Technology Acceleration: Fuel Cell Bus Evaluations

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National Renewable Energy Laboratory
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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
- FY19 DOE funding: $150K
- FY20 planned DOE funding: $150K
- Total DOE funds received to date: $4.4M (over 18 years)

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

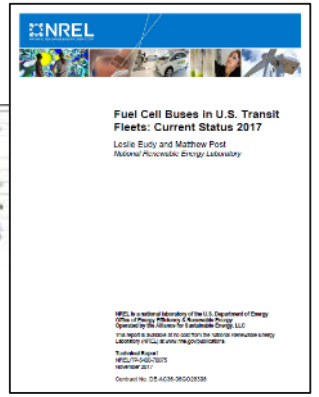
Current Targets[a]	Units	2016 Target	Ultimate Target
Bus lifetime	years/miles	12/500,000	12/500,000
Powerplant lifetime	hours	18,000	25,000
Bus availability	%	85	90
Roadcall frequency (bus/fuel cell system)	miles between roadcall	3,500/15,000	4,000/20,000
Operation time	hours per day/ days per week	20/7	20/7
Maintenance cost	$/mile	0.75	0.40
Fuel economy	miles per diesel gallon equivalent	8	8
Bus Cost	$	1,000,000	600,000

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

Approach

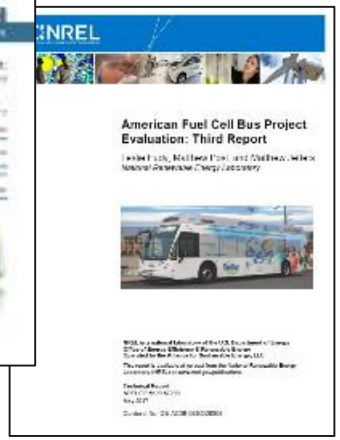
Data Collection/Analysis
- Standard protocol
- Third-party analysis
- Comparisons to conventional-technology buses in similar service (diesel, CNG, diesel hybrid)

Individual Site Reports
- Documents performance by site
- Builds database of results
- Reports posted on NREL website



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

CNG = compressed natural gas



Approach: Data Summary for 2020

Selected specifications for FCEBs included in data summary

Bus Manufacturer	Van Hool	ENC	New Flyer
Model	A330	AFCB/Axcess	Xcelsior/XHE40
Bus length/height	40 ft/136 in.	40 ft/140 in.	40 ft/130 in.
Fuel cell OEM	UTC Power	Ballard	Ballard
Model	PureMotion 120	FCvelocity–HD6	FCvelocity-HD85
Power (kW)	120	150	85
Hybrid system	Siemens ELFA, Van Hool integration	BAE Systems HybriDrive	Siemens ELFA, New Flyer integration
Design strategy	Fuel cell dominant	Fuel cell dominant	Battery dominant
Energy storage – OEM	EnerDel	A123	A123
Type	Li-ion	Li-ion	Li-ion
Capacity	17.4 kWh	11 kWh	100 kWh
Altoona tested	No	Yes	Yes

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

Approach: Data Summary for 2020

FCEB fleets included in data summary

Transit Agency	Abbreviation	Location	Bus OEM	# Buses	Data Included
AC Transit	ACT	Oakland, CA	Van Hool	13	Fuel cell hours only
SunLine Transit Agency	SL	Thousand Palms, CA	ENC	8	All, prototype bus removed
			New Flyer	5	Preliminary fuel economy data
Orange County Transportation Authority	OCTA	Santa Ana, CA	ENC	1	All
Stark Area Regional Transit Authority	SARTA	Canton, OH	ENC	5	All

