



Foothill Transit Battery Electric Bus Performance Results

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Presentation Outline

- NREL overview
- Zero emission bus (ZEB) evaluation objectives
- Foothill Transit Battery Electric Bus (BEB) project overview
- BEB performance data
- Remaining challenges and barriers for ZEBs
- Status of new BEB evaluations

NREL Snapshot

Dedicated Solely to Advancing Energy Efficiency and Renewable Energy

- Leading clean-energy innovation for more than 37 years
- ~1,760 employees with world-class facilities
- Campus is a living model of sustainable energy
- Economic impact at \$872M nationwide
- Owned by the Department of Energy and Operated by the Alliance for Sustainable Energy



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

Current and Planned ZEB Evaluations

NREL Zero Emission Bus Evaluations

Demonstration	State	City	Bus Length	# Buses	2016				2017				2018			
					1	2	3	4	1	2	3	4	1	2	3	4
ZEBA Demonstration	CA	Oakland	40	13	AC Transit											
American Fuel Cell Bus (AFCB)	CA	Thousand Palms	40	1	SunLine											
	CA	Orange County	40	1		OCTA										
	OH	Canton, Cleveland	40	2	SARTA/GCRTA/OSU											
	CA	Irvine	40	1	UCI											
AFCB (TIGGER)	CA	Thousand Palms	40	3	SunLine											
Massachusetts AFCB	MA	Boston	40	1	MBTA											
Battery Dominant AFCB	CA	Thousand Palms	40	1					SunLine							
AFCB (Low-No)	CA	Thousand Palms	40	5					SunLine							
	OH	Canton	40	5					SARTA							
Advanced Generation FCEB	CA	Oakland	60	1					AC Transit							
On-route Charge BEB (TIGGER)	CA	West Covina	35	12	Foothill Transit											
On-route Charge BEB (TIGGER)	WA	Seattle	40	3	King County Metro											
Plug-in Charge BEB (TIGGER)	CA	Long Beach	40	10		Long Beach Transit										

Color coded by Technology:

-  Fuel cell dominant electric
-  Battery dominant fuel cell electric
-  Fast-charge battery electric
-  Plug-in battery electric

Evaluations are funded by the Department of Energy, the Federal Transit Administration, and the California Air Resources Board

ZEB Evaluation Objectives

- Validate zero-emission bus¹ (ZEB) performance and cost compared to DOE/FTA targets and conventional technologies
- Document progress and “lessons learned” on implementing fuel cell systems in transit operations to address barriers to market acceptance

Current FCEB Targets ²	Units	2016 Target	Ultimate Target
Bus lifetime	Years / miles	12/500,000	12/500,000
Bus availability	%	85	90
Roadcall frequency (Bus/fuel cell system)	Miles between road call	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 ZEB technologies include fuel cell electric buses (FCEB) and battery electric buses (BEB)

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

Foothill Transit, West Covina, California

BEBs service Start: April 2014

Baseline comparison:

