

Foothill Transit Agency Battery Electric Bus Progress Report

Data Period Focus: Jan. 2018 through Jun. 2018

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NREL/PR-5400-72207

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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 2017.^{1,2,3} This report extends the data analysis through June 2018. NREL plans to publish progress reports on the Foothill Transit fleet every six months through 2020.

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

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

³ Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2017 through Dec. 2017, NREL/PR-5400-71292, www.nrel.gov/docs/fy18osti/71292.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 the first half of 2018 was 2.11 kWh/mi (17.86 mpdge) for the BEB 35FC fleet, 2.14 kWh/mi (17.61 mpdge) for the BEB 40FC fleet, and 3.82 mpgge (4.27 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 2018, the BEB fleet cost \$0.41/mi (at \$0.19/kWh) and the CNG fleet cost \$0.20/mi (at \$0.90/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: 2018 availability was 74.2% for the BEB 35FC buses, 83.5% for the BEB 40FC buses, and 96.3% 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 had an impact on BEB availability. Other downtime resulted from issues with components such as: transmission, air compressor, DC-DC converter, air conditioning, and the energy storage system.

Results Summary (continued)

Maintenance cost: Cost to maintain the buses in 2018 was \$0.71/mi for the BEB 35FC buses, \$0.29/mi for the BEB 40FC buses, and \$0.24/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:

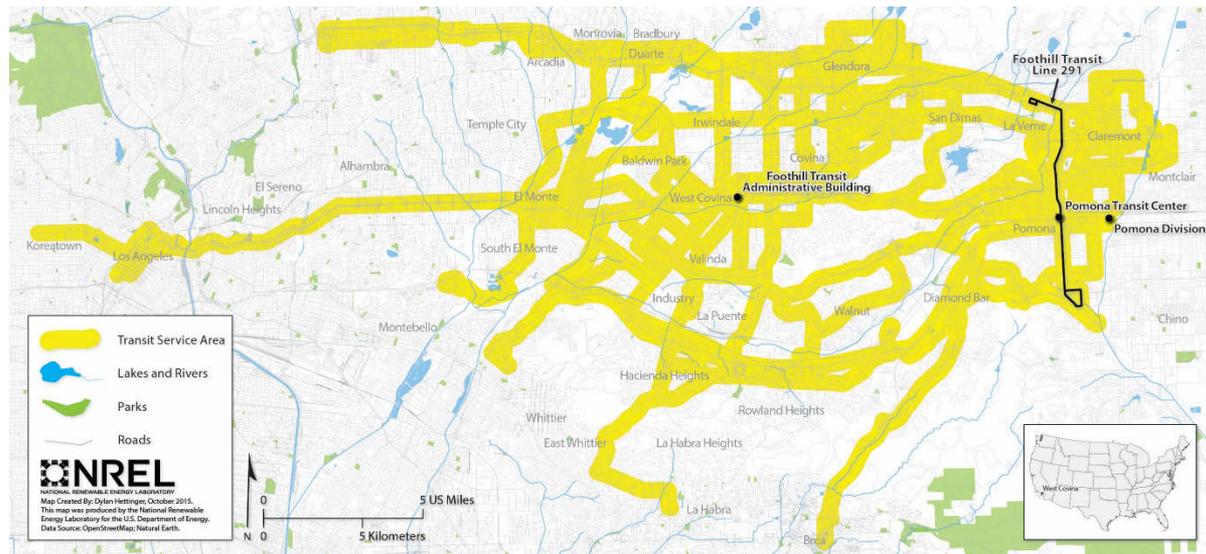
- The BEB 35FC buses are now past the warranty period for some components resulting in higher parts cost.
- All maintenance has been transitioned to onsite contractor staff, resulting in increased labor hours for training and troubleshooting as the staff become more familiar with systems and components. This is expected to drop as the learning curve improves for the maintenance staff.

Results Summary (continued)

- Foothill Transit is experiencing continued issues with the low-voltage batteries. Despite the maintenance contractor switching to a better performing battery, the batteries are still failing prematurely. One issue is that the accessories (farebox, cameras) continually draw power from these batteries. In some cases, the operators are not turning off the switches, which allows the accessories to continue to draw power. Because this issue is not related to the BEB system, NREL has provided the costs with and without the low-voltage battery replacement costs.
- Total maintenance cost without low-voltage battery costs was \$0.61/mi for the BEB 35FC buses and \$0.24/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 ^a	\$904,490	\$879,845	\$575,000
Length/width/height	35 ft/102 in./129 in.	42.5 ft/102 in./134 in.	42 ft/102 in./137 in.
GVWR/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

^a 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	4/14–6/18	1/17–6/18	10/14–6/18
Number of months	51	18	45
Total mileage in data period	1,317,208	72,712	1,705,076
Average odometer	110,825	38,067	217,943
Average monthly mileage per bus	2,152	2,020	4,736
Availability (85% is target)	87	82	97
Fuel economy (kWh/mile or mpgge ^a)	2.21	2.20	3.86
Fuel economy (mpdge ^b)	17.05	17.11	4.23
Average speed, including stops (mph)	10.60	10.60	17.60
Miles between roadcalls (MBRC) – bus ^c	5,649	6,059	31,575
MBRC – propulsion system only ^c	14,464	18,178	55,002
MBRC – ESS ^d only ^c	219,535	—	—
Total maintenance cost (\$/mile) ^e	0.32	0.31	0.23
<i>Total maintenance cost (\$/mile without low-voltage battery costs)^f</i>	<i>0.28</i>	<i>0.23</i>	<i>—</i>
Maintenance cost – propulsion system only (\$/mile)	0.08	0.09	0.08
<i>Propulsion system maintenance cost (\$/mile without low-voltage battery costs)^f</i>	<i>0.04</i>	<i>0.02</i>	<i>—</i>

^a Gasoline gallon equivalent

^b Diesel gallon equivalent

^c MBRC data cumulative from the clean point of April 2014 through June 2018

^d Energy storage system

^e Work order maintenance cost

^f See issue with the low-voltage batteries explained on slide 44

Data Summary: Jan–Jun 2018

Data Item	BEB 35FC	BEB 40FC	CNG
Number of buses	12	2	8
Data period	1/18–6/18	1/18–6/18	1/18–6/18
Number of months	6	6	6
Total mileage in data period	144,116	25,125	235,197
Average odometer	110,825	38,067	217,943
Average monthly mileage per bus	2,002	2,094	4,900
Availability (85% is target)	74	83	96
Fuel economy (kWh/mile or mpgge ^a)	2.11	2.14	3.82
Fuel economy (mpdge ^b)	17.86	17.61	4.27
Average speed, including stops (mph)	10.60	10.60	17.60
Miles between roadcalls (MBRC) – bus ^c	5,649	6,059	31,575
MBRC – propulsion system only ^c	14,464	18,178	55,002
MBRC – ESS ^d only ^c	219,535	—	—
Total maintenance cost (\$/mile) ^e	0.71	0.29	0.24
<i>Total maintenance cost (\$/mile without low-voltage battery costs)^f</i>	<i>0.61</i>	<i>0.24</i>	<i>—</i>
Maintenance cost – propulsion system only (\$/mile)	0.30	0.06	0.09
<i>Propulsion system maintenance cost (\$/mile without low-voltage battery costs)^f</i>	<i>0.20</i>	<i>0.00</i>	<i>—</i>

^a Gasoline gallon equivalent

^b Diesel gallon equivalent

^c MBRC data cumulative from the clean point of April 2014 through June 2018

^d Energy storage system

^e Work order maintenance cost

^f See issue with the low-voltage batteries explained on slide 44

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 only operated 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.

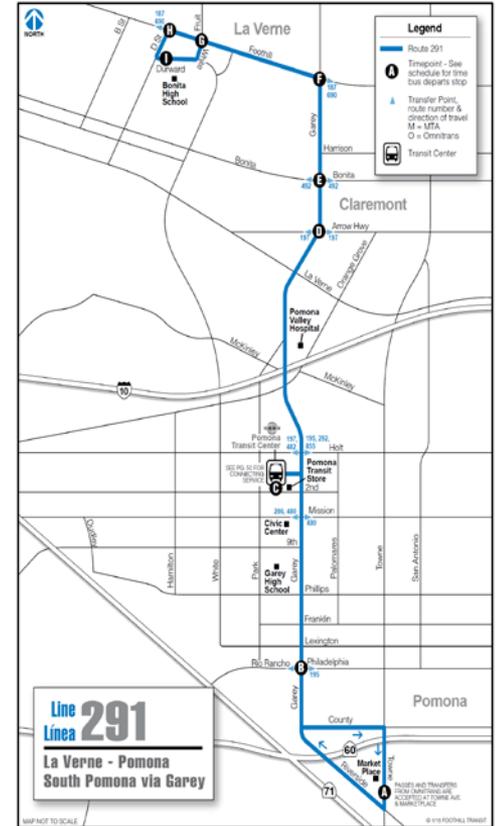
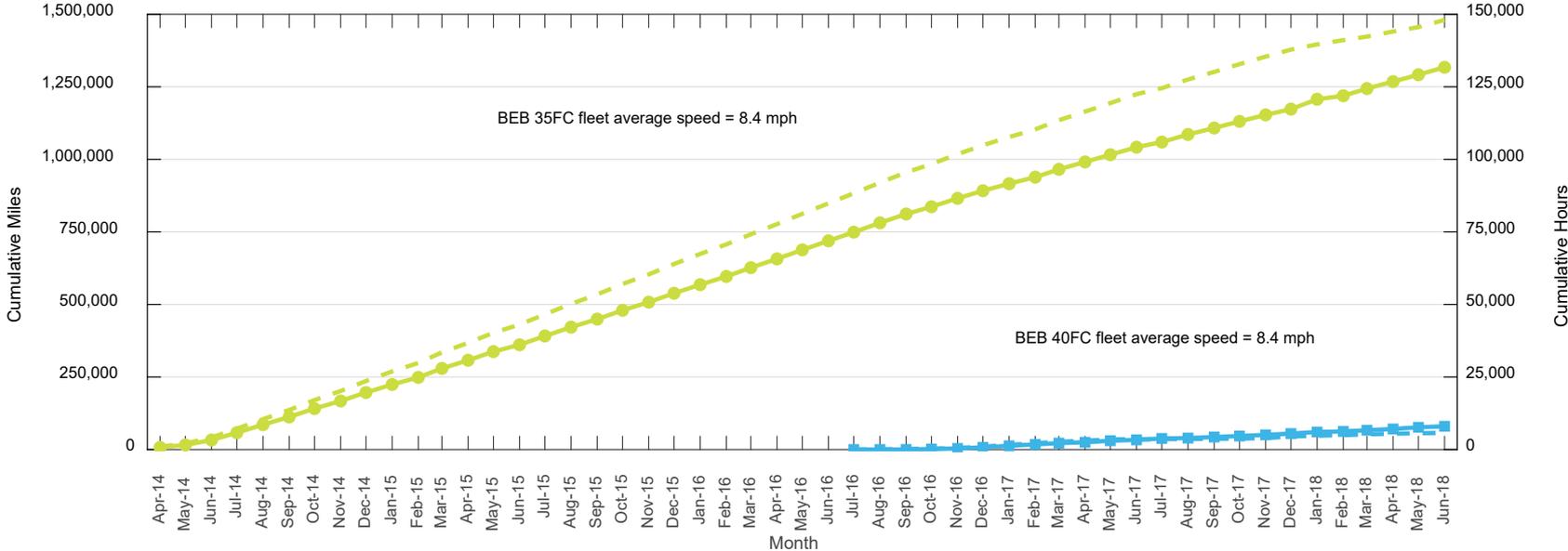