AC Transit

SARTA

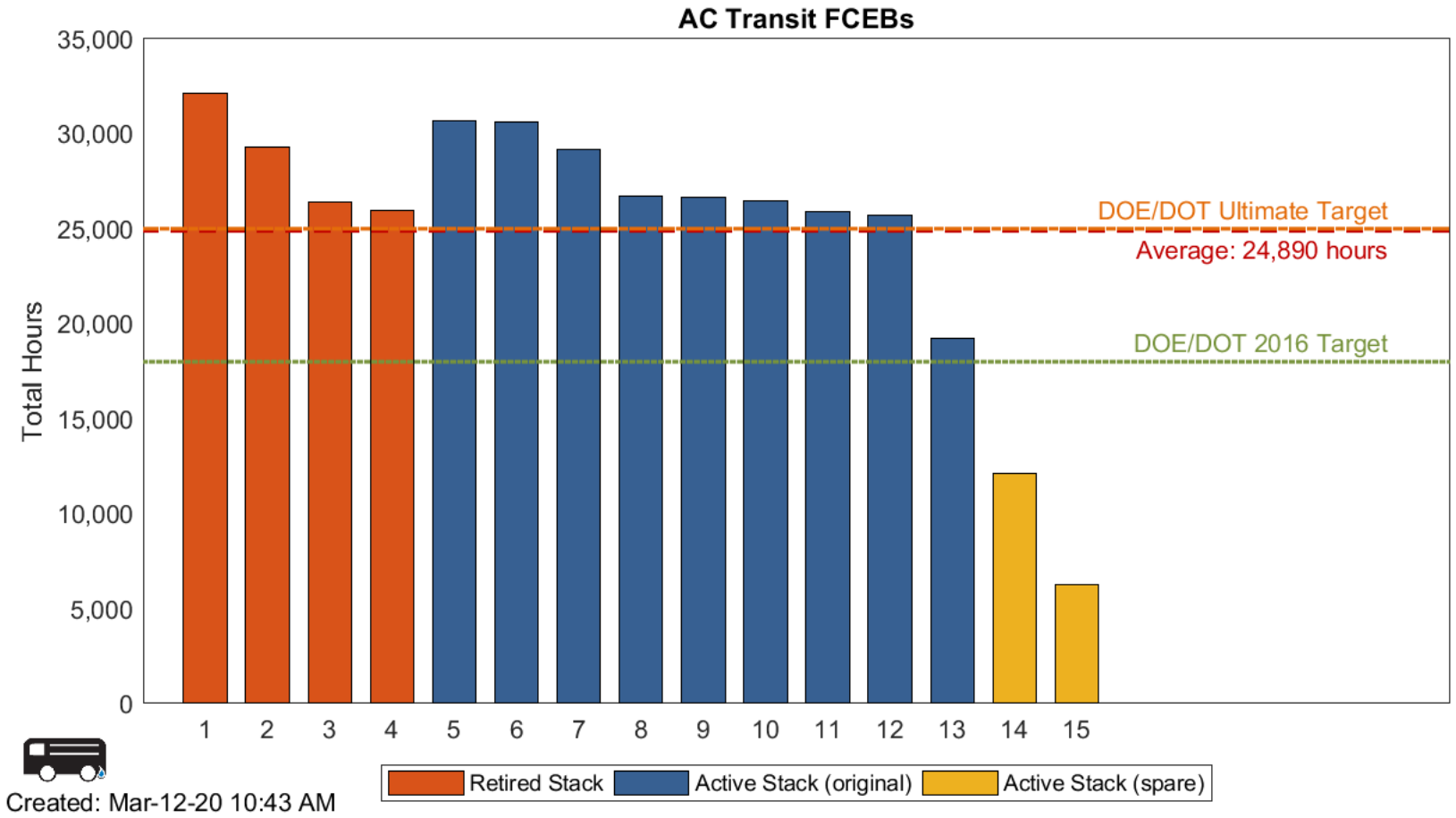
SunLine, New Flyer

OCTA

SunLine, ENC

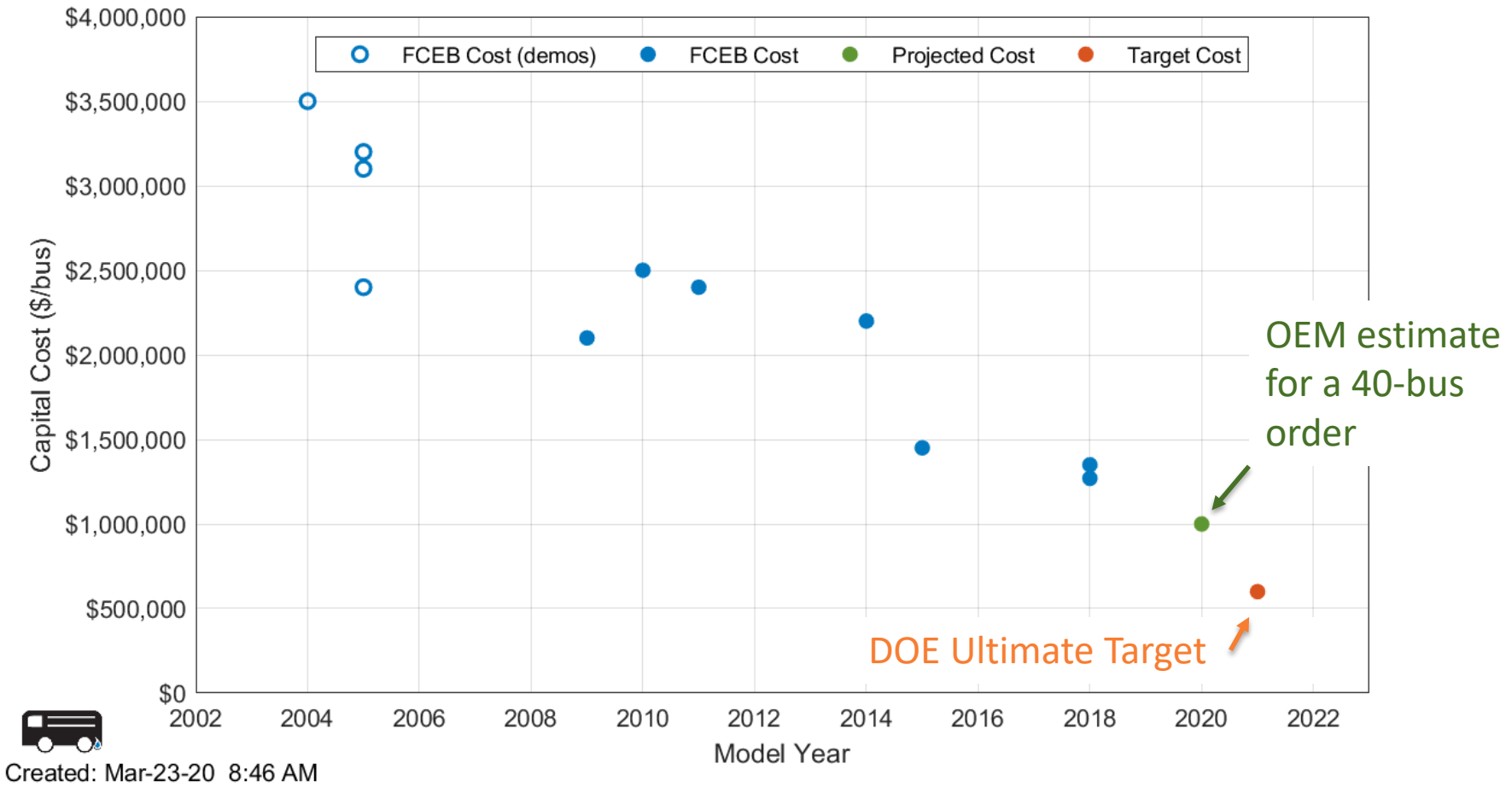
Accomplishments and Progress
Top Fuel Cell Powerplant Exceeds 32,000 Hours

