	0.20	0.97	1.24
Fuel cost per mile	0.45	0.46	0.45	0.46	0.23	0.28
Total scheduled repair cost per mile	0.08	0.09	0.08	0.10	0.12	0.12
Total unscheduled repair cost per mile	0.31	0.69	0.35	0.64	0.14	0.34
Total maintenance cost per mile	0.39	0.78	0.44	0.74	0.26	0.46
<b>Total operating cost per mile</b>	<b>0.84</b>	<b>1.24</b>	<b>0.89</b>	<b>1.20</b>	<b>0.49</b>	<b>0.74</b>

# Maintenance Cost Summary

## 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	1,253,716	145,281	93,418	20,067	1,932,057	226,981
Total parts cost	235,356.89	55,281.61	15,243.47	3,581.50	266,796.55	57,491.65
Total labor hours	5,047.1	1,165.7	509.8	225.7	4,756.2	933.4
Average labor cost (@ \$50.00 per hour)	252,356.00	58,285.00	25,490.00	11,286.50	237,809.50	46,672.00
Total maintenance cost	487,712.89	113,566.61	40,733.47	14,868.00	504,606.05	104,163.65
Total maintenance cost per bus	40,642.74	9,463.88	20,366.74	7,434.00	63,075.76	13,020.46
<b>Total maintenance cost per mile without low-voltage battery cost</b>	<b>0.389 0.344</b>	<b>0.782 0.700</b>	<b>0.436 0.342</b>	<b>0.741 0.627</b>	<b>0.261 0.256</b>	<b>0.459 0.439</b>

## 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
<b>Total Engine/Fuel-Related Systems (ATA VMRS 27, 30, 31, 32, 33, 41, 42, 43, 44, 45, 46, 65)</b>						
Parts cost	82,991.38	25,439.54	7,223.32	2,204.80	137,482.55	37,496.19
Labor hours	1,074.69	413.00	159.56	123.37	1,089.70	376.08
Average labor cost	53,734.50	20,650.00	7,978.00	6,168.50	54,485.00	18,804.00
Total cost (for system)	136,725.88	46,089.54	15,201.32	8,373.30	191,967.55	56,300.19
Total cost (for system) per bus	11,393.82	3,840.80	7,600.66	4,186.65	23,995.94	7,037.52
<b>Total cost (for system) per mile without low-voltage battery cost</b>	<b>0.109 0.064</b>	<b>0.317 0.235</b>	<b>0.163 0.069</b>	<b>0.417 0.303</b>	<b>0.099 0.095</b>	<b>0.248 0.228</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
<b>Exhaust System Repairs (ATA VMRS 43)</b>						
Parts cost	0.00	0.00	0.00	0.00	16,155.03	13,704.36
Labor hours	0.0	0.0	0.0	0.0	48.1	28.8
Average labor cost	0.00	0.00	0.00	0.00	2,405.50	1,438.00
Total cost (for system)	0.00	0.00	0.00	0.00	18,560.53	15,142.36
Total cost (for system) per bus	0.00	0.00	0.00	0.00	2,320.07	1,892.80
<b>Total cost (for system) per mile</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.010</b>	<b>0.067</b>
<b>Fuel System Repairs (ATA VMRS 44)</b>						
Parts cost	0.00	0.00	0.00	0.00	3,450.41	1,138.12
Labor hours	0.0	0.0	0.0	0.0	75.6	7.2
Average labor cost	0.00	0.00	0.00	0.00	3,778.50	361.00
Total cost (for system)	0.00	0.00	0.00	0.00	7,228.91	1,499.12
Total cost (for system) per bus	0.00	0.00	0.00	0.00	903.61	187.39
<b>Total cost (for system) per mile</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.004</b>	<b>0.007</b>
<b>Power Plant (Engine) Repairs (ATA VMRS 45)</b>						
Parts cost	1,428.22	0.00	0.00	0.00	51,407.60	5,581.21
Labor hours	48.2	17.4	1.0	1.0	333.4	173.8
Average labor cost	2,411.50	869.00	50.00	50.00	16,670.00	8,688.50
Total cost (for system)	3,839.72	869.00	50.00	50.00	68,077.61	14,269.71
Total cost (for system) per bus	319.98	72.42	25.00	25.00	8,509.70	1,783.71
<b>Total cost (for system) per mile</b>	<b>0.003</b>	<b>0.006</b>	<b>0.001</b>	<b>0.002</b>	<b>0.035</b>	<b>0.063</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
<b>Electric Propulsion Repairs (ATA VMRS 46)</b>						