Image courtesy of Foothill Transit

BEB Fleet Total Miles



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

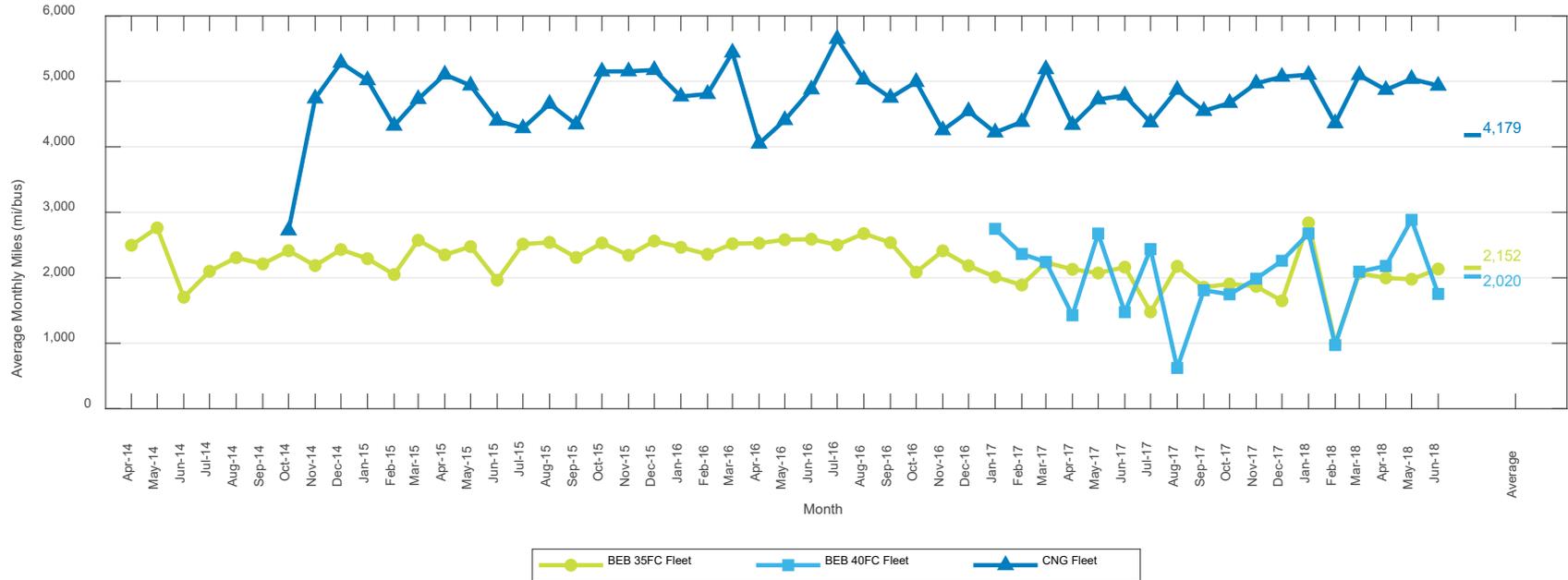
Fleet Average Monthly Miles by Bus: Jan–Jun 2018

Bus ID	Miles	Months	Average Monthly Mileage
2004	13,735	6	2,289
2005	14,550	6	2,425
2006	15,505	6	2,584
2007	14,904	6	2,484
2008	13,163	6	2,194
2009	12,913	6	2,152
2010	5,739	6	957
2011	12,024	6	2,004
2012	14,268	6	2,378
2013	4,979	6	830
2014	16,666	6	2,778
2015	5,670	6	945
BEB 35FC Total	144,116	72	2,002
2016	12,833	6	2,139
2017	12,292	6	2,049
BEB 40FC Total	25,125	12	2,094

Bus ID	Miles	Months	Average Monthly Mileage
2200	30,190	6	5,032
2201	29,565	6	4,928
2202	27,063	6	4,511
2203	30,127	6	5,021
2204	29,038	6	4,840
2205	31,336	6	5,223
2206	29,210	6	4,868
2207	28,668	6	4,778
CNG Total	235,197	48	4,900

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.

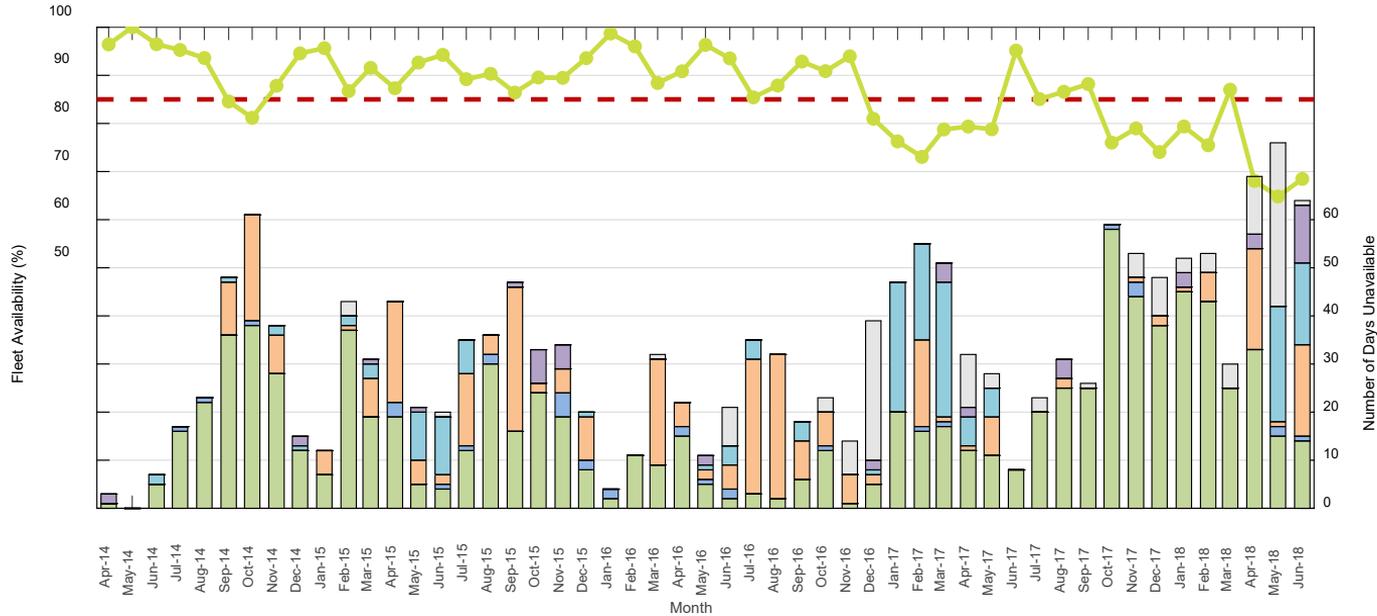
NREL presents availability as a monthly average trend and as overall availability. Unavailable time is separated into several categories to show the primary reason for downtime.

Availability Summary: Jan–Jun 2018

Category	BEB 35FC # Days	BEB 35FC %	BEB 40FC # Days	BEB 40FC %	CNG # Days	CNG %
Planned work days	1,334		224		892	
Days available	990	74.2	187	83.5	859	96.3
Unavailable	344	25.8	37	16.5	33	3.7
ESS	41	3.1	6	2.7	—	—
CNG engine	—	—	—	—	15	1.7
Electric drive	48	3.6	0	0.0	—	—
Charging issues	18	1.3	0	0.0	—	—
Preventive maintenance	3	0.2	0	0.0	4	0.4
General bus maintenance	175	13.1	23	10.3	5	0.6
Transmission	59	4.4	8	3.6	9	1.0

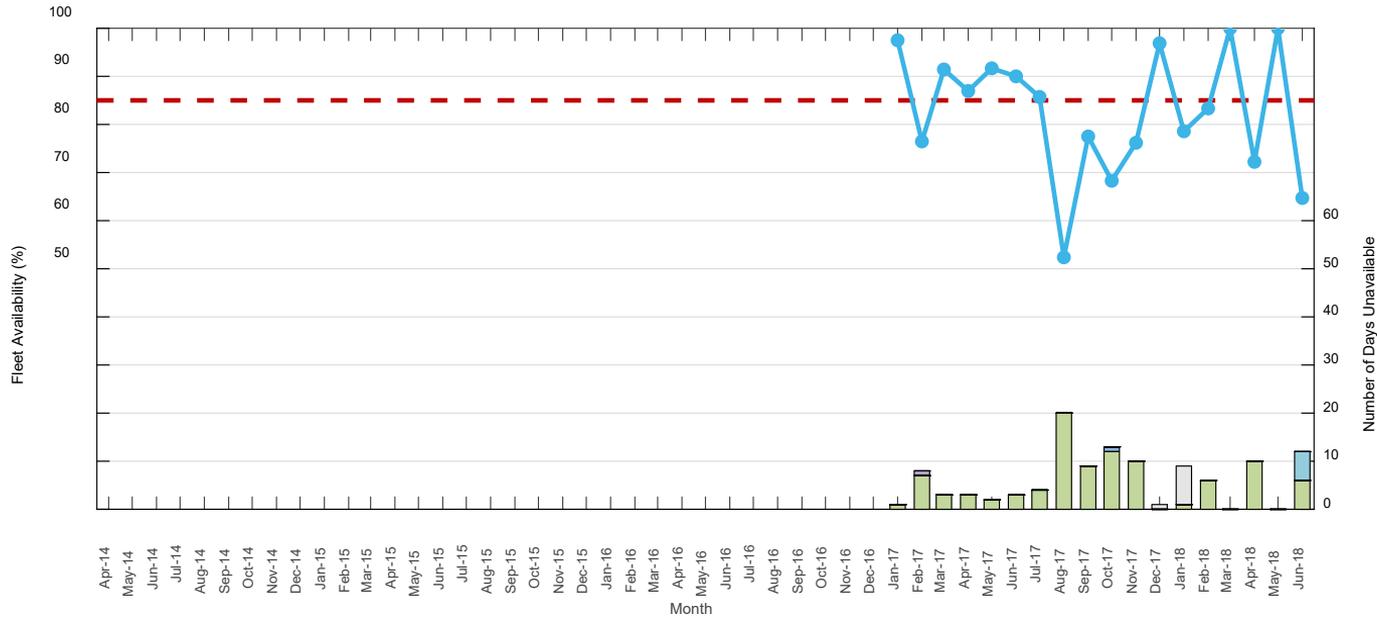
- The per-bus availability for the BEBs ranged from a low of 48% to a high of 94%
- The majority of unavailable time for the BEBs was attributed to general bus maintenance
- Issues with the low-voltage batteries lowered availability for the BEBs
- The majority of unavailable time for the CNG buses was attributed to engine issues