- Top fuel cell powerplant (FCPP) >32,000 hours
- 12 FCPPs have surpassed DOE/DOT ultimate target



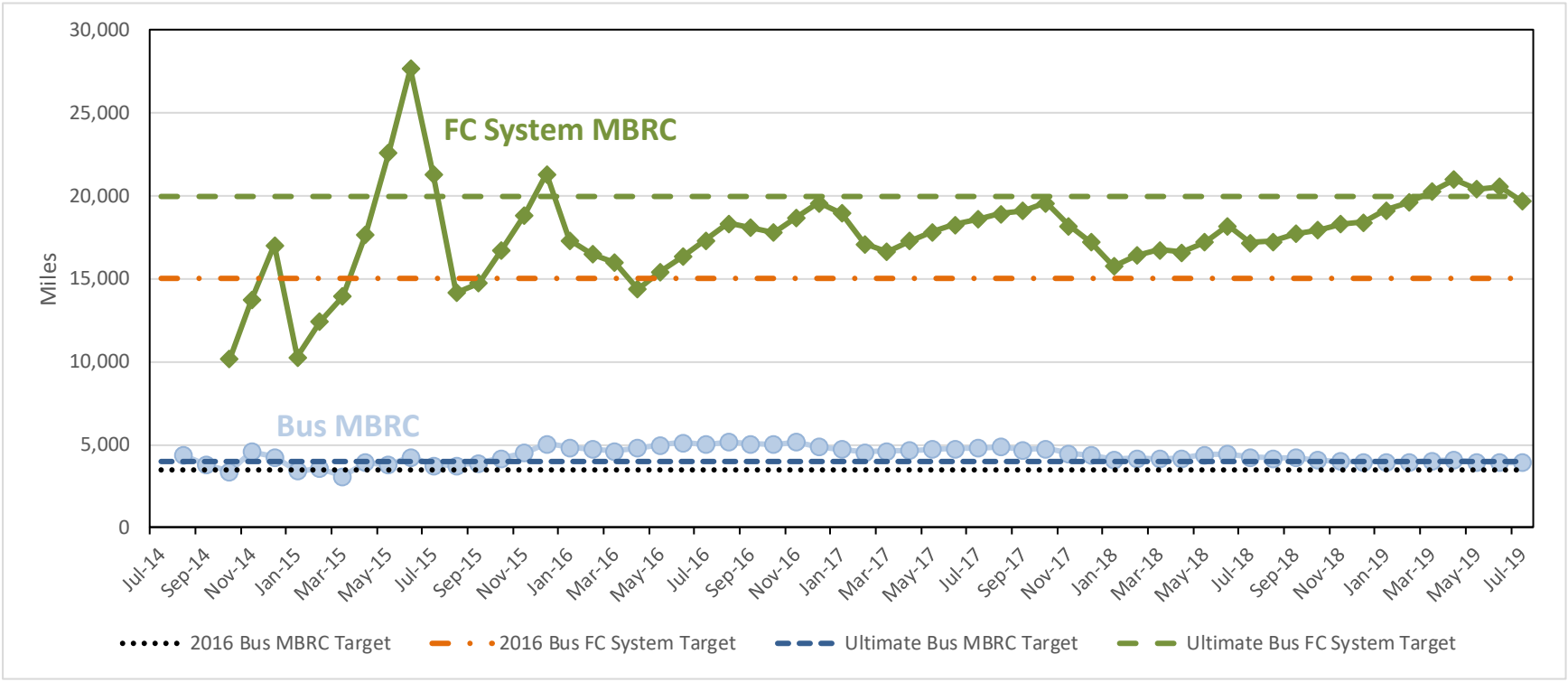
Total hours accumulated on each FCPP as of 3/1/2020