Parts cost	27,921.45	12,644.00	0.00	0.00	0.00	0.00
Labor hours	219.2	103.6	85.9	85.9	0.0	0.0
Average labor cost	10,959.50	5,181.00	4,293.00	4,293.00	0.00	0.00
Total cost (for system)	38,880.95	17,825.00	4,293.00	4,293.00	0.00	0.00
Total cost (for system) per bus	3,240.08	1,485.42	2,146.50	2,146.50	0.00	0.00
<b>Total cost (for system) per mile</b>	<b>0.031</b>	<b>0.123</b>	<b>0.046</b>	<b>0.214</b>	<b>0.000</b>	<b>0.000</b>
<b>Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)</b>						
Parts cost	49,304.34	10,518.44	7,193.24	2,174.72	26,215.75	10,196.45
Labor hours	581.8	204.4	63.8	28.6	321.2	95.6
Average labor cost	29,091.50	10,220.50	3,191.00	1,431.50	16,058.00	4,779.50
Total cost (for system)	78,395.84	20,738.94	10,384.24	3,606.22	42,273.75	14,975.95
Total cost (for system) per bus	6,532.99	1,728.25	5,192.12	1,803.11	5,284.22	1,871.99
<b>Total cost (for system) per mile</b>	<b>0.063</b>	<b>0.143</b>	<b>0.111</b>	<b>0.180</b>	<b>0.022</b>	<b>0.066</b>
<b>Air Intake System Repairs (ATA VMRS 41)</b>						
Parts cost	31.80	16.53	0.00	0.00	19,351.95	1,506.60
Labor hours	3.9	0.0	0.0	0.0	7.5	5.7
Average labor cost	195.00	0.00	0.00	0.00	372.50	285.00
Total cost (for system)	226.80	16.53	0.00	0.00	19,724.45	1,791.60
Total cost (for system) per bus	18.90	1.38	0.00	0.00	2,465.56	223.95
<b>Total cost (for system) per mile</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.010</b>	<b>0.008</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
<b>Cooling System Repairs (ATA VMRS 42)</b>						
Parts cost	2,819.80	1,563.80	30.08	30.08	15,592.84	4,857.21
Labor hours	77.2	19.2	8.9	7.9	242.9	58.4
Average labor cost	3,859.50	959.50	444.00	394.00	12,145.50	2,920.50
Total cost (for system)	6,679.30	2,523.30	474.08	424.08	27,738.34	7,777.71
Total cost (for system) per bus	556.61	210.28	237.04	212.04	3,467.29	972.21
<b>Total cost (for system) per mile</b>	<b>0.005</b>	<b>0.017</b>	<b>0.005</b>	<b>0.021</b>	<b>0.014</b>	<b>0.034</b>
<b>Hydraulic System Repairs (ATA VMRS 65)</b>						
Parts cost	0.00	0.00	0.00	0.00	0.00	0.00
Labor hours	1.5	0.0	0.0	0.0	0.0	0.0
Average labor cost	75.00	0.00	0.00	0.00	0.00	0.00
Total cost (for system)	75.00	0.00	0.00	0.00	0.00	0.00
Total cost (for system) per bus	6.25	0.00	0.00	0.00	0.00	0.00
<b>Total cost (for system) per mile</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>
<b>General Air System Repairs (ATA VMRS 10)</b>						
Parts cost	30,779.14	9,628.90	583.88	185.19	2,384.98	524.39
Labor hours	268.4	70.7	38.8	10.1	47.3	6.0
Average labor cost	13,421.00	3,535.00	1,939.00	504.00	2,367.00	299.50
Total cost (for system)	44,200.14	13,163.90	2,522.88	689.19	4,751.98	823.89
Total cost (for system) per bus	3,683.35	1,096.99	1,261.44	344.60	594.00	102.99
<b>Total cost (for system) per mile</b>	<b>0.035</b>	<b>0.091</b>	<b>0.027</b>	<b>0.034</b>	<b>0.002</b>	<b>0.004</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
<b>Brake System Repairs (ATA VMRS 13)</b>						
Parts cost	1,726.41	198.18	0.00	0.00	12,845.95	3,828.26
Labor hours	83.5	25.6	0.5	0.5	170.0	78.0
Average labor cost	4,175.00	1,281.50	25.00	25.00	8,499.00	3,901.50
Total cost (for system)	5,901.41	1,479.68	25.00	25.00	21,344.95	7,729.76
Total cost (for system) per bus	491.78	123.31	12.50	12.50	2,668.12	966.22
