California Transit Association

Fuel Cell Electric Bus Technology: Technical Capabilities & Experience

(Co-Hosted by California Hydrogen Business Council)

June 13, 2019

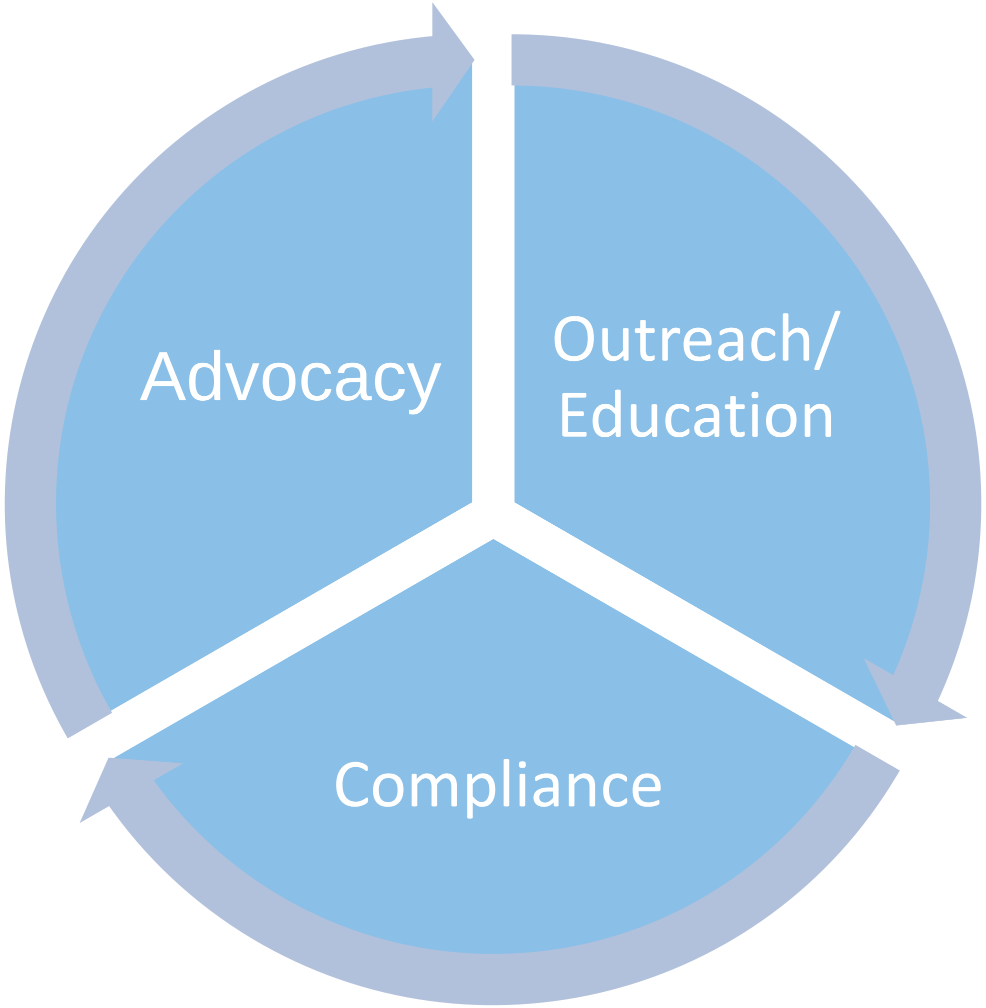
California Transit Association

- Represents more than 200 transit-affiliated entities, including more than 80 transit agencies in CA
- Advocates for policies and funding solutions that support and advance public transit

Involvement in Innovative Clean Transit Regulation

- Led negotiation with ARB on behalf of the transit industry
- Focused our advocacy efforts on the following provisions:
  - Benchmarking & Regulatory Assessment
  - ZEB Purchase Mandate Schedule
  - Waiver for Early Compliance
  - Definition of Small vs. Large Agencies
  - Access to Incentive Funding
  - Excluded Buses

