Technology Acceleration: Fuel Cell Bus Evaluations

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DOE Hydrogen and Fuel Cells Program
2019 Annual Merit Review and Peer Evaluation Meeting

Project ID # ta013

Overview

Timeline and Budget

- Project start date: 09/01/03
- FY18 DOE funding: $200K
- FY19 planned DOE funding: $150K
- Total DOE funds received to date: $4.25M (over 17 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 hydrogen 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, http://www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf

Approach

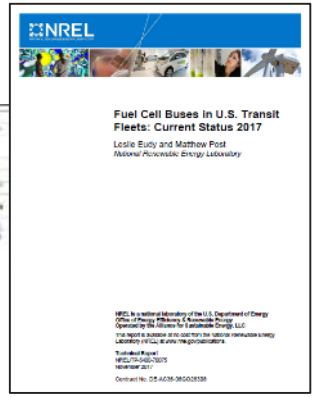
Data Collection/Analysis
NREL uses a standard protocol for collecting existing data from transit partners that:

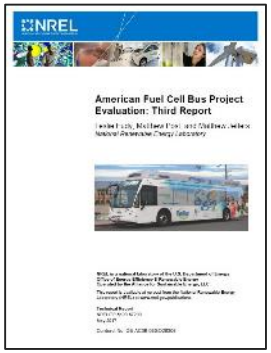
- Provides a third-party analysis
- Includes comparisons to conventional-technology buses in similar service (diesel, CNG, diesel hybrid)

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 2019

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
Altoona tested	No	Yes

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

Approach: Data Summary for 2019

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 and fuel cost only
SunLine Transit Agency	SL	Thousand Palms, CA	AFCB	4	All, prototype bus removed
Orange County Transportation Authority	OCTA	Santa Ana, CA	AFCB	1	All
Stark Area Regional Transit Authority	SARTA	Canton, OH	AFCB	5	All