Accomplishments and Progress
FCEB Capital Costs Dropping



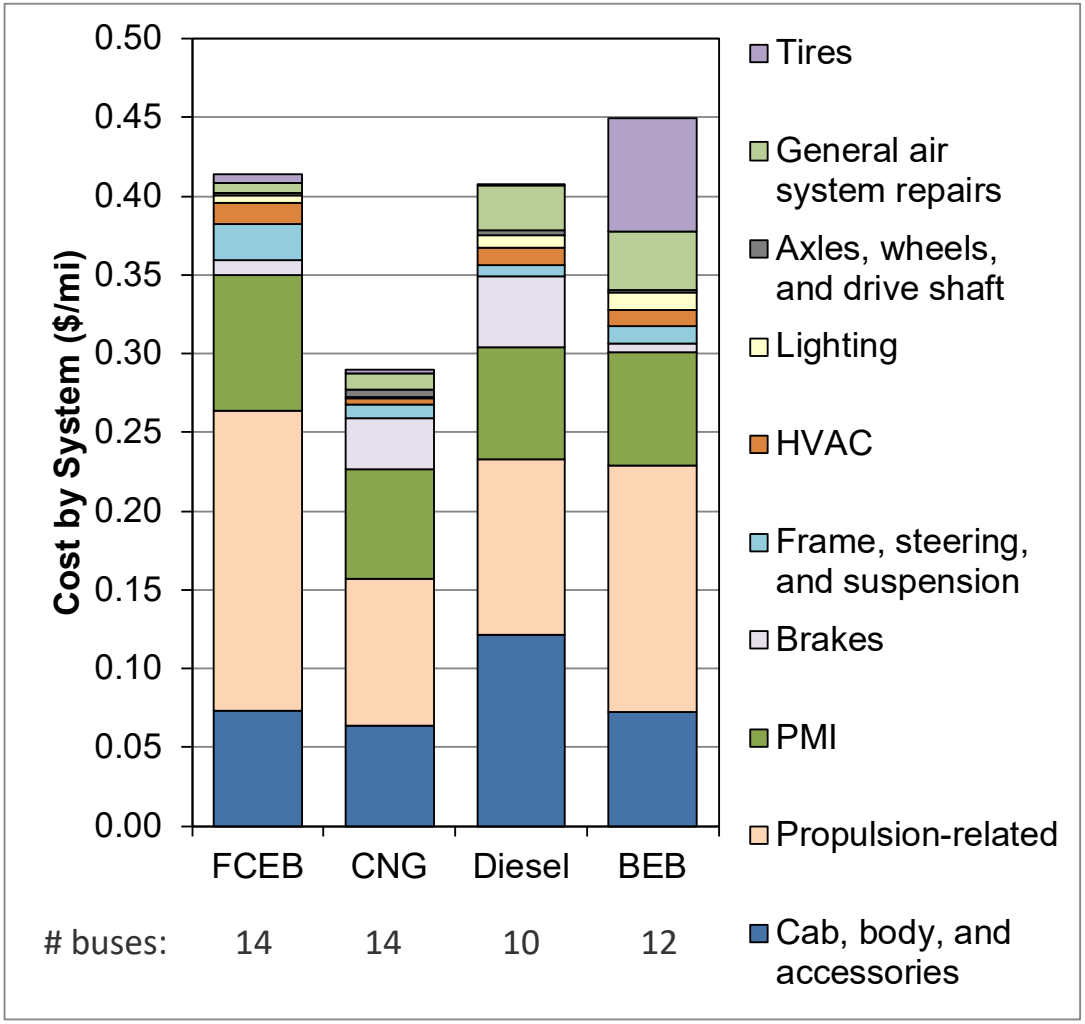
Newest FCEB order 2.8x lower cost compared to early demonstrations

Accomplishments and Progress
Reliability: Miles Between Roadcall (MBRC)



- Data from newer ENC buses
- Meeting ultimate target at the end of the data period
- Fuel cell system roadcalls are caused by balance of plant components, not stack issues

Accomplishments and Progress
Maintenance Cost by System

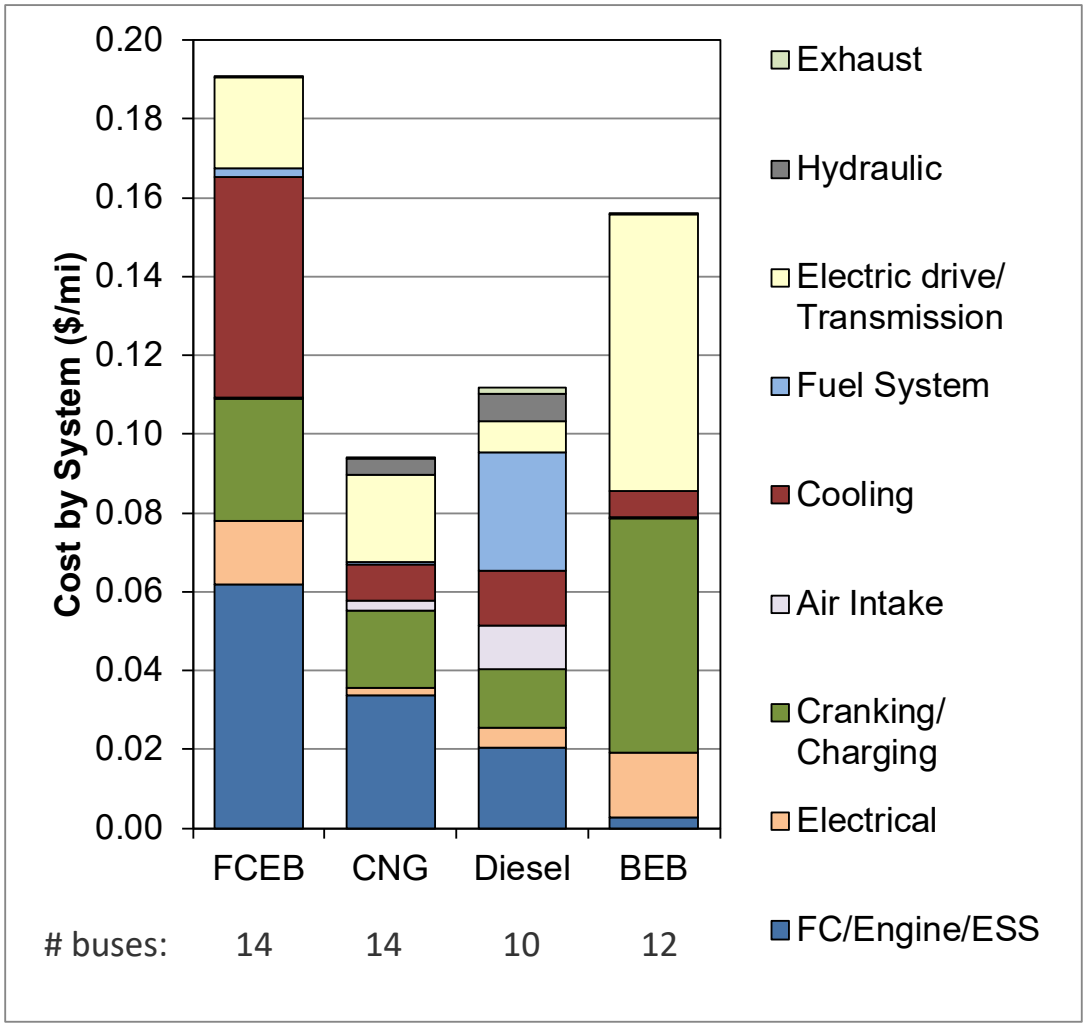


- Cost for propulsion system repairs highest for FCEBs
- Propulsion issues include:
  - Cooling system labor
  - Low-voltage batteries
  - Fuel cell BOP