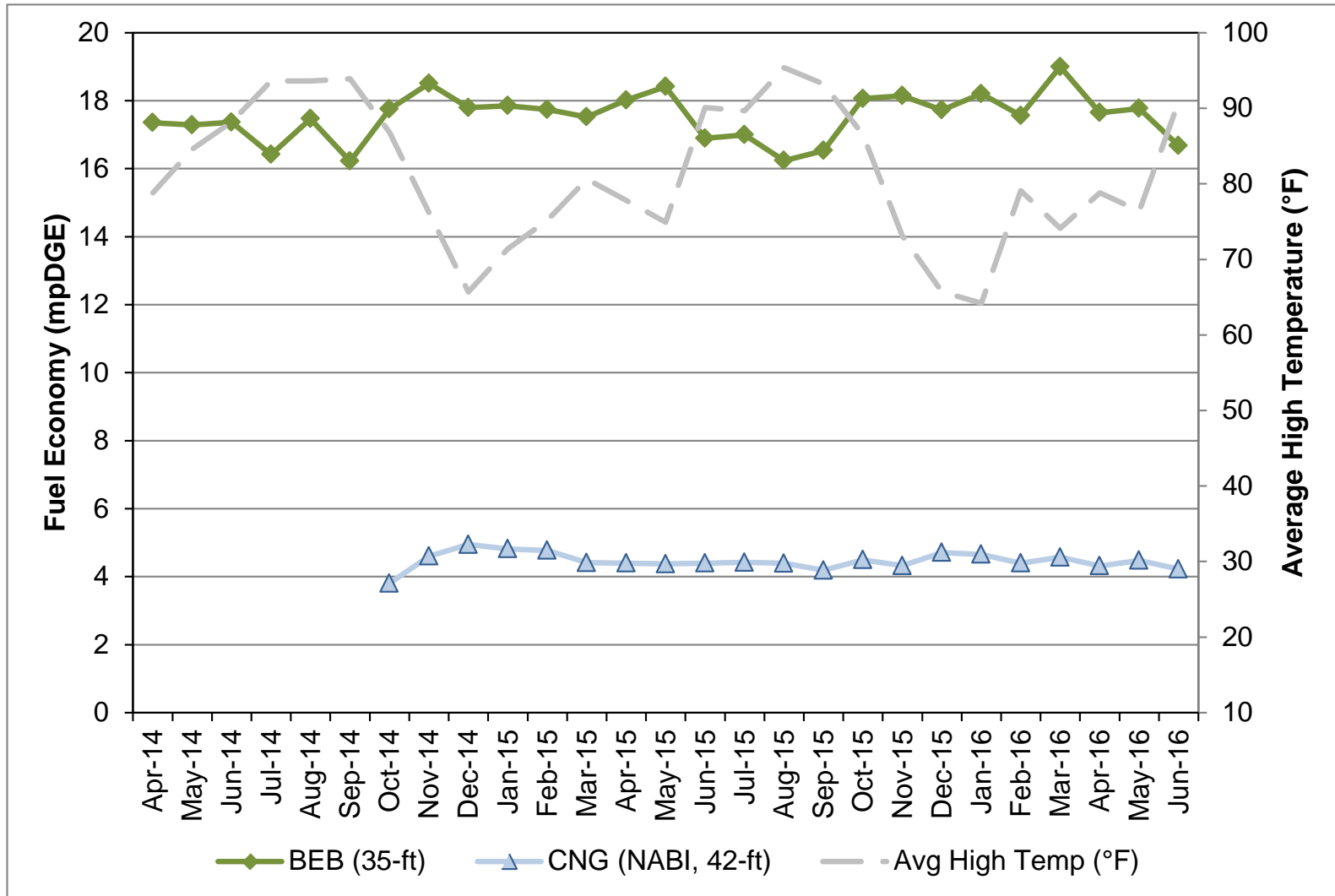
NABI CNG, 42-ft

Foothill 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	Altairnano
Type	Lithium-titanate
Capacity	368 volts, 88 kWh

