Technology Validation: Fuel Cell Bus Evaluations

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DOE Hydrogen and Fuel Cells Program
2018 Annual Merit Review and Peer Evaluation Meeting

Project ID # TV008

Overview

Timeline and Budget

- Project start date: 09/01/03
- FY17 DOE funding: $200K
- FY18 planned DOE funding: $200K
- Total DOE funds received to date: $4.1M (over 16 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 H2 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/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 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, http://www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf

Approach

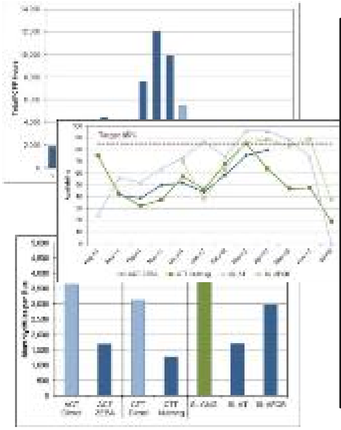
Data Collection/Analysis

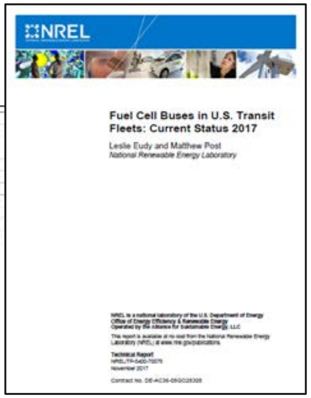
- NREL uses a standard protocol for collecting existing data from transit partners
- Provides a third-party analysis
- Includes comparisons to conventional-technology buses in similar service (diesel, CNG, diesel hybrid)

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/FTA targets

Approach: Data Summary for 2018

Selected specifications for FCEBs included in data summary

Bus Manufacturer	Van Hool	ENC
Model	A330	AFCB/Axcess
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

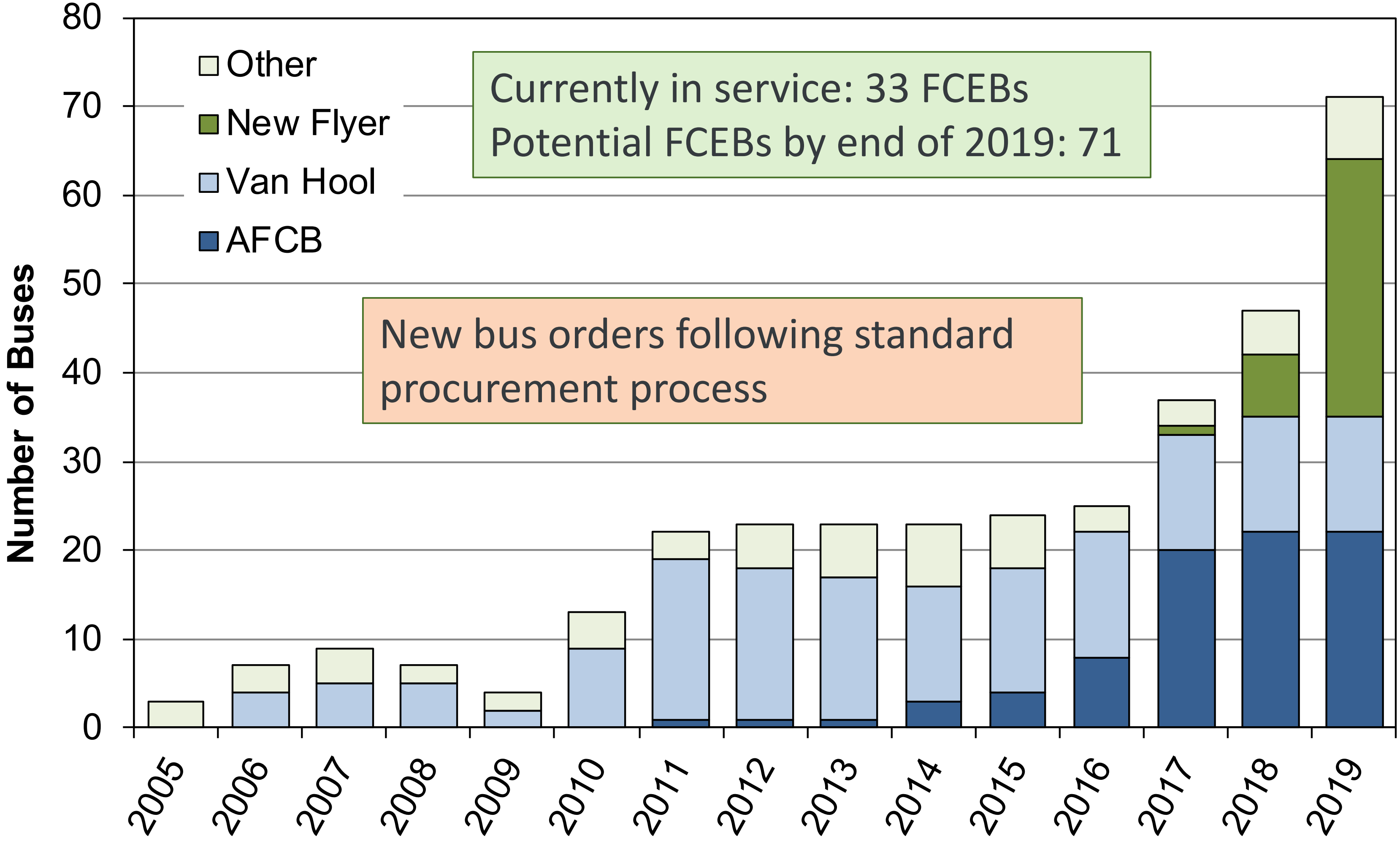
ENC = ElDorado National California
AFCB = American Fuel Cell Bus
OEM = original equipment manufacturer