AC Transit

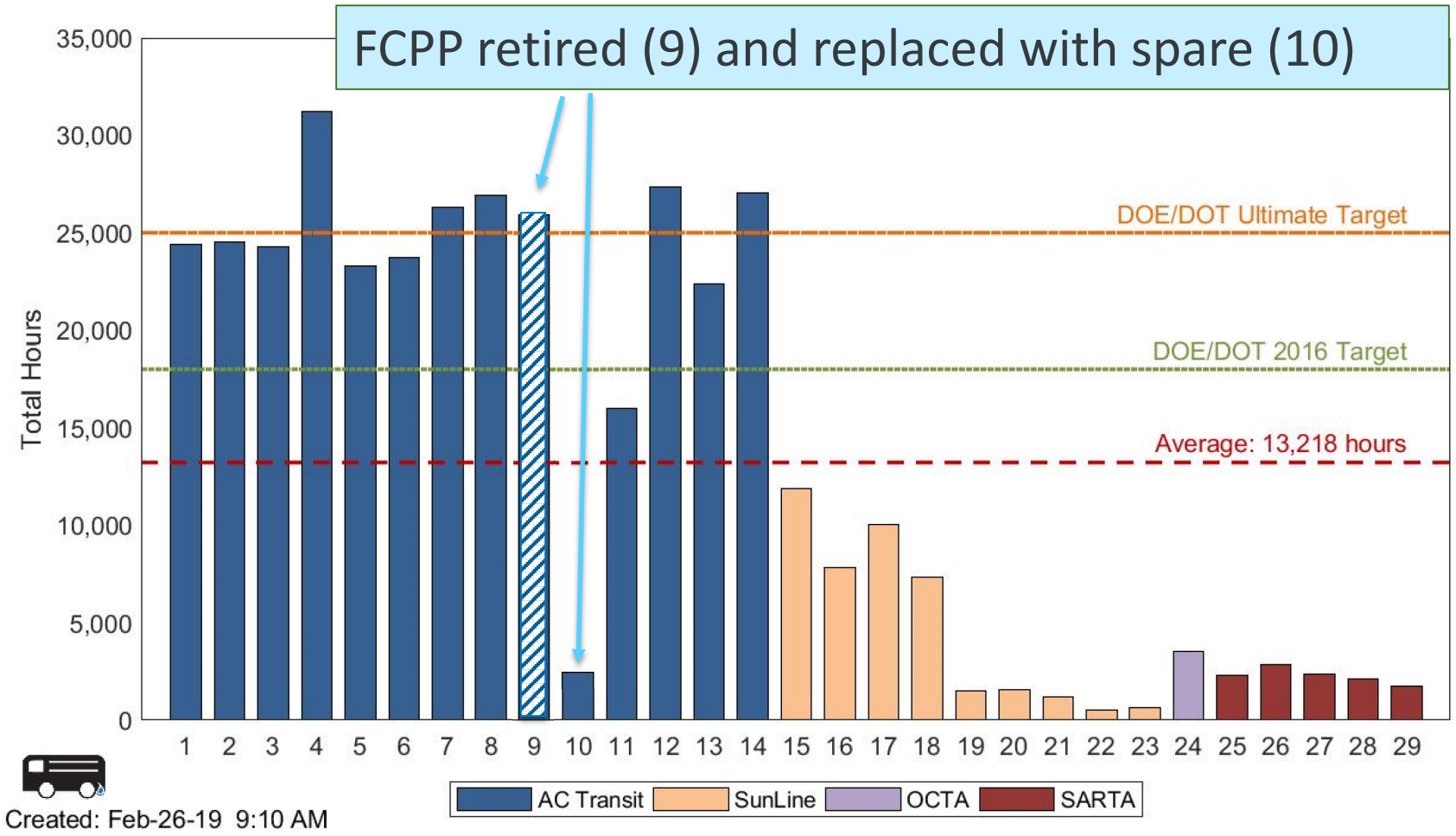
SunLine

OCTA

SARTA

Accomplishments and Progress
Top Fuel Cell Powerplant Exceeds 31,000 Hours

- Top fuel cell powerplant (FCPP) >31,200 hours
- Six FCPPs have surpassed DOE/DOT ultimate target