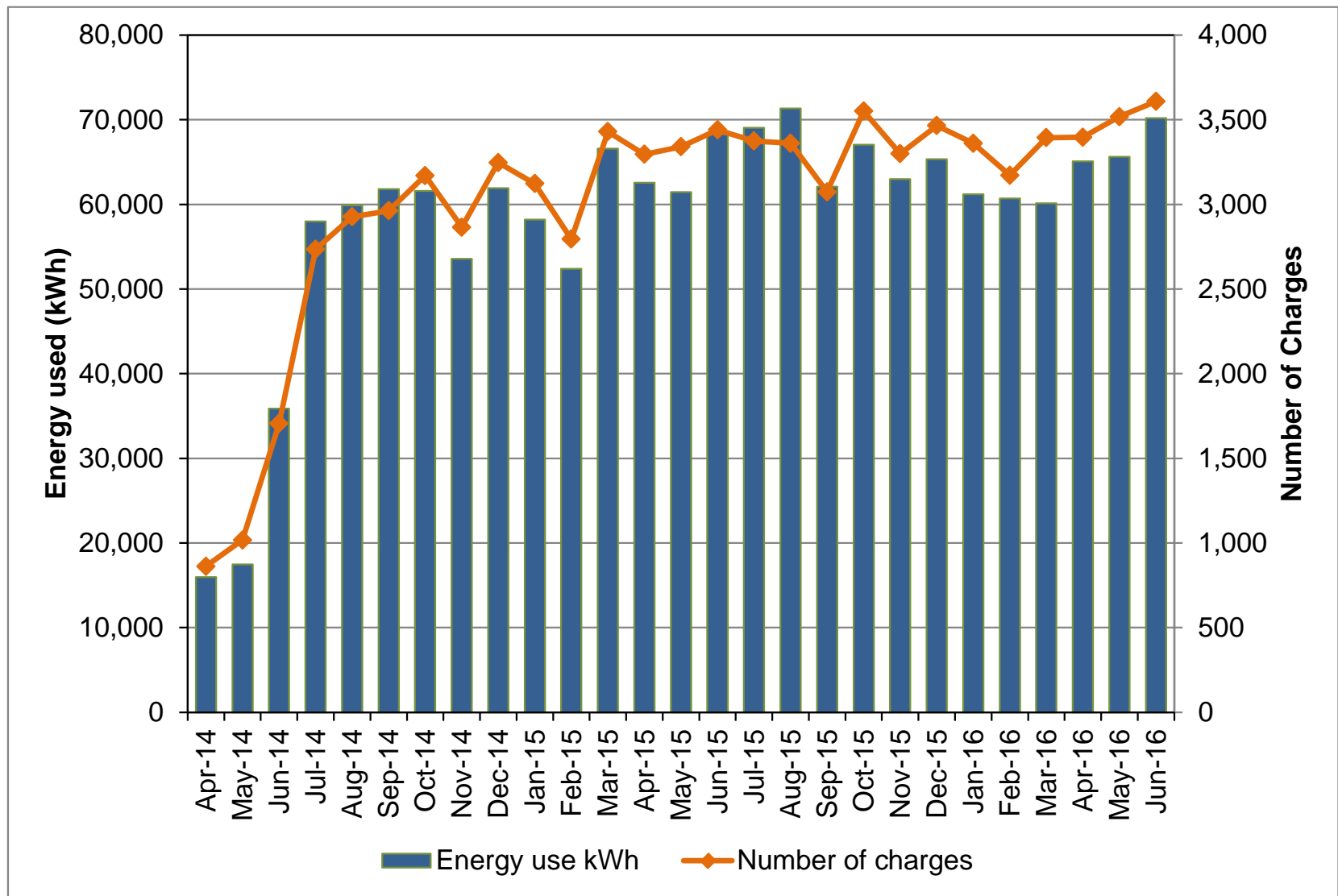


Monthly Fuel Economy compared to Baseline