Approach: Data Summary for 2018

FCEB fleets included in data summary

Transit Agency	Abbreviation	Location	Bus Type	# Buses	Data Included
AC Transit	ACT	Oakland, CA	Van Hool	13	Fuel cell hours, fueling records, reliability
SunLine Transit Agency	SL	Thousand Palms, CA	AFCB	4	All
Orange County Transportation Authority	OCTA	Santa Ana, CA	AFCB	1	All
Stark Area Regional Transit Authority	SARTA	Canton, OH	AFCB	5	Fuel cell hours only
Massachusetts Bay Transportation Authority	MBTA	Boston, MA	AFCB	1	Fuel cell hours and fueling records
University of California at Irvine	UCI	Irvine, CA	AFCB	1	All

Accomplishments and Progress
FCEB Numbers Expected to Grow



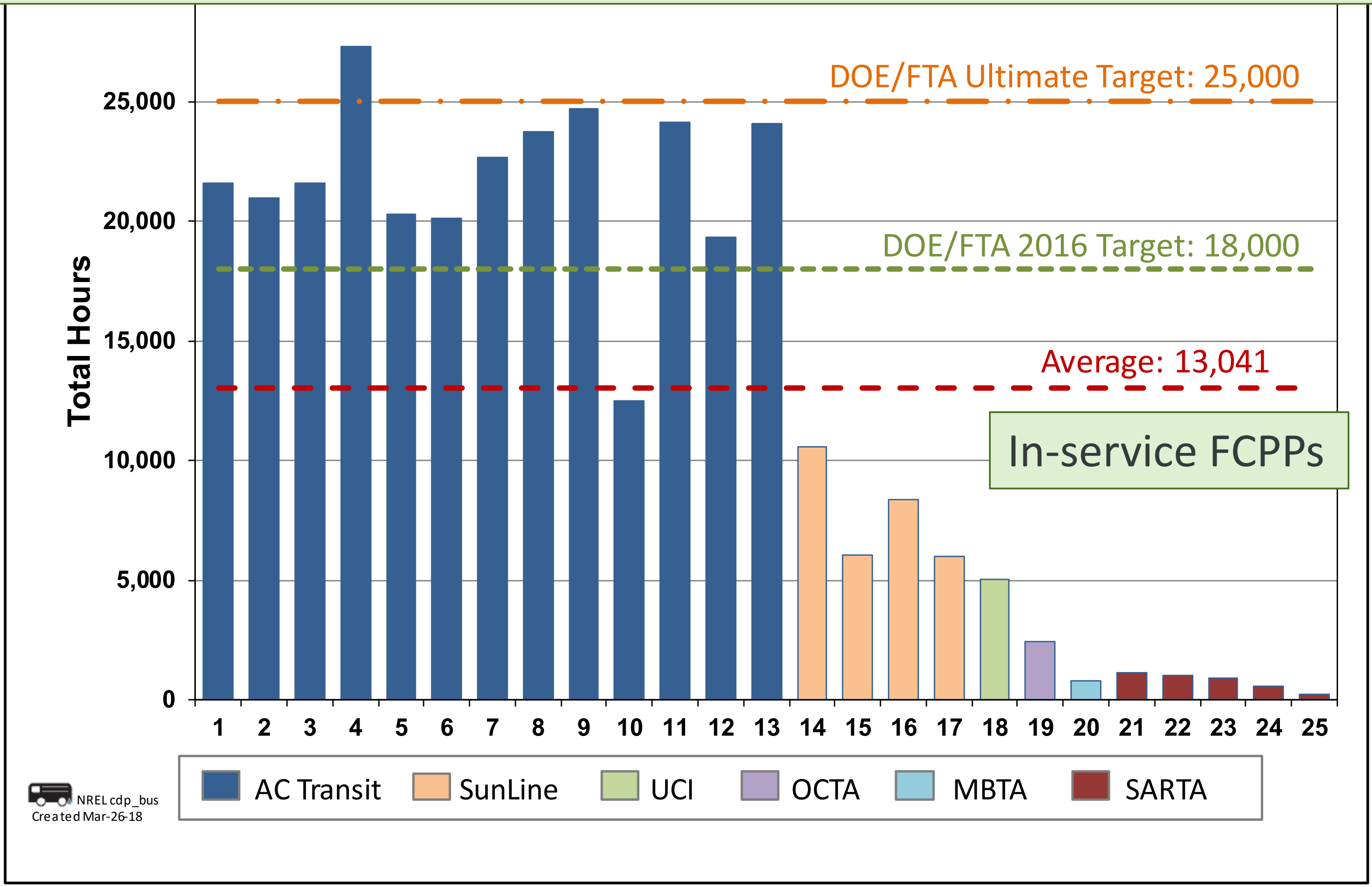
Currently in service: 33 FCEBs
Potential FCEBs by end of 2019: 71