Support for ICT Regulation Implementation



How to Ask Questions

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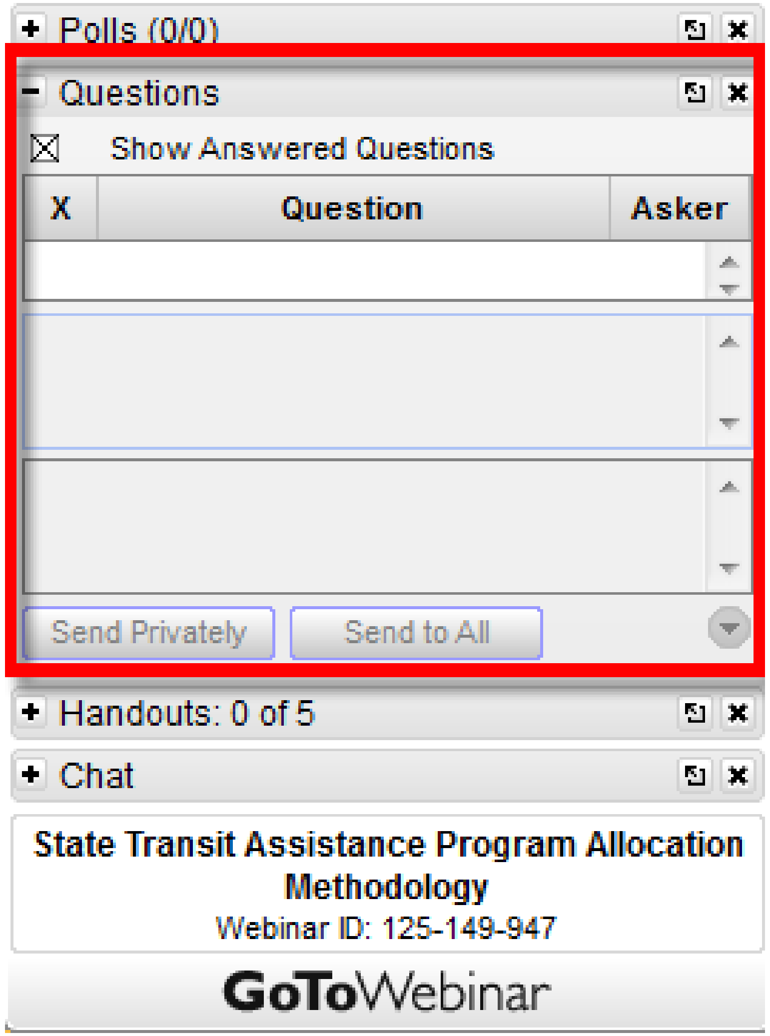

California Hydrogen Business Council

Emanuel Wagner

Deputy Director

California Hydrogen Business Council

CALIFORNIA HYDROGEN BUSINESS COUNCIL

Mission & Sector Action Groups:

The California Hydrogen Business Council (CHBC) is comprised of over 100 companies and agencies involved in the business of hydrogen. Our mission is to advance the commercialization of hydrogen in the energy sector, including transportation, goods movement, and stationary power systems to reduce emissions and dependence on oil in California.

CHBC Activities:

- Advocacy & Initiatives
  - Renewable Hydrogen, Renewable Energy and Climate
  - Hydrogen Blending and Gas System Integration
  - Hydrogen Fueling Station Build-out
  - Stakeholder Advocacy Campaign
- Communications & Business Expansion
- Goods Movement, Heavy-Duty Transportation, and Clean Ports
- Hydrogen Energy Storage and Renewable Hydrogen
- Public Transport

Our Members Include:

- Hydrogen producers and distributors
- Automotive companies
- Public transit systems and suppliers
- Fuel cell, electrolyzer, compressor and storage manufacturers
- Fueling station developers, engineers and consultants
- Municipal and state agencies
- Component suppliers

CALIFORNIA HYDROGEN BUSINESS COUNCIL

Get the Facts!

- **Fact Sheet from CHBC and California Fuel Cell Partnership:** https://www.californiahydrogen.org/wp-content/uploads/2017/10/CHBC-CaFCP-Fuel-Cell-Electric-Bus-Fact-Sheet.pdf

FUEL CELL ELECTRIC BUSES

Emissions and GHG Reductions

Performance

Scalability

Fueling

Cost

Hydrogen and Fuel Cell Electric Transit 101

Takeaways

- Fuel cells are a mature, commercially available option for public transit.
- Fuel cells electric buses (FCEBs) are one of two available zero emission options to meet the ARB ICT Regulation.
- SunLine Transit has operated FCEBs for more than a decade.
- SunLine is establishing redundancy in its hydrogen fueling infrastructure to have a secure, affordable supply.
- Deployment of FCEBs will increase drastically in the next 3-5 years, with thousands of buses ordered around the world
- If you missed the first webinar, the recording is available here: https://caltransit.org/events/webinars/fuel-cell-technology-a-four-part-series/

Events

- **Policy Summit -** Sacramento (August)
- Enabling Deep Decarbonization with **Utility-Scale Hydrogen Energy Storage Workshop** - San Francisco (Sept./Oct 2019)
- The Other Electric Bus: **Meeting California's Innovative Clean Transit Regulation with Fuel Cell Technology Workshop** (November 2019)
- Hydrogen & Fuel Cell **Ports Briefing** - POLB & POLA (December 2019)
- Stay Informed: https://www.californiahydrogen.org/chbc-events/

CALIFORNIA HYDROGEN BUSINESS COUNCIL

Thank You!

