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Technology Validation: Fuel Cell Bus Evaluations

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This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Timeline and Budget

- Project start: FY03
- End: Project continuation and direction determined annually by DOE
- FY16 DOE funding: $200K
- FY17 planned DOE funding: $200K
- Total DOE funds received to date: $3.99M (15 years)

Additional funding: U.S. Department of Transportation (DOT) Federal Transit Administration (FTA)

Barriers

- Lack of current fuel cell vehicle (bus) performance and durability data
- Lack of current H_2 fueling infrastructure performance and availability data

Partners

- Transit fleets: Operational data, fleet experience
- Manufacturers: Vehicle specs, data, and review
- Fuel providers: Fueling data and review

Relevance

- Validate fuel cell electric bus (FCEB) performance and cost compared to DOE/DOT targets and conventional technologies
- Document progress and "lessons learned" on implementing fuel cell systems in transit operations to address barriers to market acceptance

Current Targets[a]	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

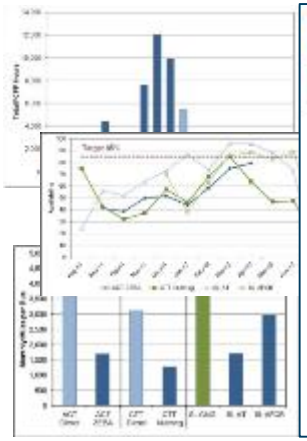
[a] Fuel Cell Technologies Program Record # 12012, Sept. 2012, www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf

Approach

Data Collection/Analysis
- NREL uses standard protocol for collecting existing data from transit partners
- Provides a third-party analysis
- Includes comparisons to conventional-technology buses in similar service (diesel, CNG, diesel hybrid)

CNG = compressed natural gas

Individual Site Reports
- Documents performance results and experience for each transit agency
- Builds database of results
- Reports published and posted on NREL website



Annual FCEB Status Report (milestone)
- Crosscutting analysis comparing results from all sites
- Assesses progress and needs for continued success
- Provides input on annual status for DOE/DOT targets

Approach: Data Summary for 2017

Specifications for FCEBs included in data summary

FCEB Identifier	ACT ZEBA	SL AFCB	UCI AFCB
Transit agency	AC Transit	SunLine	UCI
Location	Oakland, CA	Thousand Palms, CA	Irvine, CA
Number of buses	13	4	1
Bus OEM	Van Hool	ElDorado National	
Bus length/height	40 ft / 136 in.	40 ft / 140 in.	
Fuel cell OEM	UTC Power	Ballard	
Model	PureMotion 120	Fcvelocity–HD6	
Power (kW)	120	150	
Hybrid system	Siemens ELFA, Van Hool integration	BAE Systems HybriDrive	
Design strategy	Fuel cell dominant	Fuel cell dominant	
Energy storage – OEM	EnerDel	A123	
Type	Li-ion	Nanophosphate Li-ion	
Capacity	17.4 kWh	11 kWh	
Number of cylinders	8	8	
Capacity (kg)/pressure (bar)	40 / 350	50 / 350	
Technology readiness level	7	7	

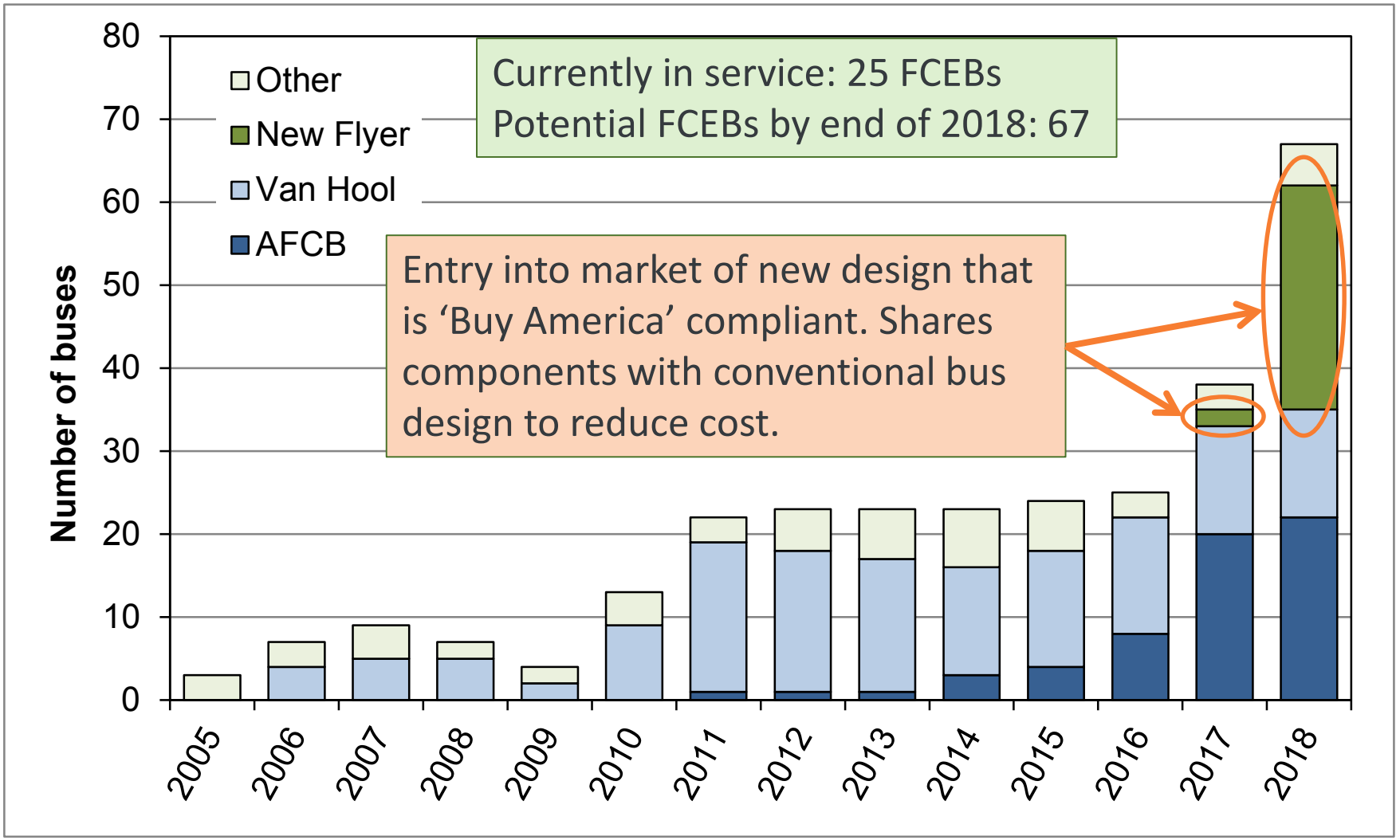
OEM = original equipment manufacturer
ACT ZEBA = AC Transit Zero Emission Bay Area
SL AFCB = SunLine American Fuel Cell Bus
UCI = University of California at Irvine