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

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

Propulsion Maintenance Cost by Sub-System



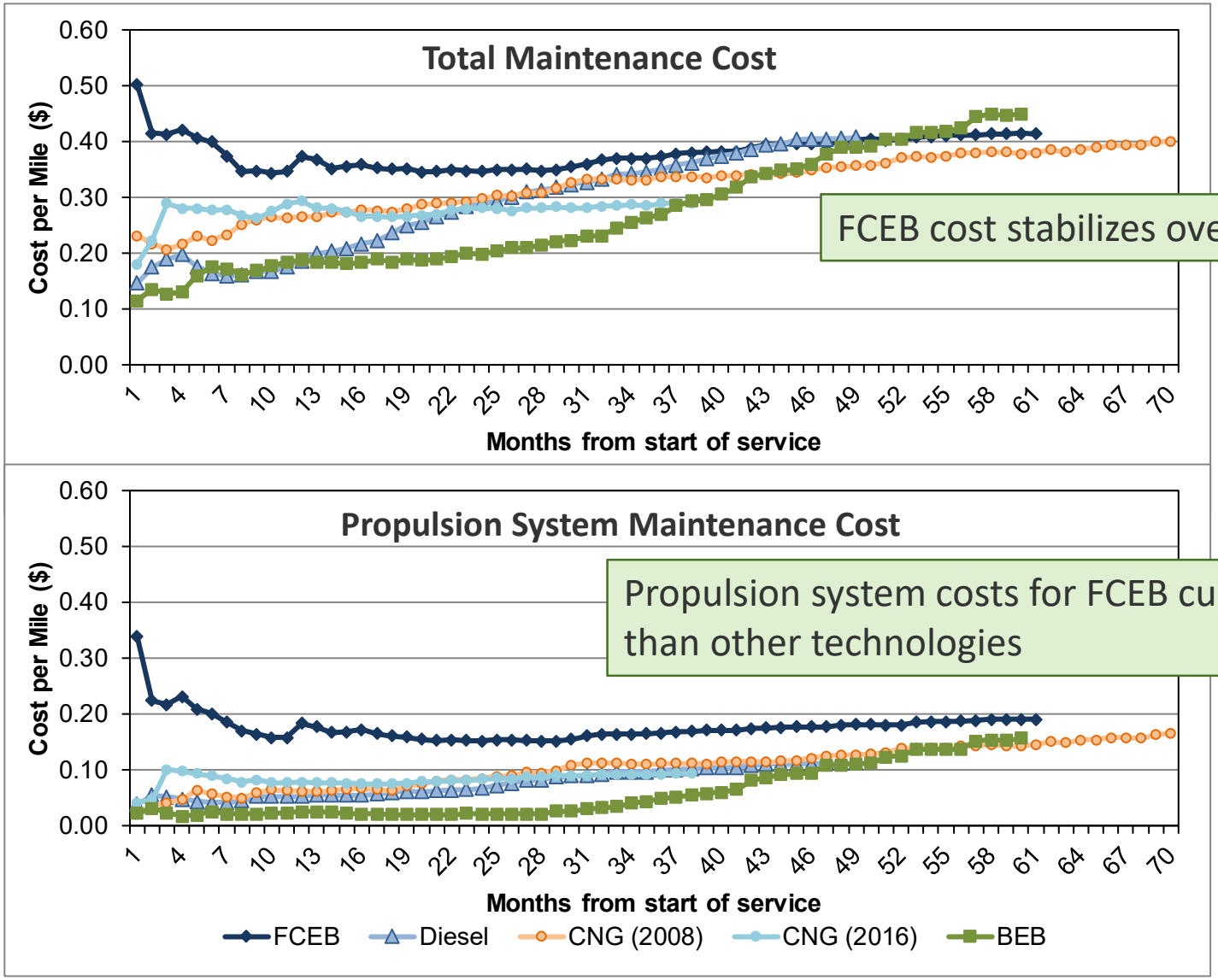
- FC costs for FCEB primarily labor
- ESS cost for FCEBs included in electric drive category
- Cooling costs primarily labor for checking/topping off fluids