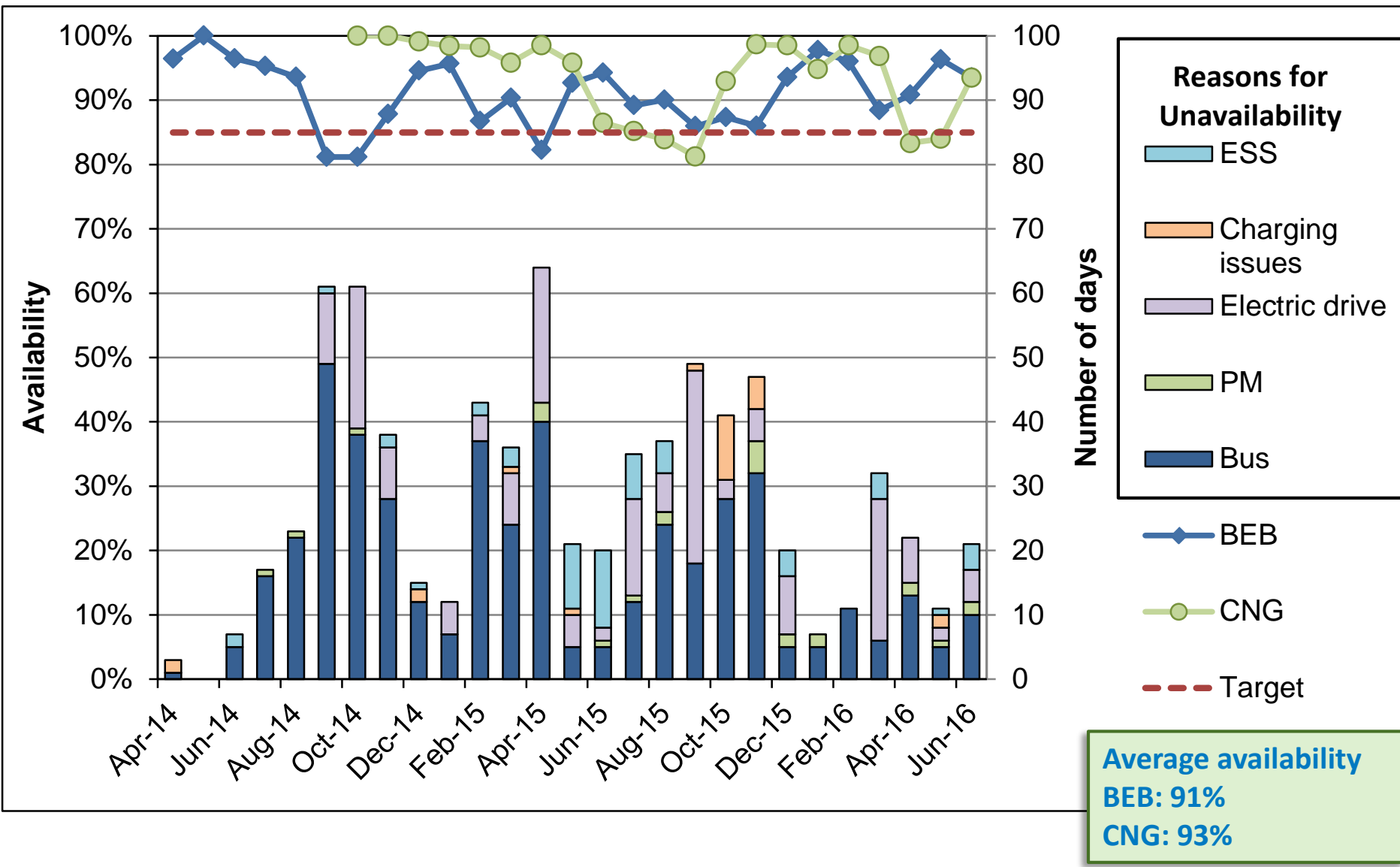


BEB average: 2.15 kWh/mi, 17.48 mi/DGE
CNG average: 4.51 mi/DGE