ACT ZEBA

SL AFCB

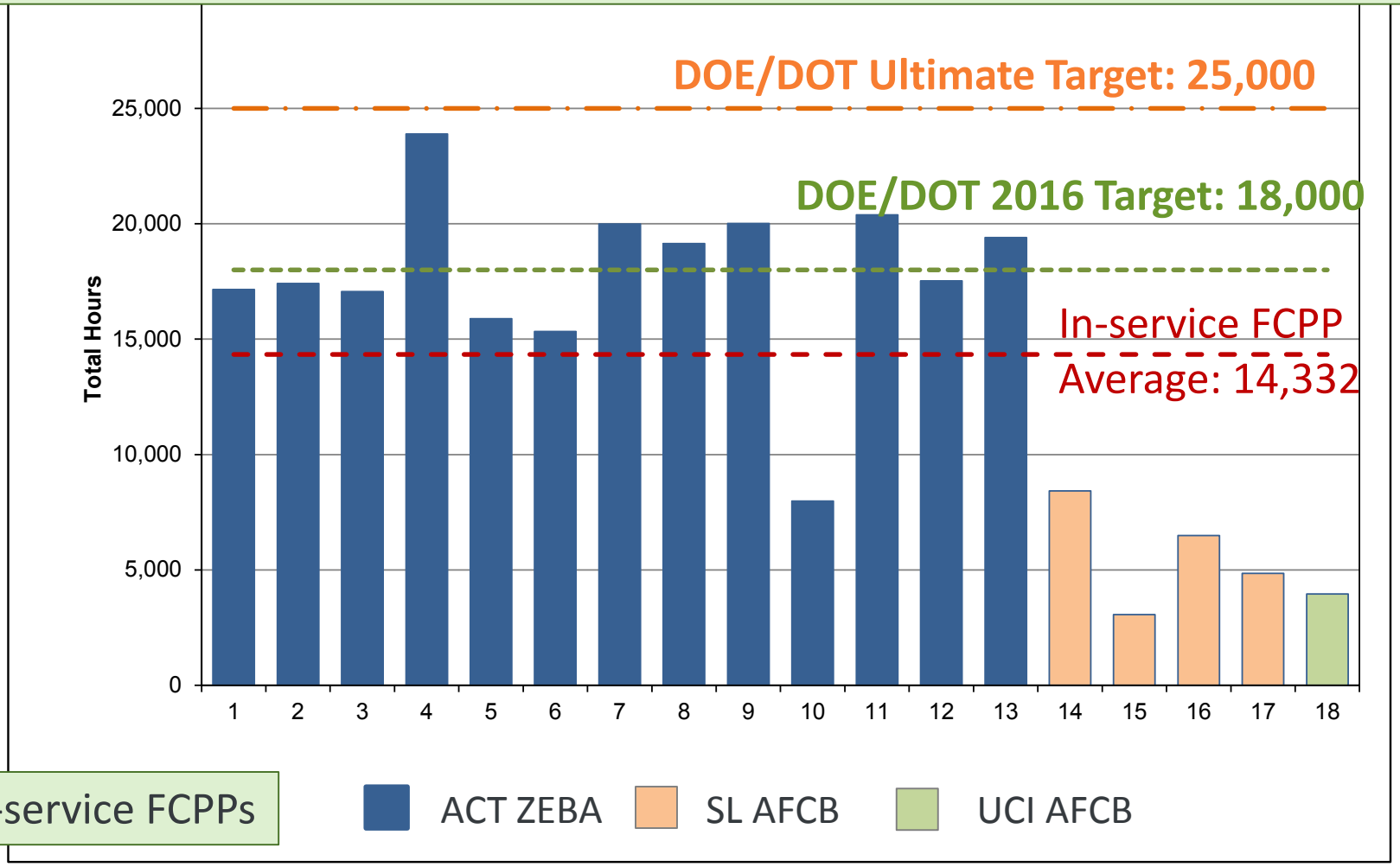
UCI AFCB

Accomplishments and Progress
FCEB Numbers Expected to Grow



Top Fuel Cell Powerplant Exceeds 23,000 Hours

Top fuel cell powerplant (FCPP) >23,800 hours, surpassing DOE/DOT 2016 target; 67% of FCPPs (12) more than 15,000 hours