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

BEB = battery electric bus
BOP = balance of plant
ESS = energy storage system

Maintenance Cost Trends

Cumulative maintenance cost from start of service

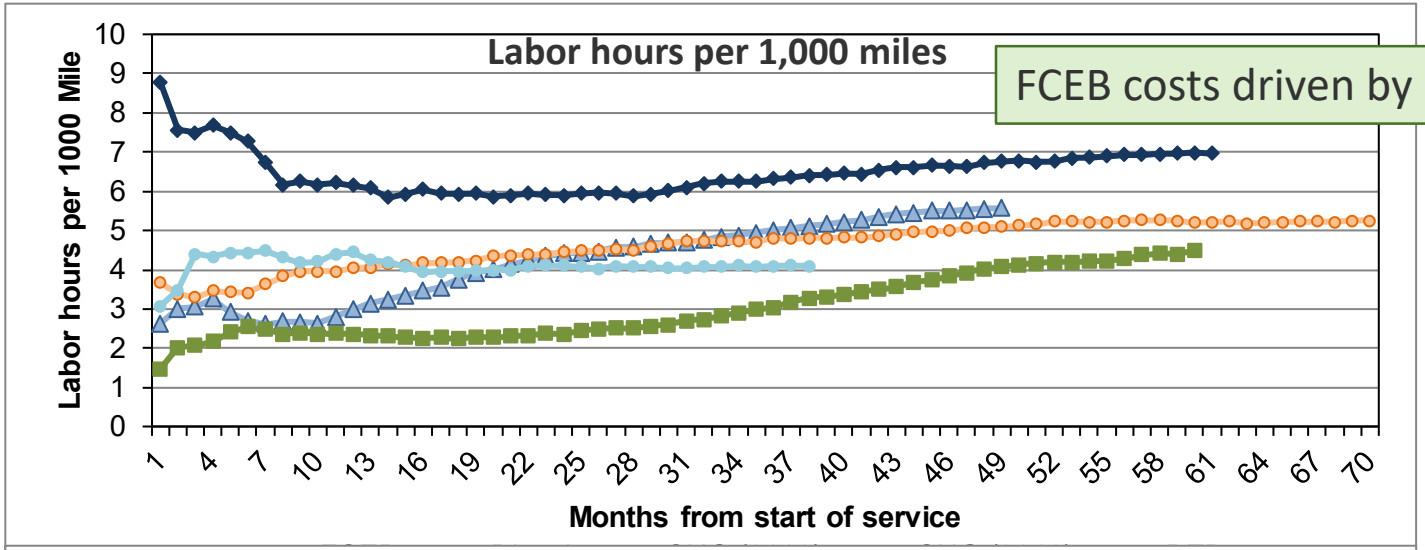


FCEB cost stabilizes over time

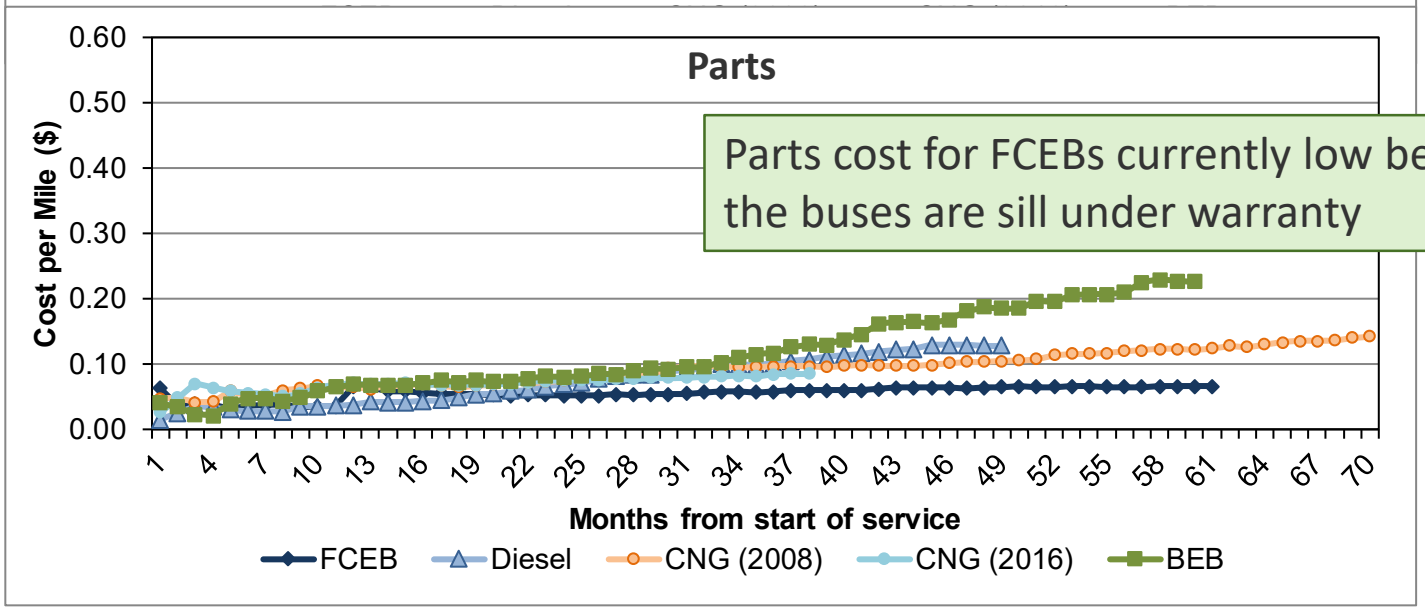
Propulsion system costs for FCEB currently higher than other technologies