New bus orders following standard procurement process

European FCEB programs: 46 active, with another 313 planned
Asia FCEB programs: 400 planned, potential for 2,000 more per year

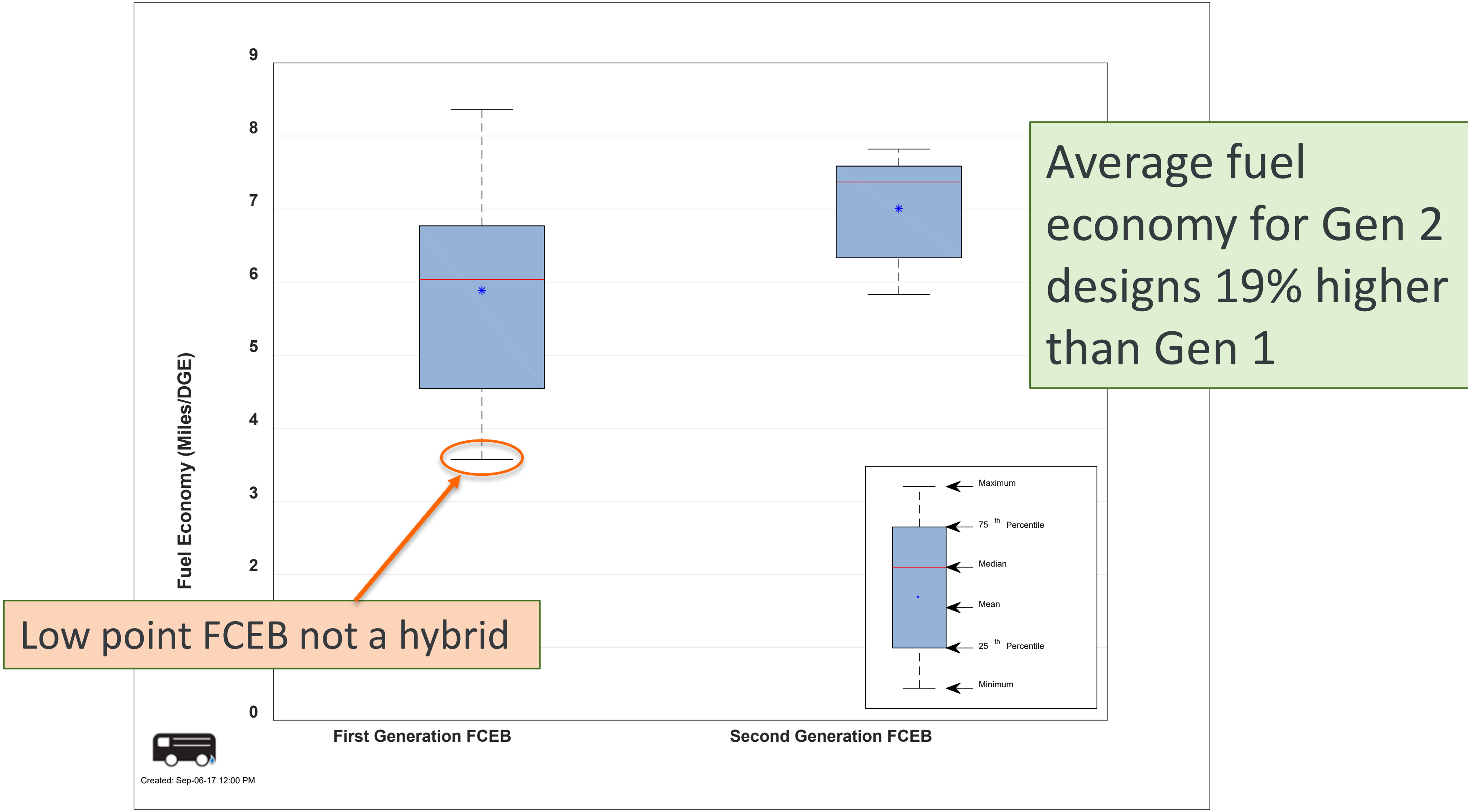
Accomplishments and Progress
Top Fuel Cell Powerplant Exceeds 27,000 Hours