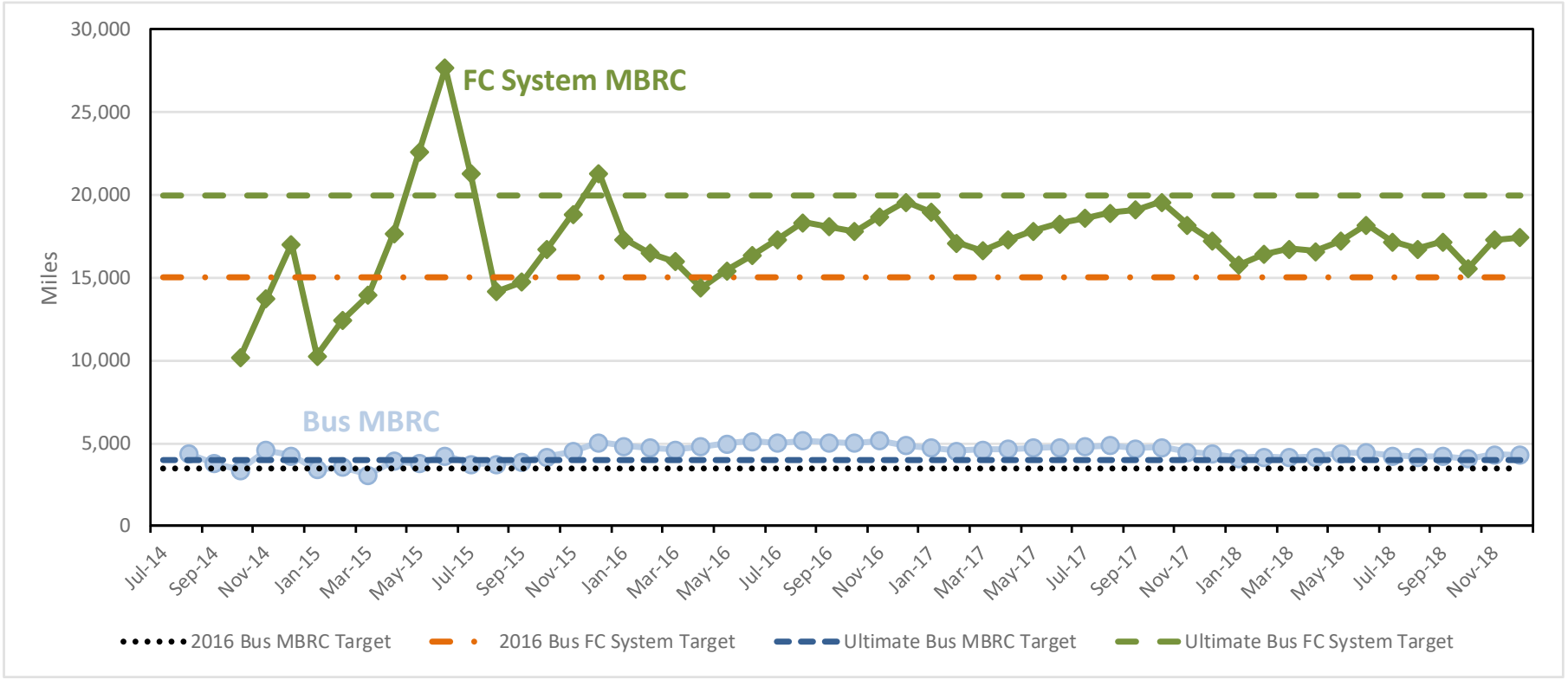


Total hours accumulated on each FCPP as of 12/31/18

Summary of Fuel Cell Powerplant Hours Data

- Data from 29 FCPPs
- 31,210: high-hour FCPP
- 10 new buses added to the data set over the last 2 years
- 13,218: average hours for all FCPPs
- 23,954: average hours for buses 7 years or older
- 6 FCPPs surpassed ultimate target of 25,000 hours
- 12 FCPPs surpassed interim target of 18,000 hours
- 1 FCPP retired in late 2018 at 25,969 hours
  - FCPP no longer provided enough power to keep schedule
  - Replaced with spare FCPP that was part of original purchase

Accomplishments and Progress
Reliability: Miles Between Roadcall (MBRC)



- Data from newer buses (in service from July 2014)
- Fuel cell system roadcalls are caused by balance of plant components, not stack issues

Accomplishments and Progress
Hydrogen Cost Data Summary, $/mi

	AC Transit[a]	SunLine[b]	OCTA[c]	SARTA[d]
Data period	2/13–7/17	3/12–12/18	3/16–12/18	2/18–12/18
Number of months	54	82	34	11
Average H_2 cost, $/kg	8.39	10.17	13.95	5.14
Maximum H_2 cost, $/kg	10.26	26.02	16.99	5.88
Minimum H_2 cost, $/kg	6.49	2.53	12.99	5.00
Overall FCEB fuel cost, $/mile	1.41	1.83	2.21	1.04
Baseline technology	Diesel	CNG	CNG	CNG/diesel hybrid
Average fuel cost, $/gal or $/gge	2.43	0.96	1.15	1.89/2.30
Overall baseline fuel cost, $/mile	0.57	0.32	0.32	0.45/0.51

