

# Foothill Transit Agency Battery Electric Bus Progress Report

Data Period Focus: Jan. 2017 through Dec. 2017

Leslie Eudy and Matthew Jeffers  
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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 December 2016.<sup>1,2</sup> This report extends the data analysis through December 2017. NREL plans to publish progress reports on the Foothill Transit fleet every six months through 2020.

<sup>1</sup> Foothill Transit Battery Electric Bus Demonstration Results, NREL/TP-5400-65274, <https://www.nrel.gov/docs/fy17osti/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>.

# 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 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 impact on the comparison of mileage, fuel economy, and costs per mile between fleets.

**Fuel economy:** BEB efficiency in 2017 was 2.18 kWh/mi (17.24 mpdge) for the BEB 35FC fleet, 2.22 kWh/mi (16.99 mpdge) for the BEB 40FC fleet, and 3.71 mpgge (4.15 mpdge) for the CNG bus fleet. 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 2.1 mpdge (see previous report for details). The BEB fuel efficiency is 8 times higher than that of the CNG buses in the same service.

# Results Summary (continued)

**Fuel cost:** Based on energy purchased in 2017, the BEB fleet cost \$0.49/mi (at \$0.19/kWh) and the CNG fleet cost \$0.26/mi (at \$0.96/gge). 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. The lower fuel economy would increase the cost of the CNG buses to an overall average of \$0.51/mi, which is slightly higher than the cost of the BEB fleet.

**Availability:** 2017 availability was 80.6% for the BEB 35FC buses, 81.3% for the BEB 40FC buses, and 96.8% for the CNG buses. The majority of unavailable time for the BEBs was due to general bus related problems. Issues with parts availability resulted in extended downtime for several BEBs. Issues with the low-voltage batteries also had an impact on BEB availability.

# Results Summary (continued)

**Maintenance cost:** Cost to maintain the buses in 2017 was \$0.41/mi for the BEB 35FC buses, \$0.32/mi for the BEB 40FC buses, and \$0.27/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:

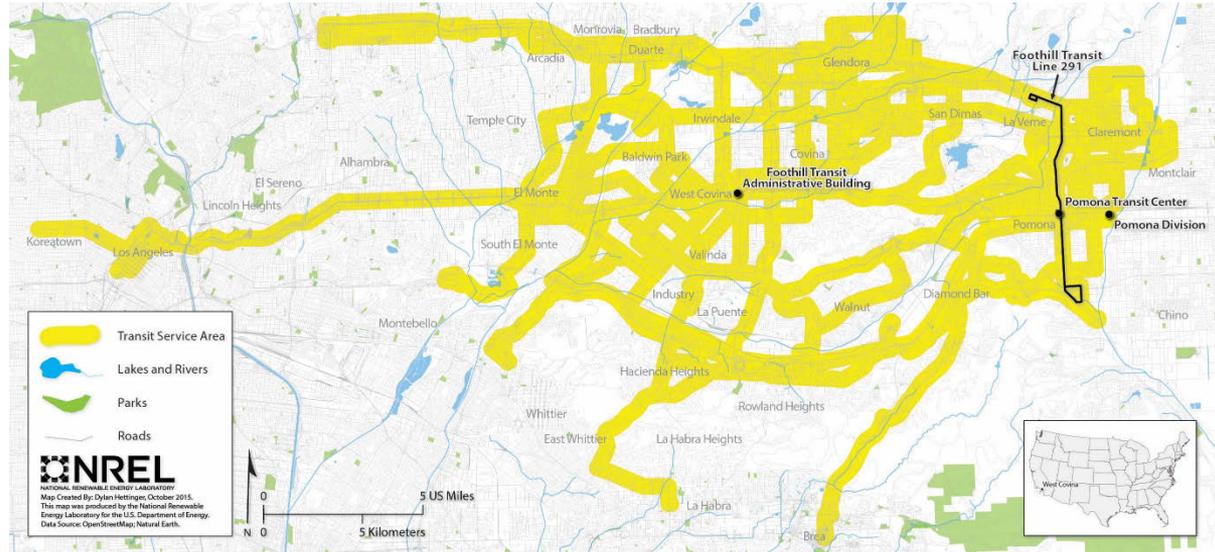
- The BEB 35FC buses are now past the warranty period for some components resulting in higher parts cost.
- In July 2017, Foothill Transit changed contractors for its Pomona Operations and Maintenance Facility. Some cost differences could be attributed to differing maintenance practices between contractors.
- Proterra is working closely with the contractor to transfer all maintenance to onsite contractor staff. This results in increased labor hours for training and troubleshooting as the staff become more familiar with systems and components. This is expected to drop as the learning curve improves for the maintenance staff.

# Results Summary (continued)

- During the second half of 2017, Foothill Transit's maintenance contractor experienced issues with the low-voltage battery on the BEBs. The maintenance contractor switched to a different manufacturer for the low-voltage batteries. The new batteries would not hold a charge very long and resulted in the need to change the batteries multiple times on all the buses. The contractor has since switched to a better performing battery to solve the issue. Because this issue is not related to the BEB system and is not expected to reoccur, NREL has provided the maintenance costs with and without the low-voltage battery replacement costs.
- Total maintenance cost without low-voltage battery costs was \$0.35/mi for the BEB 35FC buses and \$0.21/mi for the BEB 40FC buses.
- **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. Future analyses will also investigate the difference in cost for brake relines between bus types.

# 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

# Infrastructure Description

Foothill worked with the City of Pomona to establish an on-route fast charging station at the Pomona Transit Center (PTC). The station features two Eaton 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 Foothill's Line 291, typical charge times are around 7 minutes including docking time. Foothill built a layover time into the schedule to allow enough time for charging. Software controls prevent charging from surpassing the kWh limit that results in high demand charges.



# Data Summary: Total from Start of Service

Data Item	BEB 35FC	BEB 40FC	CNG
Number of buses	12	2	8
Data period	4/14–12/17	1/17–12/17	10/14–12/17
Number of months	45	12	39
Total mileage in data period	1,172,117	47,587	1,469,879
Average odometer	98,818	28,292	188,544
Average monthly mileage per bus	2,254	1,244	4,711
Total operating hours	137,582	3,510	—
Availability (85% is target)	89	81	97
Fuel economy (kWh/mile or mpgge <sup>a</sup> )	2.18	2.22	3.86
Fuel economy (mpdge <sup>b</sup> )	17.28	16.99	4.32
Average speed (mph)	10.6	10.6	17.6
Miles between roadcalls (MBRC) – bus <sup>c</sup>	5,774	6,798	30,622
MBRC – propulsion system only <sup>c</sup>	16,509	23,793	56,534
MBRC – ESS <sup>d</sup> only <sup>c</sup>	195,353	—	—
Total maintenance cost (\$/mile) <sup>e</sup>	0.26	0.32	0.23
Total maintenance cost (\$/mile without low-voltage battery costs) <sup>f</sup>	0.24	0.21	—
Maintenance cost – propulsion system only (\$/mile)	0.05	0.11	0.08
Propulsion system maintenance cost (\$/mile without low-voltage battery costs) <sup>f</sup>	0.03	0.01	—

<sup>a</sup> Gasoline gallon equivalent

<sup>b</sup> Diesel gallon equivalent

<sup>c</sup> MBRC data cumulative from the clean point of April 2014 through December 2017

<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 45

# Data Summary: 2017

Data Item	BEB 35FC	BEB 40FC	CNG
Number of buses	12	2	8
Data period	1/17–12/17	1/17–12/17	1/17–12/17
Number of months	12	12	12
Total mileage in data period	281,214	47,587	449,107
Average odometer	98,818	28,292	188,544
Average monthly mileage per bus	1,953	1,244	4,678
Total operating hours	32,960	3,510	—
Availability (85% is target)	81	81	97
Fuel economy (kWh/mile or mpgge <sup>a</sup> )	2.18	2.22	3.71
Fuel economy (mpdge <sup>b</sup> )	17.24	16.99	4.15
Average speed (mph)	10.6	10.6	17.6
Miles between roadcalls (MBRC) – bus <sup>c</sup>	4,934	6,798	34,547
MBRC – propulsion system only <sup>c</sup>	17,576	23,793	56,138
MBRC – ESS <sup>d</sup> only <sup>c</sup>	93,738	—	—
Total maintenance cost (\$/mile) <sup>e</sup>	0.41	0.32	0.27
<i>Total maintenance cost (\$/mile without low-voltage battery costs)<sup>f</sup></i>	<i>0.35</i>	<i>0.21</i>	<i>—</i>
Maintenance cost – propulsion system only (\$/mile)	0.12	0.11	0.09
<i>Propulsion system maintenance cost (\$/mile without low-voltage battery costs)<sup>f</sup></i>	<i>0.05</i>	<i>0.01</i>	<i>—</i>

<sup>a</sup> Gasoline gallon equivalent

<sup>b</sup> Diesel gallon equivalent

<sup>c</sup> MBRC data cumulative from the clean point of April 2014 through December 2017