Top fuel cell powerplant (FCPP) >27,330 hours, surpassing DOE/DOT 2016 target; 12 FCPPs have more than 19,000 hours



Total hours accumulated on each FCPP as of 2/28/18

Accomplishments and Progress
Fuel Economy



- Based on first year of data for each demonstration
- Gen 1: Six demonstrations of three FCEB designs
- Gen 2: Five demonstrations of two FCEB designs

Accomplishments and Progress

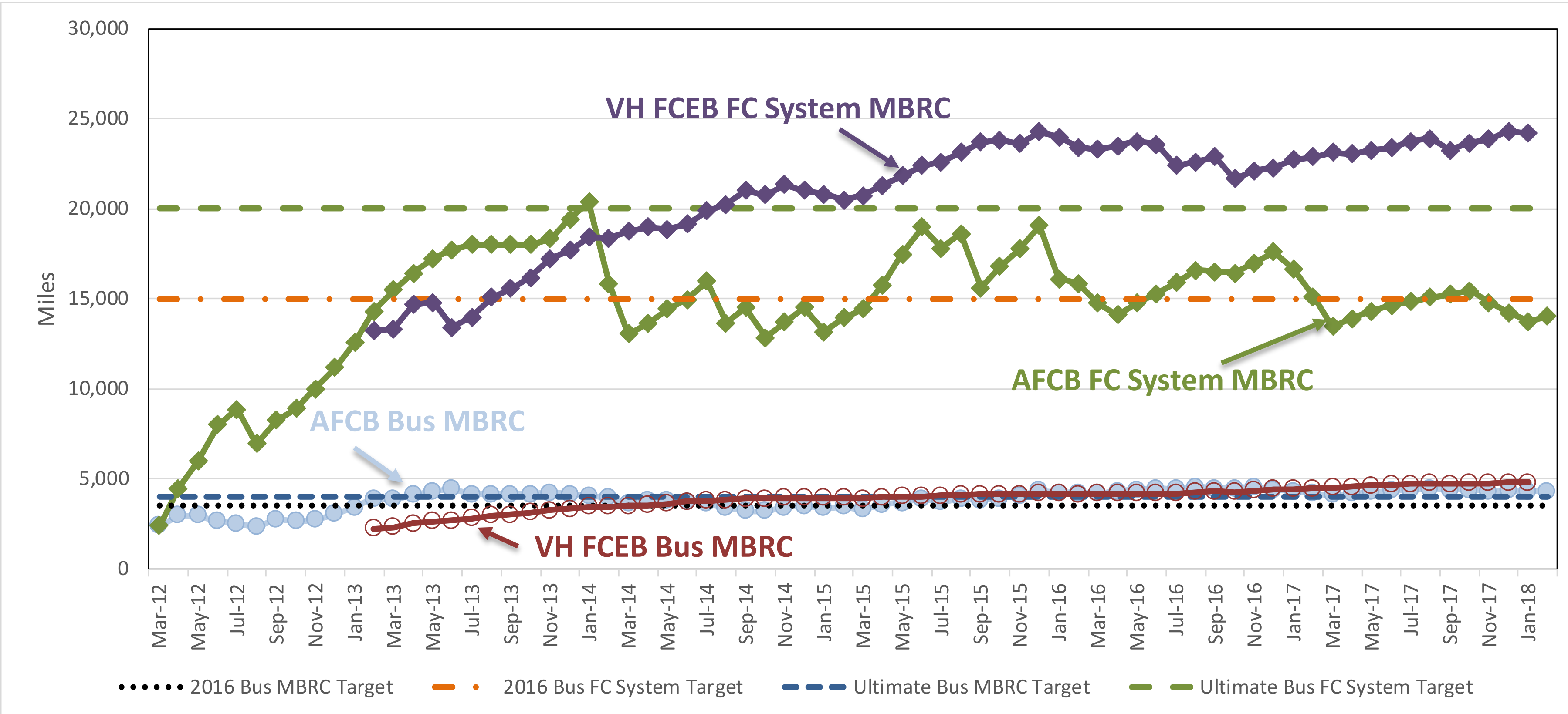
Fueling Data Summary

Summary of hydrogen use by demonstration site

	ACT	SL	UCI	OCTA	MBTA	Combined
Number of buses	13	4	1	1	1	20