Overall cost comparison to baseline

Fuel cost is based on data provided by agencies; not all are equal comparisons

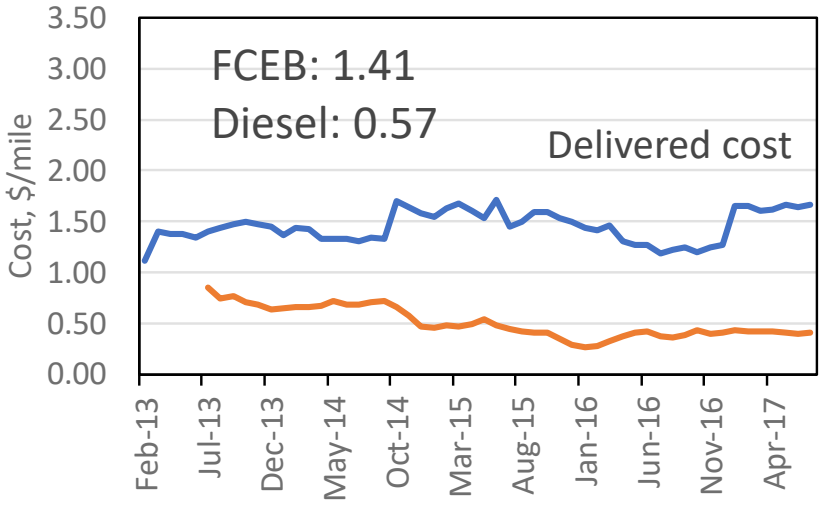
[a] Delivered cost

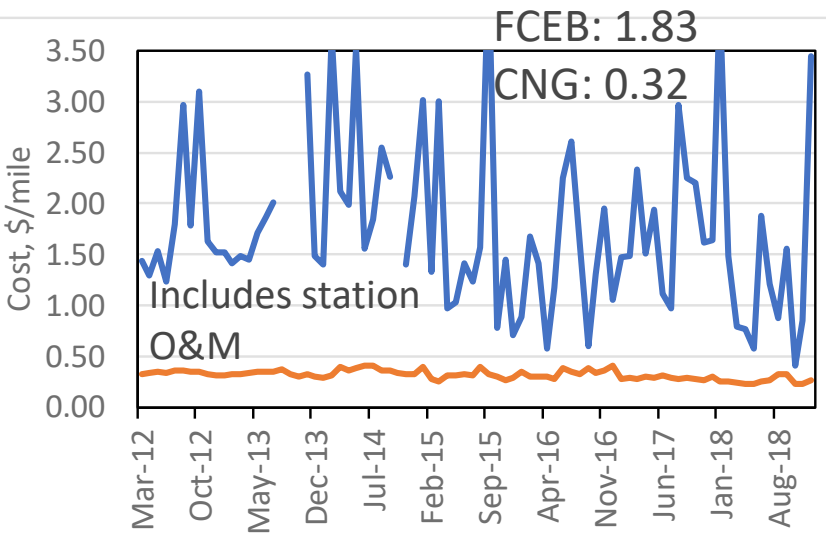
[b] Includes station operating and maintenance (O&M) costs

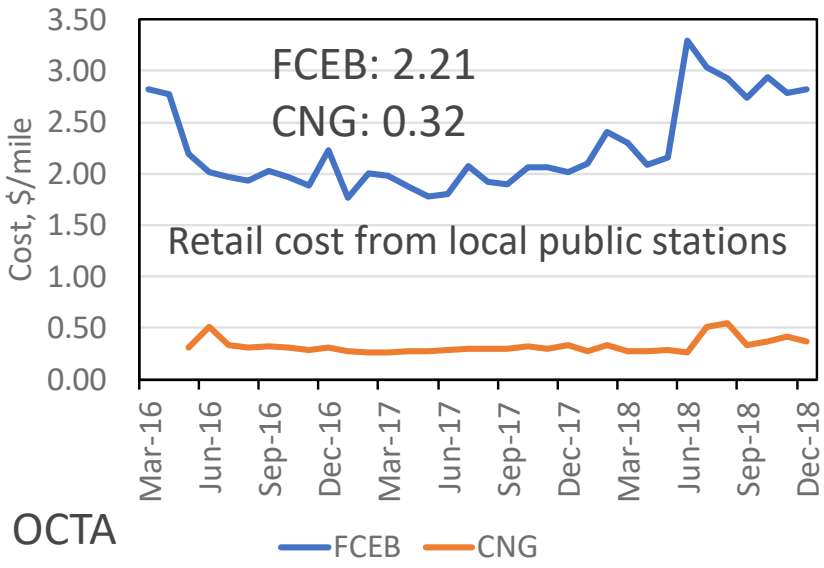
[c] Retail cost from local public stations