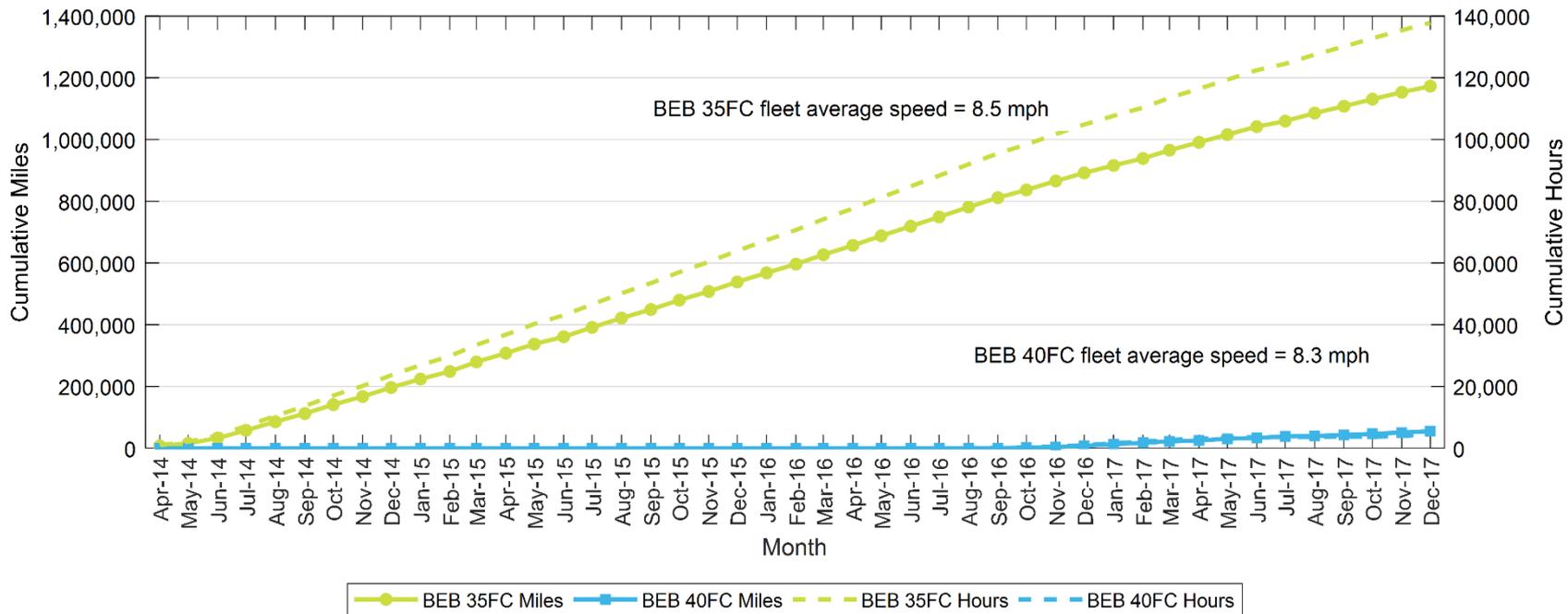
<sup>d</sup> Energy storage system

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

<sup>f</sup> See issue with the low-voltage batteries explained on slide 45



# BEB Fleet Total Miles



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

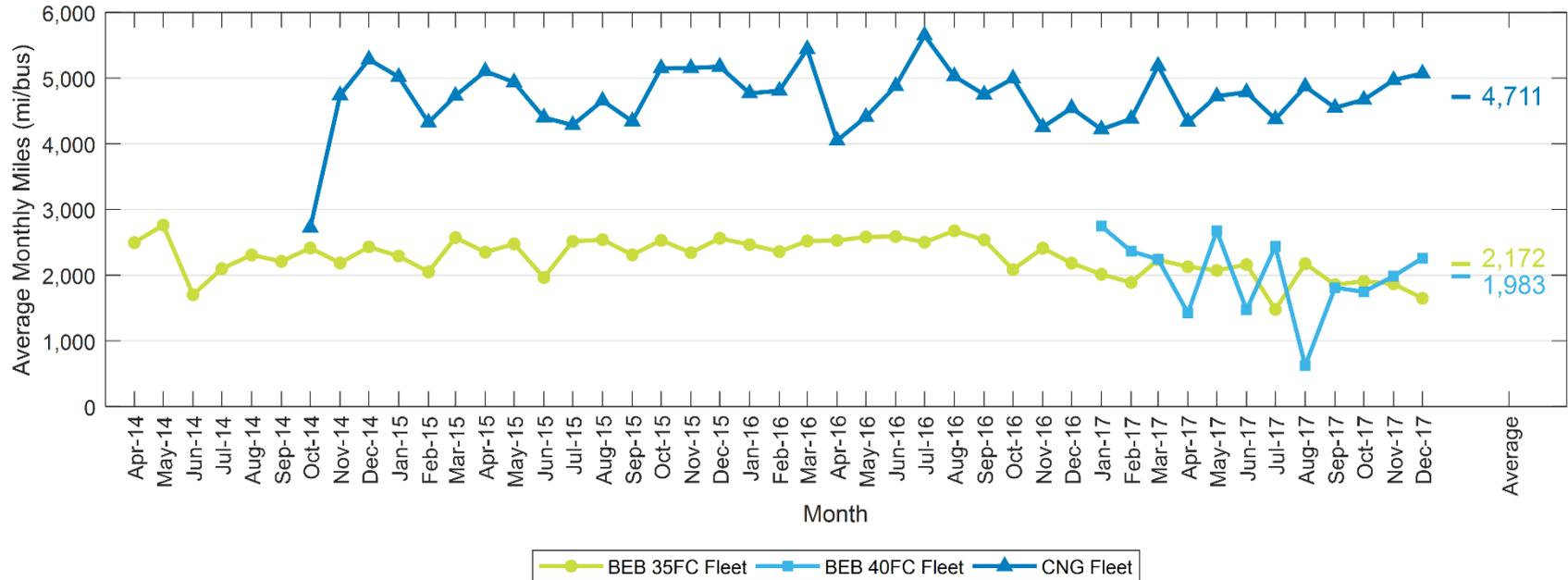
# Fleet Average Monthly Miles by Bus – 2017

Bus ID	Miles	Months	Average Monthly Mileage
2004	12,092	12	1,008
2005	20,694	12	1,724
2006	26,990	12	2,249
2007	24,780	12	2,065
2008	23,185	12	1,932
2009	29,336	12	2,445
2010	23,417	12	1,951
2011	28,523	12	2,377
2012	27,448	12	2,287
2013	15,360	12	1,280
2014	23,673	12	1,973
2015	25,719	12	2,143
<b>BEB 35FC Total</b>	<b>281,214</b>	<b>144</b>	<b>1,953</b>
2016	23,916	12	1,993
2017	23,671	12	1,973
<b>BEB 40FC Total</b>	<b>47,587</b>	<b>24</b>	<b>1,983</b>

Bus ID	Miles	Months	Average Monthly Mileage
2200	57,745	12	4,812
2201	54,722	12	4,560
2202	56,009	12	4,667
2203	52,576	12	4,381
2204	56,226	12	4,686
2205	56,940	12	4,745
2206	59,121	12	4,927
2207	55,768	12	4,647
<b>CNG Total</b>	<b>449,107</b>	<b>96</b>	<b>4,678</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



- Average monthly mileage shown for entire data period

# 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.

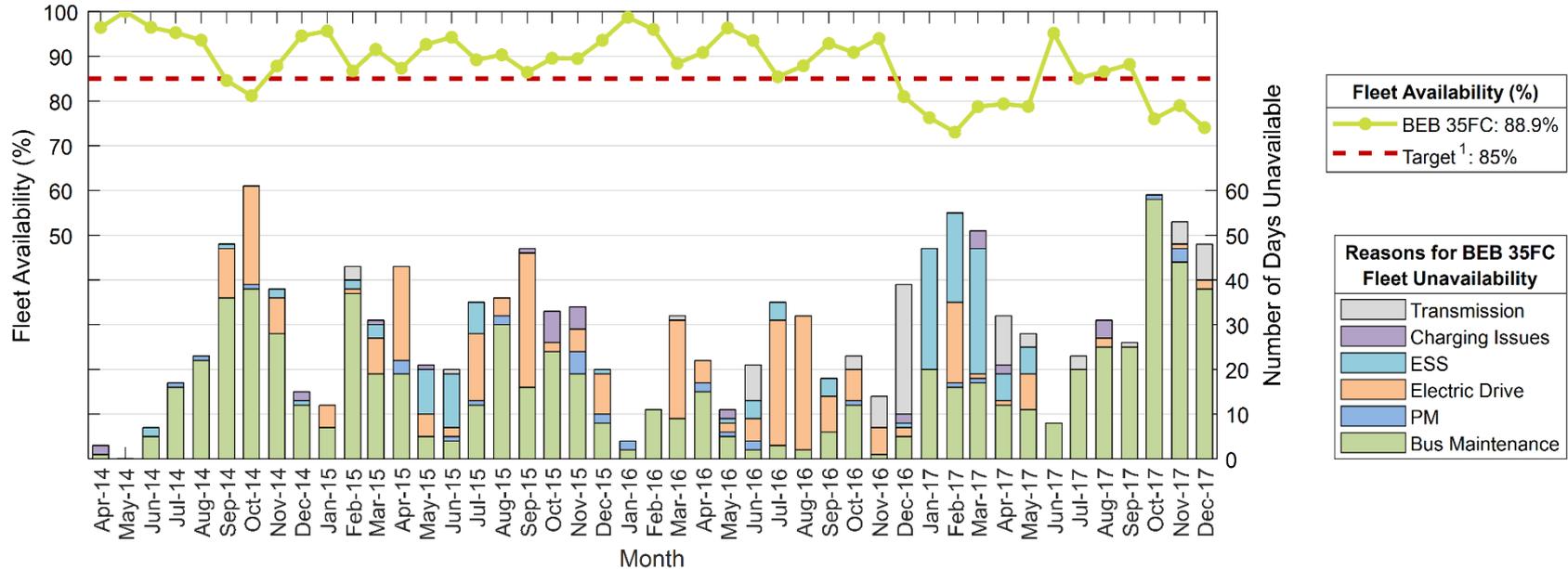
NREL presents availability as a monthly average trend and as overall availability. Unavailable time is separated into several categories to show the primary reason for downtime.

# Availability Summary – 2017

Category	BEB 35FC # Days	BEB 35FC %	BEB 40FC # Days	BEB 40FC %	CNG # Days	CNG %
Planned work days	2,382		411		1,681	
Days available	1,921	80.6	334	81.3	1,627	96.8
Unavailable	461	19.4	77	18.7	54	3.2
Energy storage system (ESS)	87	3.7	0	0.0	—	—
CNG engine	—	—	—	—	30	1.8
Electric drive	33	1.4	0	0.0	—	—
Charging issues	10	0.4	1	0.2	—	—
Preventive maintenance (PM)	6	0.3	1	0.2	5	0.3
General bus maintenance	294	12.3	74	18.0	19	1.1
Transmission	31	1.3	1	0.2	0	0.0

- The per-bus availability for the BEBs ranged from a low of 65% 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
- Parts availability resulted in extended downtime for several BEBs
- The majority of unavailable time for the CNG buses was attributed to engine issues

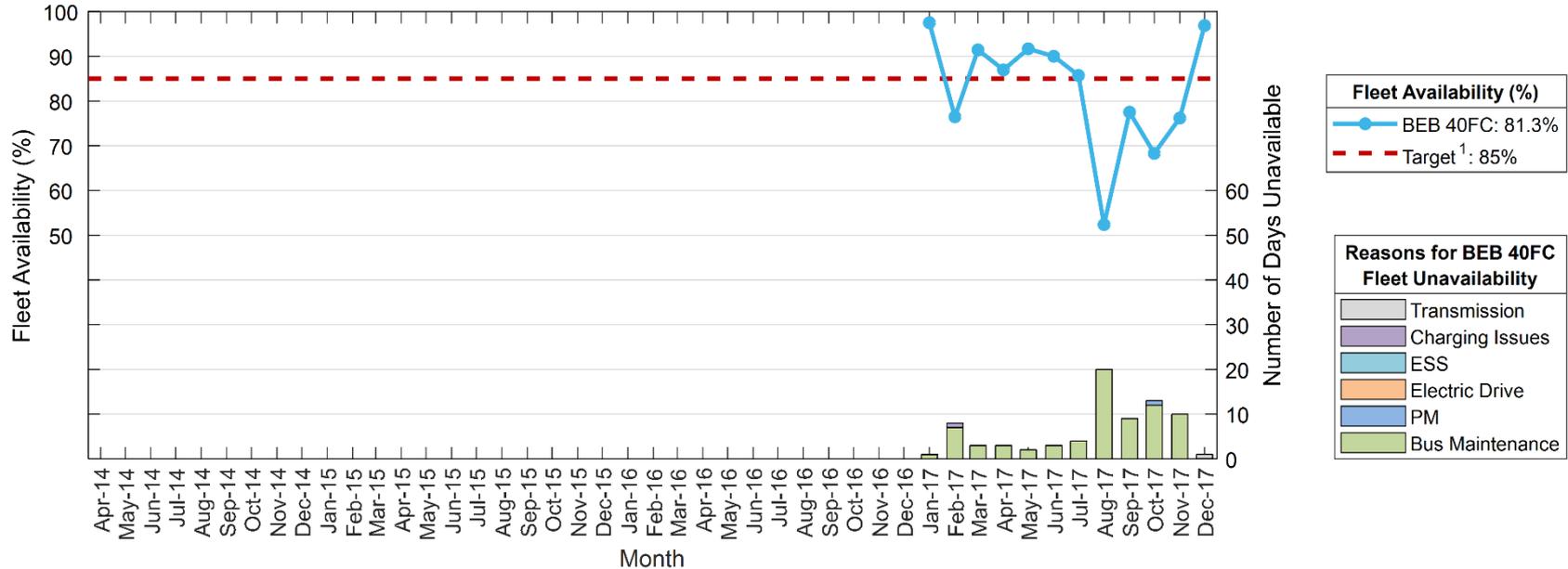
# Monthly Availability – BEB 35FC



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 each month separated by six categories
- Low-voltage batteries fall into the Bus Maintenance category