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Join us!

www.californiahydrogen.org

Capabilities of Fuel Cell Electric Buses (FCEBs)

California Transit Association and the California Hydrogen Business Council Webinar

June 13, 2019

NEW FLYER OF AMERICA

California Fuel Cell Leadership

- Industry collaboration, advocacy, and advancement with cleantech leaders:
    - California Air Resources Board (CARB) / California Climate Investments Program
    - Center for Transportation and the Environment (CTE)
    - CALSTART
    - California Fuel Cell Partnership
    - California Hydrogen Business Council
- Currently supporting OCTA, AC Transit, and Sunline with fuel cell-electric Xcelsior CHARGE H2™ buses.
- To date, New Flyer has sold over 80 electric buses to battery-electric bus programs in California.
- In April 2019, achieved 350 miles of zero-emission range in a fuel cell test demo for OCTA.
- Four California locations: Ontario, Los Alamitos, Fresno, and the Bay Area (Hayward).

Whistler BC Fuel Cell-Electric Bus Project
2009-2014

- BC Transit initiated a project with California Air Resources Board (CARB) and the US National Renewable Energy Laboratory (NREL) to test FCEBs in urban transit operation.
- At the time, became the world’s largest single location hydrogen fuel cell fleet (20 buses) for the Vancouver 2010 Olympics in British Columbia, Canada.

New Flyer: Integrator to Innovator

- **Knowledge gained through experience**
  - New Flyer needs to take ownership of system controls
  - Serviceable components need to be located in accessible areas
  - Ownership of fuel cell balance of plant needs to be with the manufacturer

- **Development of Electrical Accessories**
  - Component selection needs to align with vehicle performance expectations
  - Select technology with proven performance & reliability
  - Improve energy consumption

Fuel Cell-Electric Bus Control Strategy

THEN

- Fuel cell-dominant hybrid
- Large fuel cell/small battery
  - Ballard FCveloCity HD6-150 fuel cell (150 kW)
  - Single battery string
    - Ability to take advantage of frequent regen events

NOW

- Battery-dominant hybrid
- Small fuel cell/large battery
  - Ballard FCveloCity HD85 fuel cell (85 kW)
    - Sized to meet average Net Power of 30-45 kW
  - Two or Three String A123 ESS (100-150 kWh)
    - Ability to take advantage of frequent regen events
    - Up to 235 kW peak power for acceleration, high-speed operation and hill climbs
    - Extends range when bus is out of fuel

newflyer.com/chargeH2

xcelsior CHARGE H2™

Readiness Level

	Bus Model	Fuel Cell	Readiness
Development	40-Foot	Hydrogenics Celerity(+)	Evaluation
Production Builds	60-foot	Ballard HD85	Commercial Production
	40-foot	Ballard HD85	Commercial Production

Zero-Emission Options

xcelsior CHARGE™

- Eco-friendly
- Robust design
- Up to 220 miles range*
- 4-hour overnight charge
- Range decreases over the life of the batteries*
- One charger per 2-3 buses
- Diesel auxiliary heater recommended for cold climates

