NREL
NATIONAL RENEWABLE ENERGY LABORATORY





Battery Electric Bus Evaluation Results

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NREL Role in ZEB Evaluation

- 3rd Party evaluation of advanced technology in real-world service
- Established evaluation protocol provides consistent data collection and analysis for comparison
- Provide feedback to government (federal, state, local) to understand status and continue funding necessary R&D
- Share information with the transit industry that will aid in purchase decisions on the technology
  - Unbiased data in common format
  - Comparison to baseline technology

OEMs Offering Electric Buses

- BYD: BEB
  - 30-ft, 40-ft, 60-ft, Commuter coach
  - Plug in, Optional WAVE inductive charging on-route
- ElDorado National California: FCEB
  - 40-ft, BAE Hybrid system, Ballard fuel cell
- Gillig, BEB
  - 29-ft trolley replica
  - Plug in with WAVE inductive charging on-route
- New Flyer: BEB and FCEB
  - 40-ft Xcelsior platform
  - FCEB with Ballard or Hydrogenics fuel cell
  - BEB on-route fast charge or plug in
- Nova: BEB
  - 40-ft on-route fast charge
- Proterra: BEB
  - 35-ft, 40-ft
  - On-route fast charge or plug-in extended range

Evaluation Objectives and DOE/FTA Targets

- Validate zero emission buses[1] (ZEB) performance and cost compared to DOE/DOT targets and conventional technologies
- Document progress and "lessons learned" on implementing ZEBs in transit operations to address barriers to market acceptance

Current Targets[2]	Units	2016 Target	Ultimate Target
Bus lifetime	Years/miles	12/500,000	12/500,000
Powerplant lifetime	Hours	18,000	25,000
Bus availability	%	85	90
Roadcall frequency (bus/fuel cell system)	Miles between roadcall	3,500/15,000	4,000/20,000
Operation time	Hours per day/ days per week	20/7	20/7
Maintenance cost	$/mile	0.75	0.40
Fuel economy	Miles per diesel gallon equivalent	8	8

[1] ZEBs can be battery electric buses (BEB) or fuel cell electric buses (FCEB)

[2] Fuel Cell Technologies Program Record # 12012, Sep 2012, www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf

Current Status of BEBs

	Fleet Minimum	Fleet Maximum	Fleet Average
Bus lifetime (years)	0.8	2.9	2.3
Bus lifetime (miles)	17,960	85,274	64,045
Bus availability (%)	74	97	88
Charges (number per day)	1	31	8
Roadcall frequency – bus (MBRC)			5,656
Roadcall frequency – propulsion system			15,023
Roadcall frequency – energy storage system			320,496
Operation time per day (hours)	<1	22.4	9
Scheduled and unscheduled maintenance cost ($/mile)[1]	0.13	0.29	0.19
Fuel economy (miles per DGE)	16.09	18.72	17.29

Data from 2 fleets – 15 total buses

[1] Buses are currently under warranty – all advanced technology maintenance is handled by OEM