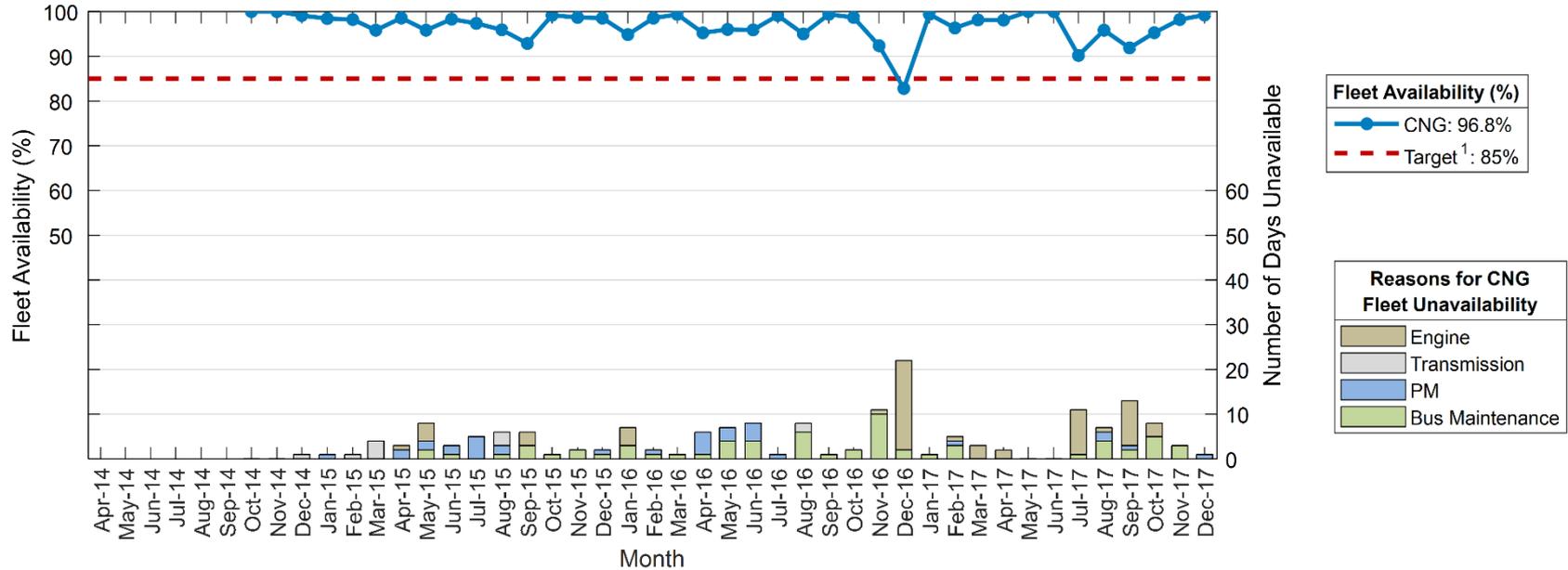
# Monthly Availability – BEB 40FC



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 each month separated by six categories
- Issues with the low-voltage battery during August lowered the availability

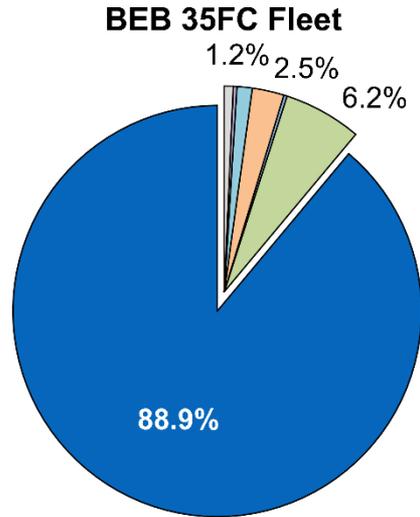
# Monthly Availability – CNG



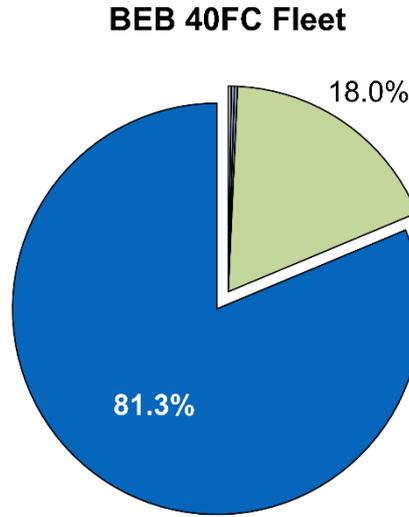
1. Target of 85% fleet availability is a general expectation for transit agencies

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

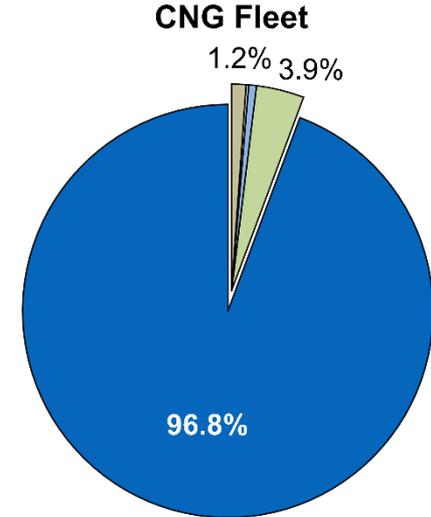
# Overall Fleet Availability – Full Data Period



Date Range: Apr 2014 - Dec 2017  
Days Planned: 11,781



Date Range: Jan 2017 - Dec 2017  
Days Planned: 411

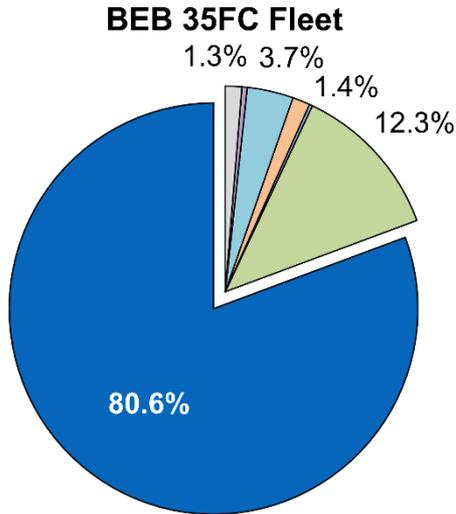


Date Range: Oct 2014 - Dec 2017  
Days Planned: 5,409

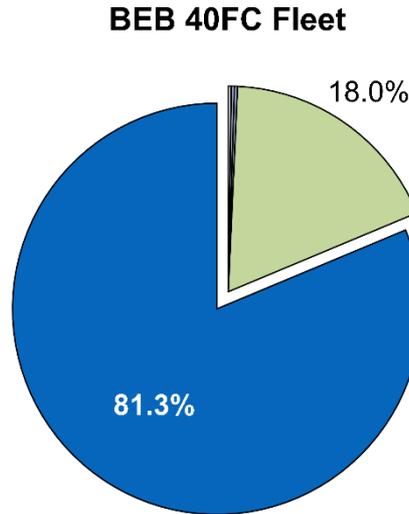


Data labels omitted for pie slices representing < 1.0%

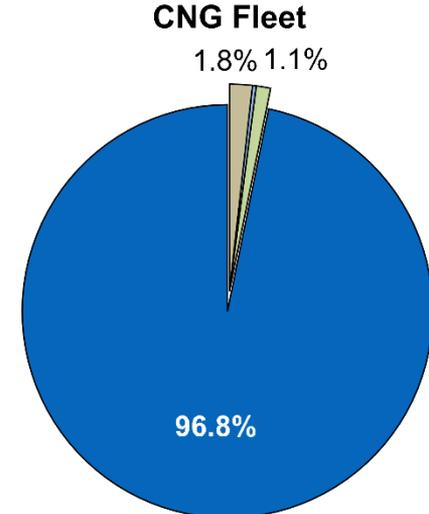
# Overall Fleet Availability – 2017



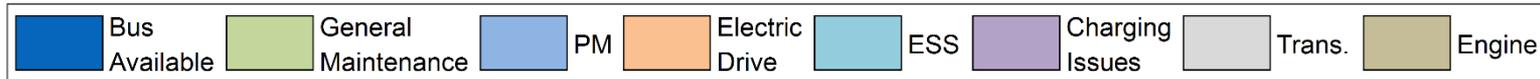
Date Range: Jan 2017 - Dec 2017  
Days Planned: 2,382



Date Range: Jan 2017 - Dec 2017  
Days Planned: 411



Date Range: Jan 2017 - Dec 2017  
Days Planned: 1,681



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

- 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: 1.15 gge/dge

# Fuel Economy by Bus – 2017

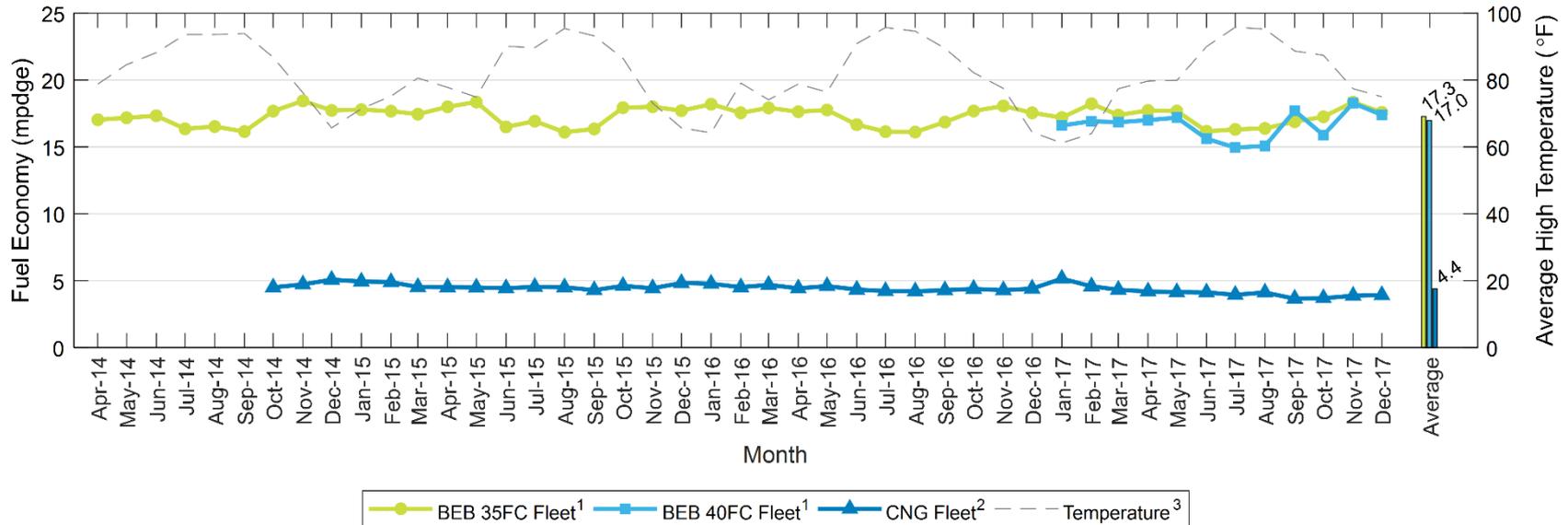
Bus ID	Miles	Energy <sup>a</sup> (kWh)	kWh/mi	Diesel gallon equiv.	Fuel economy (mpdge)
2004	12,092	25,600.7	2.12	679.8	17.79
2005	20,694	47,015.0	2.27	1,248.5	16.57
2006	26,990	61,472.1	2.28	1,632.4	16.53
2007	24,780	53,835.8	2.17	1,429.6	17.33
2008	23,185	52,606.1	2.27	1,397.0	16.60
2009	29,336	62,148.9	2.12	1,650.4	17.78
2010	23,417	52,585.8	2.25	1,396.4	16.77
2011	28,523	61,660.9	2.16	1,637.4	17.42
2012	27,448	56,549.6	2.06	1,501.7	18.28
2013	15,360	30,878.5	2.01	820.0	18.73
2014	23,673	50,778.4	2.14	1,348.4	17.56
2015	25,719	59,045.7	2.30	1,568.0	16.40
<b>BEB 35FC Total</b>	<b>281,214</b>	<b>614,177.5</b>	<b>2.18</b>	<b>16,309.6</b>	<b>17.24</b>
2016	15,876	34,774.7	2.19	923.4	17.19
2017	13,988	31,431.6	2.25	834.7	16.76
<b>BEB 40FC Total</b>	<b>29,864</b>	<b>66,206.3</b>	<b>2.22</b>	<b>1,758.1</b>	<b>16.99</b>

Bus ID	Miles	CNG (gge)	mi/gge	Diesel gallon equiv.	Fuel economy (mpdge)
2200	51,791	12,826.0	4.04	11,479.2	4.51
2201	50,127	14,177.8	3.54	12,689.1	3.95
2202	49,113	13,177.8	3.73	11,794.1	4.16
2203	48,093	13,560.0	3.55	12,136.2	3.96
2204	51,464	13,904.8	3.70	12,444.8	4.14
2205	51,523	13,704.3	3.76	12,265.3	4.20
2206	52,707	13,971.4	3.77	12,504.4	4.22
2207	50,449	13,829.7	3.65	12,377.6	4.08
<b>CNG Total</b>	<b>405,267</b>	<b>109,151.8</b>	<b>3.71</b>	<b>97,690.7</b>	<b>4.15</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 2.1 mpdge on Line 291, which is 8 times lower than that of the BEBs.