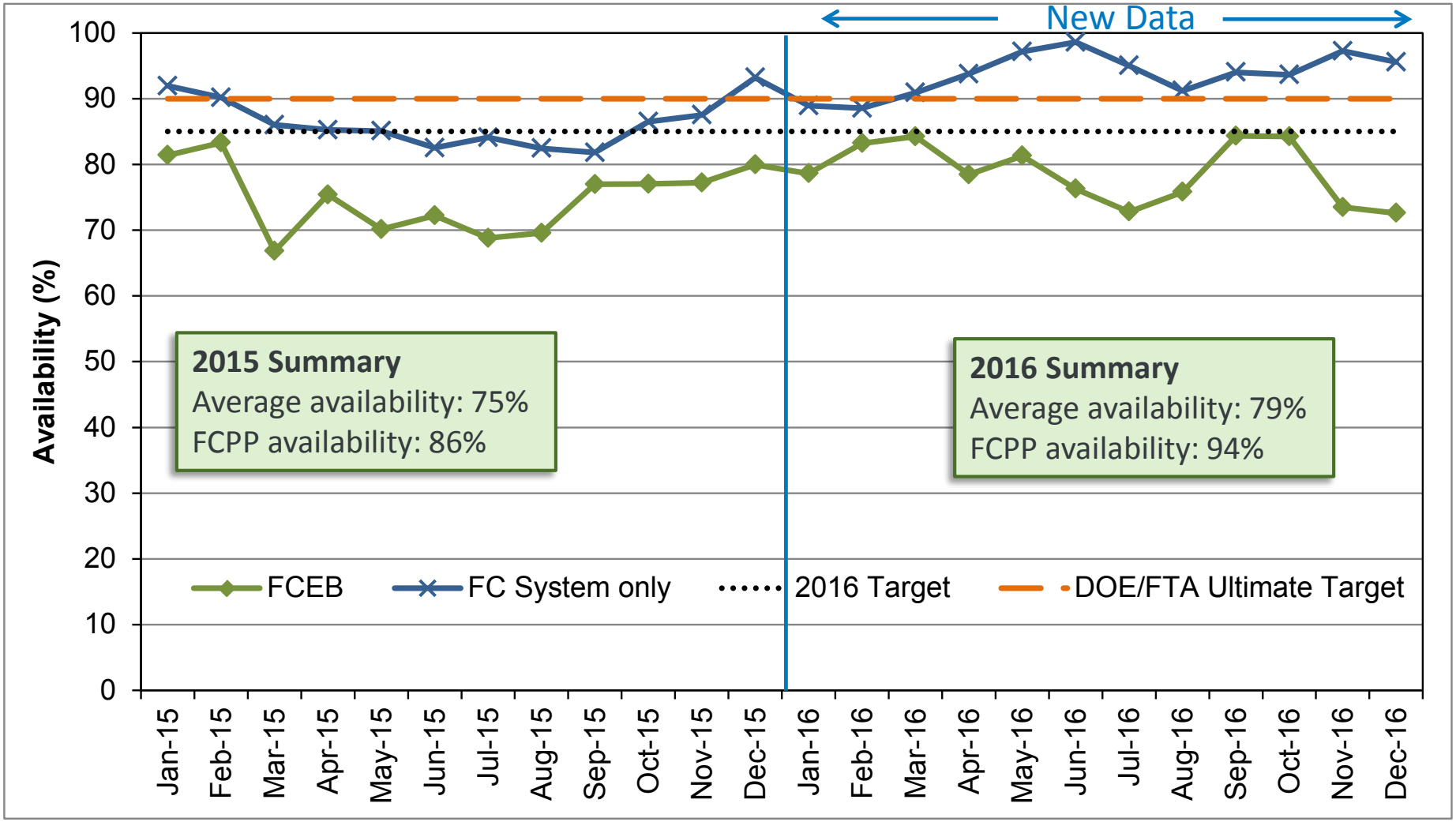


Total hours accumulated on each FCPP as of 2/28/17

Accomplishments and Progress

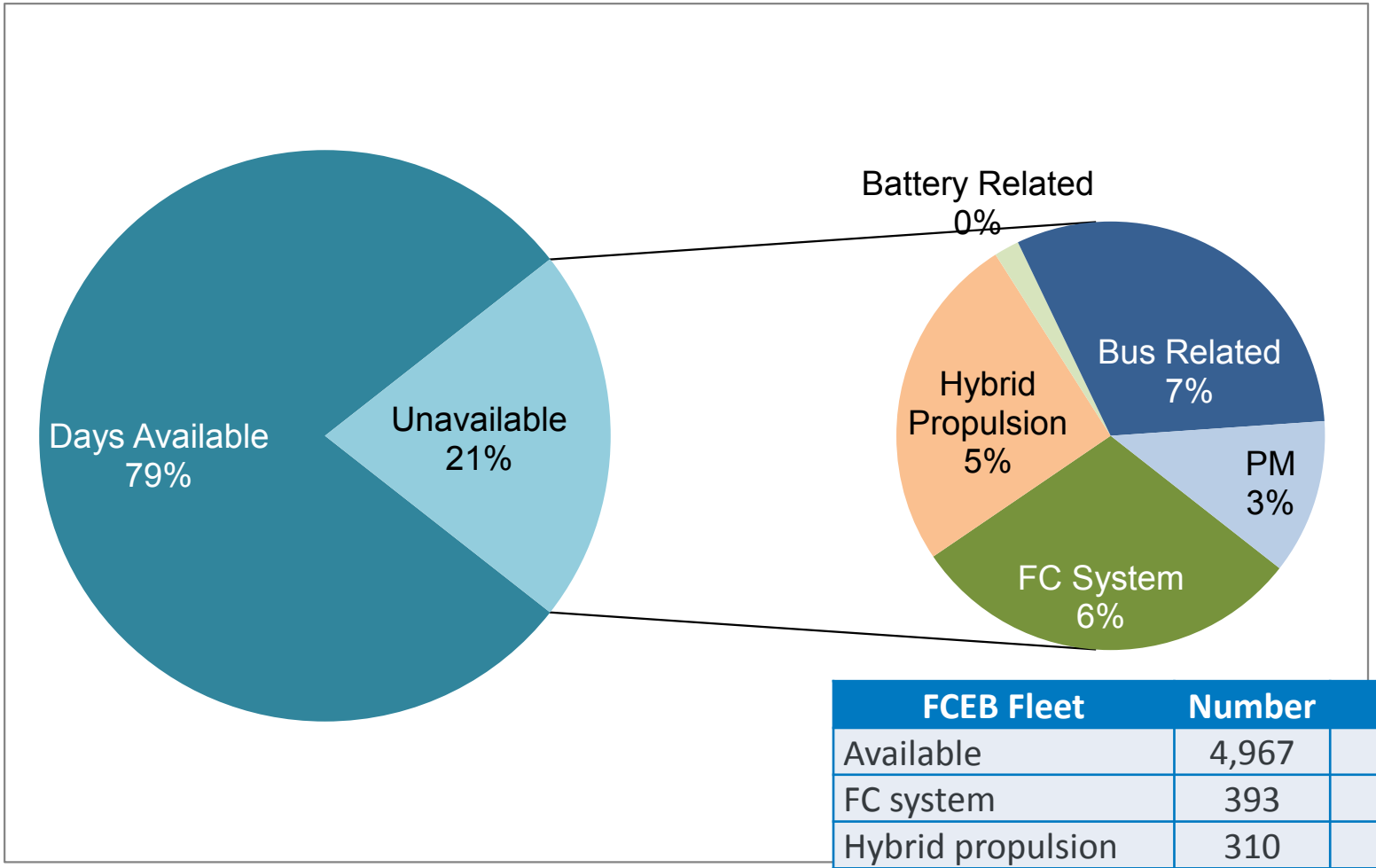
Average Bus Availability Improves to 79%