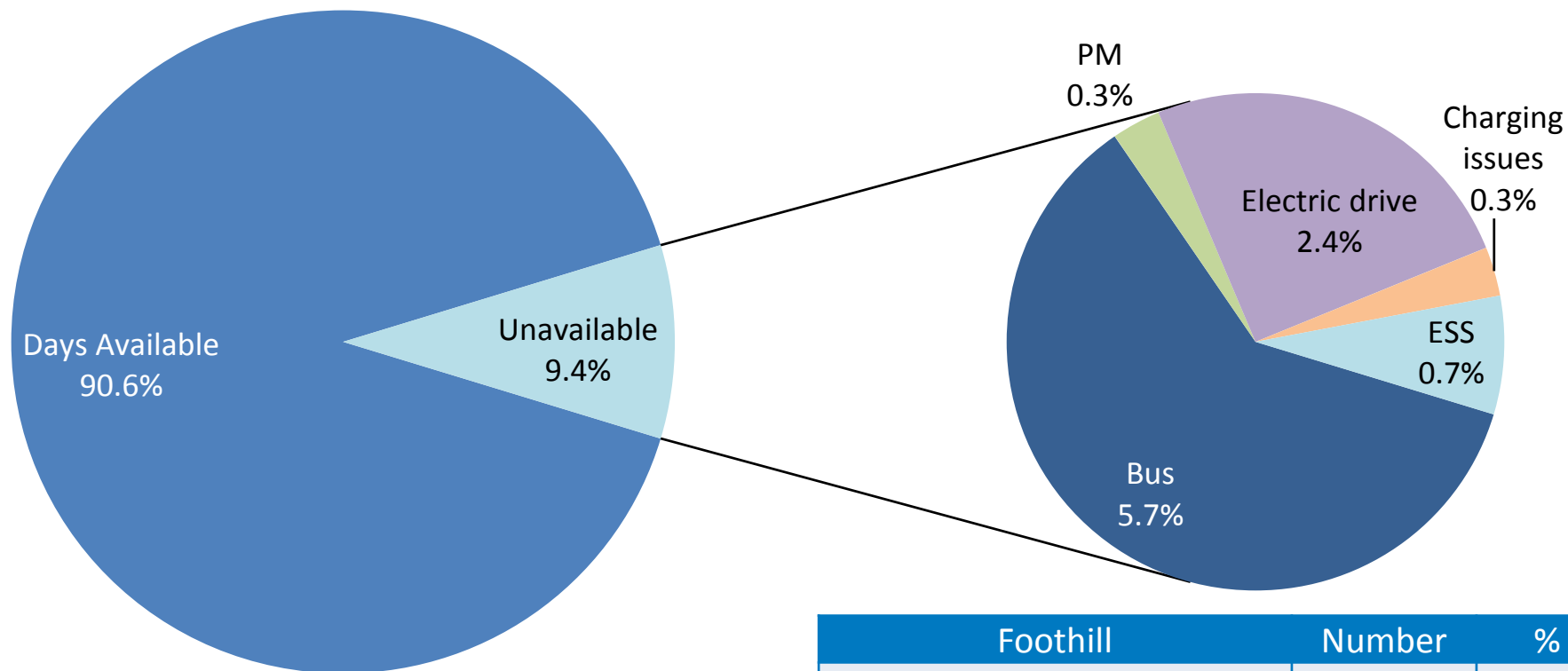
BEB Fleet Total Monthly Charges and Energy Consumption