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

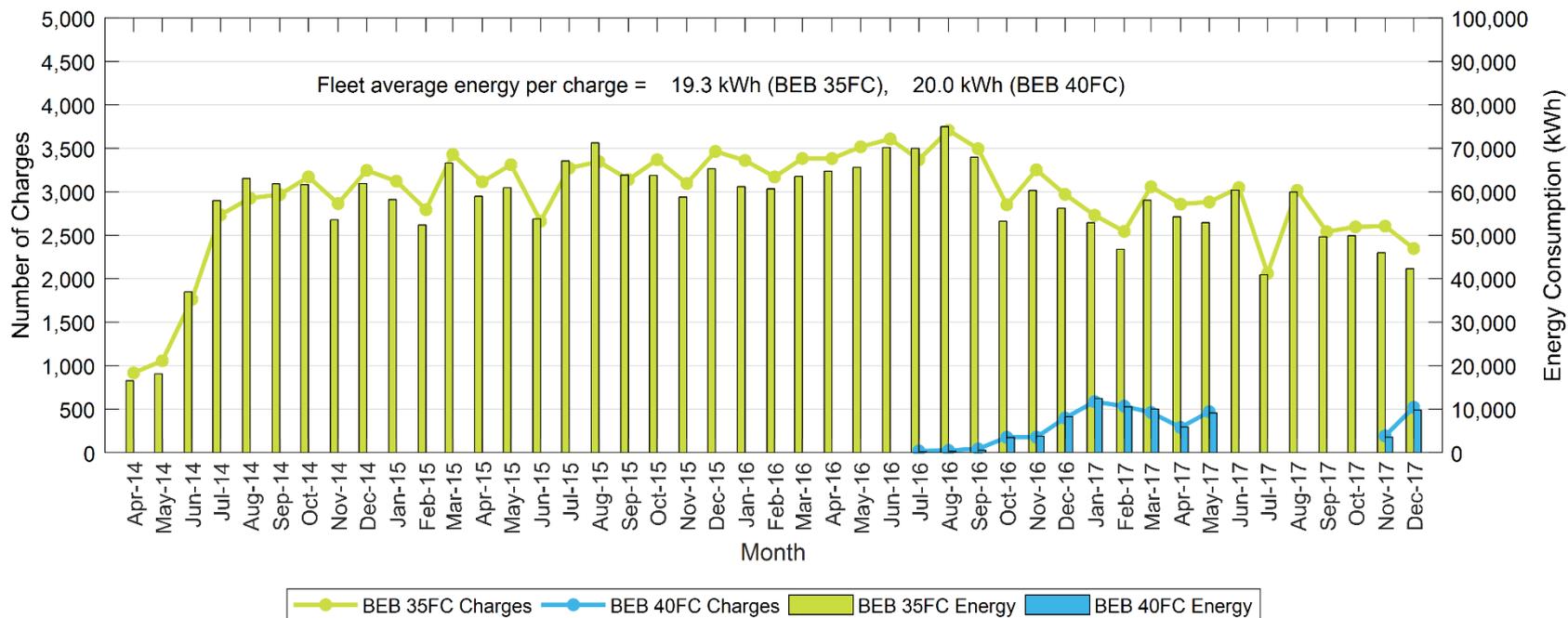
# Fleet Average Monthly Fuel Economy



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 = 1.15 gge/dge
3. Average daily high temperatures at Ontario International Airport, CA; data acquired from: <https://www.ncdc.noaa.gov/>

Bus	Overall		2017	
	kWh/mi, mpgge	mpdge	kWh/mi, mpgge	mpdge
BEB 35FC	2.18	17.28	2.18	17.24
BEB 40FC	2.22	16.99	2.22	16.99
CNG	3.86	4.32	3.71	4.15

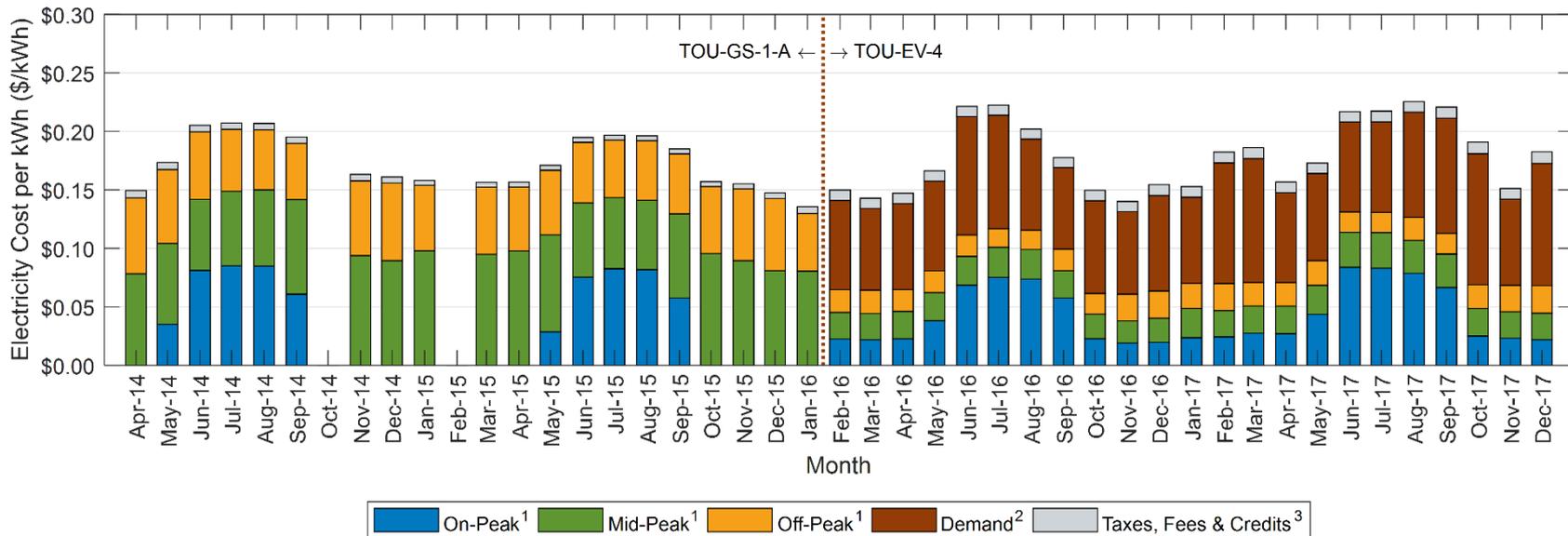
# Total Monthly Charges and Energy Consumption



	BEB 35FC Overall	BEB 35FC 2017	BEB 40FC 2017
Total kWh	2,553,624	614,178	66,206
Average monthly kWh used per bus	4,729	4,265	2,759
Average # charging events per month per bus	244	224	137

A technical issue with the data loggers on the BEB 40FC buses resulted in missing data from June 2017 through October 2017

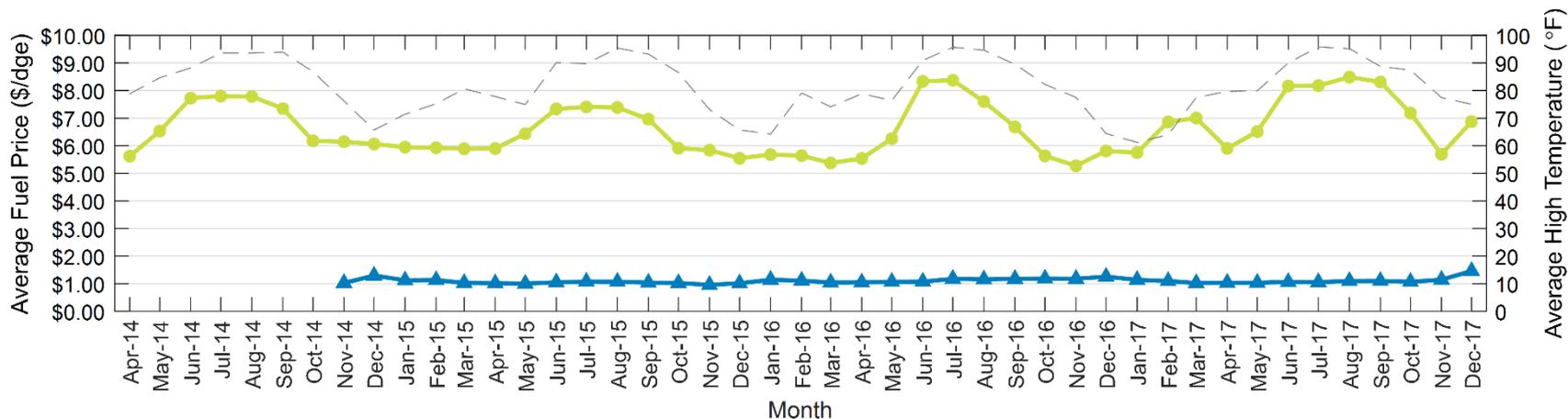
# Monthly Electric Utility Costs



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 2017: \$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	\$6.67/dge	\$1.08/dge	
2017 average fuel price	\$7.09/dge	\$1.11/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 = 1.15 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 year
- CNG cost includes price of fuel, transmission, and operations and maintenance cost for station
- On average, electricity cost is more than six 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 mpdgc.

During 2017, Foothill Transit paid an average of \$0.96/ggc for CNG. The average cost of electricity during 2017 was \$0.19/kWh. 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 \$0.51/mi, which is slightly higher than that of the BEBs.