Maintenance Cost Trends

Cumulative maintenance cost from start of service

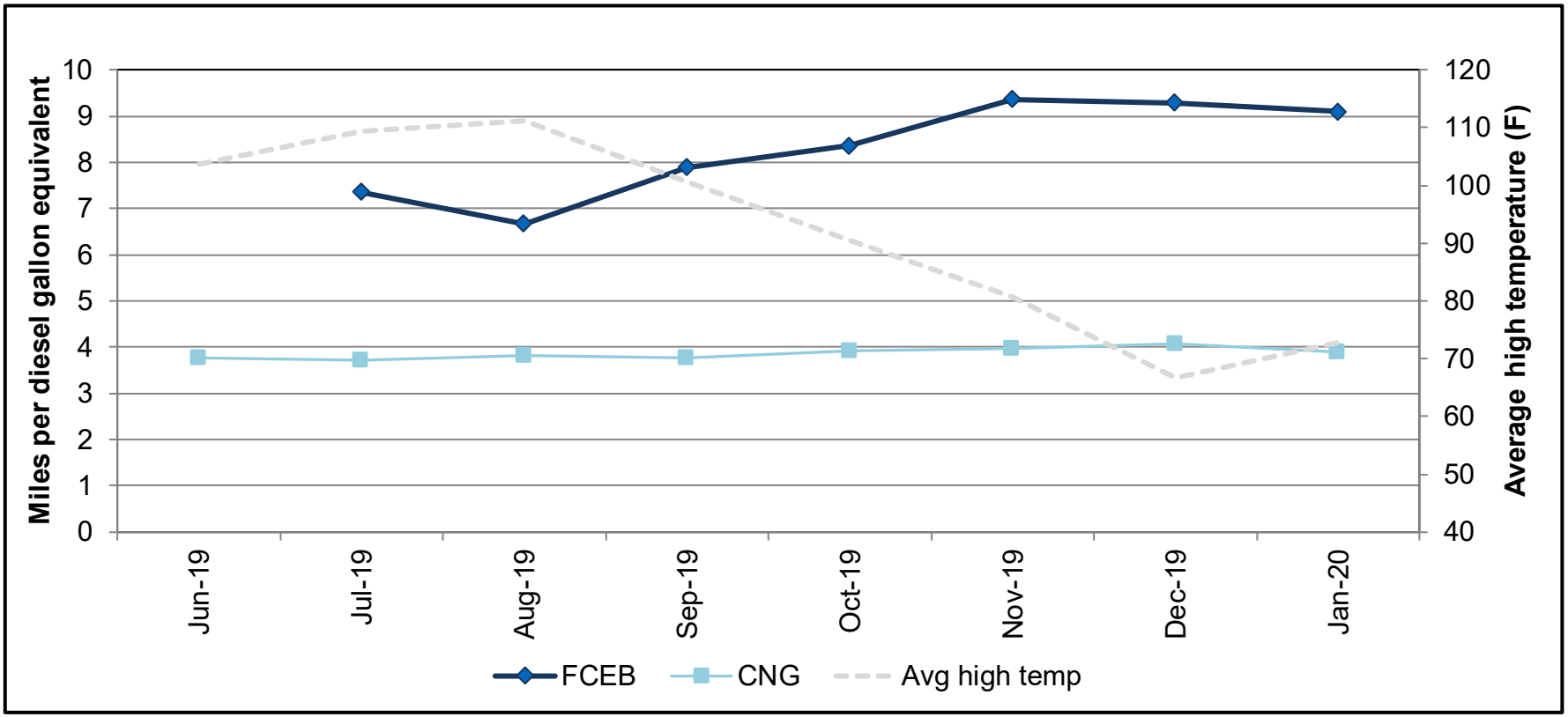


FCEB costs driven by labor costs



Parts cost for FCEBs currently low because most of the buses are sill under warranty

Accomplishments and Progress
Fuel Economy



- Preliminary data on new design FCEBs
- Average fuel economy: 7.52 mi/kg, 8.52 mpdge
- Meets DOE/DOT ultimate target

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- Project should combine key data to generate insight into the total cost of ownership.
  - Response: NREL is evaluating how to incorporate this type of analysis in the future.
- Provide data in more severe climates (hot and humid, extreme cold)
  - Response: As FCEBs are deployed in different locations, NREL will explore the potential to add those vehicles to the data collection and analysis.
- Expand the scope to other emerging applications
  - NREL will be evaluating medium and heavy-duty fuel cell trucks as they are deployed.

Collaboration and Coordination

- Transit agencies (1) provide data on buses, fleet experience, and training and (2) review reports
  - California: AC Transit, SunLine, OCTA
- 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 provided funding to cover evaluations of both FCEBs and BEBs – funding ended in 2019
- 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
    - Incorporate training into current course work
    - Accelerate learning curve for staff
    - Add trained technicians to staff at local OEM support centers
  - Install hydrogen stations
    - High capital cost to install, but easier to scale up compared to battery fleet
    - Standardization: each installation is different, making it challenging to plan budget

Proposed Future Work

- Remainder of FY 2020
  - Data collection focused on new designs at three fleets:
    - SunLine, 5 New Flyer FCEBs, 1 battery dominant FCEB
    - OCTA, 10 New Flyer FCEBs
    - AC Transit, 10 New Flyer FCEBs
  - Complete the following data analyses/reports:
    - SunLine AFCB Report, May 2020 (final report for this design)
    - 2020 Annual Status Report, September 2020
  - Analyze fuel cell truck projects
- FY 2021
  - Analyze and report on data from New Flyer FCEBs
  - Complete annual crosscutting analysis across sites

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

- Bus lifetime target: 12 years/ 500,000 miles
  - Multiple buses have reached 8 years in service
- Powerplant lifetime: 25K hours ultimate target
  - Ultimate target met
- Capital cost: $600K
  - New orders 2.8 times lower cost compared to early demo buses
- Fuel economy/range: 8 mpg/300 miles
  - Preliminary data on new bus model meets target
- Both FCEB U.S. models have completed Altoona testing
- Increasing interest in the U.S. primarily driven by advantages over BEB technology: increased range, fast fueling, easier scale-up of infrastructure
- Availability: 85% interim, 90% ultimate
  - Current data show FCEBs do not yet meet interim target (72%)
- Operation cost: $0.75/mi interim, $0.40/mi ultimate
  - Current cost is slightly more than ultimate target, some buses still under warranty. Need to track cost for newest design after warranty ends.