Foothill Transit, West Covina, California

BEBs service Start: April 2014

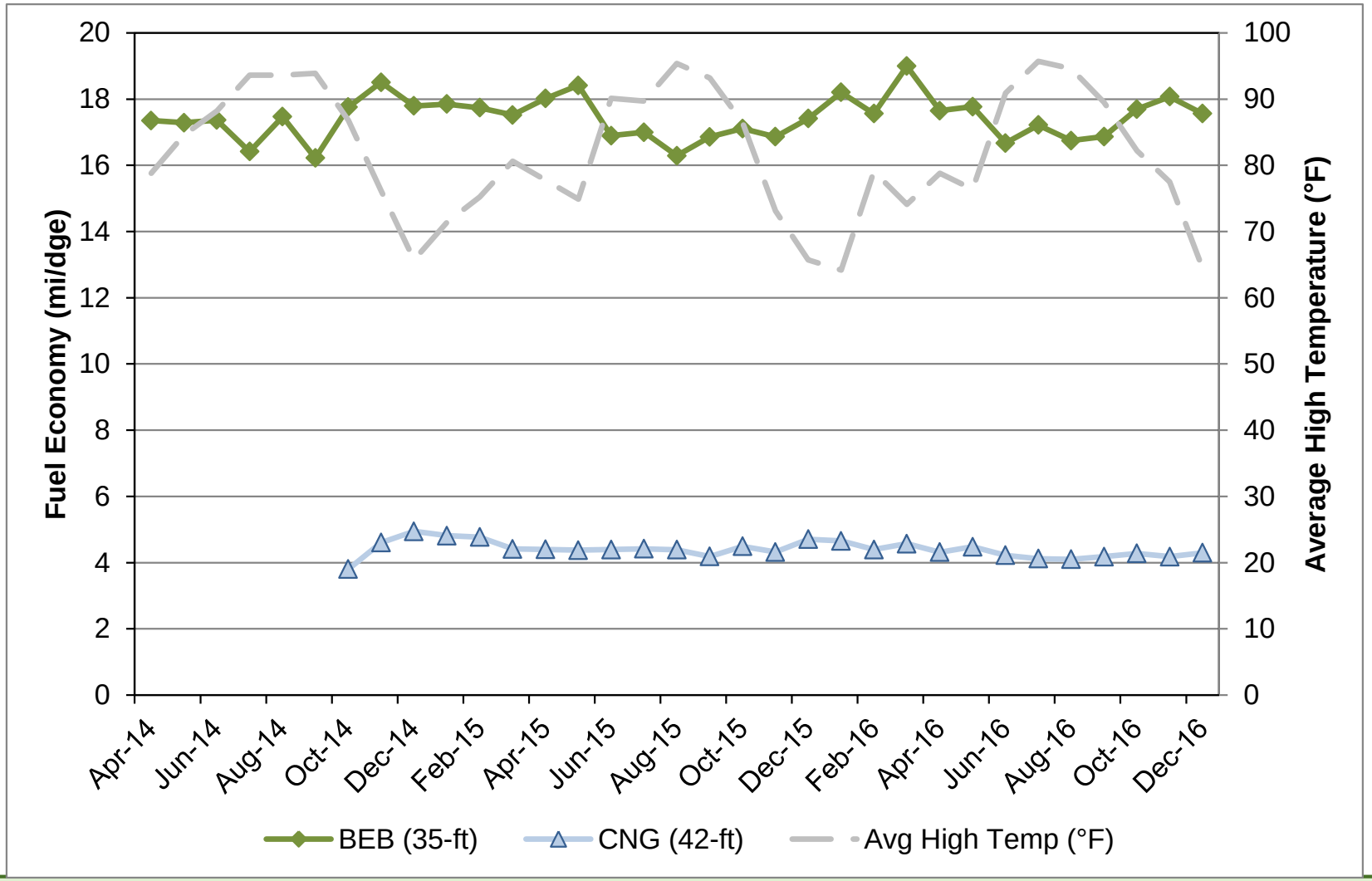
Baseline comparison:

NABI CNG, 42-ft

Foothill Transit BEB Specifications

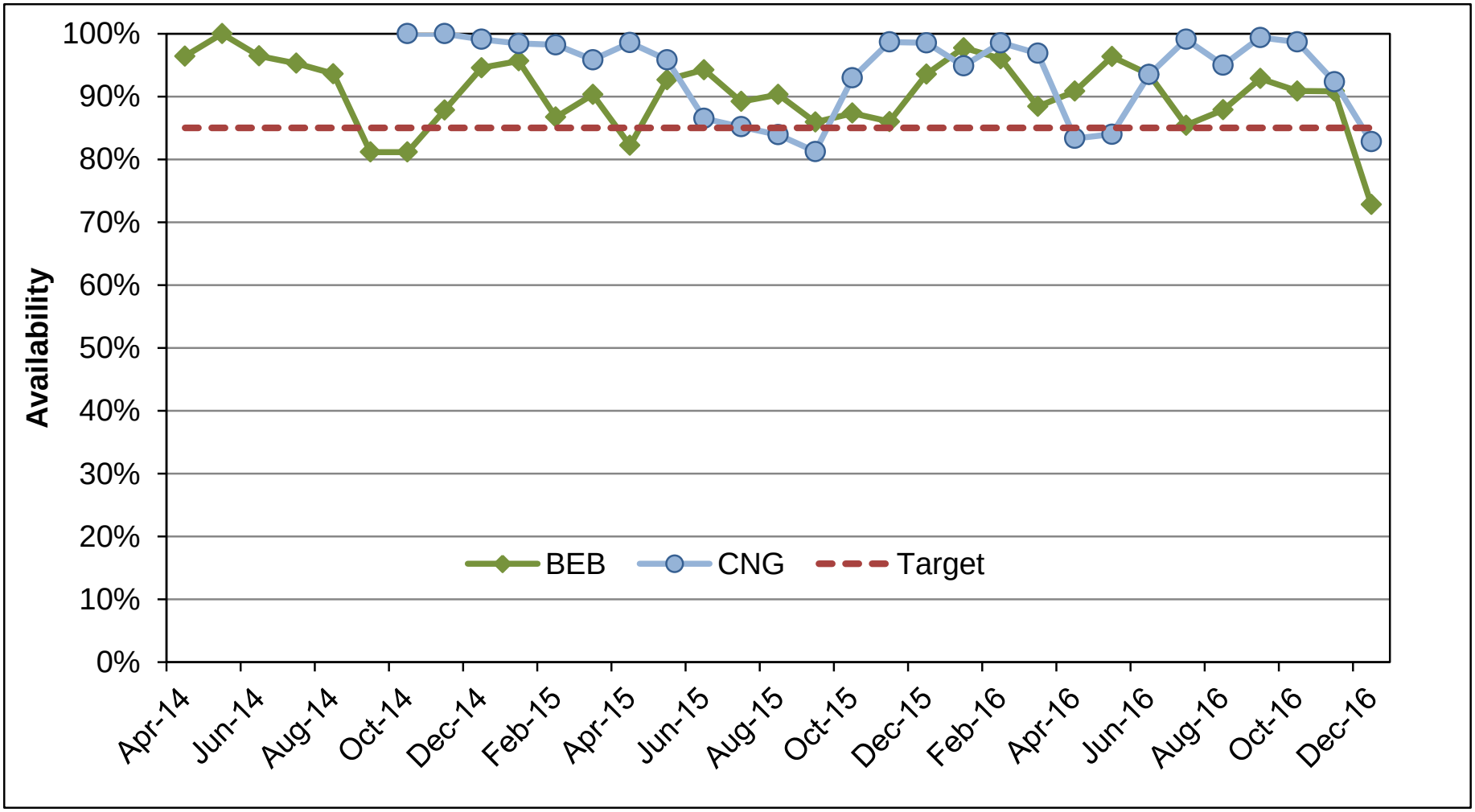
FCEB Identifier	BEB
Number of Buses	12
Bus OEM	Proterra
Bus length/height	35 ft / 126 in
Charging strategy	Fast-charge, on-route
Motor	Permanent magnet, UQM, PP220
Rated Power (kW)	220 (peak)
Energy Storage - OEM	Lithium-titanate
Capacity	368 volts, 88 kWh