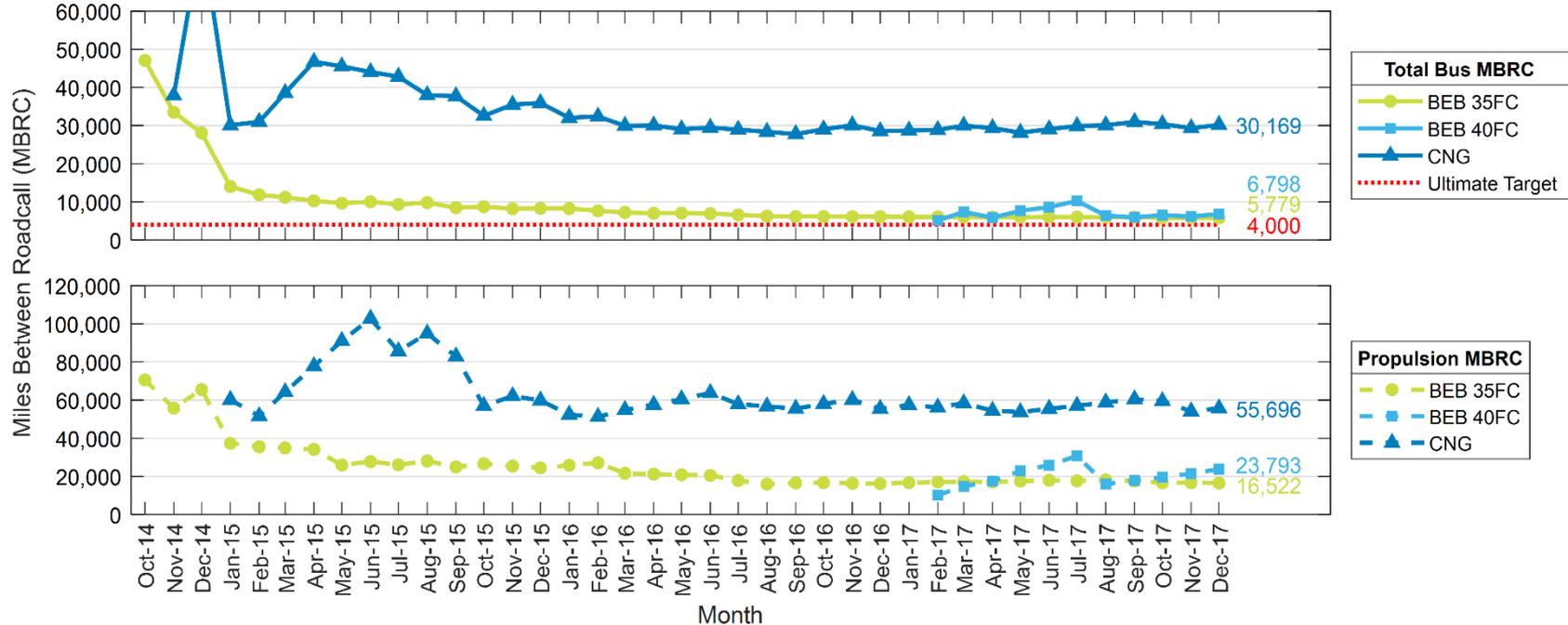
	Average Service Speed (mph)	Fuel Economy (mpdgc)	Overall \$/mi	2017 \$/mi
BEB 35FC	10.6	17.24	0.44	0.49
BEB 40FC	10.6	16.99	0.49	0.49
CNG	17.6	4.15	0.25	0.26
CNG on Line 291	10.6	2.09	0.51	0.51

# Roadcall Analysis

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

The transit industry measures reliability as mean distance between failures, also documented as miles between roadcalls (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



- The upper chart shows cumulative MBRC for all chargeable roadcalls
- The lower chart shows MBRC for propulsion-related roadcalls

# 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 advanced propulsion system changes for the buses.

# Maintenance Analysis Results – 2017

Bus ID	Mileage	Parts (\$)	Labor hours	Total Cost per Mile (\$)	Scheduled Cost (\$/mi)	Unscheduled Cost (\$/mi)
2004	12,092	\$2,817.06	88.8	\$0.60	\$0.11	\$0.49
2005	20,694	\$9,554.28	140.9	\$0.80	\$0.10	\$0.70
2006	26,990	\$3,996.29	117.6	\$0.37	\$0.08	\$0.28
2007	24,780	\$4,284.01	140.2	\$0.46	\$0.08	\$0.38
2008	23,185	\$5,189.01	153.5	\$0.55	\$0.08	\$0.48
2009	29,336	\$3,082.48	105.6	\$0.29	\$0.07	\$0.22
2010	23,417	\$3,981.48	124.1	\$0.44	\$0.10	\$0.33
2011	28,523	\$2,066.86	101.4	\$0.25	\$0.08	\$0.17
2012	27,448	\$2,246.25	74.8	\$0.22	\$0.06	\$0.16
2013	15,360	\$609.61	96.0	\$0.35	\$0.10	\$0.25
2014	23,673	\$1,665.87	89.7	\$0.26	\$0.07	\$0.19
2015	25,719	\$8,625.39	115.2	\$0.56	\$0.08	\$0.48
<b>BEB 35FC</b>	<b>281,214</b>	<b>\$48,118.59</b>	<b>1,347.7</b>	<b>\$0.41</b>	<b>\$0.08</b>	<b>\$0.33</b>
2016	23,916	\$4,974.59	85.63	\$0.39	\$0.07	\$0.32
2017	23,671	\$1,716.46	87.19	\$0.26	\$0.07	\$0.18
<b>BEB 40FC</b>	<b>47,587</b>	<b>\$6,691.05</b>	<b>172.82</b>	<b>\$0.32</b>	<b>\$0.07</b>	<b>\$0.25</b>

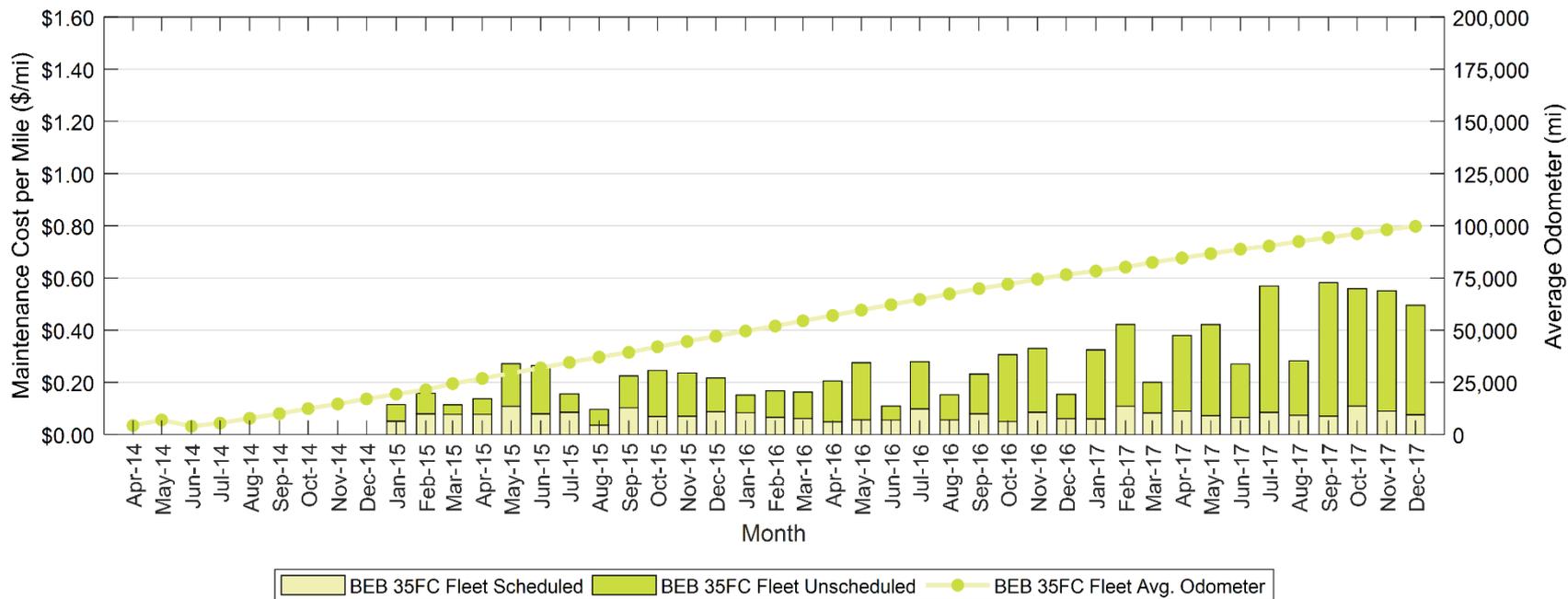
OEM: original equipment manufacturer

Bus ID	Mileage	Parts (\$)	Labor hours	Total Cost per Mile (\$)	Scheduled Cost (\$/mi)	Unscheduled Cost (\$/mi)
2200	57,745	\$5,811.80	170.0	\$0.25	\$0.11	\$0.14
2201	54,722	\$9,674.69	164.9	\$0.33	\$0.15	\$0.18
2202	56,009	\$7,495.22	122.8	\$0.24	\$0.14	\$0.10
2203	52,576	\$7,108.25	146.8	\$0.27	\$0.13	\$0.15
2204	56,226	\$9,403.26	151.6	\$0.30	\$0.13	\$0.17
2205	56,940	\$5,919.07	170.7	\$0.25	\$0.12	\$0.14
2206	59,121	\$7,850.49	162.4	\$0.27	\$0.13	\$0.14
2207	55,768	\$7,444.56	146.7	\$0.26	\$0.11	\$0.16
<b>CNG</b>	<b>449,107</b>	<b>\$60,707.34</b>	<b>1,235.7</b>	<b>\$0.27</b>	<b>\$0.13</b>	<b>\$0.15</b>

Reasons for cost increase over previous report (\$0.21/mi):

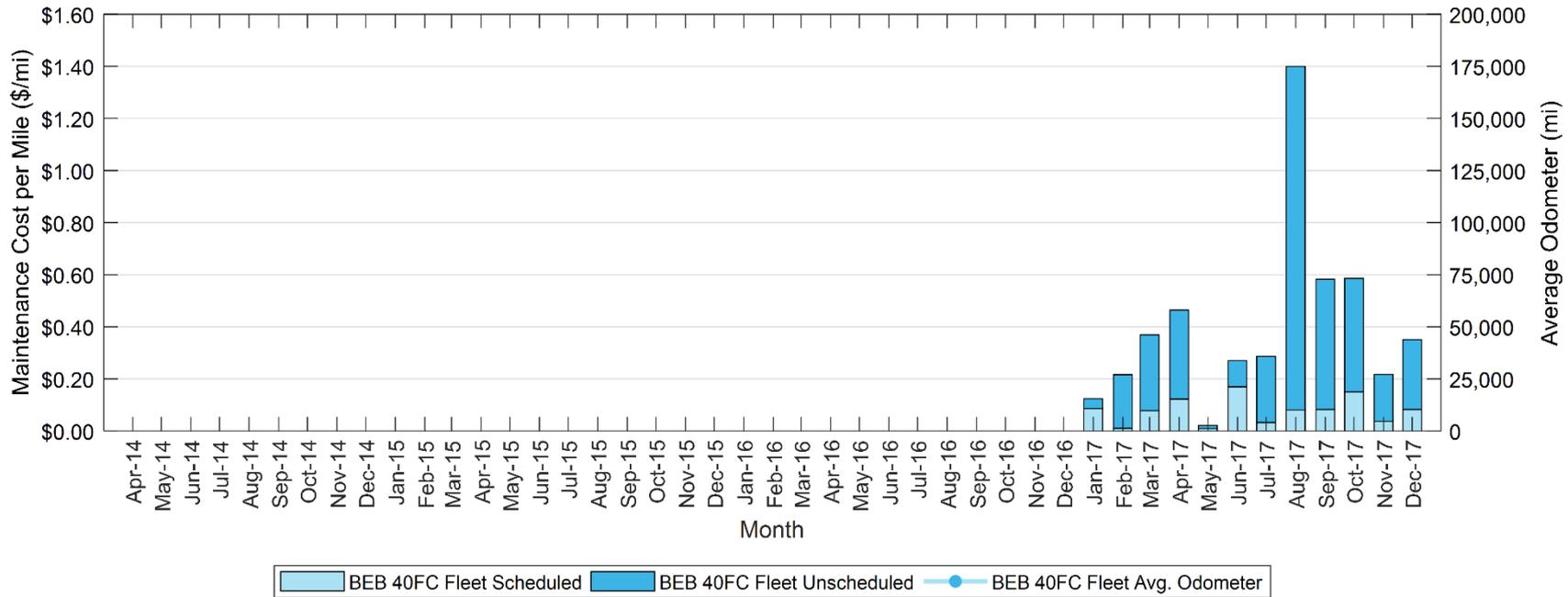
- Issues with the low-voltage batteries
- Maintenance being transferred from OEM to contractor, which results in more labor hours
- Change of contractor in July 2017
- BEB 35FC buses nearing end of warranty for some systems