Number of fueling days	1,794	2,371	342	607	142	5,256
Monthly H2 (kg)	309,463	96,665	8,580	4,240	1,680	420,628
Number of occurrences	14,814	4,581	319	222	118	20,054
Average daily fuel use (kg)	172.5	40.8	25.1	7.0	11.8	80.0
Average fill amount (kg)	20.9	21.1	26.9	19.1	14.2	21.0

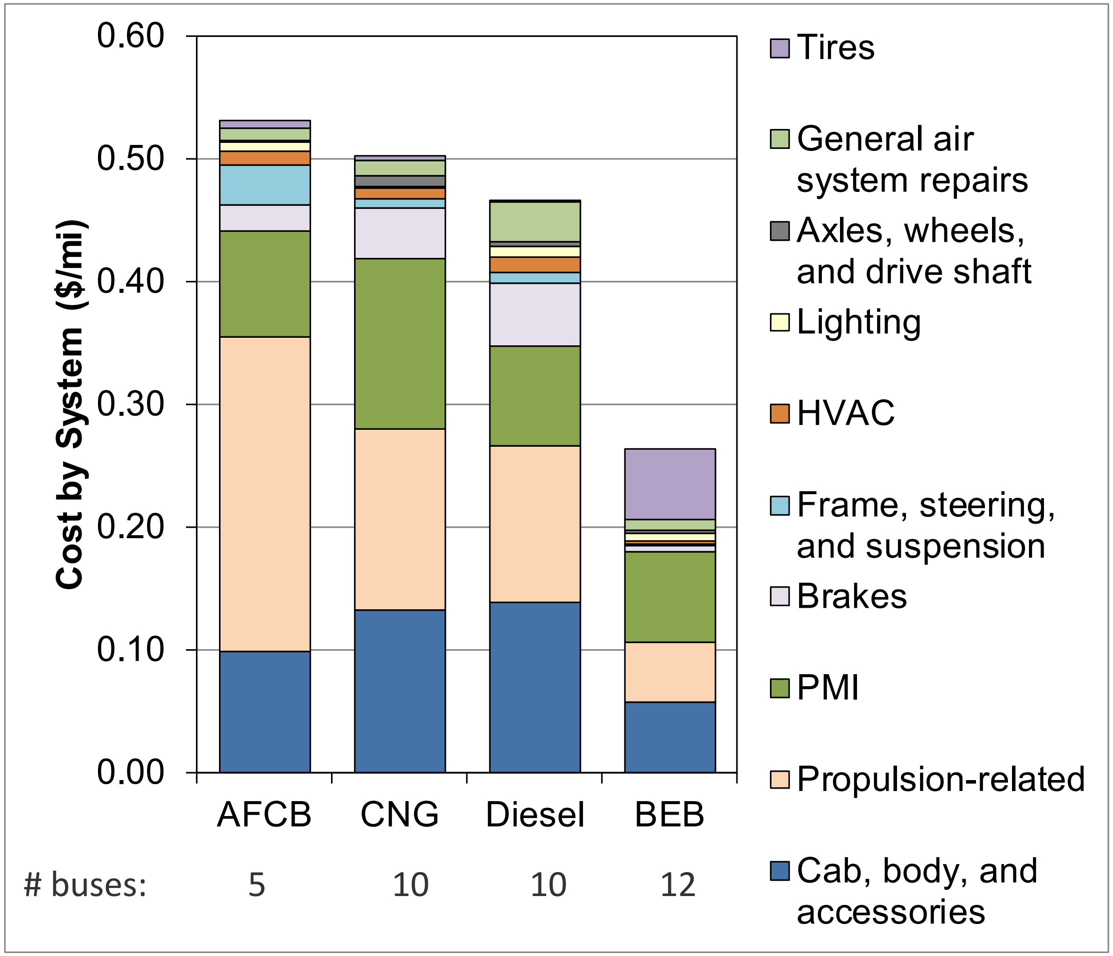
- Transit agencies typically fill the buses every day during a 6–8-hour window after the end of service
- Stations must be capable of back-to-back fueling of up to 40 kg per fill, although the average fill is 21 kg
- Agency goal of fueling in less than 10 minutes