Monthly Availability: BEB 35FC



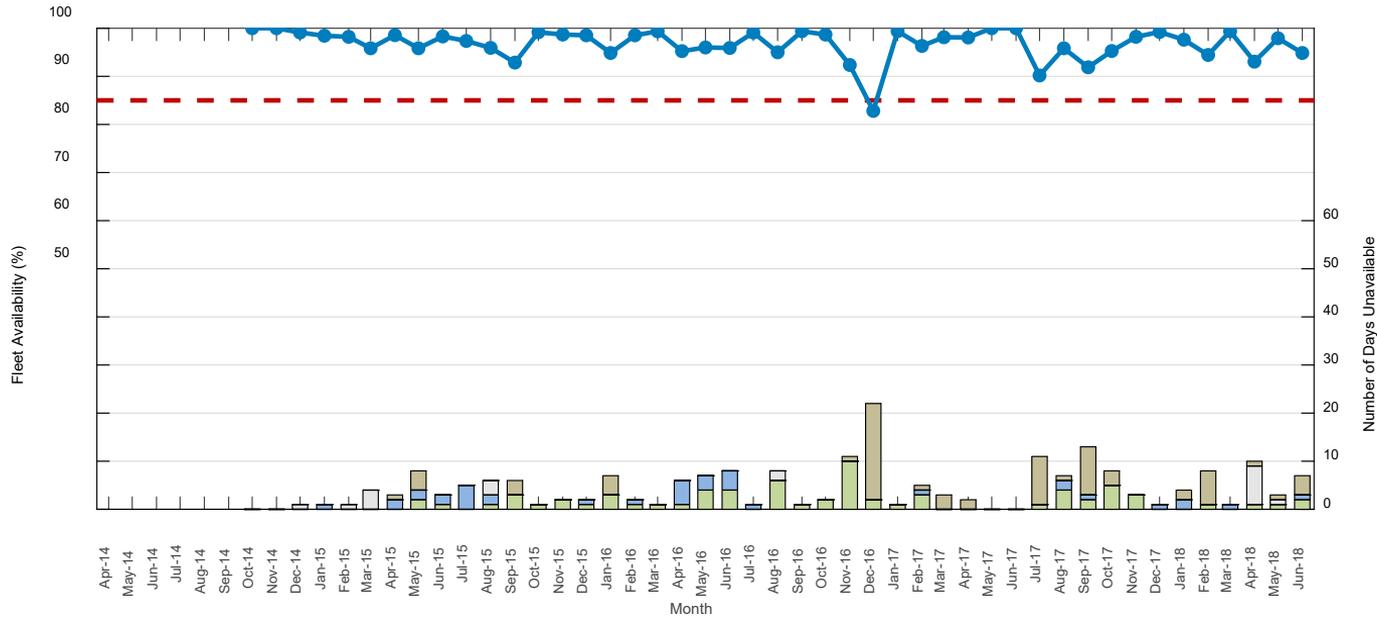
- The green line tracks the average monthly availability for the BEB 35FC fleet
- The stacked bars provide the number of unavailable days each month separated by six categories
- Low-voltage batteries fall into the Bus Maintenance category

Monthly Availability: BEB 40FC



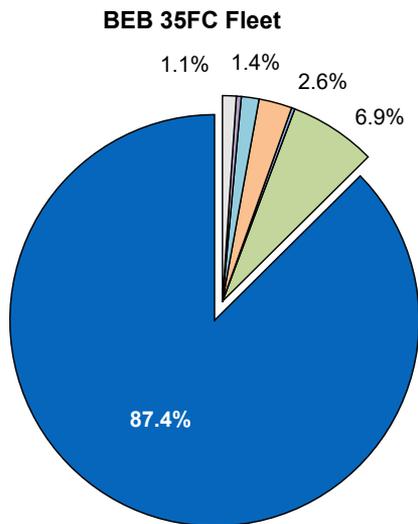
- The blue line tracks the average monthly availability for the BEB 40FC fleet
- The stacked bars provide the number of unavailable days each month separated by six categories
- Issues with the low-voltage battery during August 2017 lowered the availability

Monthly Availability: CNG



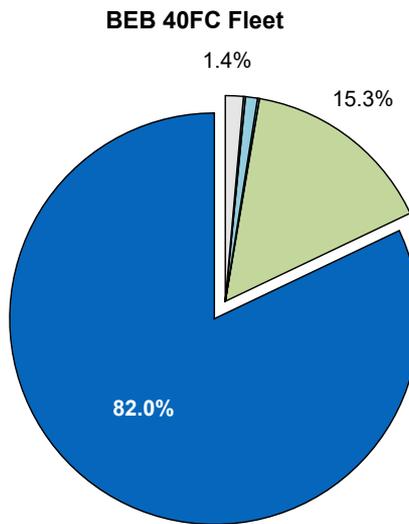
- The blue line tracks the average monthly availability for the CNG fleet
- The stacked bars provide the number of unavailable days each month separated by four categories