Foothill Transit BEB Efficiency



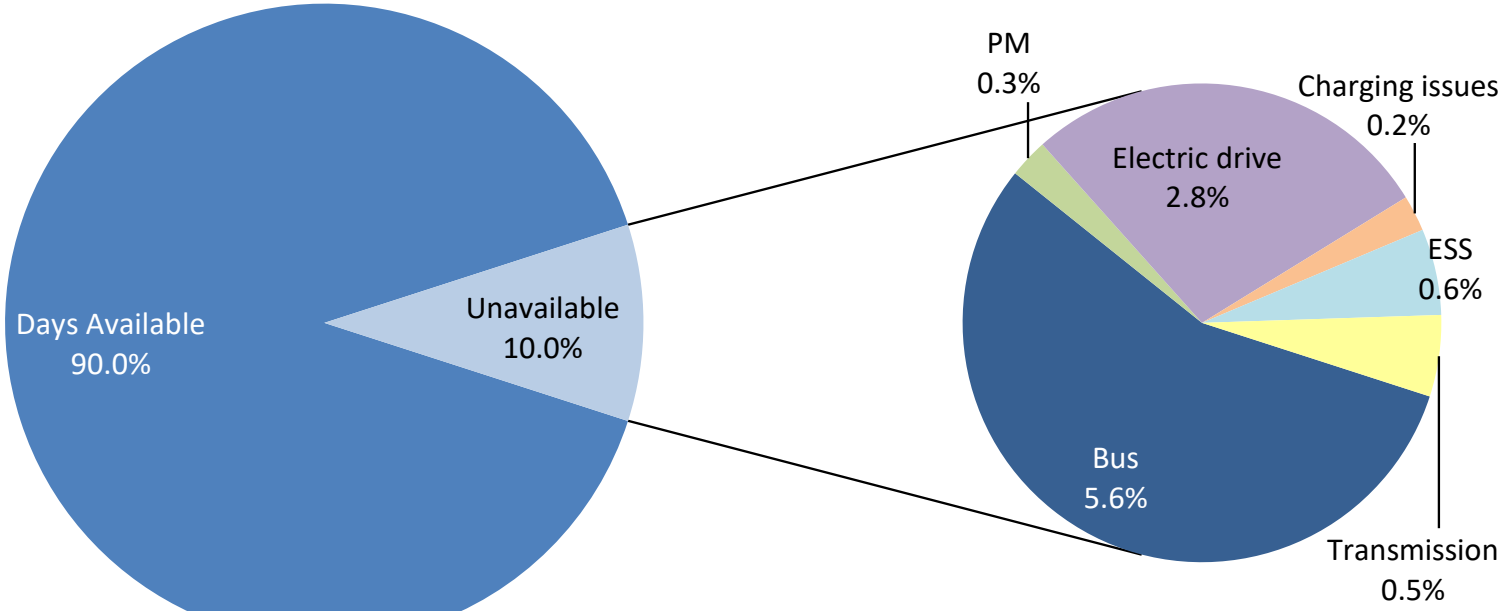
BEB equivalent fuel economy 4x higher than CNG buses. High cost of electricity results in higher cost per mile.

Foothill Transit BEB Availability by Month



Availability generally over the target. Overall availability for data period is 90%