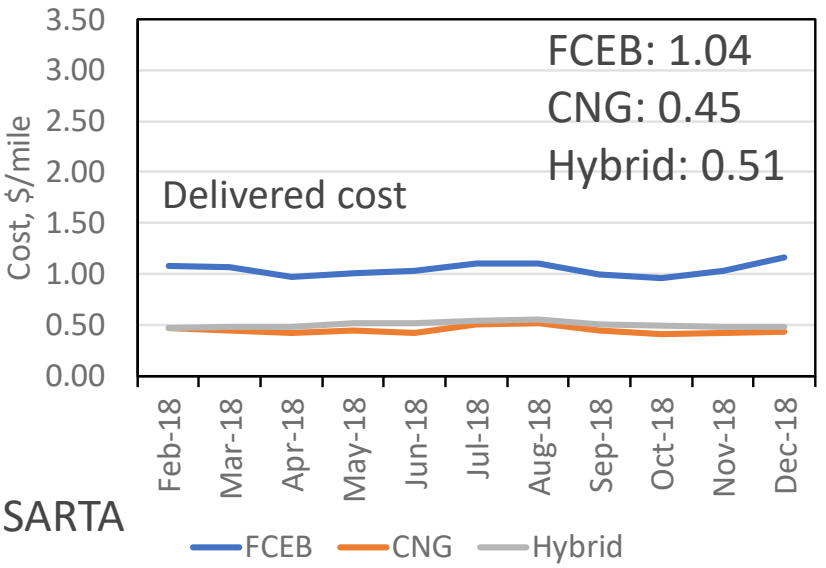
[d] Delivered cost

Accomplishments and Progress
Fueling Cost Data Summary, $/mi

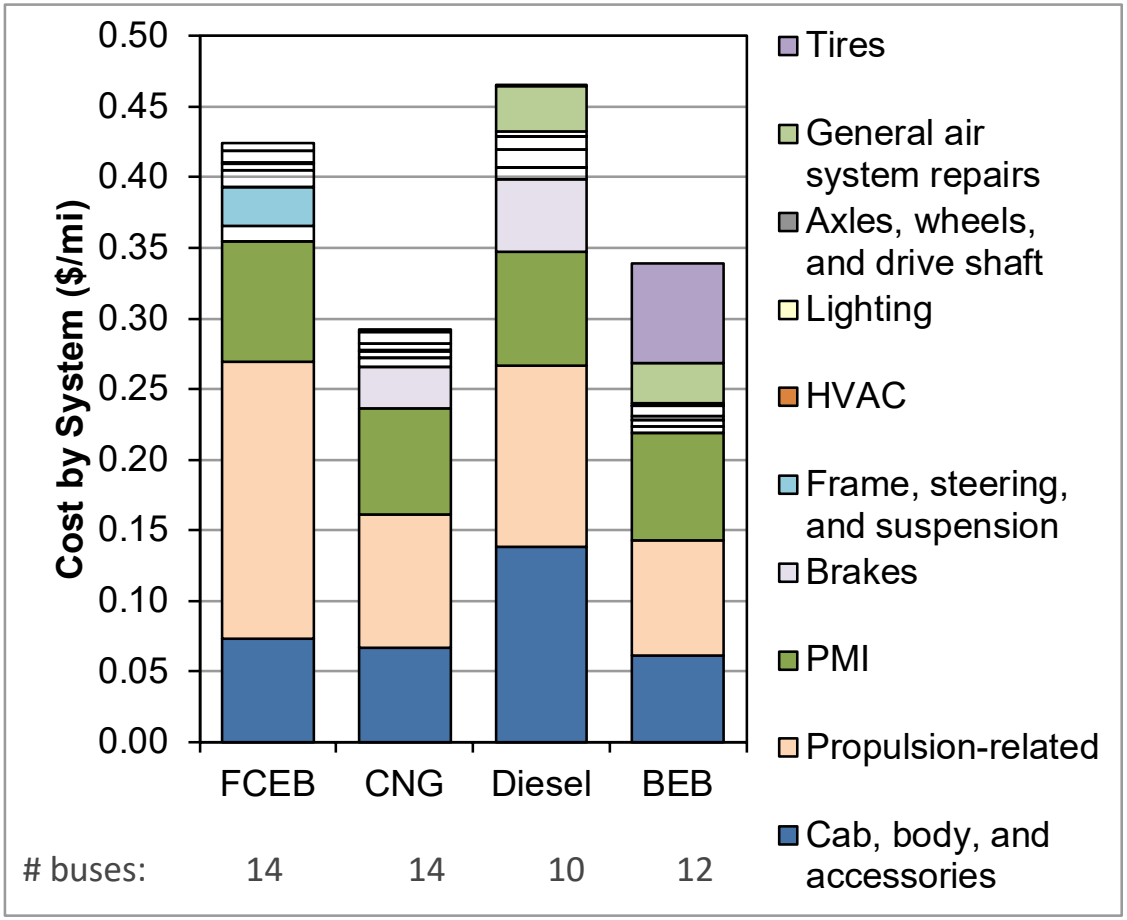