Overall Fleet Availability: Full Data Period



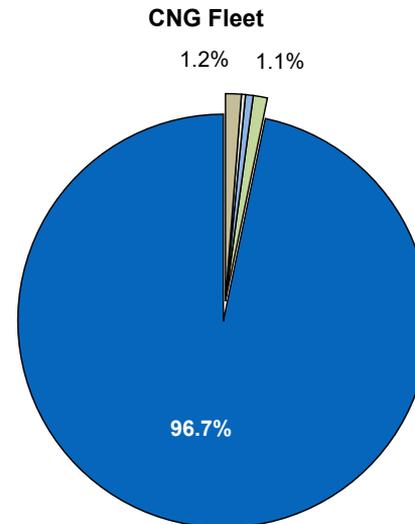
Date Range: Apr 2014 - Jun 2018

Days Planned: 13,115



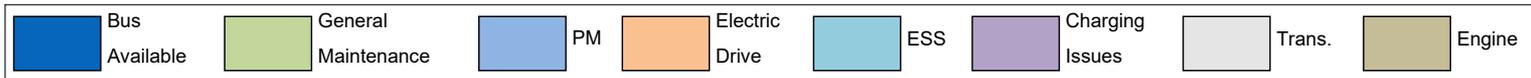
Date Range: Jan 2017 - Jun 2018

Days Planned: 635



Date Range: Oct 2014 - Jun 2018

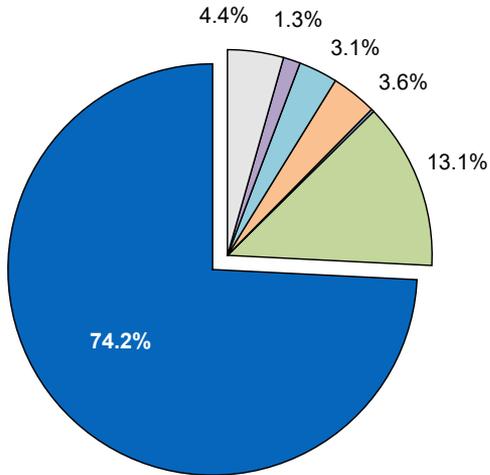
Days Planned: 6,301



Data labels omitted for pie slices representing < 1.0%

Overall Fleet Availability: Jan–Jun 2018

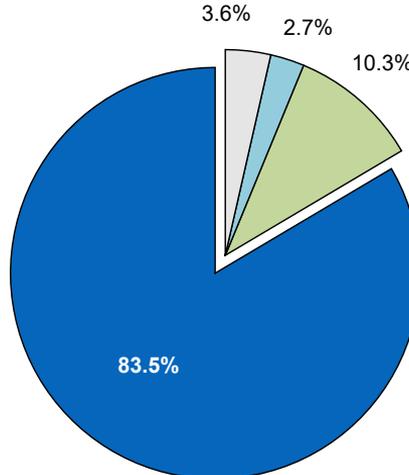
BEB 35FC Fleet



Date Range: Jan 2018 - Jun 2018

Days Planned: 1,334

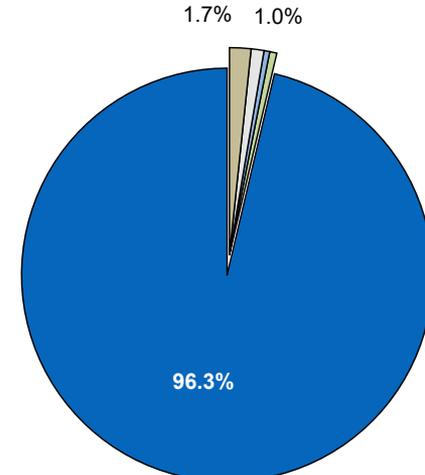
BEB 40FC Fleet



Date Range: Jan 2018 - Jun 2018

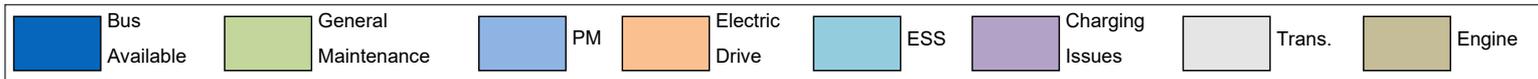
Days Planned: 224

CNG Fleet



Date Range: Jan 2018 - Jun 2018

Days Planned: 892



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: Jan–Jun 2018

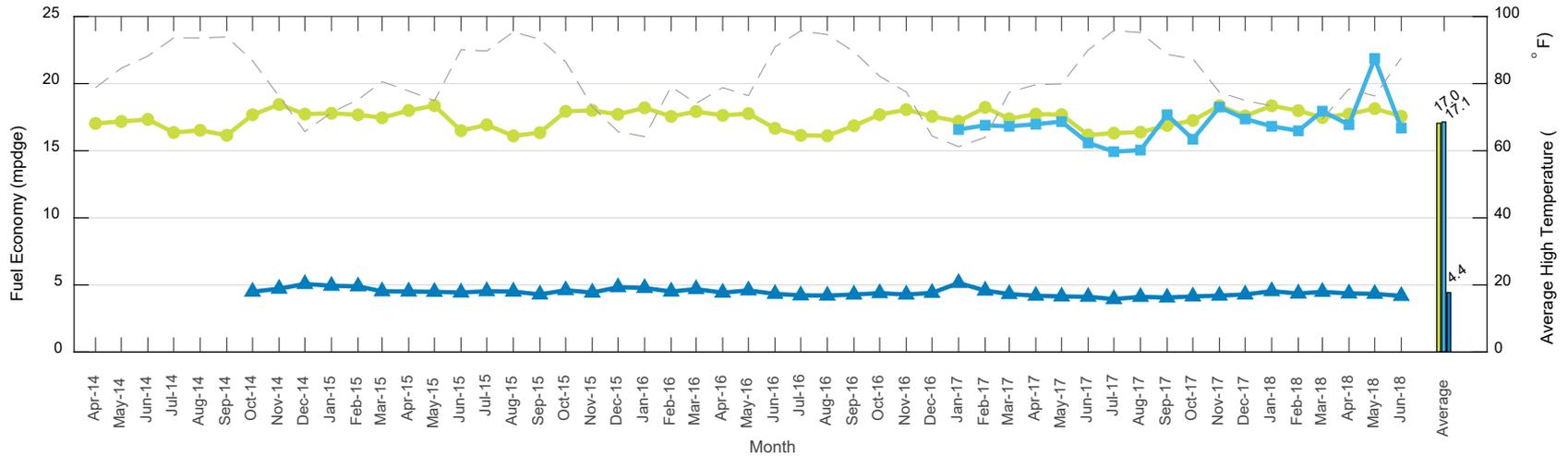
Bus ID	Miles	Energy ^a (kWh)	kWh/mi	Diesel gallon equiv.	Fuel economy (mpdge)
2004	11,756	25,409.7	2.16	675.1	17.41
2005	6,643	14,162.4	2.13	376.3	17.65
2006	9,980	21,181.5	2.12	562.7	17.74
2007	8,720	17,748.3	2.04	471.5	18.49
2008	12,097	26,791.3	2.21	711.8	16.99
2009	4,071	8,117.9	1.99	215.7	18.88
2010	3,858	8,114.8	2.10	215.6	17.89
2011	3,758	7,216.0	1.92	191.7	19.60
2012	12,324	25,060.1	2.03	665.8	18.51
2013	3,199	6,471.4	2.02	171.9	18.60
2014	7,756	16,716.9	2.16	444.1	17.46
2015	2,791	6,271.5	2.25	166.6	16.75
BEB 35FC Total	86,952	183,261.7	2.11	4,868.8	17.86
2016	5,702	11,842.3	2.08	314.6	18.12
2017	5,058	11,161.0	2.21	296.5	17.06
BEB 40FC Total	10,760	23,003.3	2.14	611.1	17.61

Bus ID	Miles	CNG (gge)	mi/gge	Diesel gallon equiv.	Fuel economy (mpdge)
2200	26,305	7,026.3	3.74	6,288.6	4.18
2201	24,996	6,772.4	3.69	6,061.3	4.12
2202	24,762	6,034.1	4.10	5,400.5	4.59
2203	25,508	6,527.8	3.91	5,842.3	4.37
2204	24,884	6,640.0	3.75	5,942.8	4.19
2205	27,034	6,949.0	3.89	6,219.3	4.35
2206	22,097	6,127.6	3.61	5,484.2	4.03
2207	23,852	6,073.1	3.93	5,435.5	4.39
CNG Total	199,438	52,150.3	3.82	46,674.5	4.27

- 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.

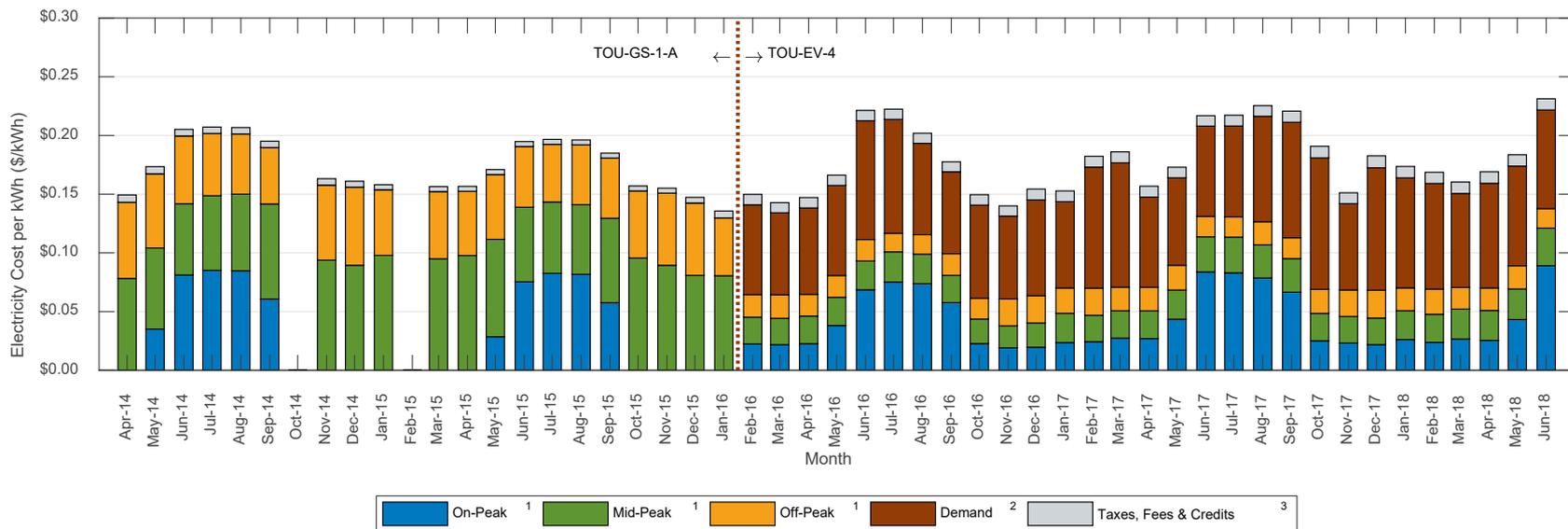
^a Total energy consumed by the bus, does not include losses during charging

Fleet Average Monthly Fuel Economy



Bus	Overall		2018	
	kWh/mi, mpgge	mpdgc	kWh/mi, mpgge	mpdgc
BEB 35FC	2.21	17.05	2.11	17.86
BEB 40FC	2.20	17.11	2.14	17.61
CNG	3.86	4.23	3.82	4.27

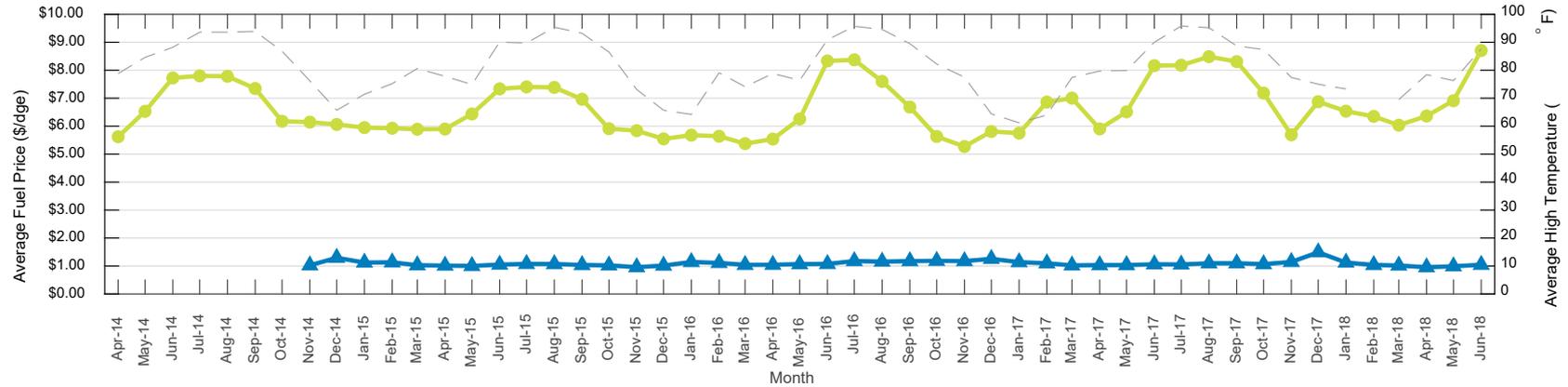
Monthly Electric Utility Costs



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: \$0.18/kWh

Monthly Average Fuel Price



- 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 2018, Foothill Transit paid an average of \$0.90/ggc for CNG. The average cost of electricity during 2018 was \$0.18/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.

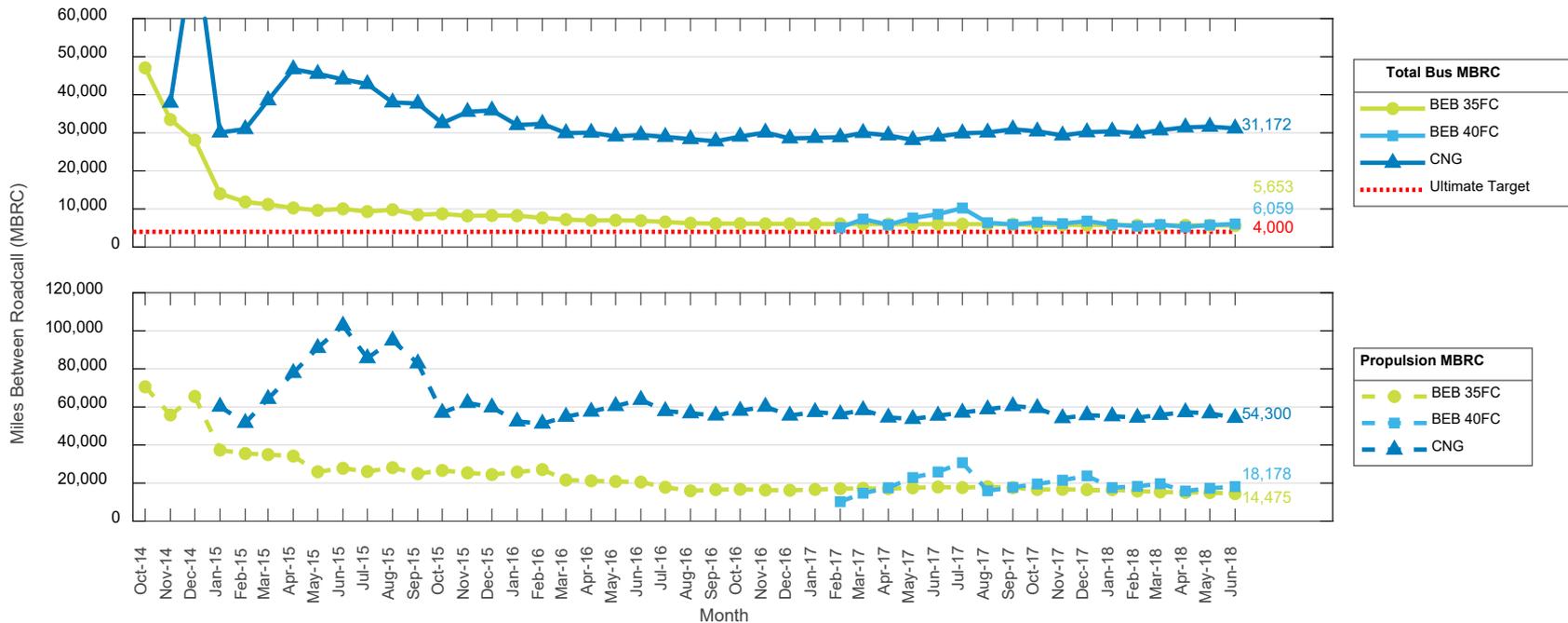
	Average Service Speed (mph)	Fuel Economy (mpdgc)	Overall \$/mi	2018 \$/mi
BEB 35FC	10.6	17.05	0.44	0.41
BEB 40FC	10.6	17.11	0.44	0.41
CNG	17.6	4.23	0.22	0.20
CNG on Line 291	10.6	2.09	0.51	0.51