# Monthly Scheduled and Unscheduled Maintenance Cost – BEB 35FC



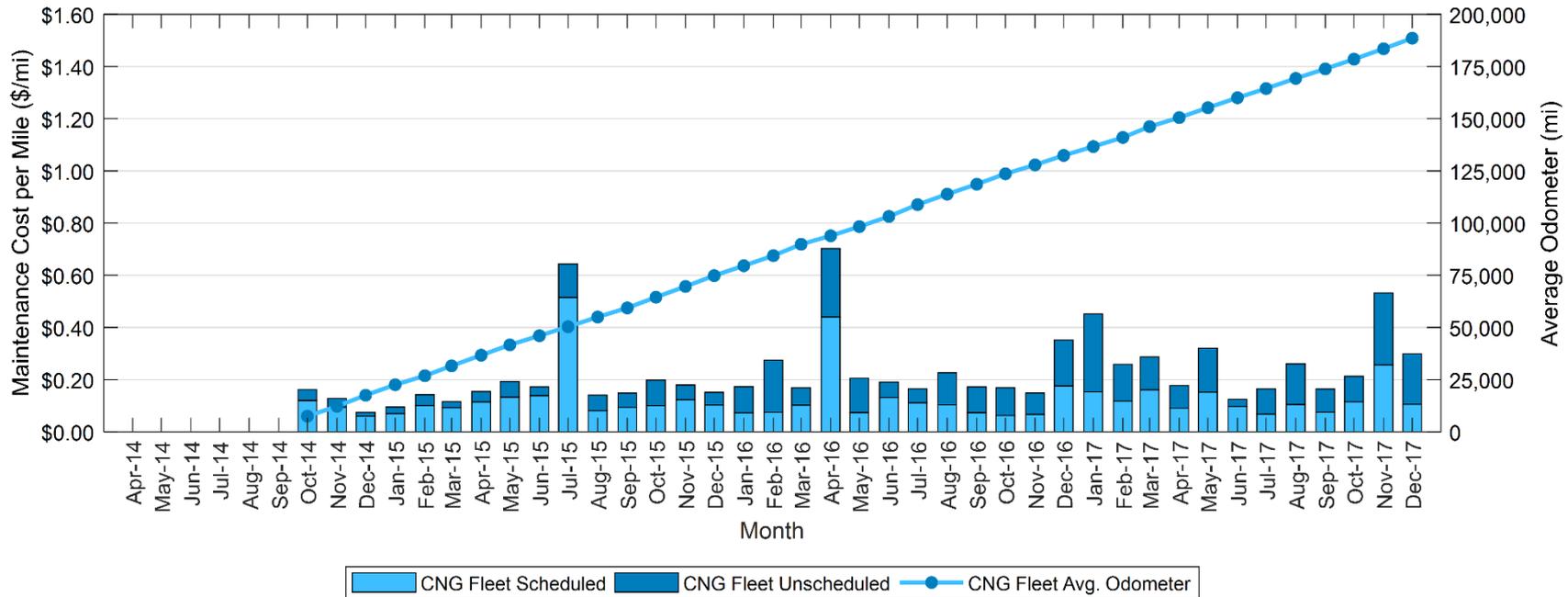
- The buses are nearing the end of the warranty period and transit staff are taking on more maintenance work
- Issues with the low-voltage batteries resulted in higher costs in 2017

# Monthly Scheduled and Unscheduled Maintenance Cost – BEB 40FC



- 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
- Odometer readings are not available at this time

# Monthly Scheduled and Unscheduled Maintenance Cost – CNG



- Higher scheduled costs during July 2015 and April 2016 are caused by multiple buses reaching the mileage target for a major preventive maintenance (PM)

# Maintenance Cost per Mile by System – 2017

System	BEB 35FC		BEB 40FC		CNG	
	Cost per Mile (\$)	Percent of Total (%)	Cost per Mile (\$)	Percent of Total (%)	Cost per Mile (\$)	Percent of Total (%)
Propulsion-related	0.115	28	0.114	35	0.093	34
Cab, body, and accessories	0.080	20	0.086	27	0.048	17
PMI	0.081	20	0.071	22	0.065	24
Brakes	0.014	3	0.000	0	0.015	5
Frame, steering, and suspension	0.007	2	0.000	0	0.016	6
HVAC	0.005	1	0.000	0	0.002	1
Lighting	0.018	4	0.001	0	0.002	1
Air, general	0.007	2	0.016	5	0.010	4
Axles, wheels, and drive shaft	0.026	6	0.000	0	0.004	1
Tires	0.047	11	0.028	9	0.017	6
Towing charges	0.011	3	0.006	2	0.001	1
<b>Total</b>	<b>0.41</b>	<b>100</b>	<b>0.32</b>	<b>100</b>	<b>0.27</b>	<b>100</b>
<b>Total w/o low-voltage battery costs</b>	<b>0.35</b>		<b>0.21</b>		–	

Color coding:

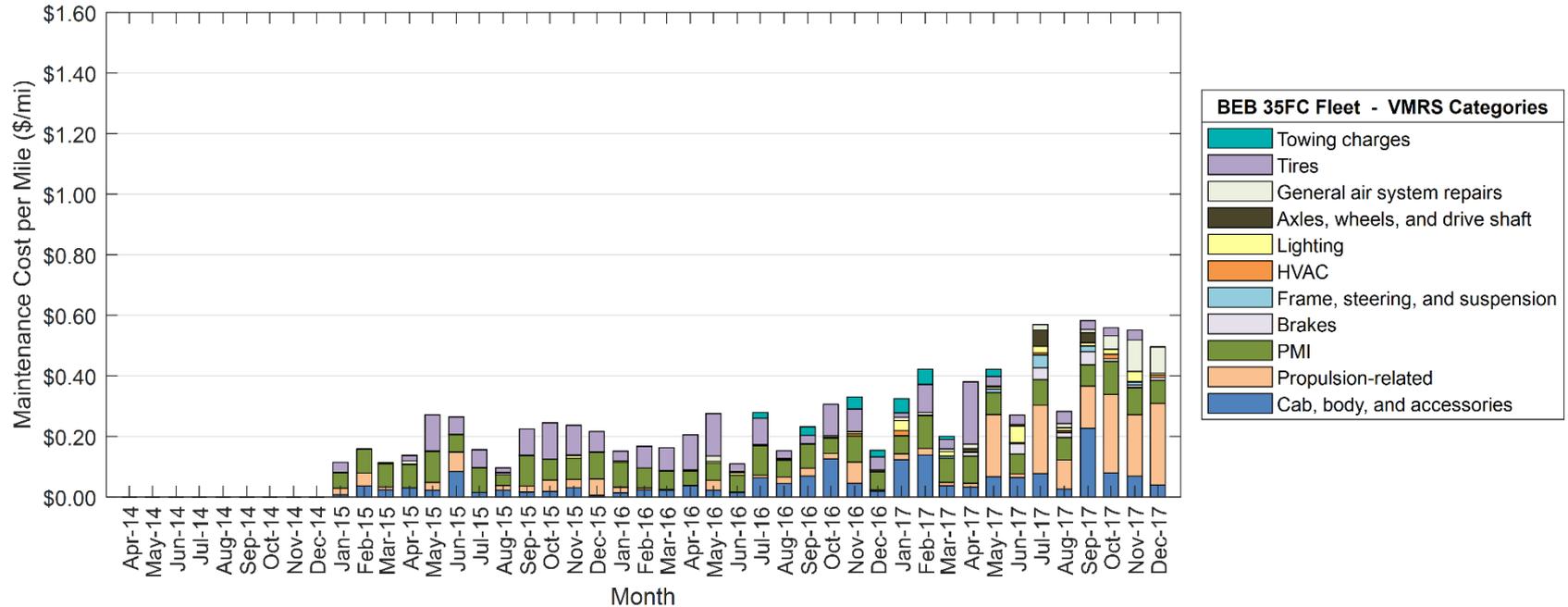
 Highest cost

 Second highest cost

 Third highest cost

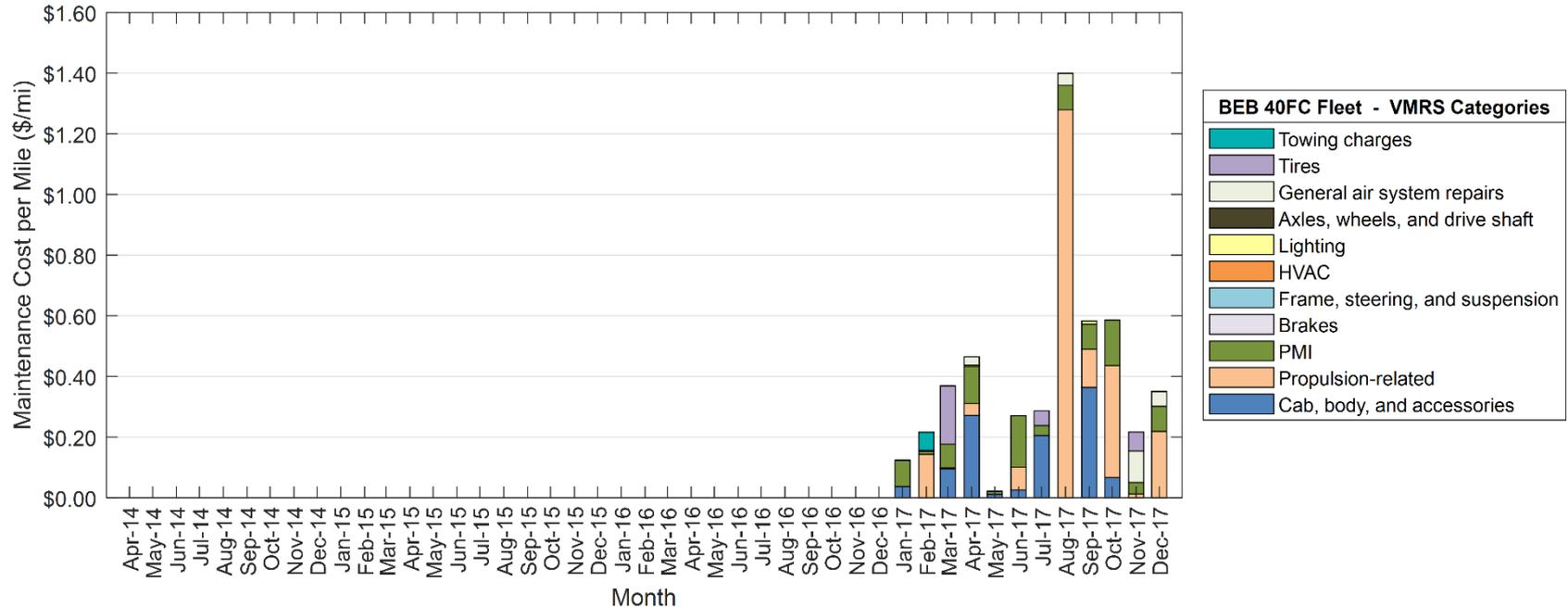
- Propulsion-related repairs for the BEBs: low-voltage batteries, battery equalizer, cooling system, inverter
- Overall cost per mile without low-voltage battery costs for the BEB 35FC buses was 28% higher than the CNG bus cost; cost for the BEB 40FC buses was 21% less than the CNG bus cost