Monthly bus availability



Availability = planned operation days compared to actual operation days

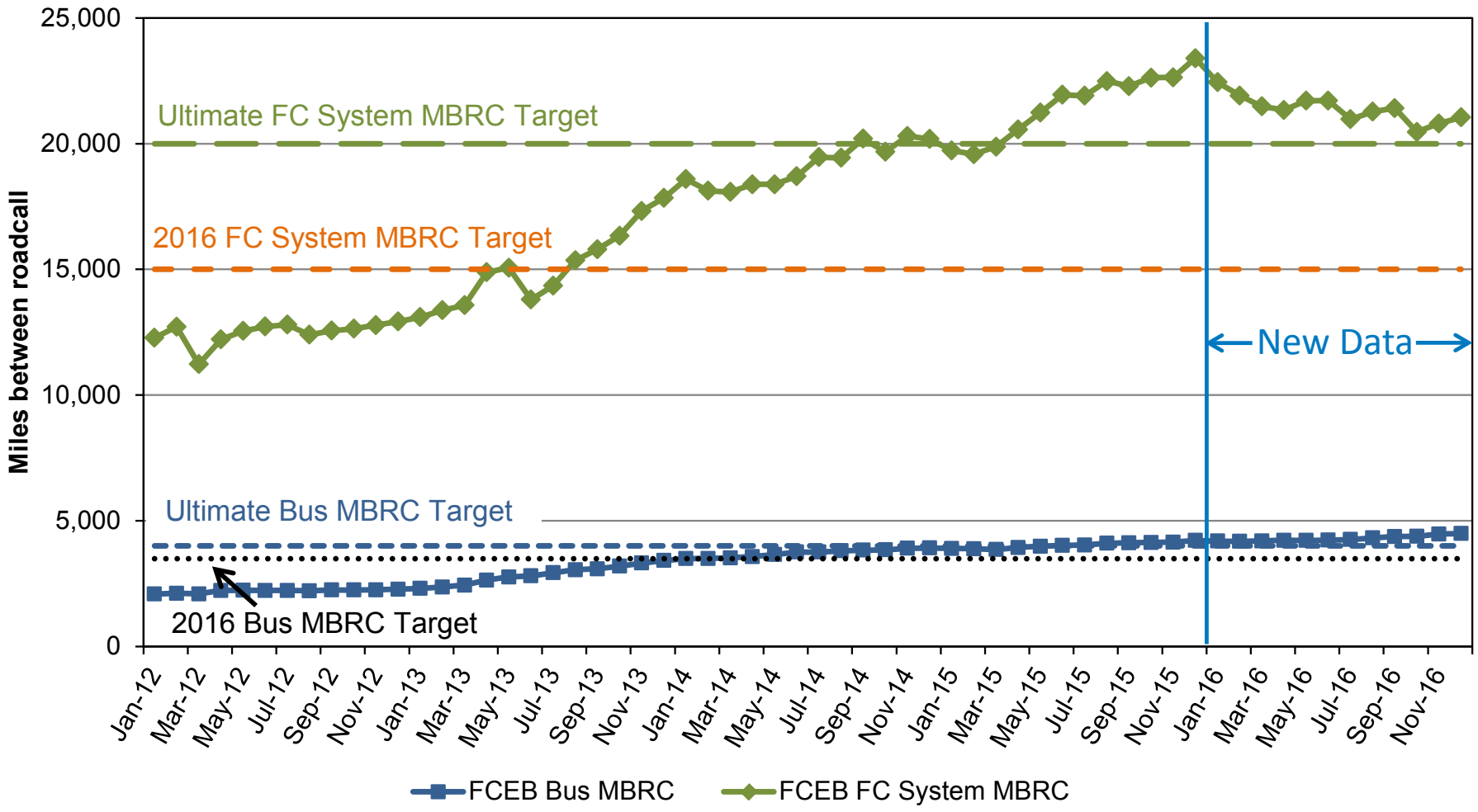
Accomplishments and Progress
Availability Summary: 2016 Data