Accomplishments and Progress
Reliability: Miles Between Roadcall



- Reliability trends are shown for two FCEB designs: AFCB and Van Hool (VH)
- Fuel cell system roadcalls are caused by balance of plant components, not stack issues
- The higher trend for the Van Hool FCEBs is due to the increasing use of the buses and the competence level of the maintenance staff in preventive maintenance—better able to anticipate and repair issues before they cause an in-service failure

Accomplishments and Progress
Maintenance Cost by System



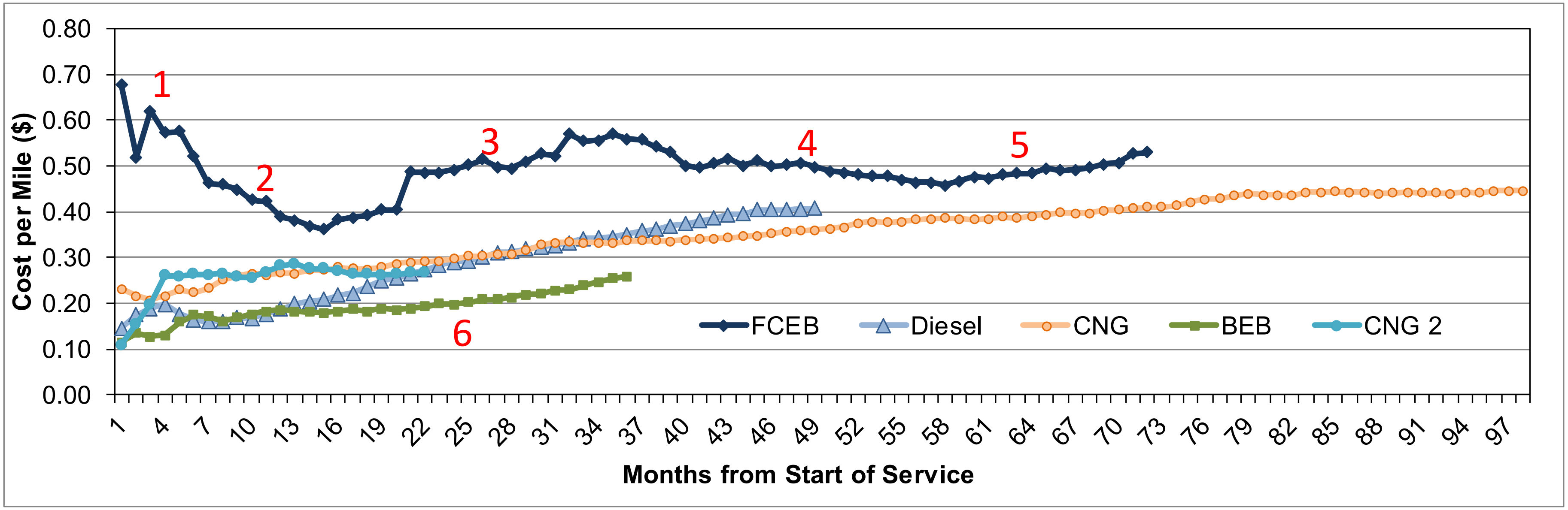
- Cost for propulsion system repairs highest for AFCBs
- Propulsion issues include:
  - Cooling system leaks
  - Low-voltage batteries
  - Fuel cell BOP
- Other issues:
  - Air compressor
  - Suspension

- Cumulative cost from in-service date
- Labor @ $50/h
- Cost per mile sensitive to number of buses in a fleet

BEB = battery electric bus
BOP = balance of plant
PMI = preventive maintenance inspection
HVAC = heating, ventilation, and air conditioning