# Maintenance Cost by System – BEB 35FC Fleet



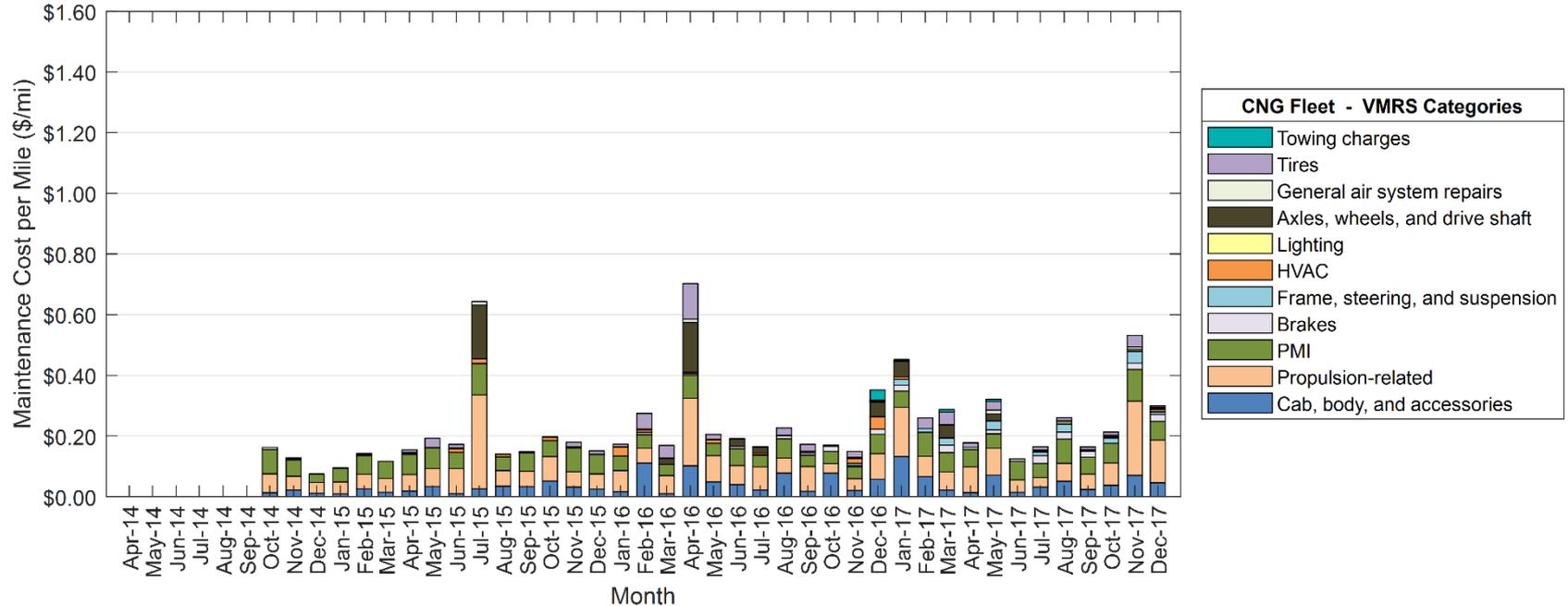
- The BEB 35FC fleet experienced an increase in propulsion-related maintenance costs in 2017
- The primary driver for the higher cost was issues with the low-voltage batteries

# Maintenance Cost by System – BEB 40FC Fleet



- The high propulsion cost during August was primarily due to the low-voltage battery issue, including four battery changeouts for one bus
- Because the fleet consists of only two buses, the cost per mile is more sensitive to cost increases

# 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-Related Maintenance Costs by Subsystem – 2017

Maintenance System		BEB 35FC	BEB 40FC	CNG
Mileage		281,214	47,587	449,107
Total Propulsion-Related Systems (Roll-Up of All Systems)	Parts cost (\$)	21,435.22	4,181.81	30,261.89
	Labor hours	220.1	24.4	227.3
	Total cost (\$)	32,438.72	5,403.81	41,625.39
	Total cost (\$) per mile	<b>0.115</b>	<b>0.019</b>	<b>0.093</b>
	Without battery changeouts	<b>0.053</b>	<b>0.006</b>	
Exhaust System Repairs	Parts cost (\$)	0.00	0.00	2,293.47
	Labor hours	0.0	0.0	16.9
	Total cost (\$)	0.00	0.00	3,135.97
	Total cost (\$) per mile	<b>0.000</b>	<b>0.000</b>	<b>0.007</b>
Fuel System Repairs	Parts cost (\$)	0.00	0.00	1,364.40
	Labor hours	0.0	0.0	11.4
	Total cost (\$)	0.00	0.00	1,934.40
	Total cost (\$) per mile	<b>0.000</b>	<b>0.000</b>	<b>0.004</b>
Powerplant System Repairs (Energy Storage System for BEBs)	Parts cost (\$)	1,428.22	0.00	10,324.02
	Labor hours	13.4	0.0	19.6
	Total cost (\$)	2,095.72	0.00	11,303.02
	Total cost (\$) per mile	<b>0.007</b>	<b>0.000</b>	<b>0.025</b>
Electric Propulsion System Repairs	Parts cost (\$)	2,311.45	0.00	0.00
	Labor hours	22.4	0.0	0.0
	Total cost (\$)	3,432.45	0.00	0.00
	Total cost (\$) per mile	<b>0.012</b>	<b>0.000</b>	<b>0.000</b>

# Propulsion-Related Maintenance Costs by Subsystem – 2017

Maintenance System		BEB 35FC	BEB 40FC	CNG
Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)	Parts cost (\$)	16,686.66	4,181.81	5,078.01
	Labor hours	135.1	23.4	109.2
	Total cost (\$)	23,439.16	5,353.81	10,539.01
	Total cost (\$) per mile	<b>0.083</b>	<b>0.019</b>	<b>0.023</b>
Air Intake System Repairs	Parts cost (\$)	0.00	0.00	4,242.09
	Labor hours	0.0	0.0	1.0
	Total cost (\$)	0.00	0.00	4,292.09
	Total cost (\$) per mile	<b>0.000</b>	<b>0.000</b>	<b>0.010</b>
Cooling System Repairs	Parts cost (\$)	929.89	0.00	3,233.89
	Labor hours	39.5	1.0	47.0
	Total cost (\$)	2,904.89	50.00	5,581.39
	Total cost (\$) per mile	<b>0.010</b>	<b>0.000</b>	<b>0.012</b>
Transmission System Repairs	Parts cost (\$)	79.00	0.00	3,726.01
	Labor hours	8.3	0.0	22.3
	Total cost (\$)	491.50	0.00	4,839.51
	Total cost (\$) per mile	<b>0.002</b>	<b>0.000</b>	<b>0.011</b>
Hydraulic System Repairs	Parts cost (\$)	0.00	0.00	0.00
	Labor hours	1.5	0.0	0.0
	Total cost (\$)	75.00	0.00	0.00
	Total cost (\$) per mile	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>

# Maintenance Challenges

During the second half of 2017, Foothill Transit's maintenance contractor experienced issues with the low-voltage battery on the BEBs. The maintenance contractor switched to a different manufacturer for the low-voltage batteries. The new batteries would not hold a charge very long and resulted in the need to change the batteries multiple times on all the buses. Another problem is that the accessories (farebox, cameras) continually draw power from these batteries. The contractor has since switched to a better performing battery to solve the issue. Because this issue is not related to the BEB system and is not expected to reoccur, NREL has provided the costs with and without the low-voltage battery replacement costs.

Foothill Transit continues to have high costs for tire replacements. The agency believes the primary cause is due to the differing use between the BEBs and CNG buses. The local routes tend to have more road damage, such as potholes and broken curbs, and require more stop-and-go driving. Because the BEBs are operated mainly on local routes, they incur more tire-related damage compared with the CNG buses that are often driven on freeways.

# Summary of Lessons Learned

- Infrastructure for BEBs is very important. A fleet can't move beyond 5–10 buses without a comprehensive plan to build out the needed charging infrastructure. An agency needs to work closely with utility and manufacturer partners to understand what is required.
- High driver turnover results in added training for operation of BEBs, especially with respect to the docking procedure for the fast charge station.
- Maintenance costs are rising as the warranty period ends and agency contractor staff take over the maintenance of the BEBs. Costs are expected to increase as maintenance staff learn how to troubleshoot and repair BEB systems, and then stabilize as workers become familiar with the technology differences.

# Contacts

NREL

Leslie Eudy

Phone: 303-275-4412

Email: [leslie.eudy@nrel.gov](mailto:leslie.eudy@nrel.gov)

Foothill Transit

Roland Cordero

Phone: 626-931-7246

Email: [rcordero@foothilltransit.org](mailto:rcordero@foothilltransit.org)

California Air Resources Board

Yachun Chow

Phone: 919-322-7450

Email: [yachun.chow@arb.ca.gov](mailto:yachun.chow@arb.ca.gov)

Proterra

Mike Finnern

Phone: 864-214-0393

Email: [mfinnern@Proterra.com](mailto:mfinnern@Proterra.com)

# Acronyms and Abbreviations

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

# Acknowledgments

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# Appendix: Fleet Summary Statistics

# Fleet Summary Statistics

	BEB 35FC All data	BEB 35FC 2017	BEB 40FC 2017	CNG All data	CNG 2017
Number of vehicles	12	12	2	8	8
Period used for fuel and oil analysis	4/14–12/17	1/17–12/17	1/17–12/17	10/14–12/17	1/17–12/17
Total number of months in period	45	12	12	39	12
Fuel and oil analysis base fleet mileage	1,172,117	281,214	29,864	1,334,718	405,267
Period used for maintenance analysis	1/15–12/17	1/17–12/17	1/17–12/17	10/14–12/17	1/17–12/17
Total number of months in period	36	12	12	39	12
Maintenance analysis base fleet mileage	976,513	281,214	47,587	1,469,879	449,107
Average monthly mileage per vehicle	2,254	1,953	1,244	4,711	4,678
Availability	89	81	81	97	97
Fleet fuel/energy usage in kWh (BEB)/gge (CNG)	2,553,624.3	614,177.5	66,206.3	345,497.1	109,151.6
Roadcalls	203	57	7	48	13
Total MBRC	5,774	4,934	6,798	30,622	34,547
Propulsion roadcalls	71	16	2	26	8
Propulsion MBRC	16,509	17,576	23,793	56,534	56,138
Fleet kWh/mile (BEB) or miles/gge (CNG)	2.18	2.18	2.22	3.86	3.71
Representative fleet mpg (energy equiv.)	17.28	17.24	16.99	4.32	4.15
Energy cost per kWh/CNG cost per gge	0.18	0.19	0.19	0.95	0.96
Fuel cost per mile	0.44	0.49	0.49	0.25	0.26
Total scheduled repair cost per mile	0.07	0.08	0.07	0.12	0.13
Total unscheduled repair cost per mile	0.18	0.33	0.25	0.10	0.15
Total maintenance cost per mile	0.26	0.41	0.32	0.23	0.27
<b>Total operating cost per mile</b>	<b>0.70</b>	<b>0.90</b>	<b>0.81</b>	<b>0.47</b>	<b>0.53</b>

# Maintenance Cost Summary

## Maintenance Cost Summary

	BEB 35FC All data	BEB 35FC 2017	BEB 40FC 2017	CNG All data	CNG 2017
Fleet mileage	976,513	281,214	47,587	1,469,879	449,107
Total parts cost	103,029.31	48,118.59	6,691.05	169,014.79	60,707.34
Total labor hours	2,995.7	1,347.7	172.8	3,230.0	1,235.7
Average labor cost (@ \$50.00 per hour)	149,783.50	67,386.50	8,641.00	161,497.50	61,782.50
Total maintenance cost	252,812.81	115,505.09	15,332.05	330,512.29	122,489.84
Total maintenance cost per bus	21,067.73	9,625.42	1,277.67	41,314.04	15,311.23
<b>Total maintenance cost per mile without low-voltage battery cost</b>	<b>0.26</b> <b>0.24</b>	<b>0.41</b> <b>0.35</b>	<b>0.32</b> <b>0.21</b>	<b>0.22</b> —	<b>0.27</b> —

## Propulsion System Maintenance Cost Summary

	BEB 35FC All data	BEB 35FC 2017	BEB 40FC 2017	CNG All data	CNG 2017
<b>Total Engine/Fuel-Related Systems (ATA VMRS 27, 30, 31, 32, 33, 41, 42, 43, 44, 45, 46, 65)</b>					
Parts cost	30,676.41	21,435.22	4,181.81	87,456.20	30,261.89
Labor hours	336.34	220.07	24.44	538.62	227.27
Average labor cost	16,817.00	11,003.50	1,222.00	26,931.00	11,363.50
Total cost (for system)	47,493.41	32,438.72	5,403.81	114,387.20	41,625.39
Total cost (for system) per bus	1,055.41	720.86	120.08	2,541.94	925.01
<b>Total cost (for system) per mile without low-voltage battery cost</b>	<b>0.049</b> <b>0.031</b>	<b>0.115</b> <b>0.053</b>	<b>0.114</b> <b>0.006</b>	<b>0.078</b> —	<b>0.093</b> —