Thank You

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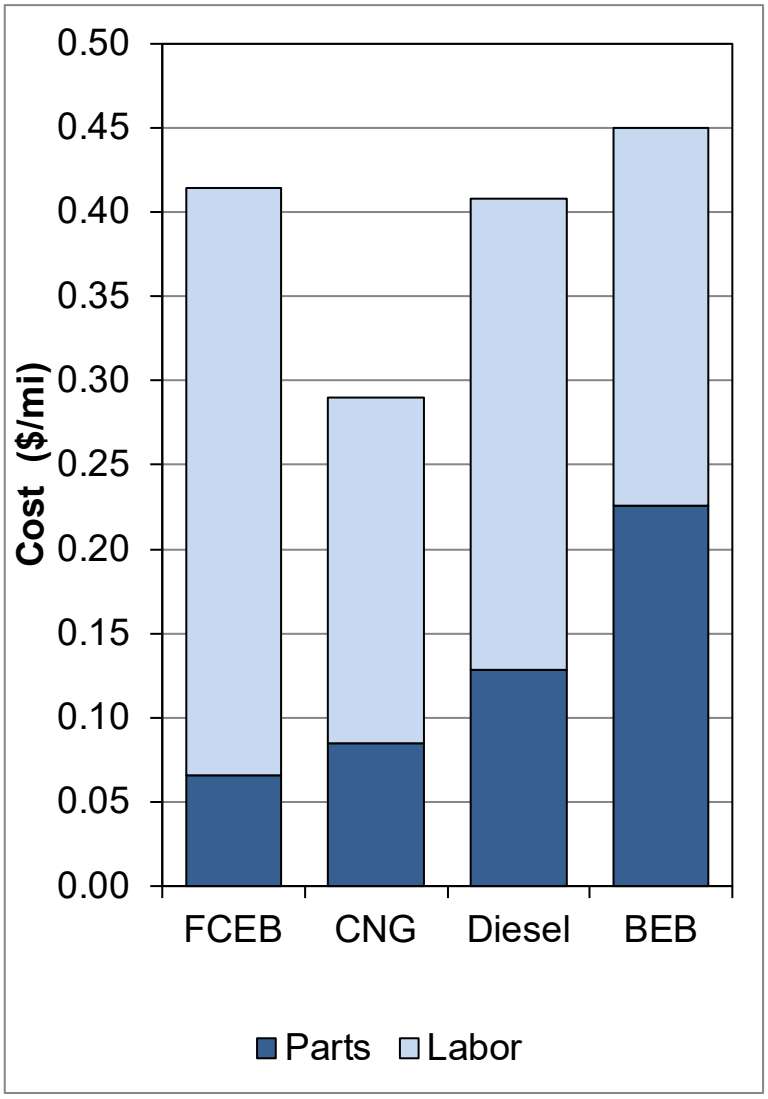
Backup Slides

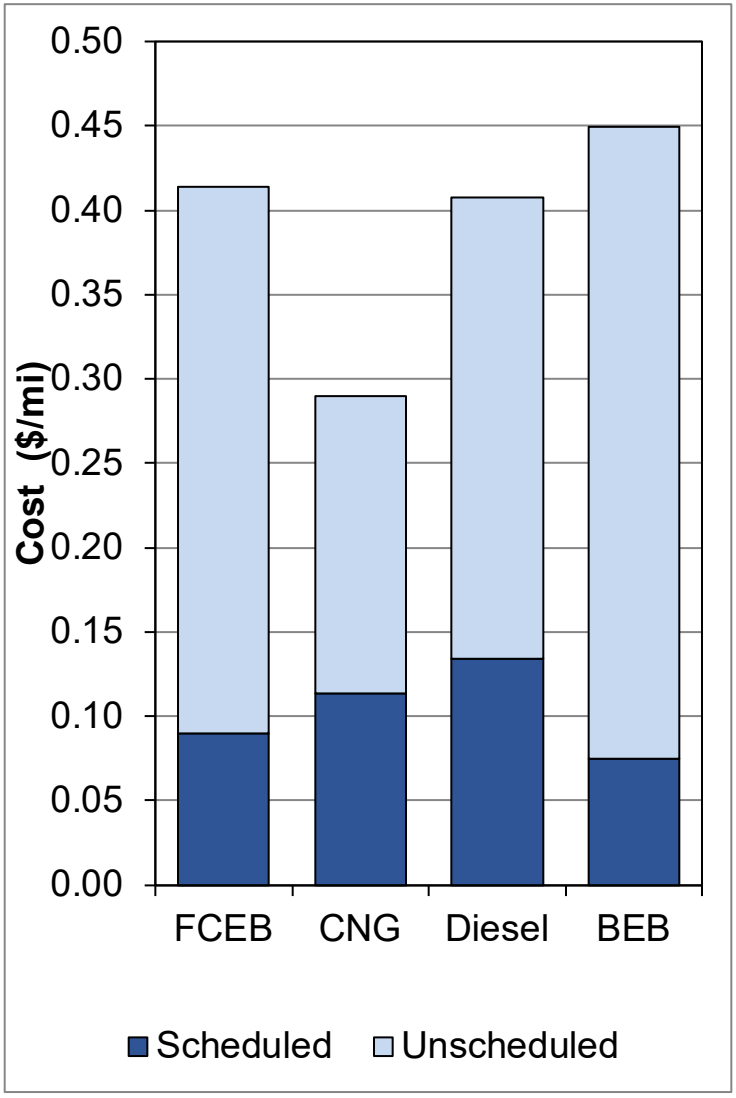
Maintenance Cost: Parts and Labor



- Majority of FCEB cost is from labor—troubleshooting and training increase labor hours
- Parts costs are low while the buses are under warranty
- BEBs out of warranty, some replacement parts are expensive (DC-DC converter >$14K)

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

Maintenance Cost: Scheduled and Unscheduled



- Similar costs for scheduled maintenance, with BEB the lowest
- Diesel buses experiencing issues with emissions equipment as they age
- BEBs had increased cost for parts once out of warranty – low-voltage batteries as well as advanced technology components

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