Accomplishments and Progress
Maintenance Cost Trends

Cumulative maintenance cost from start of service



1. Low miles and introduction of new technology leads to higher cost in early stage of FCEB introduction
2. Cost drops as miles increase—most repairs handled under warranty
3. Cost trends up with learning curve for troubleshooting and repair as agency staff take on more maintenance work
4. Costs decrease as mechanics become more familiar with technology
5. Parts cost increase as the Warranty period ends for some FCEBs
6. BEB maintenance work handled by on-site OEM staff; costs increase as agency takes over and warranty period ends

Accomplishments and Progress

Technical Issues Affecting Cost

- Majority of issues with fuel cell system due to balance of plant:
  - Air handling—blowers
  - Cooling—pumps, plumbing
- Electrical system: low-voltage batteries
  - Electric accessories can cause a continual drain that shortens battery life (includes IT equipment such as cameras and fareboxes)
  - Issue also affects BEBs
- Cooling system leaks
  - Significant labor to locate
- Added labor hours for troubleshooting problems

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- Project would benefit from the inclusion of additional bus projects.
  - Response: Sites are added as buses go into service within funding limits. NREL began collecting data on five new FCEBs at SARTA. SunLine is adding at least six new buses in 2018. Results from these buses will be added once we have sufficient data.
- Project would be improved by doing a comparison against battery buses as well as the baseline diesel or CNG, because batteries are the main competitor to fuel cells in the zero-emission bus space. Agencies will want to see what the comparative benefits are.
  - Response: We now have battery bus data and can make comparisons.
- Would like to see data on fueling cycles at the sites.
  - Response: We have included a slide to show fueling data summary (Slide 10).

Collaboration and Coordination

- Transit agencies (1) provide data on buses, fleet experience, and training and (2) review reports
  - California: AC Transit, SunLine, UC Irvine, OCTA
  - Massachusetts: MBTA
  - Ohio: SARTA
- Manufacturers provide some data on buses and review reports
  - Bus OEMs: New Flyer, ElDorado National
  - Fuel cell OEMs: Ballard, Hydrogenics, US Hybrid
  - Hybrid system OEMs: BAE Systems, New Flyer
- Federal Transit Administration provides funding to cover evaluations of both FCEBs and BEBs (follows same protocol)
- Other organizations share information and analysis results
  - California Air Resources Board, Center for Transportation and the Environment, CALSTART

Remaining Challenges and Barriers

- For technology validation and data collection project:
  - Continue data collection to track progress of newer-generation designs
  - Establish good relationships with additional transit agencies to add to the data set
- For industry to commercialize FCEBs:
  - Develop robust supply chain for components and parts to lower cost and downtime
    - Multiple component suppliers to stabilize supply
    - Standardize with conventional bus components to lower cost
  - Deploy larger fleets—large agencies have challenges introducing small fleets of advanced buses
    - Steep learning curve for staff
    - Larger fleets require commitment
  - Reduce cost, both capital and operating
    - Parts and labor increasing as fleets surpass warranty period
  - Competition with other zero-emission technologies

Proposed Future Work

- Remainder of FY 2018
  - Complete the following data analyses/reports:
    - SunLine AFCB Report, May 2018
    - 2018 Annual Status Report, September 2018
    - Preliminary reports on SARTA and OCTA (FTA-funded)
  - Provide feedback to DOE on technical issues with systems and components
  - Begin analysis of fuel cell truck projects
- FY 2019
  - 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

<table>
<tr><th colspan="17">Fuel Cell Electric Bus Evaluations for DOE and FTA</th></tr>
<tr><th rowspan="2">Demonstration</th><th rowspan="2">State</th><th rowspan="2">City</th><th rowspan="2">Bus Length</th><th rowspan="2"># Buses</th><th colspan="4">2017</th><th colspan="4">2018</th><th colspan="4">2019</th></tr>
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<tr><td rowspan="4">American Fuel Cell Bus (AFCB)</td><td>CA</td><td>Thousand Palms</td><td>40</td><td>1</td><td colspan="10">SunLine</td><td></td><td></td></tr>
<tr><td>CA</td><td>Orange County</td><td>40</td><td>1</td><td></td><td colspan="7">OCTA</td><td></td><td></td><td></td><td></td></tr>
<tr><td>OH</td><td>Canton, Cleveland</td><td>40</td><td>2</td><td></td><td></td><td colspan="10">SARTA/GCRTA/OSU</td></tr>
<tr><td>CA</td><td>Irvine</td><td>40</td><td>1</td><td colspan="7">UCI</td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Battery Dominant AFCB</td><td>CA</td><td>Thousand Palms</td><td>40</td><td>1</td><td></td><td></td><td></td><td></td><td colspan="8">SunLine</td></tr>
<tr><td rowspan="2">AFCB (Low-No)</td><td>CA</td><td>Thousand Palms</td><td>40</td><td>5</td><td></td><td></td><td></td><td></td><td></td><td colspan="7">SunLine</td></tr>
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<tr><td>Advanced Generation FCEB</td><td>CA</td><td>Oakland</td><td>60</td><td>1</td><td></td><td></td><td></td><td></td><td></td><td colspan="7">AC Transit</td></tr>
</table>