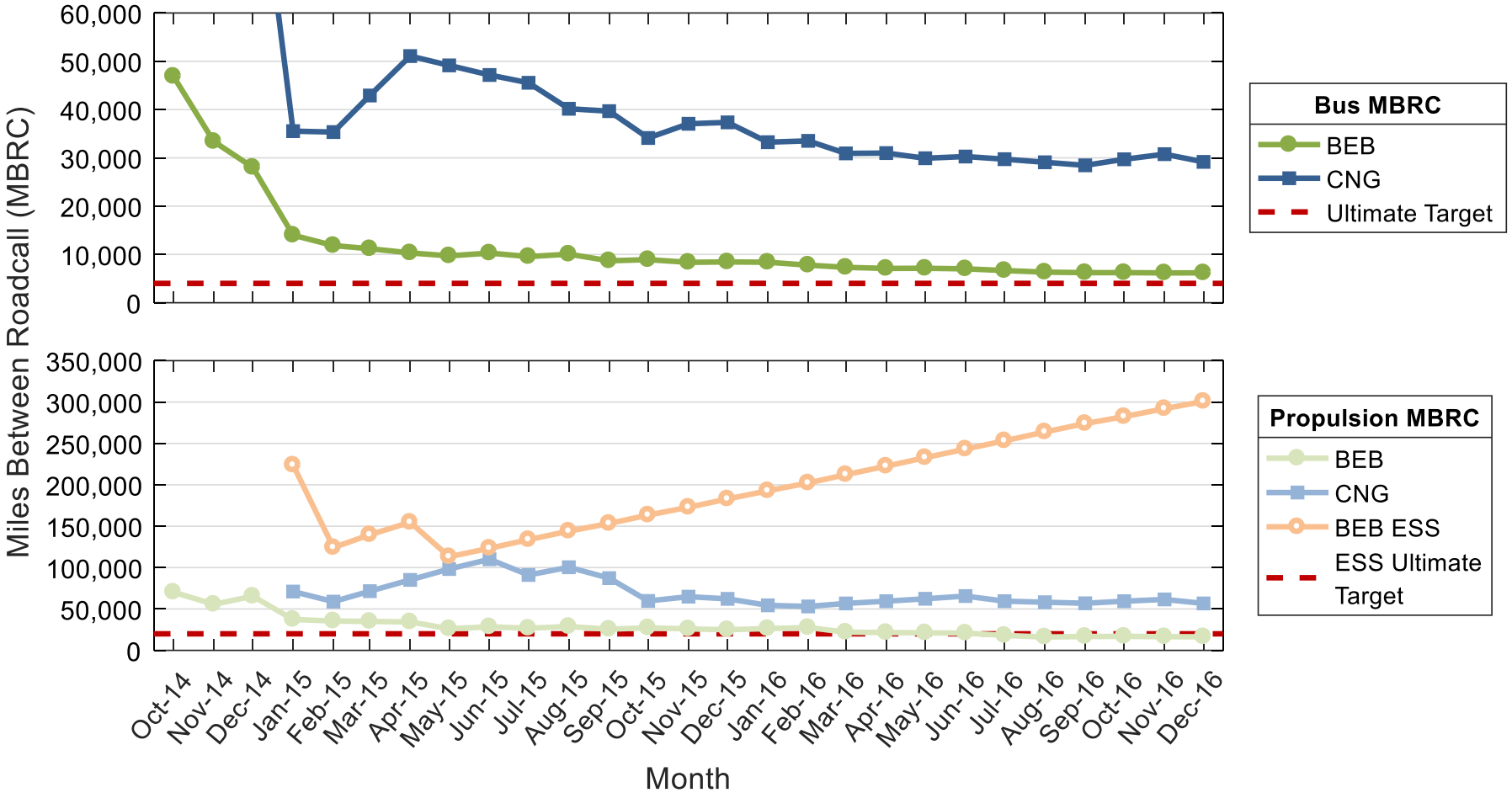
Foothill Transit BEB Availability - Overall



BEB Fleet	Number	%
Available	8,550	90
Bus	527	5.6
PM	25	0.3
Electric Drive	263	2.8
Charging issues	23	0.2
ESS	55	0.6
Transmission	52	0.5
Total days	9,495	100

Bus issues are the primary reasons for unavailability, followed by electric drive

Foothill Transit BEB Reliability



Early results show the BEB performance exceeds the ultimate targets.