FC = fuel cell
PM = preventive maintenance

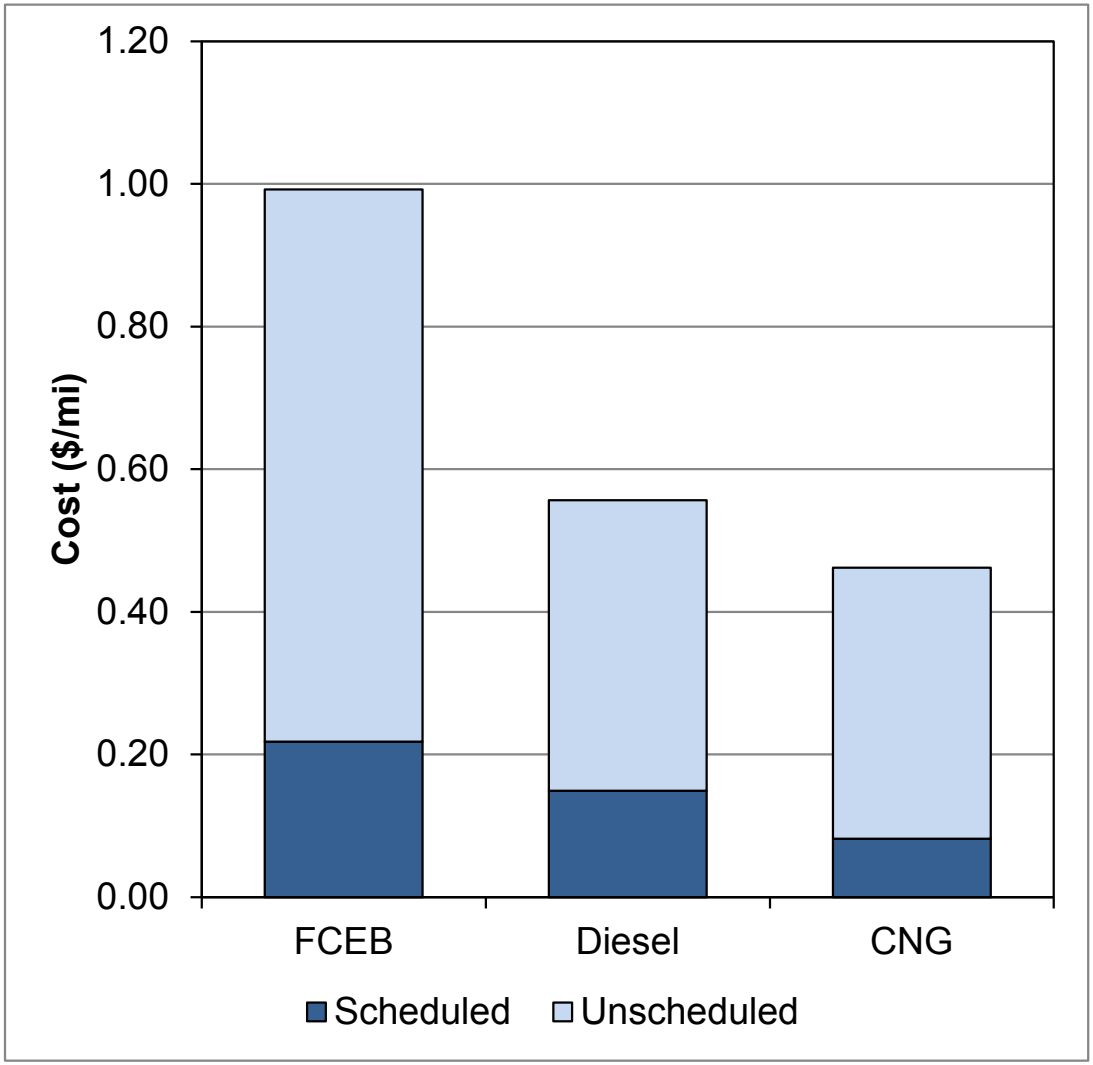
FCEB Fleet	Number	%
Available	4,967	79
FC system	393	6
Hybrid propulsion	310	5
Traction batteries	25	<1
Bus maintenance	411	7
PM	157	3
Total days	6,263	100

Accomplishments and Progress
Reliability: Miles Between Roadcall (MBRC)



- FCEB reliability **surpassed ultimate targets in early 2015**
- Maintenance staff becoming more familiar with system, applying new tools to anticipate and fix issues before they fail in service