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
- The ESS-related MBRC for the BEB 35FC fleet is 219,535
- 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 advanced propulsion system changes for the buses.

Maintenance Analysis Results: Jan–Jun 2018

Bus ID	Mileage	Parts (\$)	Labor Hours	Total Cost (\$/mi)	Scheduled Cost (\$/mi)	Unscheduled Cost (\$/mi)
2004	13,735	\$7,873.93	68.5	\$0.82	\$0.08	\$0.74
2005	14,550	\$1,309.42	49.1	\$0.26	\$0.08	\$0.18
2006	15,505	\$1,731.20	96.3	\$0.42	\$0.08	\$0.34
2007	14,904	\$2,321.59	84.1	\$0.44	\$0.07	\$0.36
2008	13,163	\$19,789.76	96.5	\$1.87	\$0.07	\$1.80
2009	12,913	\$2,278.16	61.4	\$0.41	\$0.10	\$0.32
2010	5,739	\$1,372.09	93.8	\$1.06	\$0.18	\$0.88
2011	12,024	\$7,557.65	67.5	\$0.91	\$0.07	\$0.84
2012	14,268	\$3,382.74	84.4	\$0.53	\$0.07	\$0.46
2013	4,979	\$3,657.77	80.2	\$1.54	\$0.14	\$1.40
2014	16,666	\$2,830.62	78.4	\$0.41	\$0.08	\$0.33
2015	5,670	\$1,744.50	80.8	\$1.02	\$0.11	\$0.91
BEB 35FC Fleet	144,116	\$55,849.43	940.8	\$0.71	\$0.09	\$0.63
2016	12,833	\$483.42	60.3	\$0.27	\$0.10	\$0.17
2017	12,292	\$696.29	63.0	\$0.31	\$0.08	\$0.24
BEB 40FC Fleet	25,125	\$1,179.71	123.3	\$0.29	\$0.09	\$0.20

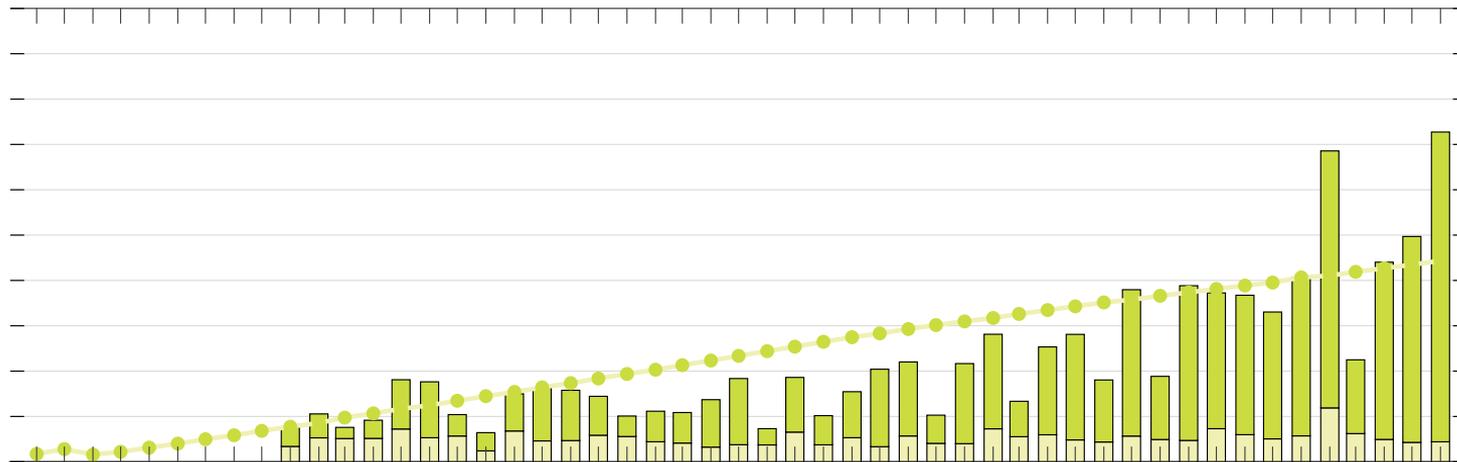
OEM: original equipment manufacturer

Bus ID	Mileage	Parts (\$)	Labor Hours	Total Cost (\$/mi)	Scheduled Cost (\$/mi)	Unscheduled Cost (\$/mi)
2200	30,190	\$2,054.98	63.9	\$0.17	\$0.09	\$0.09
2201	29,565	\$2,735.64	75.0	\$0.22	\$0.10	\$0.12
2202	27,063	\$3,158.48	77.8	\$0.26	\$0.11	\$0.16
2203	30,127	\$2,597.30	78.8	\$0.22	\$0.09	\$0.12
2204	29,038	\$5,121.51	90.5	\$0.33	\$0.08	\$0.25
2205	31,336	\$2,505.18	64.0	\$0.18	\$0.07	\$0.12
2206	29,210	\$2,596.06	79.5	\$0.22	\$0.08	\$0.15
2207	28,668	\$5,249.22	102.4	\$0.36	\$0.10	\$0.27
CNG Fleet	235,197	\$26,018.37	631.9	\$0.24	\$0.09	\$0.16

Reasons for cost increase over previous report (BEB 35FC: \$0.41/mi, BEB 40FC: \$0.32/mi):

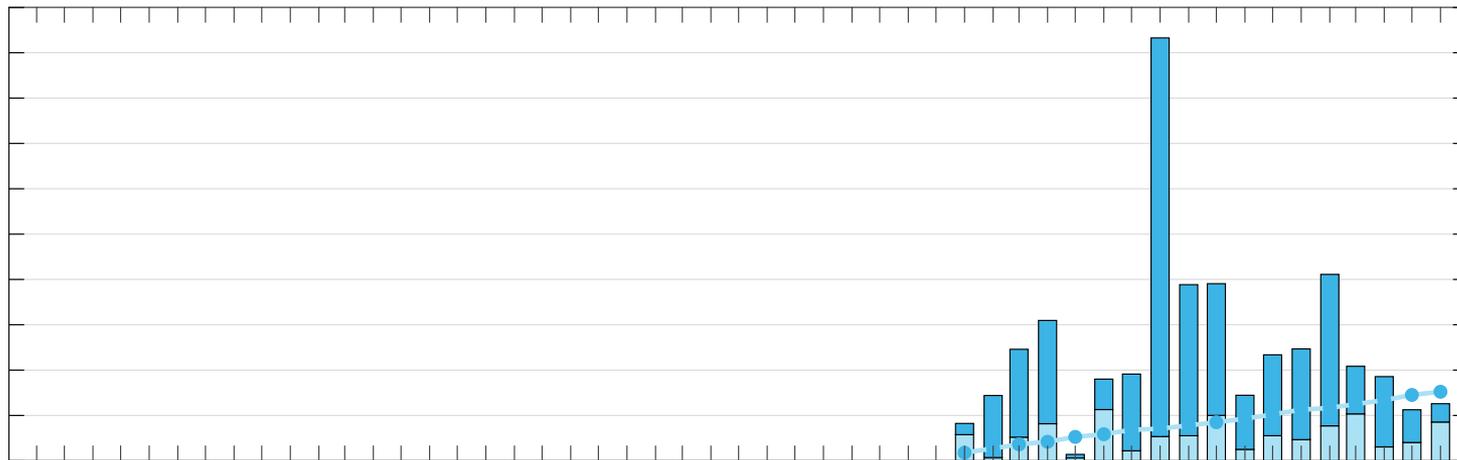
- Issues with the low-voltage batteries
- Issues with the bus air compressor
- Replacement of one DC-DC converter
- Maintenance being transferred from OEM to contractor, which results in more labor hours
- Warranty ended for some systems

Monthly Scheduled and Unscheduled Maintenance Cost: BEB 35FC



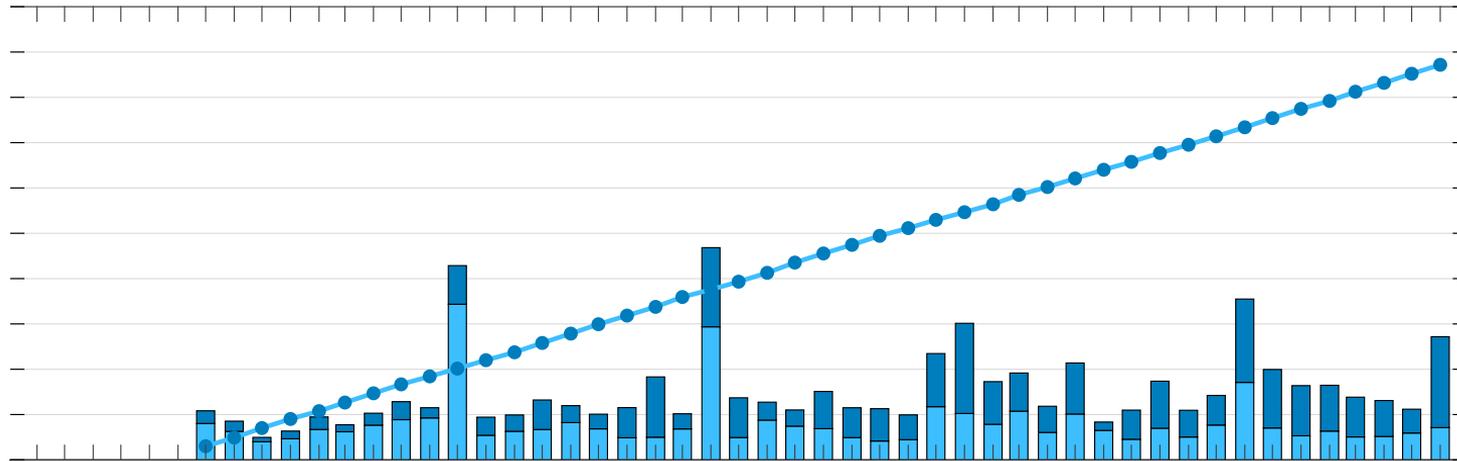
- The warranty period has ended and transit staff are handling most of the maintenance work
- Issues with the low-voltage batteries continue to result in increasing costs