Accomplishments and Progress
Maintenance Cost by System



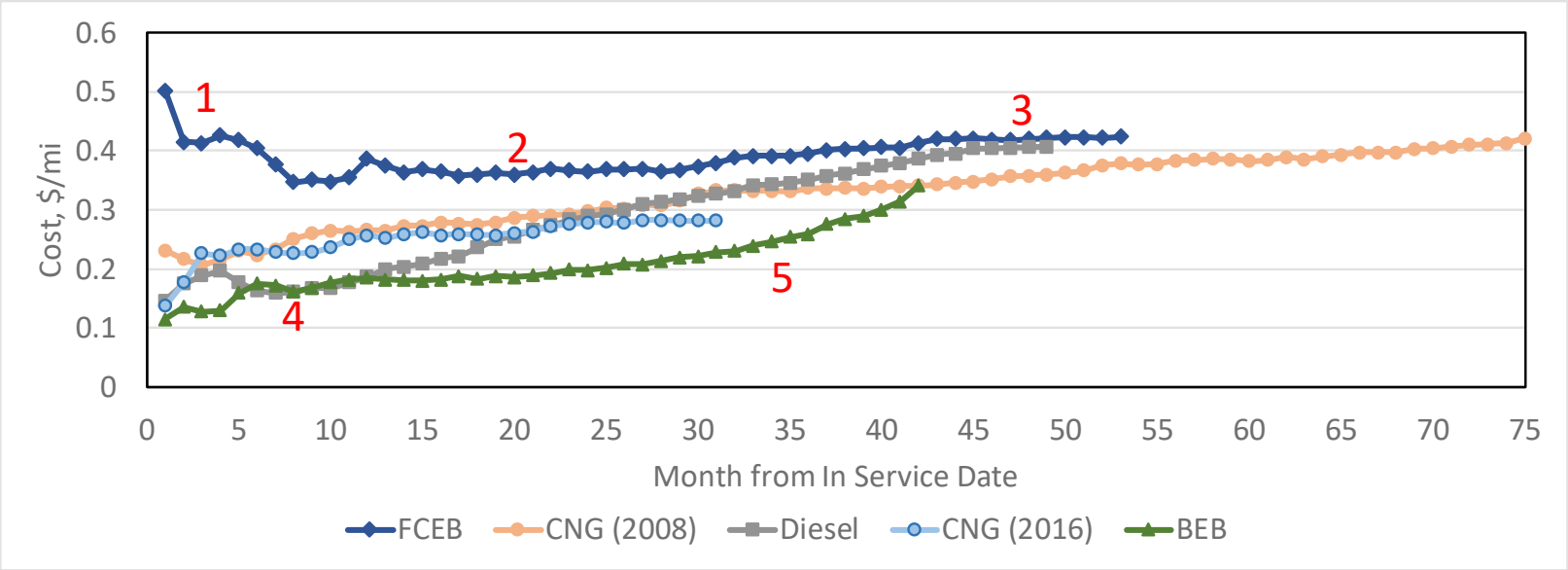
- Cumulative cost from in-service date
- Labor @ $50/h