# Maintenance Cost by Vehicle System

	BEB 35FC All data	BEB 35FC 2017	BEB 40FC 2017	CNG All data	CNG 2017
<b>Exhaust System Repairs (ATA VMRS 43)</b>					
Parts cost	0.00	0.00	0.00	2,450.67	2,293.47
Labor hours	0.0	0.0	0.0	18.4	16.9
Average labor cost	0.00	0.00	0.00	917.50	842.50
Total cost (for system)	0.00	0.00	0.00	3,368.17	3,135.97
Total cost (for system) per bus	0.00	0.00	0.00	74.85	69.69
<b>Total cost (for system) per mile</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.002</b>	<b>0.007</b>
<b>Fuel System Repairs (ATA VMRS 44)</b>					
Parts cost	0.00	0.00	0.00	1,916.97	1,364.40
Labor hours	0.0	0.0	0.0	36.6	11.4
Average labor cost	0.00	0.00	0.00	1,830.00	570.00
Total cost (for system)	0.00	0.00	0.00	3,746.97	1,934.40
Total cost (for system) per bus	0.00	0.00	0.00	83.27	42.99
<b>Total cost (for system) per mile</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.003</b>	<b>0.004</b>
<b>Power Plant (Engine) Repairs (ATA VMRS 45)</b>					
Parts cost	1,428.22	1,428.22	0.00	42,258.89	10,324.02
Labor hours	24.4	13.4	0.0	108.9	19.6
Average labor cost	1,217.50	667.50	0.00	5,444.00	979.00
Total cost (for system)	2,645.72	2,095.72	0.00	47,702.89	11,303.02
Total cost (for system) per bus	58.79	46.57	0.00	1,060.06	251.18
<b>Total cost (for system) per mile</b>	<b>0.003</b>	<b>0.007</b>	<b>0.000</b>	<b>0.032</b>	<b>0.025</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All data	BEB 35FC 2017	BEB 40FC 2017	CNG All data	CNG 2017
<b>Electric Propulsion Repairs (ATA VMRS 46)</b>					
Parts cost	2,311.45	2,311.45	0.00	0.00	0.00
Labor hours	45.3	22.4	0.0	0.0	0.0
Average labor cost	2,266.00	1,121.00	0.00	0.00	0.00
Total cost (for system)	4,577.45	3,432.45	0.00	0.00	0.00
Total cost (for system) per bus	101.72	76.28	0.00	0.00	0.00
<b>Total cost (for system) per mile</b>	<b>0.005</b>	<b>0.012</b>	<b>0.000</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	25,904.03	16,686.66	4,181.81	11,002.78	5,078.01
Labor hours	211.8	135.1	23.4	188.8	109.2
Average labor cost	10,591.00	6,752.50	1,172.00	9,441.00	5,461.00
Total cost (for system)	36,495.03	23,439.16	5,353.81	20,443.78	10,539.01
Total cost (for system) per bus	811.00	520.87	118.97	454.31	234.20
<b>Total cost (for system) per mile</b>	<b>0.037</b>	<b>0.083</b>	<b>0.113</b>	<b>0.014</b>	<b>0.023</b>
<b>Air Intake System Repairs (ATA VMRS 41)</b>					
Parts cost	0.00	0.00	0.00	16,299.88	4,242.09
Labor hours	3.9	0.0	0.0	1.8	1.0
Average labor cost	195.00	0.00	0.00	87.50	50.00
Total cost (for system)	195.00	0.00	0.00	16,387.38	4,292.09
Total cost (for system) per bus	4.33	0.00	0.00	364.16	95.38
<b>Total cost (for system) per mile</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.011</b>	<b>0.010</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All data	BEB 35FC 2017	BEB 40FC 2017	CNG All data	CNG 2017
<b>Cooling System Repairs (ATA VMRS 42)</b>					
Parts cost	953.71	929.89	0.00	9,392.19	3,233.89
Labor hours	42.0	39.5	1.0	145.3	47.0
Average labor cost	2,100.00	1,975.00	50.00	7,262.50	2,347.50
Total cost (for system)	3,053.71	2,904.89	50.00	16,654.69	5,581.39
Total cost (for system) per bus	67.86	64.55	1.11	370.10	124.03
<b>Total cost (for system) per mile</b>	<b>0.003</b>	<b>0.010</b>	<b>0.001</b>	<b>0.011</b>	<b>0.012</b>
<b>Hydraulic System Repairs (ATA VMRS 65)</b>					
Parts cost	0.00	0.00	0.00	0.00	0.00
Labor hours	1.5	1.5	0.0	0.0	0.0
Average labor cost	75.00	75.00	0.00	0.00	0.00
Total cost (for system)	75.00	75.00	0.00	0.00	0.00
Total cost (for system) per bus	1.67	1.67	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>General Air System Repairs (ATA VMRS 10)</b>					
Parts cost	2,546.68	2,492.64	131.76	1,797.19	528.12
Labor hours	120.7	95.0	12.7	38.9	23.0
Average labor cost	6,036.00	4,748.50	635.00	1,942.50	1,147.50
Total cost (for system)	8,582.68	7,241.14	766.76	3,739.69	1,675.62
Total cost (for system) per bus	190.73	160.91	17.04	83.10	37.24
<b>Total cost (for system) per mile</b>	<b>0.009</b>	<b>0.026</b>	<b>0.016</b>	<b>0.003</b>	<b>0.004</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All data	BEB 35FC 2017	BEB 40FC 2017	CNG All data	CNG 2017
<b>Brake System Repairs (ATA VMRS 13)</b>					
Parts cost	1,528.23	1,528.23	0.00	6,416.78	4,135.78
Labor hours	52.9	46.2	0.0	63.0	51.8
Average labor cost	2,643.50	2,308.50	0.00	3,147.50	2,587.50
Total cost (for system)	4,171.73	3,836.73	0.00	9,564.28	6,723.28
Total cost (for system) per bus	92.71	85.26	0.00	212.54	149.41
<b>Total cost (for system) per mile</b>	<b>0.004</b>	<b>0.014</b>	<b>0.000</b>	<b>0.007</b>	<b>0.015</b>
<b>Transmission Repairs (ATA VMRS 27)</b>					
Parts cost	79.00	79.00	0.00	4,134.83	3,726.01
Labor hours	9.5	8.3	0.0	39.0	22.3
Average labor cost	472.50	412.50	0.00	1,948.50	1,113.50
Total cost (for system)	551.50	491.50	0.00	6,083.33	4,839.51
Total cost (for system) per bus	12.26	10.92	0.00	135.19	107.54
<b>Total cost (for system) per mile</b>	<b>0.001</b>	<b>0.002</b>	<b>0.000</b>	<b>0.004</b>	<b>0.011</b>
<b>Inspections Only—No Parts Replacements (101)</b>					
Parts cost	0.00	0.00	0.00	0.00	0.00
Labor hours	1,436.4	457.0	67.7	1,703.2	584.1
Average labor cost	71,817.50	22,847.50	3,386.00	85,159.00	29,204.00
Total cost (for system)	71,817.50	22,847.50	3,386.00	85,159.00	29,204.00
Total cost (for system) per bus	1,595.94	507.72	75.24	1,892.42	648.98
<b>Total cost (for system) per mile</b>	<b>0.074</b>	<b>0.081</b>	<b>0.071</b>	<b>0.058</b>	<b>0.065</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All data	BEB 35FC 2017	BEB 40FC 2017	CNG All data	CNG 2017
<b>Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)</b>					
Parts cost	9,140.26	5,390.87	1,200.08	25,950.14	10,359.19
Labor hours	727.0	343.0	57.8	633.6	220.9
Average labor cost	36,348.50	17,150.00	2,891.50	31,682.00	11,047.00
Total cost (for system)	45,488.76	22,540.87	4,091.58	57,632.14	21,406.19
Total cost (for system) per bus	1,010.86	500.91	90.92	1,280.71	475.69
<b>Total cost (for system) per mile</b>	<b>0.047</b>	<b>0.080</b>	<b>0.086</b>	<b>0.039</b>	<b>0.048</b>
<b>HVAC System Repairs (ATA VMRS 01)</b>					
Parts cost	450.20	394.61	0.00	4,947.20	492.63
Labor hours	27.6	17.6	0.0	48.1	7.1
Average labor cost	1,377.50	877.50	0.00	2,405.00	355.00
Total cost (for system)	1,827.70	1,272.11	0.00	7,352.20	847.63
Total cost (for system) per bus	40.62	28.27	0.00	163.38	18.84
<b>Total cost (for system) per mile</b>	<b>0.002</b>	<b>0.005</b>	<b>0.000</b>	<b>0.005</b>	<b>0.002</b>
<b>Lighting System Repairs (ATA VMRS 34)</b>					
Parts cost	2,041.10	1,854.28	0.00	252.92	232.40
Labor hours	88.6	62.0	1.0	15.5	13.5
Average labor cost	4,427.50	3,100.00	50.00	772.50	675.00
Total cost (for system)	6,468.60	4,954.28	50.00	1,025.42	907.40
Total cost (for system) per bus	143.75	110.10	1.11	22.79	20.16
<b>Total cost (for system) per mile</b>	<b>0.007</b>	<b>0.018</b>	<b>0.001</b>	<b>0.001</b>	<b>0.002</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All data	BEB 35FC 2017	BEB 40FC 2017	CNG All data	CNG 2017
<b>Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)</b>					
Parts cost	552.50	552.50	0.00	5,387.15	5,000.13
Labor hours	28.1	28.1	0.0	48.6	41.9
Average labor cost	1,404.00	1,404.00	0.00	2,428.50	2,093.50
Total cost (for system)	1,956.50	1,956.50	0.00	7,815.65	7,093.63
Total cost (for system) per bus	43.48	43.48	0.00	173.68	157.64
<b>Total cost (for system) per mile</b>	<b>0.002</b>	<b>0.007</b>	<b>0.000</b>	<b>0.005</b>	<b>0.016</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	1,665.40	0.00	20,161.34	4,457.44
Labor hours	7.0	7.0	0.0	10.0	2.0
Average labor cost	350.00	350.00	0.00	500.00	100.00
Total cost (for system)	2,015.40	2,015.40	0.00	20,661.34	4,557.44
Total cost (for system) per bus	44.79	44.79	0.00	459.14	101.28
<b>Total cost (for system) per mile</b>	<b>0.002</b>	<b>0.007</b>	<b>0.000</b>	<b>0.014</b>	<b>0.010</b>
<b>Tire Repairs (ATA VMRS 17)</b>					
Parts cost	48,143.53	9,654.84	892.40	14,807.87	4,604.76
Labor hours	169.2	69.9	9.1	129.6	64.2
Average labor cost	8,462.00	3,497.00	456.50	6,479.50	3,209.50
Total cost (for system)	56,605.53	13,151.84	1,348.90	21,287.37	7,814.26
Total cost (for system) per bus	1,257.90	292.26	29.98	473.05	173.65
<b>Total cost (for system) per mile</b>	<b>0.058</b>	<b>0.047</b>	<b>0.028</b>	<b>0.014</b>	<b>0.017</b>

# Maintenance Cost by Vehicle System

	BEB 35FC All data	BEB 35FC 2017	BEB 40FC 2017	CNG All data	CNG 2017
<b>Towing Charges</b>					
Charge	6,285.00	3,150.00	285.00	1,838.00	635.00
Labor hours	0.00	0.00	0.00	1.0	0.0
Average labor cost	0.00	0.00	0.00	50.00	0.00
Total cost (for system)	6,285.00	3,150.00	285.00	1,888.00	635.00
Total cost (for system) per bus	139.67	70.00	6.33	41.96	14.11
<b>Total cost (for system) per mile</b>	<b>0.006</b>	<b>0.011</b>	<b>0.006</b>	<b>0.001</b>	<b>0.001</b>

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