Maintenance Costs per Mile – 2016

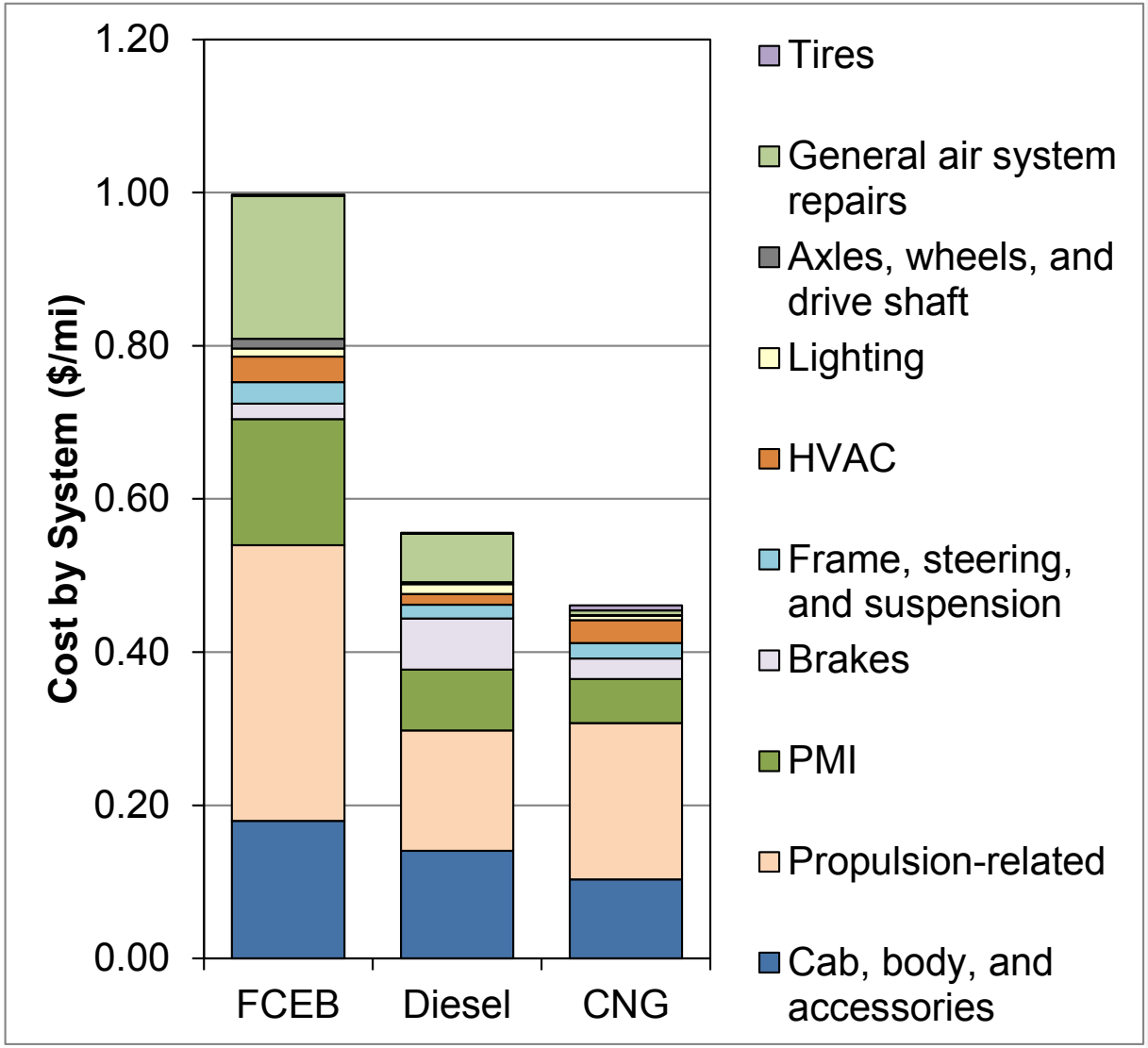


2016 Cost ($/mi)	FCEB	Diesel	CNG
Scheduled	0.22	0.15	0.08
Unscheduled	0.77	0.41	0.38
Total	0.99	0.56	0.46

- All baseline buses and most FCEBs are out of warranty
- Costs tend to rise as buses age and pass warranty period
- Average miles for each bus type – FCEB: 118,900; Diesel: 196,800; CNG: 463,400
- FCEB costs include added labor for training (~$0.04/mi estimated for PMIs based on average time)

PMI = preventive maintenance inspection

Accomplishments and Progress
Maintenance Costs per Mile by System – 2016



PMI = preventive maintenance inspection

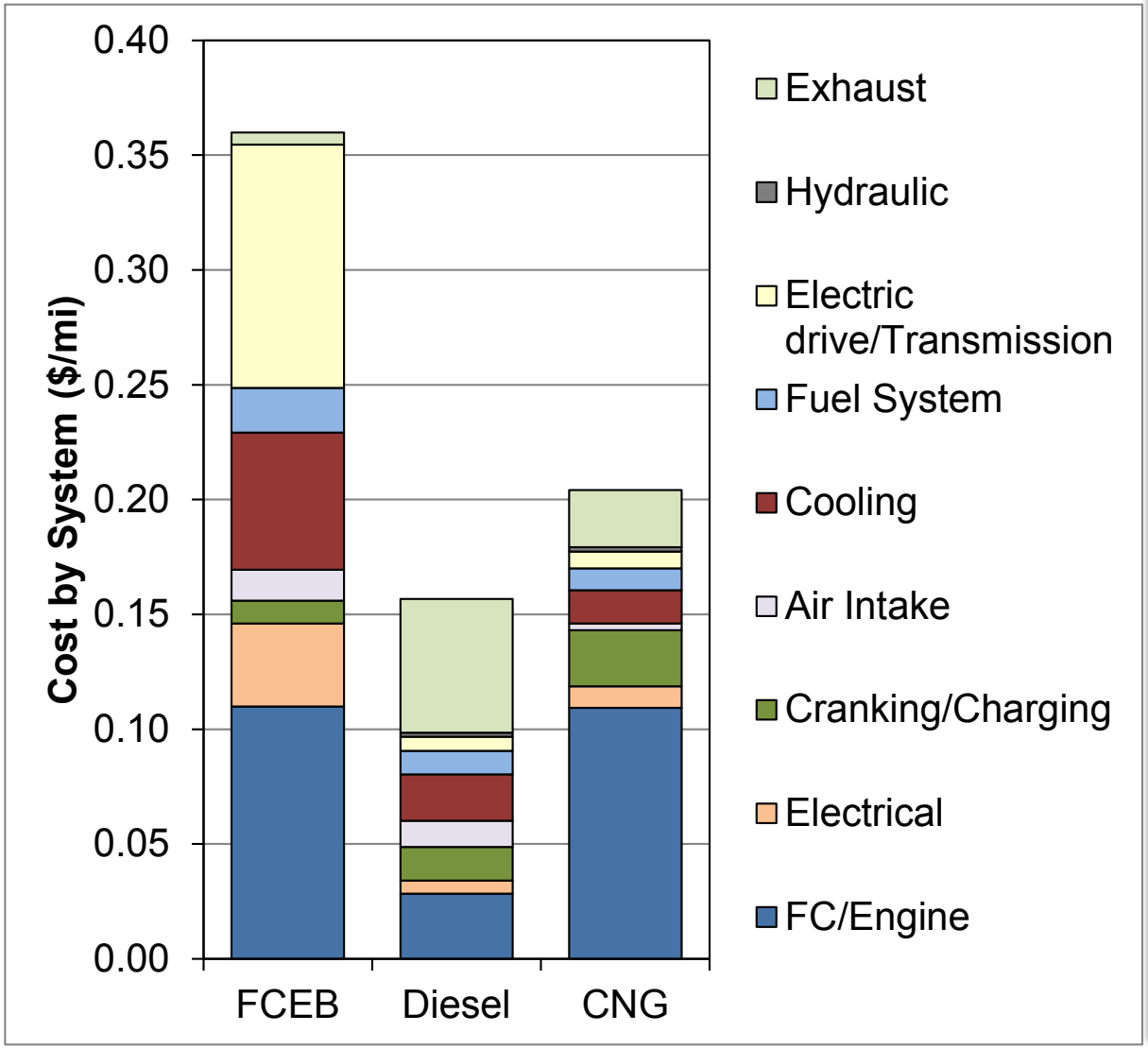
Systems with highest percent of costs

FCEB
Propulsion system: 36.1%
Air system: 18.7%
Cab, body, access.: 18.0%
PMI: 16.5%