- 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

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

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 and stabilizes 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. BEB maintenance work handled by on-site OEM staff
5. BEB costs increase as agency takes over and warranty period ends

Technical Issues Affecting Cost

- Fuel cell system issues—majority due to balance of plant
  - Air handling—blowers, compressors, controller
  - 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
- Bus air compressor
- Added labor hours for troubleshooting problems

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- While the project provides value in tracking long-term reliability and life of the fuel cell system and buses, that presents a weakness in that the technology being examined is increasingly obsolete—and in some cases, technology from companies that are no longer in business is being used. It could be useful to separate out newer FCEBs from the older-generation FCEBs in the analysis.
  - Response: The primary analysis in this presentation is for the newest buses that began service in July 2014. The AFCB prototype was removed from the analysis and the data from the AC Transit buses are limited to FCPP hours and fuel cost.
- Recommended the project team also indicate which buses are tested by the Altoona Bus Research and Testing Center
  - Response: This has been added to the bus specifications slide. The AFCB and New Flyer FCEBs have completed Altoona testing.

Collaboration and Coordination

- Transit agencies (1) provide data on buses, fleet experience, and training and (2) review reports
  - California: AC Transit, SunLine, OCTA
  - 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
- FTA 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 acceleration 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:
  - Deploy larger fleets
    - Lower per-bus price: OEMs estimate ~$1M/bus for higher volumes
    - Accelerate learning curve for staff
    - Combine orders for multiple agencies
  - Incorporate training for FCEBs into standard maintenance training
  - Install hydrogen stations
    - High capital cost to install, but easier to scale up compared to battery fleet
    - Turn-key stations where fuel provider owns, operates, and maintains station can help with stabilizing cost for long-term budget planning
    - Long-term fuel contracts can lock in lower cost
    - Station utilization—higher volumes can mean lower per-unit cost

Proposed Future Work

- Remainder of FY 2019
  - Complete the following data analyses/reports:
    - SunLine AFCB Report, May 2019
    - 2019 Annual Status Report, September 2019
    - Preliminary reports on SARTA and OCTA (FTA-funded)
  - Provide feedback to DOE on technical issues with systems and components
  - Analyze fuel cell truck projects
- FY 2020
  - Kick off new FCEB evaluations as buses go into service—target new designs from different OEMs
  - Complete annual crosscutting analysis across sites

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

Proposed Future Work

Fuel Cell Electric Bus Evaluations for DOE and FTA																
Demonstration	State	City	Bus Length	# Buses	2018				2019				2020			
					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							
AFCB (TIGGER)	CA	Thousand Palms	40	3	SunLine											
Battery Dominant AFCB	CA	Thousand Palms	40	1				SunLine								
AFCB (Low-No)	CA	Thousand Palms	40	5		SunLine										
	OH	Canton	40	5	SARTA											
FCEB Commercialization Consortium	CA	Oakland	40	10						AC Transit						
	CA	Orange County	40	10						OCTA						
SunLine FCEB & H2 generation	CA	Thousand Palms	40	5						SunLine						
Advanced Generation FCEB	CA	Oakland	60	1						AC Transit						

Color coded by Technology:

Fuel cell dominant electric

Battery dominant fuel cell electric

- Current data collection includes a total of 29 FCEBs at six transit sites
- New sites could add 26 buses from a third OEM