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

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: Jan–Jun 2018

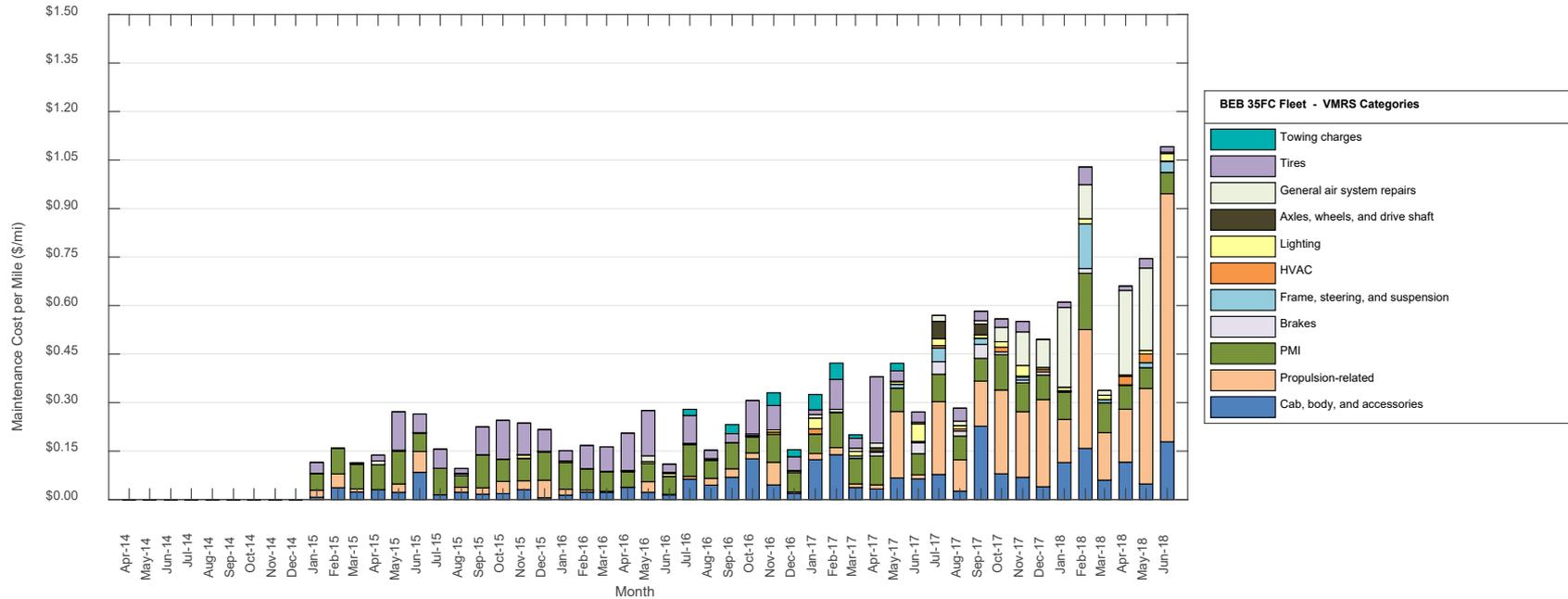
System	BEB 35FC		BEB 40FC		CNG	
	Cost per Mile (\$)	Percent of Total (%)	Cost per Mile (\$)	Percent of Total (%)	Cost per Mile (\$)	Percent of Total (%)
Cab, body, and accessories	0.109	15	0.062	21	0.038	16
Propulsion-related	0.299	42	0.057	19	0.084	34
PMI	0.085	12	0.090	31	0.067	27
Brakes	0.002	0	0.000	0	0.020	8
Frame, steering, and suspension	0.022	3	0.000	0	0.011	5
HVAC	0.010	1	0.010	3	0.012	5
Lighting	0.013	2	0.006	2	0.004	2
Axles, wheels, and drive shaft	0.000	0	0.000	0	0.001	0
Air, general	0.156	22	0.042	15	0.001	0
Tires	0.018	3	0.026	9	0.006	3
Towing charges	0.000	0	0.000	0	0.000	0
Total	0.71	100	0.29	100	0.24	100
Total w/o low-voltage battery costs	0.61		0.24		–	

Color coding:

-  Highest cost
-  Second highest cost
-  Third highest cost

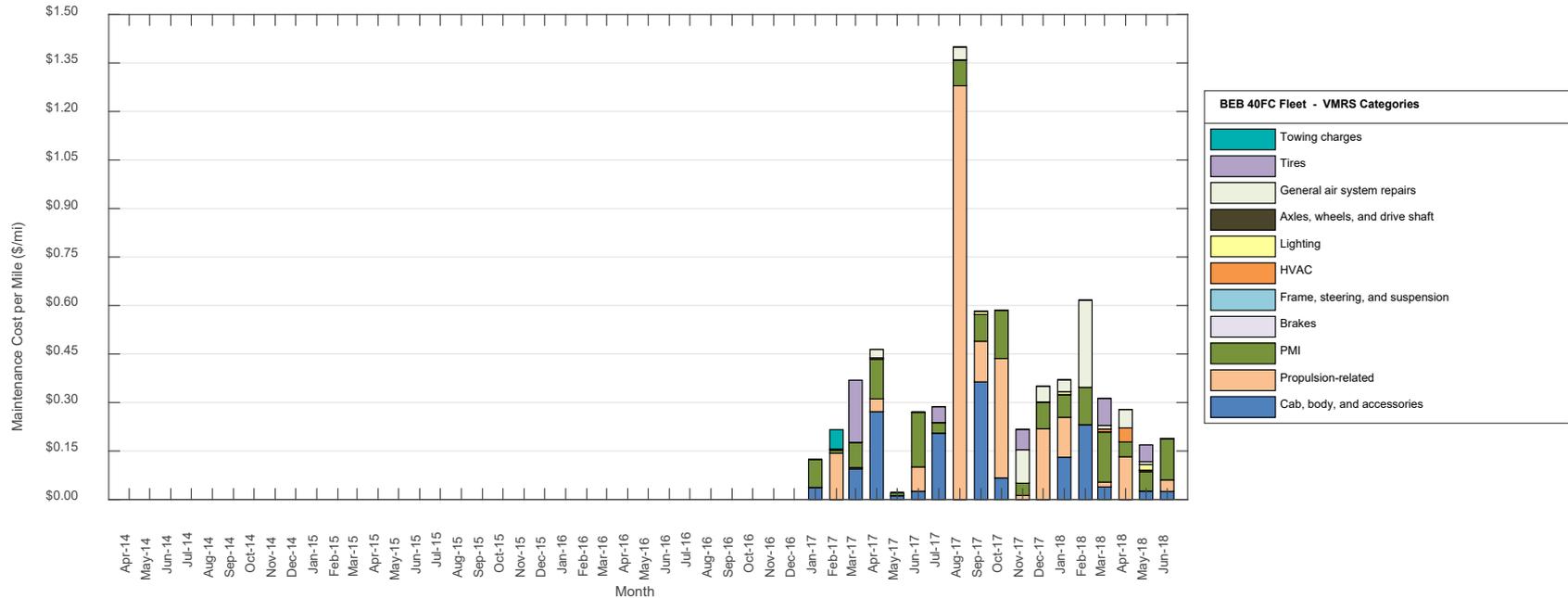
- Propulsion-related repairs for the BEBs: low-voltage batteries, battery equalizer, cooling system, DC-DC converter
- Overall cost per mile without low-voltage battery costs for the BEB 35FC buses was 2.9 times higher than the CNG bus cost; cost for the BEB 40FC buses was the same as the CNG bus cost

Maintenance Cost by System: BEB 35FC Fleet



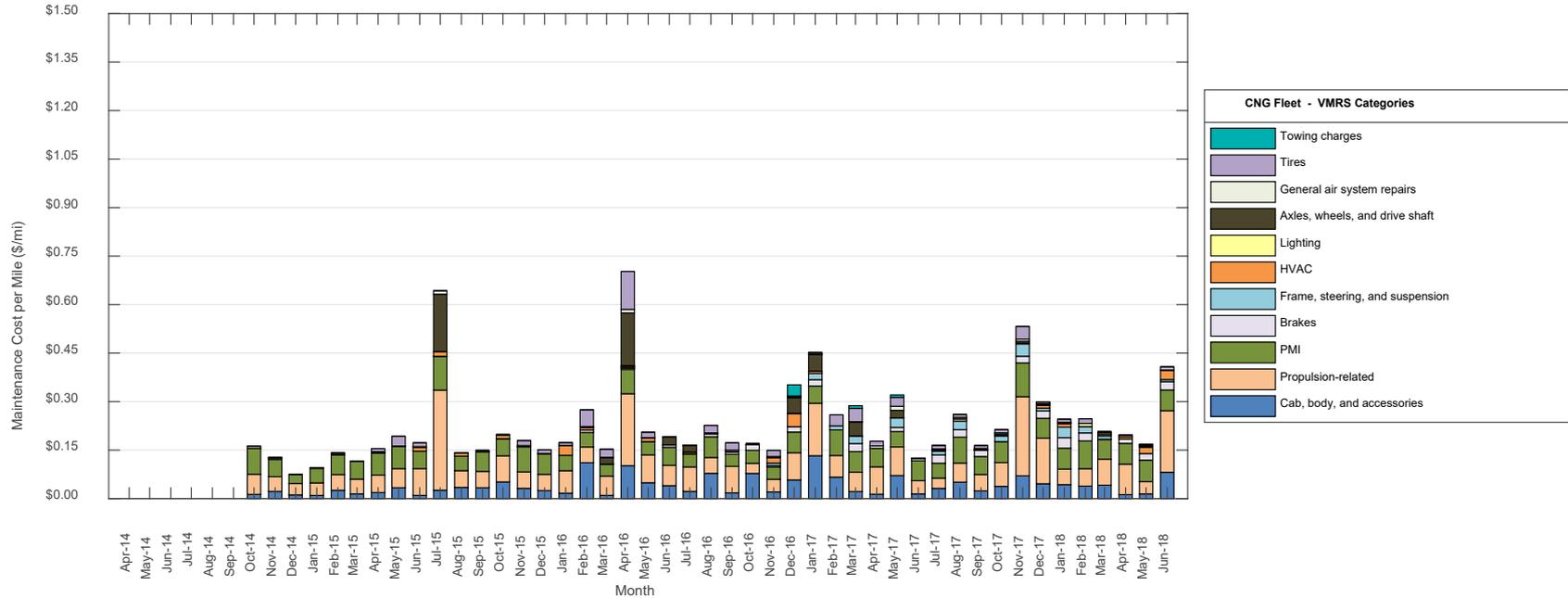
- Costs for the BEB 35FC fleet continue to increase since the warranty ended and transit staff are learning to repair all systems
- The primary driver for the higher propulsion-related cost was issues with the low-voltage batteries