<b>Total cost (for system) per mile</b>	<b>0.005</b>	<b>0.010</b>	<b>0.000</b>	<b>0.001</b>	<b>0.011</b>	<b>0.034</b>
<b>Transmission Repairs (ATA VMRS 27)</b>						
Parts cost	1,485.77	696.77	0.00	0.00	5,308.97	512.24
Labor hours	142.9	68.4	0.0	0.0	61.1	6.6
Average labor cost	7,142.50	3,420.00	0.00	0.00	3,055.00	331.50
Total cost (for system)	8,628.27	4,116.77	0.00	0.00	8,363.97	843.74
Total cost (for system) per bus	719.02	343.06	0.00	0.00	1,045.50	105.47
<b>Total cost (for system) per mile</b>	<b>0.007</b>	<b>0.028</b>	<b>0.000</b>	<b>0.000</b>	<b>0.004</b>	<b>0.004</b>
<b>Inspections Only—No Parts Replacements (101)</b>						
Parts cost	0.00	0.00	0.00	0.00	0.00	0.00
Labor hours	1948.3	267.5	153.2	40.5	2191.6	268.5
Average labor cost	97,414.50	13,374.50	7,662.00	2,026.00	109,580.00	13,426.00
Total cost (for system)	97,414.50	13,374.50	7,662.00	2,026.00	109,580.00	13,426.00
Total cost (for system) per bus	8,117.88	1,114.54	3,831.00	1,013.00	13,697.50	1,678.25
<b>Total cost (for system) per mile</b>	<b>0.078</b>	<b>0.092</b>	<b>0.082</b>	<b>0.101</b>	<b>0.057</b>	<b>0.059</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
<b>Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)</b>						
Parts cost	25,014.34	7,553.04	2,030.78	830.70	34,415.88	2,925.09
Labor hours	1077.3	201.5	122.8	34.0	888.3	120.4
Average labor cost	53,865.50	10,074.50	6,142.00	1,700.50	44,412.50	6,018.00
Total cost (for system)	78,879.84	17,627.54	8,172.78	2,531.20	78,828.38	8,943.09
Total cost (for system) per bus	6,573.32	1,468.96	4,086.39	1,265.60	9,853.55	1,117.89
<b>Total cost (for system) per mile</b>	<b>0.063</b>	<b>0.121</b>	<b>0.087</b>	<b>0.126</b>	<b>0.041</b>	<b>0.039</b>
<b>HVAC System Repairs (ATA VMRS 01)</b>						
Parts cost	1,360.85	337.06	76.07	0.00	7,962.90	993.18
Labor hours	64.2	20.6	7.0	3.5	81.5	17.3
Average labor cost	3,208.50	1,031.00	352.00	177.00	4,076.50	864.00
Total cost (for system)	4,569.35	1,368.06	428.07	177.00	12,039.40	1,857.18
Total cost (for system) per bus	380.78	114.01	214.04	88.50	1,504.93	232.15
<b>Total cost (for system) per mile</b>	<b>0.004</b>	<b>0.009</b>	<b>0.005</b>	<b>0.009</b>	<b>0.006</b>	<b>0.008</b>
<b>Lighting System Repairs (ATA VMRS 34)</b>						
Parts cost	3,304.86	790.13	172.33	172.33	462.55	19.38
Labor hours	161.6	45.3	17.7	13.7	31.8	2.4
Average labor cost	8,079.00	2,266.50	884.50	684.50	1,592.00	119.50
Total cost (for system)	11,383.86	3,056.63	1,056.83	856.83	2,054.55	138.88
Total cost (for system) per bus	948.66	254.72	528.42	428.42	256.82	17.36
<b>Total cost (for system) per mile</b>	<b>0.009</b>	<b>0.021</b>	<b>0.011</b>	<b>0.043</b>	<b>0.001</b>	<b>0.001</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
<b>Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)</b>						
Parts cost	3,047.82	1,493.14	188.48	188.48	8,354.41	959.17
Labor hours	140.8	69.3	0.0	0.0	80.7	16.6
Average labor cost	7,038.50	3,464.50	1.00	1.00	4,034.50	831.00
Total cost (for system)	10,086.32	4,957.64	189.48	189.48	12,388.91	1,790.17
Total cost (for system) per bus	840.53	413.14	94.74	94.74	1,548.61	223.77
<b>Total cost (for system) per mile</b>	<b>0.008</b>	<b>0.034</b>	<b>0.002</b>	<b>0.009</b>	<b>0.006</b>	<b>0.008</b>
<b>Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)</b>						
Parts cost	1,665.40	0.00	0.00	0.00	21,583.71	1,283.09
Labor hours	13.1	6.1	0.0	0.0	30.8	18.8
Average labor cost	656.50	306.50	0.00	0.00	1,539.50	939.50