Diesel
Propulsion system: 28.2%
Cab, body, access.: 25.3%
PMI: 14.3%

CNG
Propulsion system: 44.3%
Cab, body, access.: 22.4%
PMI: 12.5%

Maintenance Cost per Mile by Propulsion Sub-System – 2016



Sub-systems with highest percent of costs

FCEB
Fuel cell: 30.5%
Electric drive: 29.5%
Cooling: 16.6%

Diesel
Exhaust: 37.2%
Engine: 18.1%
Cooling: 12.9%

CNG
Engine: 53.6%
Exhaust: 12.2%
Cranking/charging: 12.0%

Developed Maintenance Readiness Level Guideline

Technology Maintenance Readiness Level	TMRL Definition	Description
TMRL 9	Maintenance staff fully maintaining ZEBs	All designated maintenance staff are trained on ZEB technology. Training is incorporated into standard training program. Spare parts are readily available for all components. OEMs have regional support centers or third-party repair facilities are available. Maintenance and repair training is available from external organizations (e.g., tech schools, community colleges); incoming maintenance staff is fully trained.
TMRL 8	Transition of maintenance to staff finalized	All maintenance is handled by staff. OEM is off site but available on an as-needed basis (usually remotely). Full manuals are available and all special tools and equipment needed have been acquired and incorporated into the facility. A large percentage of designated maintenance staff is fully trained. Training curriculum is complete.
TMRL 7	Transition of maintenance to staff begins	Select maintenance staff is fully trained and takes on training duties. OEM makes periodic site visits and provides remote assistance. More than 50% of designated maintenance staff is fully trained.
TMRL 6	Training transitioned to select maintenance staff	OEM is on site, but maintenance staff is doing most maintenance with supervision. Select maintenance staff is beginning to train other staff. Maintenance manuals and troubleshooting guides are in final stage of development. Special tools are available and spare parts supplies are readily available for most components.
TMRL 5	Training of select maintenance staff begins	OEM is on site and begins training select group of maintenance staff on advanced technology components. Maintenance staff is doing all general preventive maintenance inspections and vehicle maintenance but begins assisting OEM with other repairs. Maintenance manuals and troubleshooting guides are in advanced stage of development. OEM and fleet owner are developing spare parts list for technology and identifying what parts need to be in on-site inventory. All maintenance staff has completed familiarization training.
TMRL 4	Initial implementation of ZEB technology	OEM is on site doing all maintenance work on advanced technology components; maintenance staff begins doing vehicle-level maintenance work and preventive maintenance inspections. Maintenance manuals and troubleshooting guides are in draft form. OEM is developing special tools needed for advanced technology components. Facility modifications are complete.
TMRL 3	Draft training plan developed	Fleet owns/leases ZEBs, which are used in limited or expanded service. Fleet develops a training plan and begins to implement familiarization training for maintenance staff.
TMRL 2	Technology selected and implementation planned	Fleet takes ownership/lease of commercially available ZEB. ZEB is operated in limited service and is fully repaired and maintained by OEM (without significant zero emission component maintenance from fleet staff, fleet contractor, or third party repair facility). Maintenance staff begins to plan for training.
TMRL 1	Initial ZEB demonstration or development of technology of interest	Pre-commercial ZEB (owned by OEM) in limited use by fleet with additional research and development planned by OEM. Fleet initiates modifications to facilities for specific technology.

- **Transition of knowledge to transit staff essential for commercialization**
- **Guideline helps fleet operators assess readiness for maintaining zero-emission vehicles**
- **Developed with fleet and OEM partner input**
- **Next step: present guideline at transit conference and coordinate with FTA-funded project to develop training curriculum**

Responses to Previous Year Reviewers' Comments

- Provide a comparison of maintenance cost per mile by system for baseline buses.
  - Slides are included to show overall maintenance cost per mile by system for FCEBs, diesel buses, and CNG buses (Slides 13, 14).
- NREL should collect data on more buses.
  - Delays in project start are out of NREL control. We plan to begin data analysis on new fleets as soon as they go into service. Several new projects are expected to begin in 2017.
- Lessons learned should be documented.
  - Lessons learned are documented in individual site reports.

Collaborations

- Transit agencies (1) provide data on buses, fleet experience, and training and (2) review reports
  - California: AC Transit, SunLine, UC Irvine, Orange County Transportation Authority
  - Massachusetts: Massachusetts Bay Transportation Authority
- Manufacturers provide some data on buses and review reports
  - Bus OEMs: Van Hool, New Flyer, ElDorado National
  - Fuel cell OEMs: Ballard, Hydrogenics, US Hybrid
  - Hybrid system OEMs: BAE Systems, Van Hool, US Hybrid
- Other organizations share information and analysis results
  - National: California Air Resources Board, Northeast Advanced Vehicle Consortium, Center for Transportation and the Environment, CALSTART
  - International: Various organizations from Germany, Brazil, Canada, Japan, England, Norway, Italy, Sweden

Remaining Challenges and Barriers

- For technology validation and data collection project:
  - Establish good relationships with additional transit agencies to allow data collection for new FCEB designs
  - Continue data collection to track progress of newer generation designs