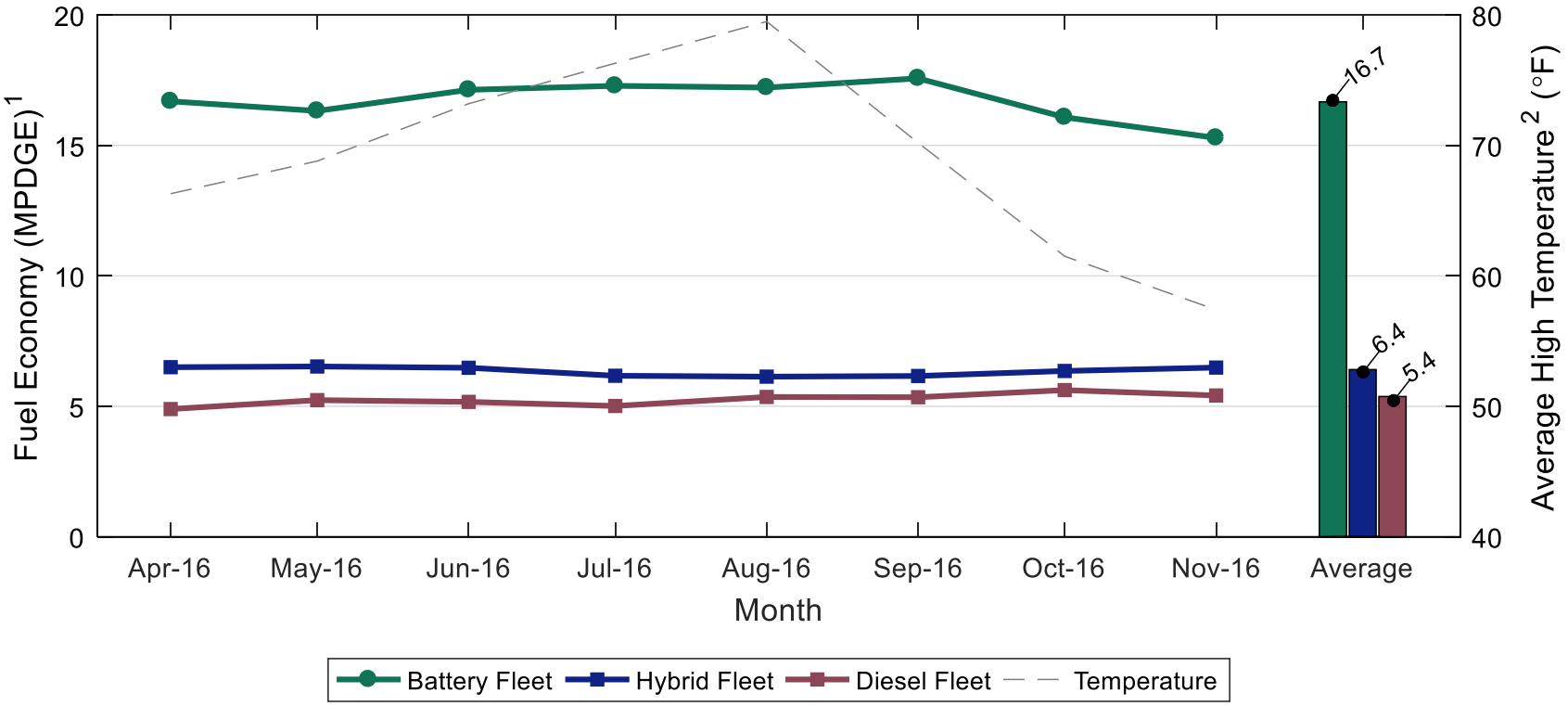
King County Metro, Seattle, WA (TIGGER)

- BEB in service date: April 2016
- 3 Proterra, 40-ft Catalyst buses and fast charging station (8 more on order)
- Baseline buses: diesel, diesel hybrid, and electric trolley buses

KC Metro BEB Specifications

FCEB Identifier	BEB
Number of Buses	3
Bus OEM	Proterra
Bus length/height	40 ft / 126 in
Charging strategy	Fast-charge, on-route
Motor	Permanent magnet, UQM, PP220
Rated Power (kW)	220 (peak)
Energy Storage	Lithium-titanate
Capacity	331 volts, 106 kWh