Total cost (for system)	2,321.90	306.50	0.00	0.00	23,123.21	2,222.59
Total cost (for system) per bus	193.49	25.54	0.00	0.00	2,890.40	277.82
<b>Total cost (for system) per mile</b>	<b>0.002</b>	<b>0.002</b>	<b>0.000</b>	<b>0.000</b>	<b>0.012</b>	<b>0.010</b>
<b>Tire Repairs (ATA VMRS 17)</b>						
Parts cost	79,181.69	9,841.62	4,683.61	0.00	38,602.42	9,462.90
Labor hours	215.3	46.0	10.1	0.0	143.5	29.4
Average labor cost	10,763.00	2,301.00	506.50	0.00	7,173.50	1,469.00
Total cost (for system)	89,944.69	12,142.62	5,190.11	0.00	45,775.92	10,931.90
Total cost (for system) per bus	7,495.39	1,011.89	2,595.06	0.00	5,721.99	1,366.49
<b>Total cost (for system) per mile</b>	<b>0.072</b>	<b>0.084</b>	<b>0.056</b>	<b>0.000</b>	<b>0.024</b>	<b>0.048</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
<b>Towing Charges</b>						
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	1.0	0.0
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
<b>Total cost (for system) per mile</b>	<b>0.005</b>	<b>0.000</b>	<b>0.003</b>	<b>0.000</b>	<b>0.001</b>	<b>0.000</b>

# Fleet Summary Statistics: 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	4/14–12/18	7/18–12/18	1/17–12/18	7/18–12/18	10/14–12/18	7/18–12/18
Total number of months in period	57	6	24	6	51	6
Fuel and oil analysis base fleet kilometers	2,263,513	233,800	48,059	—	2,774,914	302,191
Period used for maintenance analysis	1/15–12/18	7/18–12/18	1/17–12/18	7/18–12/18	10/14–12/18	7/18–12/18
Total number of months in period	48	6	24	6	51	6
Maintenance analysis base fleet kilometers	2,017,605	233,800	150,338	32,293	3,109,259	365,281
Average monthly kilometers per vehicle	3,513	3,247	3,132	2,691	7,621	7,610
Availability	86	76	80	75	96	90
Fleet fuel/energy usage in kWh (BEB) or gge (CNG)	3,056,096.9	316,276.0	66,206.3	—	1,701,245.1	195,985.9
Roadcalls	254	21	14	2	72	18
Total KBRC	9,183	11,133	10,738	16,147	43,184	20,293
Propulsion roadcalls	94	3	4	0	45	14
Propulsion KBRC	24,813	77,933	37,585	—	69,095	26,091
Representative fleet kg/100 km (energy equiv.)	13.56	13.58	13.83	—	53.50	56.59
Energy cost per kWh or CNG cost per gge	0.18	0.20	0.19	0.20	0.26	0.32
Fuel cost per kilometer	0.28	0.29	0.28	0.29	0.16	0.21
Total scheduled repair cost per km	0.05	0.06	0.05	0.06	0.07	0.07
Total unscheduled repair cost per km	0.19	0.43	0.22	0.40	0.09	0.21
Total maintenance cost per km	0.24	0.49	0.27	0.46	0.16	0.29
<b>Total operating cost per km</b>	<b>0.52</b>	<b>0.77</b>	<b>0.55</b>	<b>0.75</b>	<b>0.32</b>	<b>0.49</b>

# Maintenance Cost Summary: 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	2,017,605	233,800	150,338	32,293	3,109,259	365,281
Total parts cost	235,356.89	55,281.61	15,243.47	3,581.50	266,796.55	57,491.65
Total labor hours	5,047.1	1,165.7	509.8	225.7	4,756.2	933.4
Average labor cost (@ \$50.00 per hour)	252,356.00	58,285.00	25,490.00	11,286.50	237,809.50	46,672.00
Total maintenance cost	487,712.89	113,566.61	40,733.47	14,868.00	504,606.05	104,163.65
Total maintenance cost per bus	40,642.74	9,463.88	20,366.74	7,434.00	63,075.76	13,020.46
<b>Total maintenance cost per km</b>	<b>0.24</b>	<b>0.49</b>	<b>0.27</b>	<b>0.46</b>	<b>0.16</b>	<b>0.29</b>
<i>without low-voltage battery cost</i>	<i>0.21</i>	<i>0.43</i>	<i>0.21</i>	<i>0.39</i>	<i>0.16</i>	<i>0.27</i>

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