Average Bus Availability by Month

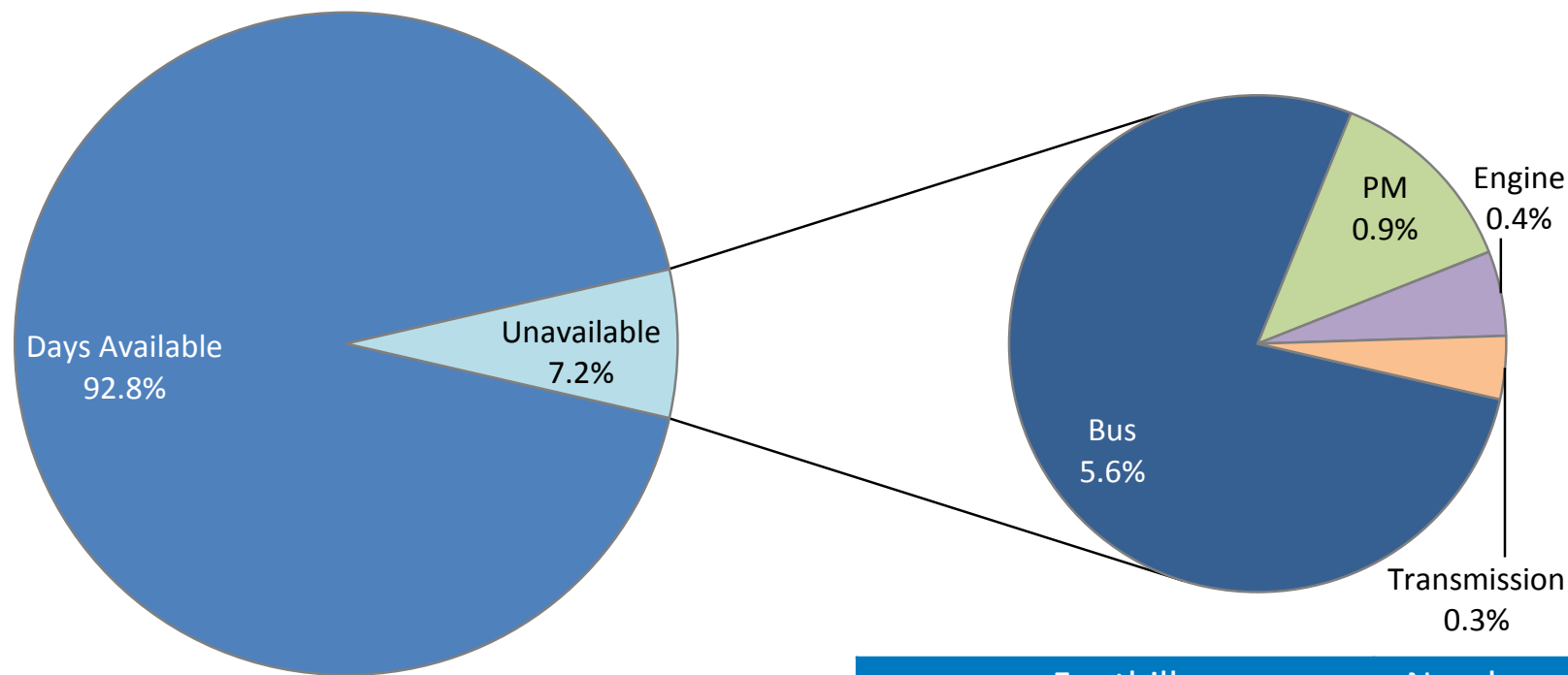


Availability Summary BEBs



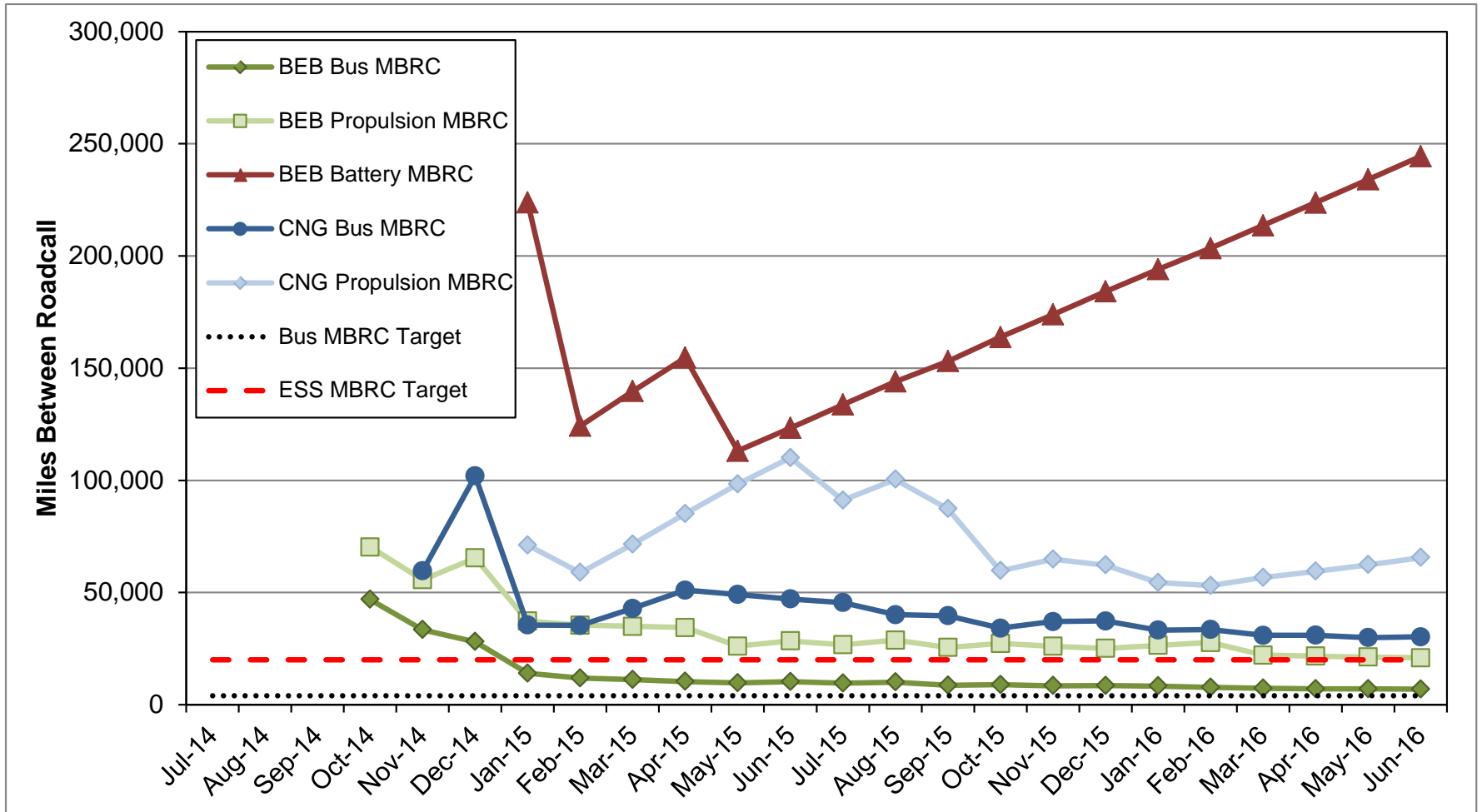
	Foothill	Number	%
Energy Storage System (ESS)		58	0.7
Electric drive		190	2.4
Charging issues		24	0.3
Bus maintenance		458	5.7
Preventive maintenance		24	0.3
Total unavailable days		754	9.4
Total available days		8,019	90.6

Availability Summary CNG Baselines



	Foothill	Number	%
Engine		12	0.4
Transmission		9	0.3
Bus maintenance		169	5.6
Preventive maintenance		28	0.9
Total unavailable days		218	7.2
Total available days		3,016	92.8

Reliability: Miles Between Roadcall (MBRC)



	BEB	CNG
Bus MBRC	6,918	30,270
Propulsion MBRC	20,951	65,586
ESS MBRC	244,424	--

Early results show the BEB performance exceeds the ultimate targets.

Remaining Challenges and Barriers for ZEBs

Common to all ZEBs

- Develop robust supply chain for components and parts
- Increase learning curve for maintenance staff—training and tools
- Reduce cost, both capital and operating

Specific to BEBs

- Plan/build of opportunity charging stations & garage chargers
- Select appropriate routes for technology
- Address challenge of electric rates and demand charges

King County Metro, Seattle, WA (TIGGER)

- 3 Proterra, 40-ft Catalyst buses and fast charging station (8 more on order)
- Baseline buses: diesel, diesel hybrid, and electric trolley buses
- Evaluation Status:
 - Buses in service February 2016
 - Kicked off evaluation in March 2016
 - Data collected and analyzed through July 2016



Long Beach Transit, Long Beach, CA (TIGGER)

- 10 BYD, 40-ft BEBs with in-depot and inductive on-route charging station
- Baseline buses: Gillig CNG
- Evaluation Status:
 - Kicked off evaluation in August 2016
 - Initializing data collection
 - Buses expected to go into service by November



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