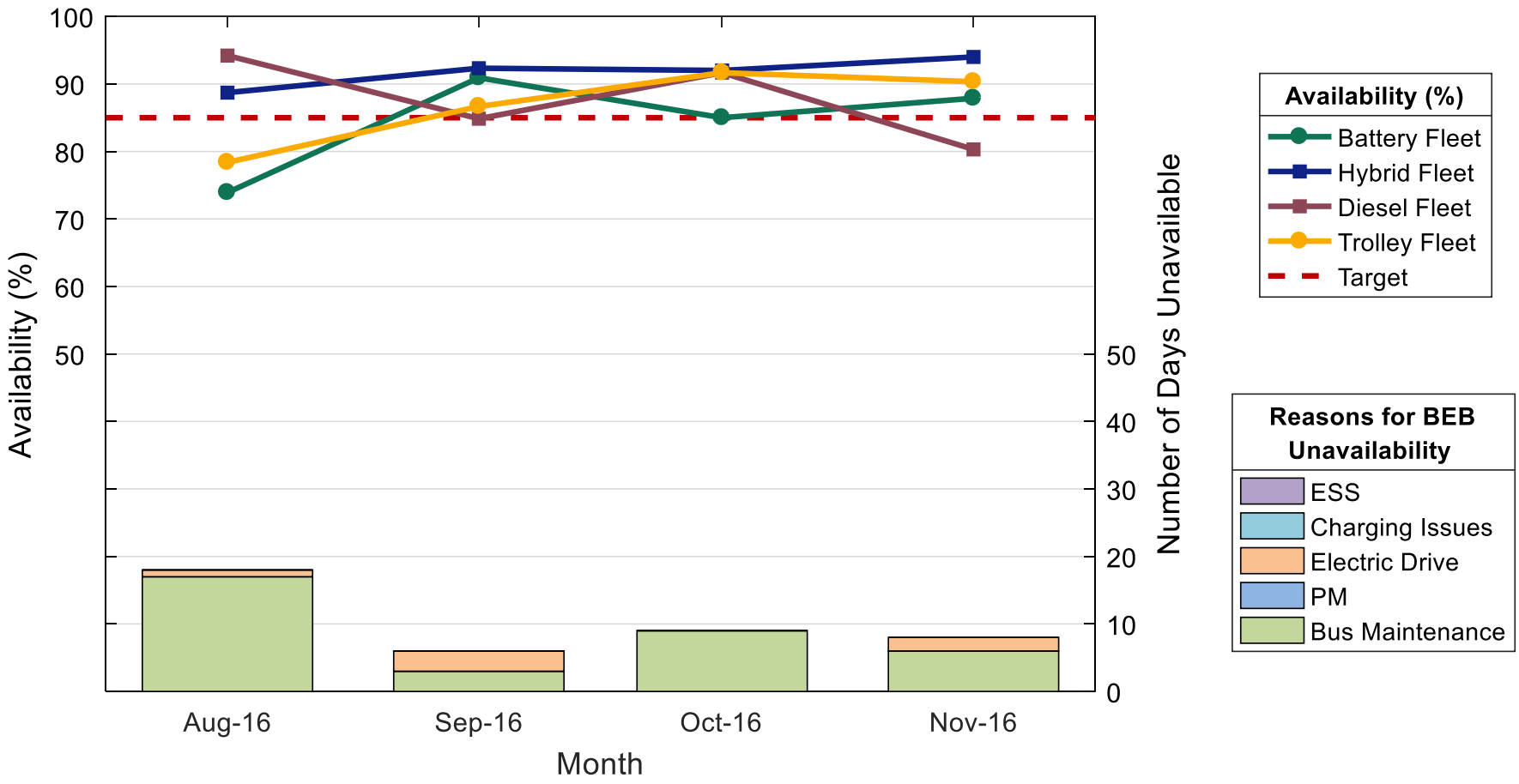
KC Metro BEB Efficiency



1. BEB electrical energy converted to diesel gallon equivalent (DGE); conversion factor = 37.7 kWh/diesel gallon, based on the energy content of electricity (3,412 Btu) and diesel fuel LHV (128,488 Btu).
2. Renton Municipal Airport average daily high temperatures; data acquired from: *https://www.ncdc.noaa.gov/*

BEB equivalent fuel economy 3x higher than diesel buses and 2.6x higher than diesel hybrid buses. High cost of electricity results in higher cost per mile.

KC Metro Availability by Month



Overall availability for data period:

BEB 84% Diesel hybrids 92%

Diesel 88% Trolley 87%

Remaining Challenges and Barriers for ZEBs

- Plan/build of opportunity charging stations & garage chargers
- Select appropriate routes for technology – fast-charge, in-depot charging
- Address challenge of electric rates and demand charges
- Scale up for larger fleets – how best to accommodate plug in charging/ parking
- Training transition for maintenance staff
- Develop supply chain for parts

Web site:

http://www.nrel.gov/hydrogen/proj_fc_bus_eval.html

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