Maintenance Cost by System: BEB 40FC Fleet



- The high propulsion cost during August 2017 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: Jan–Jun 2018

Maintenance System		BEB 35FC	BEB 40FC	CNG
Mileage		144,116	25,125	235,197
Total Propulsion-Related Systems (Roll-Up of All Systems)	Parts cost (\$)	26,875.43	836.71	12,530.16
	Labor hours	326.4	11.8	146.5
	Total cost (\$)	43,192.93	1,424.21	19,855.16
	Total cost (\$) per mile	0.300	0.057	0.084
	Without battery changeouts	0.200	0.000	
Exhaust System Repairs	Parts cost (\$)	0.00	0.00	0.00
	Labor hours	0.0	0.0	1.0
	Total cost (\$)	0.00	0.00	50.00
	Total cost (\$) per mile	0.000	0.000	0.000
Fuel System Repairs	Parts cost (\$)	0.00	0.00	395.32
	Labor hours	3.0	0.0	0.3
	Total cost (\$)	150.00	0.00	407.82
	Total cost (\$) per mile	0.001	0.000	0.002
Powerplant System Repairs (Energy Storage System for BEBs)	Parts cost (\$)	0.00	0.00	3,567.51
	Labor hours	6.5	0.0	53.8
	Total cost (\$)	325.00	0.00	6,255.01
	Total cost (\$) per mile	0.002	0.000	0.027
Electric Propulsion System Repairs	Parts cost (\$)	12,966.00	0.00	0.00
	Labor hours	70.3	0.0	0.0
	Total cost (\$)	16,478.50	0.00	0.00
	Total cost (\$) per mile	0.114	0.000	0.000

Propulsion-Related Maintenance Costs by Subsystem: Jan–Jun 2018

Maintenance System		BEB 35FC	BEB 40FC	CNG
Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)	Parts cost (\$)	12,881.87	836.71	5,016.52
	Labor hours	165.6	11.8	36.8
	Total cost (\$)	21,161.87	1,424.21	6,854.02
	Total cost (\$) per mile	0.147	0.057	0.029
Air Intake System Repairs	Parts cost (\$)	15.27	0.00	1,545.47
	Labor hours	0.0	0.0	0.0
	Total cost (\$)	15.27	0.00	1,545.47
	Total cost (\$) per mile	0.000	0.000	0.007
Cooling System Repairs	Parts cost (\$)	302.29	0.00	1,343.44
	Labor hours	16.0	0.0	39.3
	Total cost (\$)	1,102.29	0.00	3,305.94
	Total cost (\$) per mile	0.008	0.000	0.014
Transmission System Repairs	Parts cost (\$)	710.00	0.00	661.90
	Labor hours	65.0	0.0	15.5
	Total cost (\$)	3,960.00	0.00	1,436.90
	Total cost (\$) per mile	0.027	0.000	0.006
Hydraulic System Repairs	Parts cost (\$)	0.00	0.00	0.00
	Labor hours	0.0	0.0	0.0
	Total cost (\$)	0.00	0.00	0.00
	Total cost (\$) per mile	0.000	0.000	0.000

Maintenance Challenges

Foothill Transit continues to have issues with the low-voltage batteries. Despite the maintenance contractor switching to a better performing battery, the batteries are still failing prematurely. One issue is that the accessories (farebox, cameras) continually draw power from these batteries. In some cases, the operators are not turning off the master switch, which allows the accessories to continue to draw power. Because this issue is not related to the BEB system, NREL has provided the costs with and without the low-voltage battery replacement costs.

The agency also experienced several failed air compressors. This component is part of the general bus system. This could be due to incomplete preventive maintenance, which can result in failure.

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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 Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Number of vehicles	12	12	2	2	8	8
Period used for fuel and oil analysis	4/14–6/18	1/16–6/18	1/17–6/18	1/16–6/18	10/14–6/18	1/16–6/18
Total number of months in period	51	6	18	6	45	6
Fuel and oil analysis base fleet mileage	1,260,044	86,952	40,624	10,760	1,536,521	199,438
Period used for maintenance analysis	1/15–6/18	1/18–6/18	1/17–6/18	1/18–6/18	10/14–6/18	1/18–6/18
Total number of months in period	42	6	18	6	45	6
Maintenance analysis base fleet mileage	1,120,629	144,116	72,712	25,125	1,705,076	235,197
Availability	87	74	82	83	97	96
Fleet fuel/energy usage in BEB kWh/CNG gge	2,738,775.6	183,261.7	89,209.6	23,003.3	397,647.3	52,150.3
Roadcalls	233	30	12	5	54	6
Total MBRC	5,653	4,804	6,059	5,025	31,575	39,200
Propulsion roadcalls	91	20	4	2	31	5
Propulsion MBRC	14,475	7,206	18,178	12,563	55,002	47,039
Fleet kWh/mile (BEB) or miles/gge (CNG)	2.21	2.11	2.20	2.14	3.86	3.82
Representative fleet MPG (energy equiv)	17.05	17.86	17.11	17.61	4.23	4.27
Energy cost per kWh/ CNG cost per gge	0.18	0.18	0.19	0.18	0.95	0.90
Fuel cost per mile	0.44	0.41	0.44	0.41	0.22	0.20
Total scheduled repair cost per mile	0.08	0.09	0.08	0.09	0.12	0.09
Total unscheduled repair cost per mile	0.24	0.63	0.23	0.20	0.11	0.16
Total maintenance cost per mile	0.32	0.71	0.31	0.29	0.23	0.24
Total operating cost per mile	0.76	1.13	0.76	0.71	0.45	0.44

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	1,120,629	144,116	72,712	25,125	1,705,076	235,197
Total parts cost	158,878.74	55,849.43	7,870.76	1,179.71	195,033.16	26,018.37
Total labor hours	3,934.4	940.8	296.1	123.3	3,861.8	631.8
Average labor cost (@ \$50.00 per hour)	196,721.00	47,037.50	14,803.50	6,162.50	193,087.50	31,590.00
Total maintenance cost	355,599.74	102,886.93	22,674.26	7,342.21	388,120.66	57,608.37
Total maintenance cost per bus	29,633.31	8,573.91	1,889.52	611.85	48,515.08	7,201.05
Total maintenance cost per mile without low-voltage battery cost	0.32 0.28	0.71 0.61	0.31 0.23	0.29 0.24	0.23	0.24

Propulsion System Maintenance Cost Summary

	BEB 35FC All Data	BEB 35FC Data Period	BEB 40FC All Data	BEB 40FC Data Period	CNG All Data	CNG Data Period
Total Engine/Fuel-Related Systems (ATA VMRS 27, 30, 31, 32, 33, 41, 42, 43, 44, 45, 46, 65)						
Parts cost	57,551.84	26,875.43	5,018.52	836.71	99,986.36	30,261.89
Labor hours	662.69	326.35	36.19	11.75	685.12	227.27
Average labor cost	33,134.50	16,317.50	1,809.50	587.50	34,256.00	11,363.50
Total cost (for system)	90,686.34	43,192.93	6,828.02	1,424.21	134,242.36	41,625.39
Total cost (for system) per bus	7,557.20	3,599.41	3,414.01	712.11	16,780.30	5,203.17
Total cost (for system) per mile without low-voltage battery cost	0.081 0.041	0.300 0.201	0.094 0.016	0.057 0.000	0.079	0.093

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
Exhaust System Repairs (ATA VMRS 43)						
Parts cost	0.00	0.00	0.00	0.00	2,450.67	2,293.47
Labor hours	0.0	0.0	0.0	0.0	19.4	16.9
Average labor cost	0.00	0.00	0.00	0.00	967.50	842.50
Total cost (for system)	0.00	0.00	0.00	0.00	3,418.17	3,135.97
Total cost (for system) per bus	0.00	0.00	0.00	0.00	427.27	392.00
Total cost (for system) per mile	0.000	0.000	0.000	0.000	0.002	0.007
Fuel System Repairs (ATA VMRS 44)						
Parts cost	0.00	0.00	0.00	0.00	2,312.29	1,364.40
Labor hours	3.0	3.0	0.0	0.0	36.9	11.4
Average labor cost	150.00	150.00	0.00	0.00	1,842.50	570.00
Total cost (for system)	150.00	150.00	0.00	0.00	4,154.79	1,934.40
Total cost (for system) per bus	12.50	12.50	0.00	0.00	519.35	241.80
Total cost (for system) per mile	0.000	0.001	0.000	0.000	0.002	0.004
Power Plant (Engine) Repairs (ATA VMRS 45)						
Parts cost	1,428.22	0.00	0.00	0.00	45,826.40	10,324.02
Labor hours	30.9	6.5	0.0	0.0	162.6	19.6
Average labor cost	1,542.50	325.00	0.00	0.00	8,131.50	979.00
Total cost (for system)	2,970.72	325.00	0.00	0.00	53,957.90	11,303.02
Total cost (for system) per bus	247.56	27.08	0.00	0.00	6,744.74	1,412.88
Total cost (for system) per mile	0.003	0.002	0.000	0.000	0.032	0.025