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 2018

	2017 Fleet Average	2018 Fleet Max	2018 Fleet Average	2016 Target	Ultimate Target	Target Met
Bus lifetime (years)	5.5	8.4	4.6	12	12	
Bus lifetime[a] (miles)	128,656	237,483	125,613	500,000	500,000	
Powerplant lifetime[a] (hours)	13,041	31,210	13,218	18,000	25,000	Ultimate
Bus availability (%)	71	100	73	85	90	
Roadcall frequency[b] (bus)	4,516	4,375	3,997	3,500	4,000	2016
Roadcall frequency (fuel cell system)	18,026	43,806	15,449	15,000	20,000	2016
Maintenance cost ($/mi)	0.53	0.62	0.42	0.75	0.40	2016
Fuel economy (mpdge)[c]	7.01	7.82	7.01	8	8	
Range (miles)[d]	300	360	277	300	300	Ultimate

[a] Bus miles or fuel cell hours accumulated to date. 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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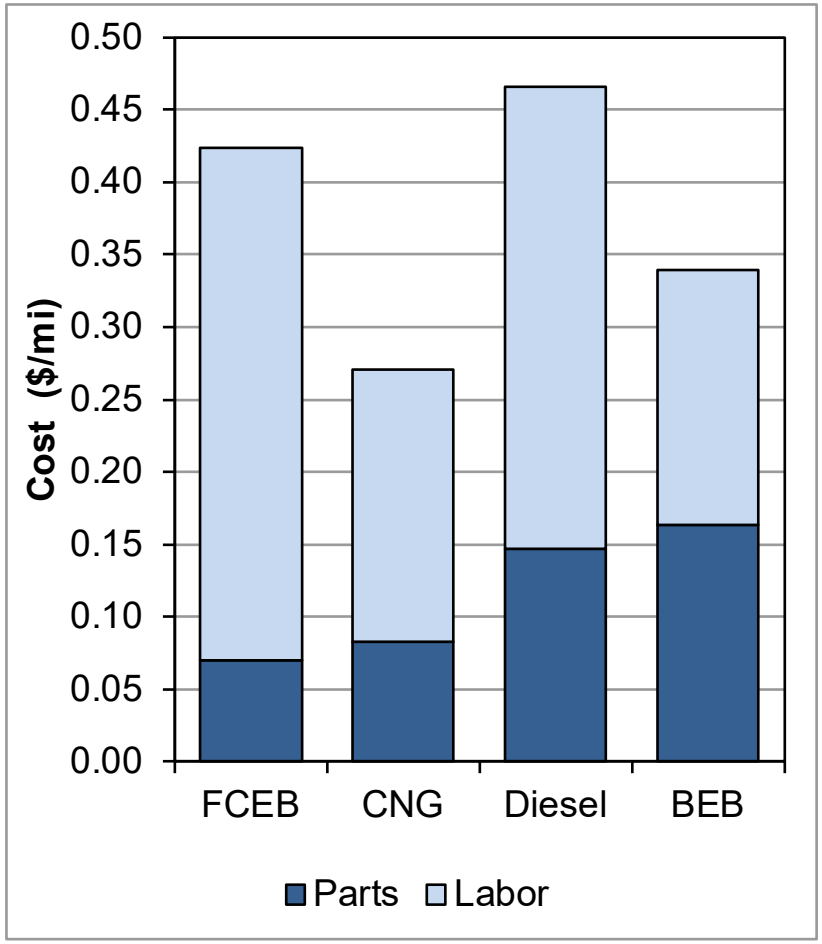
Backup Slides

Maintenance Cost: Parts and Labor



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

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

Accomplishments and Progress
Electric Cost Data Summary for BEBs

Agency	Foothill Transit	County Connection	King County Metro
Data period	4/14–7/18	6/17–5/18	4/16–3/17
Number of months	51	12	12
Average energy cost, $/kWh	0.18	0.22	0.20
Summer cost, $/kWh	0.21	0.25	0.19
Winter cost, $/kWh	0.16	0.20	0.21
Overall BEB energy cost, $/mile	0.46	0.73	0.57
Baseline technology	CNG	Diesel	Diesel/Hybrid
Average fuel cost, $/gal or $/gge	0.95	2.02	1.59
Overall baseline fuel cost, $/mile	0.24	0.54	0.30/0.25

Overall cost comparison to baseline

Accomplishments and Progress
Electric Cost Data Summary for BEBs