Color coded by Technology:
- (green) Fuel cell dominant electric
- (blue) Battery dominant fuel cell electric

- Current data collection includes a total of 25 FCEBs at six transit sites
- New sites could add 44 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 February 2018

	2017 Fleet Average	2018 Fleet Max	2018 Fleet Average	2016 Target	Ultimate Target	Target Met
Bus lifetime (years)	4.7	7.5	5.5	12	12	
Bus lifetime (miles)	118,989	189,168	128,656	500,000	500,000	
Powerplant lifetime[a] (hours)	13,801	27,330	13,041	18,000	25,000	2016
Bus availability (%)	76	90	71	85	90	
Roadcall frequency[b] (bus)	4,710	4,715	4,516	3,500	4,000	Ultimate
Roadcall frequency (fuel cell system)	20,705	23,741	18,026	15,000	20,000	Ultimate
Maintenance cost ($/mi)	1.03	0.56	0.53	0.75	0.40	
Fuel economy (mpdge)[c]	6.51	7.82	7.01	8	8	
Range (miles)[d]	247	357	300	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.

Thank You

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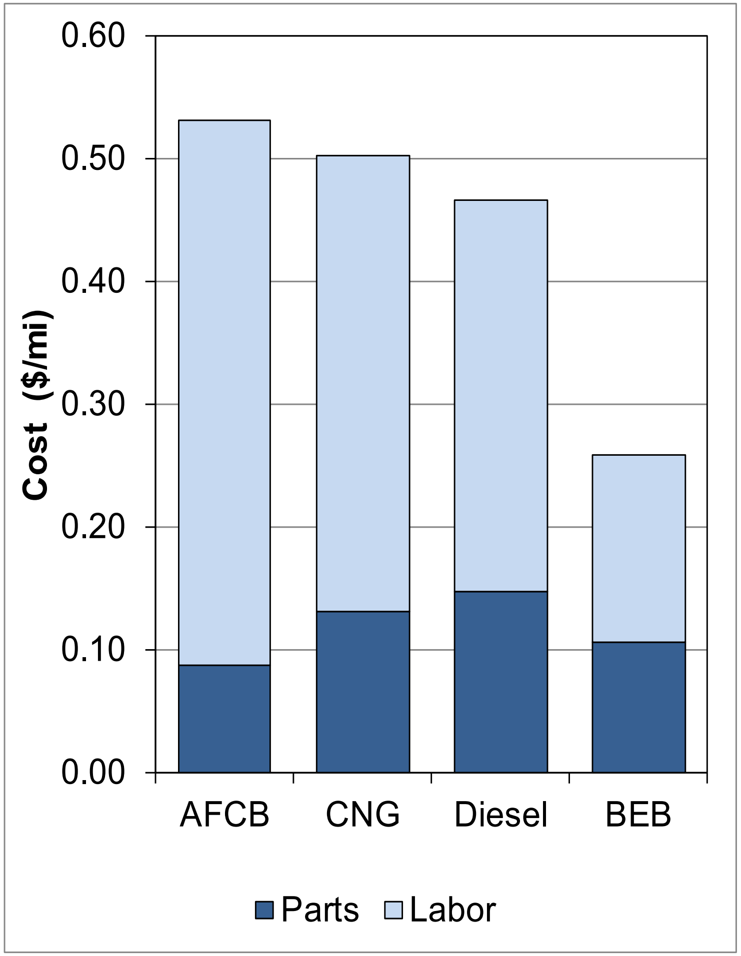
Backup Slides

Accomplishments and Progress
Maintenance Cost: Parts and Labor



- Cumulative cost from in-service date
- Labor @ $50/h

- Majority of FCEB cost is from labor— troubleshooting and training increase labor hours
- Parts costs are low while the buses are under warranty

BEB = battery electric bus