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
Electric Propulsion Repairs (ATA VMRS 46)						
Parts cost	15,277.45	12,966.00	0.00	0.00	0.00	0.00
Labor hours	115.6	70.3	0.0	0.0	0.0	0.0
Average labor cost	5,778.50	3,512.50	0.00	0.00	0.00	0.00
Total cost (for system)	21,055.95	16,478.50	0.00	0.00	0.00	0.00
Total cost (for system) per bus	1,754.66	1,373.21	0.00	0.00	0.00	0.00
Total cost (for system) per mile	0.019	0.114	0.000	0.000	0.000	0.000
Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)						
Parts cost	38,785.90	12,881.87	5,018.52	836.71	16,019.30	5,078.01
Labor hours	375.4	165.6	35.2	11.8	225.6	109.2
Average labor cost	18,771.00	8,280.00	1,759.50	587.50	11,278.50	5,461.00
Total cost (for system)	57,556.90	21,161.87	6,778.02	1,424.21	27,297.80	10,539.01
Total cost (for system) per bus	4,796.41	1,763.49	3,389.01	712.11	3,412.23	1,317.38
Total cost (for system) per mile	0.051	0.147	0.093	0.057	0.016	0.023
Air Intake System Repairs (ATA VMRS 41)						
Parts cost	15.27	15.27	0.00	0.00	17,845.35	4,242.09
Labor hours	3.9	0.0	0.0	0.0	1.8	1.0
Average labor cost	195.00	0.00	0.00	0.00	87.50	50.00
Total cost (for system)	210.27	15.27	0.00	0.00	17,932.85	4,292.09
Total cost (for system) per bus	17.52	1.27	0.00	0.00	2,241.61	536.51
Total cost (for system) per mile	0.000	0.000	0.000	0.000	0.011	0.010

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
Cooling System Repairs (ATA VMRS 42)						
Parts cost	1,256.00	302.29	0.00	0.00	10,735.63	3,233.89
Labor hours	58.0	16.0	1.0	0.0	184.5	47.0
Average labor cost	2,900.00	800.00	50.00	0.00	9,225.00	2,347.50
Total cost (for system)	4,156.00	1,102.29	50.00	0.00	19,960.63	5,581.39
Total cost (for system) per bus	346.33	91.86	25.00	0.00	2,495.08	697.67
Total cost (for system) per mile	0.004	0.008	0.001	0.000	0.012	0.012
Hydraulic System Repairs (ATA VMRS 65)						
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
Total cost (for system) per mile	0.000	0.000	0.000	0.000	0.000	0.000
General Air System Repairs (ATA VMRS 10)						
Parts cost	21,150.24	18,603.56	398.69	266.93	1,860.59	528.12
Labor hours	197.7	77.0	28.7	16.0	41.4	23.0
Average labor cost	9,886.00	3,850.00	1,435.00	800.00	2,067.50	1,147.50
Total cost (for system)	31,036.24	22,453.56	1,833.69	1,066.93	3,928.09	1,675.62
Total cost (for system) per bus	2,586.35	1,871.13	916.85	533.47	491.01	209.45
Total cost (for system) per mile	0.028	0.156	0.025	0.042	0.002	0.004

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
Brake System Repairs (ATA VMRS 13)						
Parts cost	1,528.23	0.00	0.00	0.00	9,555.68	4,135.78
Labor hours	57.9	5.0	0.0	0.0	92.0	51.8
Average labor cost	2,893.50	250.00	0.00	0.00	4,597.50	2,587.50
Total cost (for system)	4,421.73	250.00	0.00	0.00	14,153.18	6,723.28
Total cost (for system) per bus	368.48	20.83	0.00	0.00	1,769.15	840.41
Total cost (for system) per mile	0.004	0.002	0.000	0.000	0.008	0.015
Transmission Repairs (ATA VMRS 27)						
Parts cost	789.00	710.00	0.00	0.00	4,796.73	3,726.01
Labor hours	74.5	65.0	0.0	0.0	54.5	22.3
Average labor cost	3,722.50	3,250.00	0.00	0.00	2,723.50	1,113.50
Total cost (for system)	4,511.50	3,960.00	0.00	0.00	7,520.23	4,839.51
Total cost (for system) per bus	375.96	330.00	0.00	0.00	940.03	604.94
Total cost (for system) per mile	0.004	0.027	0.000	0.000	0.004	0.011
Inspections Only—No Parts Replacements (101)						
Parts cost	0.00	0.00	0.00	0.00	0.00	0.00
Labor hours	1680.8	244.5	112.7	45.0	2019.6	584.1
Average labor cost	84,040.00	12,222.50	5,636.00	2,250.00	100,979.00	29,204.00
Total cost (for system)	84,040.00	12,222.50	5,636.00	2,250.00	100,979.00	29,204.00
Total cost (for system) per bus	7,003.33	1,018.54	2,818.00	1,125.00	12,622.38	3,650.50
Total cost (for system) per mile	0.075	0.085	0.078	0.090	0.059	0.065

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
Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)						
Parts cost	17,461.30	8,321.04	1,200.08	0.00	31,490.79	10,359.19
Labor hours	874.8	147.9	88.8	31.0	703.9	220.9
Average labor cost	43,741.00	7,392.50	4,441.50	1,550.00	35,194.50	11,047.00
Total cost (for system)	61,202.30	15,713.54	5,641.58	1,550.00	66,685.29	21,406.19
Total cost (for system) per bus	5,100.19	1,309.46	2,820.79	775.00	8,335.66	2,675.77
Total cost (for system) per mile	0.055	0.109	0.078	0.062	0.039	0.048
HVAC System Repairs (ATA VMRS 01)						
Parts cost	1,023.79	573.59	76.07	76.07	6,969.72	492.63
Labor hours	43.6	16.0	3.5	3.5	64.3	7.1
Average labor cost	2,177.50	800.00	175.00	175.00	3,212.50	355.00
Total cost (for system)	3,201.29	1,373.59	251.07	251.07	10,182.22	847.63
Total cost (for system) per bus	266.77	114.47	125.54	125.54	1,272.78	105.95
Total cost (for system) per mile	0.003	0.010	0.003	0.010	0.006	0.002
Lighting System Repairs (ATA VMRS 34)						
Parts cost	2,514.73	473.63	0.00	0.00	417.25	232.40
Labor hours	116.3	27.7	4.0	3.0	29.5	13.5
Average labor cost	5,812.50	1,385.00	200.00	150.00	1,472.50	675.00
Total cost (for system)	8,327.23	1,858.63	200.00	150.00	1,889.75	907.40
Total cost (for system) per bus	693.94	154.89	100.00	75.00	236.22	113.43
Total cost (for system) per mile	0.007	0.013	0.003	0.006	0.001	0.002

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
Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)						
Parts cost	1,554.68	1,002.18	0.00	0.00	7,286.47	5,000.13
Labor hours	71.5	43.4	0.0	0.0	64.1	41.9
Average labor cost	3,574.00	2,170.00	0.00	0.00	3,203.50	2,093.50
Total cost (for system)	5,128.68	3,172.18	0.00	0.00	10,489.97	7,093.63
Total cost (for system) per bus	427.39	264.35	0.00	0.00	1,311.25	886.70
Total cost (for system) per mile	0.005	0.022	0.000	0.000	0.006	0.016
Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)						
Parts cost	1,665.40	0.00	0.00	0.00	20,300.62	4,457.44
Labor hours	7.0	0.0	0.0	0.0	12.0	2.0
Average labor cost	350.00	0.00	0.00	0.00	600.00	100.00
Total cost (for system)	2,015.40	0.00	0.00	0.00	20,900.62	4,557.44
Total cost (for system) per bus	167.95	0.00	0.00	0.00	2,612.58	569.68
Total cost (for system) per mile	0.002	0.000	0.000	0.000	0.012	0.010
Tire Repairs (ATA VMRS 17)						
Parts cost	48,143.53	0.00	892.40	0.00	15,327.68	4,604.76
Labor hours	222.2	53.0	22.1	13.0	149.1	64.2
Average labor cost	11,112.00	2,650.00	1,106.50	650.00	7,454.50	3,209.50
Total cost (for system)	59,255.53	2,650.00	1,998.90	650.00	22,782.18	7,814.26
Total cost (for system) per bus	4,937.96	220.83	999.45	325.00	2,847.77	976.78
Total cost (for system) per mile	0.053	0.018	0.027	0.026	0.013	0.017

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
Towing Charges						
Charge	6,285.00	0.00	285.00	0.00	1,838.00	635.00
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	1,888.00	635.00
Total cost (for system) per bus	523.75	0.00	142.50	0.00	236.00	79.38
Total cost (for system) per mile	0.006	0.000	0.004	0.000	0.001	0.001

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	4/14–6/18	1/18–6/18	1/17–6/18	1/18–6/18	10/14–6/18	1/18–6/18
Total number of months in period	51	6	18	6	45	6
Fuel and oil analysis base fleet kilometers	1,996,407	139,932	65,376	17,316	2,472,723	320,956
Period used for maintenance analysis	1/15–6/18	1/18–6/18	1/17–6/18	1/18–6/18	10/14–6/18	1/18–6/18
Total number of months in period	42	6	18	6	45	6
Maintenance analysis base fleet kilometers	1,571,503	231,926	117,015	40,434	2,743,979	378,503
Average monthly kilometers per vehicle	3,581	3,221	3,584	3,369	7,622	7,885
Availability	87	74	81	83	97	96
Fleet fuel/energy usage in kWh (BEB)/gge (CNG)	2,738,775.6	183,261.7	89,209.6	23,003.3	1,505,258.9	197,410.4
Roadcalls	233	30	12	5	54	6
Total KBRC	9,091	7,731	9,751	8,087	50,814	63,084
Propulsion roadcalls	91	20	4	2	31	5
Propulsion KBRC	23,277	11,596	29,254	20,217	88,515	75,701
Representative fleet kg/100km (energy equiv.)	13.77	13.15	13.70	13.34	54.48	55.05
Energy cost per kWh/CNG cost per gge	0.18	0.18	0.19	0.18	0.25	0.24
Fuel cost per kilometer	0.28	0.26	0.28	0.26	0.15	0.15
Total scheduled repair cost per km	0.05	0.05	0.05	0.06	0.07	0.05
Total unscheduled repair cost per km	0.15	0.39	0.15	0.13	0.07	0.10
Total maintenance cost per km	0.20	0.44	0.19	0.18	0.14	0.15
Total operating cost per km	0.47	0.70	0.47	0.44	0.29	0.30

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	1,803,429	231,926	117,015	40,434	2,743,979	378,503
Total parts cost	158,878.74	55,849.43	7,870.76	1,179.71	195,033.16	26,018.37
Total labor hours	3,934.4	940.8	296.1	123.3	3,861.8	631.8
Average labor cost (@ \$50.00 per hour)	196,721.00	47,037.50	14,803.50	6,162.50	193,087.50	31,590.00
Total maintenance cost	355,599.74	102,886.93	22,674.26	7,342.21	388,120.66	57,608.37
Total maintenance cost per bus	29,633.31	8,573.91	1,889.52	611.85	48,515.08	7,201.05
Total maintenance cost per km	0.20	0.44	0.19	0.18	0.14	0.15
<i>without low-voltage battery cost</i>	<i>0.17</i>	<i>0.38</i>	<i>0.15</i>	<i>0.15</i>	—	—

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