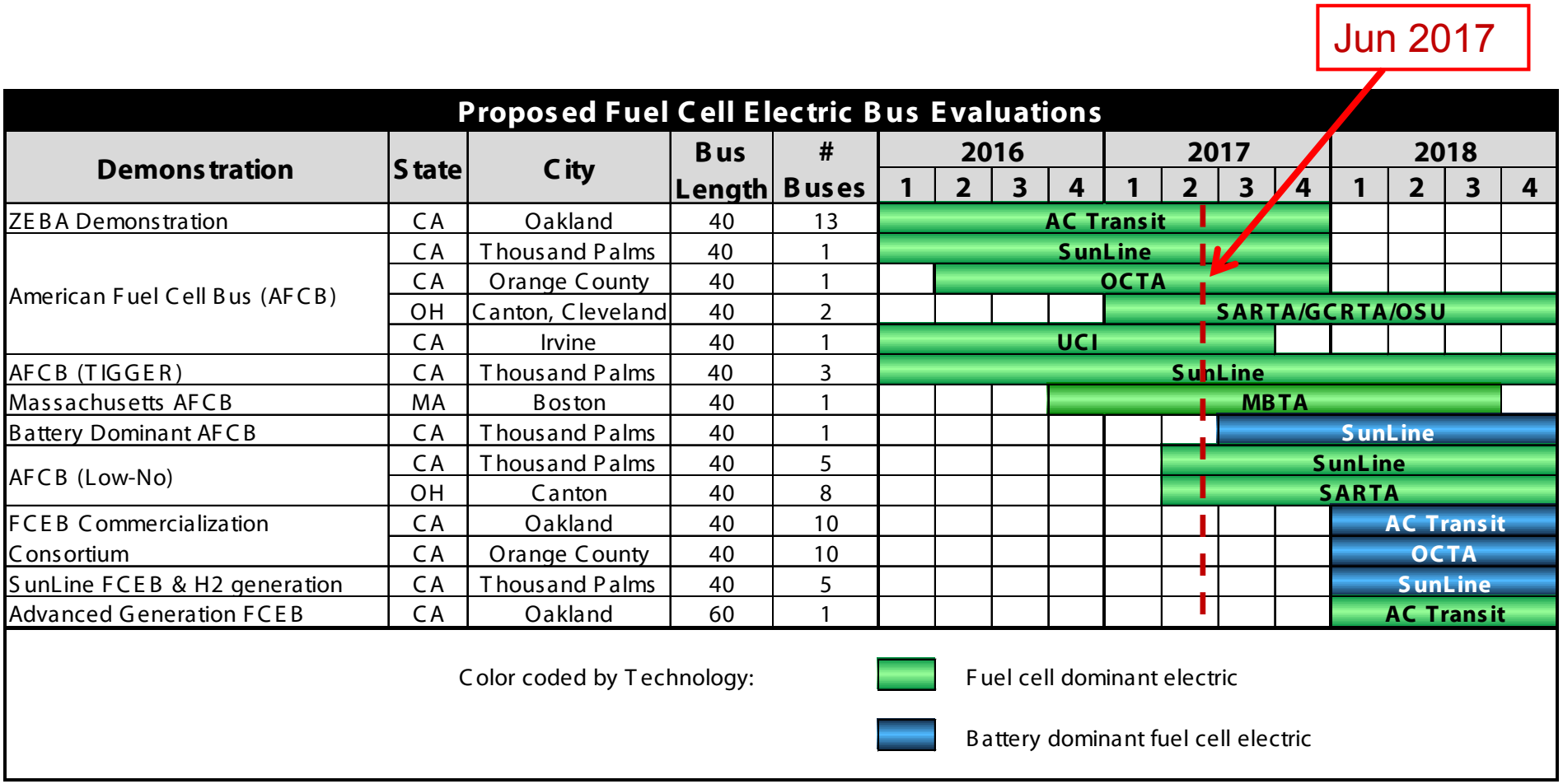
- For industry to meet technical targets and commercialize FCEBs:
  - Increase durability and reliability of the fuel cell, battery system, and other components
  - Develop robust supply chain for components and parts to lower cost and downtime
    - Multiple component suppliers to stabilize supply
    - Standardized with conventional bus components to lower cost
  - Establish support centers for advanced technology components
  - Increase learning curve for maintenance staff
    - Develop training specific to FCEBs and incorporate in traditional classes
    - Provide tools to agencies for monitoring and troubleshooting issues
  - Reduce cost, both capital and operating

Proposed Future Work

- Remainder of FY 2017
  - Complete the following data analyses/reports:
    - SunLine AFCB Report, May 2017
    - AC Transit, ZEBA Report, June 2017
    - 2017 Annual Status Report, September 2017
  - Begin data collection on FCEBs at MBTA, OCTA, SARTA: adds data from FCEBs in colder climates
  - Provide feedback to DOE on technical issues with systems and components
- FY 2018
  - Kick off new FCEB evaluations as buses go into service – target new designs from different OEMs
  - Complete individual site reports as scheduled
  - Complete annual crosscutting analysis across sites

Any proposed future work is subject to change based on funding levels

Proposed Future Work



- Current data collection includes a total of 21 FCEBs at six transit sites
- New sites would add 41 buses and four new designs

Any proposed future work is subject to change based on funding levels

Technology Transfer Activities

- Project provides non-biased evaluation of technology developed by industry
- Project documents performance results and lessons learned to aid market in understanding needs for full commercialization
  - Manufacturers
  - Transit agencies
  - Policymaking organizations
  - Funding organizations
- No technology (hardware/software) is developed through this project

Summary: Progress Toward Targets

Summary of FCEB Data through December 2016

	Fleet Min	Fleet Max	Fleet Average	2016 Target	Ultimate Target	Target Met
Bus lifetime (years)	1.3	6.4	4.7	12	12	
Bus lifetime (miles)	32,485	167,352	118,989	500,000	500,000	
Powerplant lifetime[a] (hours)	3,589	23,423	13,801	18,000	25,000	2016
Bus availability (%)	44	93	76	85	90	
Roadcall frequency[b] (bus)	--	--	4,710	3,500	4,000	Ultimate
Roadcall frequency (fuel cell system)	--	--	20,705	15,000	20,000	Ultimate
Maintenance cost ($/mi)	0.46	1.61	1.03	0.75	0.40	
Fuel economy (mpdge)[c]	5.66	7.22	6.51	8	8	
Range (miles)[d]	215	274	247	300	300	

[a] Fuel cell hours accumulated to date from newest FCPP to oldest FCPP. Does not indicate end of life.
[b] MBRC: average for current designs.
[c] Miles per diesel gallon equivalent
[d] Estimated range based on fuel economy and 95% tank capacity. Transit agencies report lower real-world range.