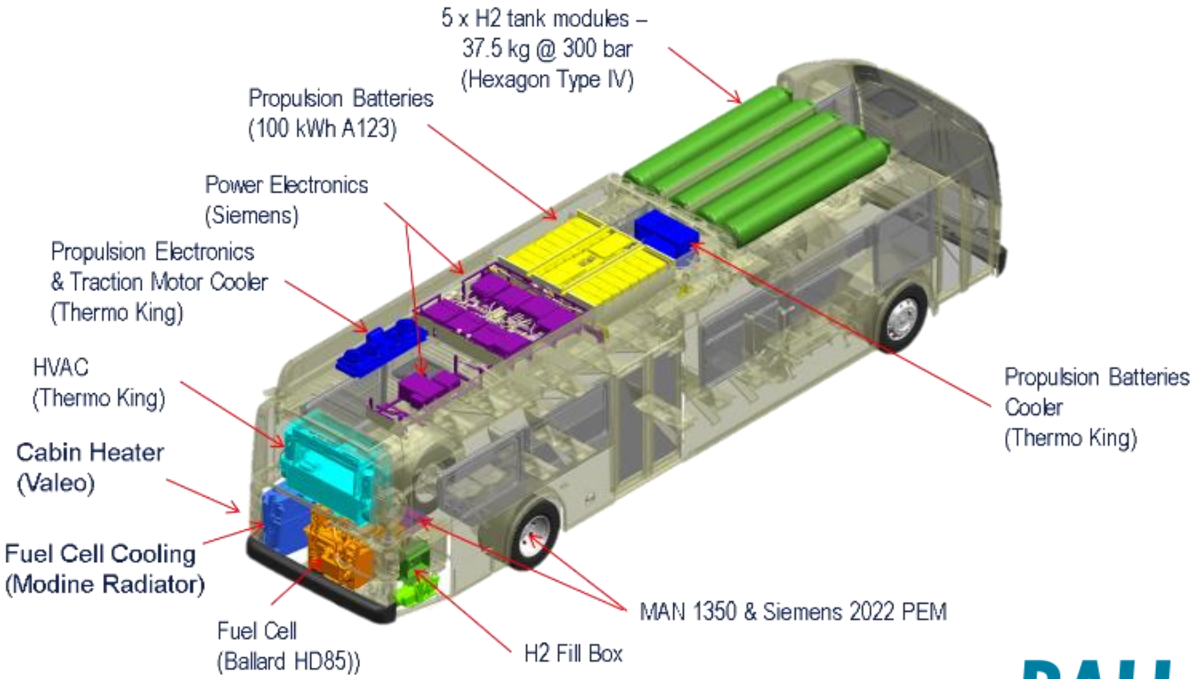
xcelsior CHARGE H2™

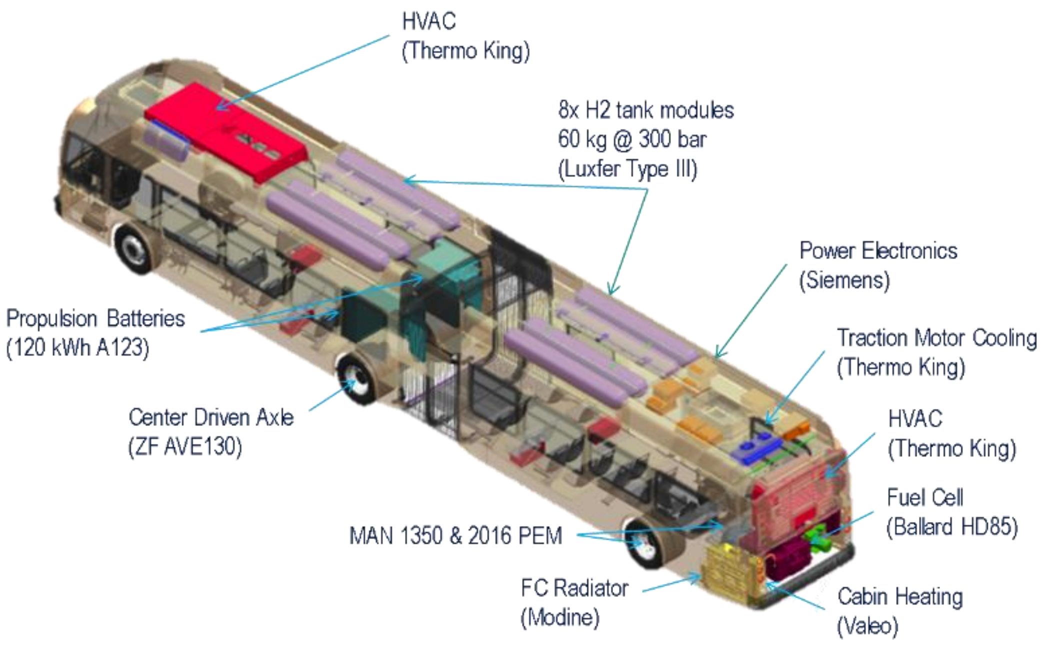
- Eco-friendly
- Robust design
- Up to 350 miles range*
- 6-20 minutes fill time
- Range consistent over the life of the batteries & fuel cell*
- Fill station scalable by fleet size
- No secondary auxiliary heater required for cold climates

*40-foot on APTA BAC transit duty cycle

xcelsior CHARGE H2™

40-foot & 60-foot Components, Specs, and Design Layout





BALLARD®

FCveloCity®–HD

xcelsior CHARGE H2™

Altoona Range @ SLW

	CBD	ART	COM	Average
Power Consumption [kWh/mile]	3.25	3.68	2.10	3.04
Fuel Consumption [miles/kg]	4.74	3.91	7.42	5.36
Fuel Cell Range [miles]	277.61	227.61	431.96	293.97
Battery Range [miles]	22.16	19.54	34.37	23.66
Total Range [miles]	**299.77**	**247.16**	**466.33**	**317.90**

Real Life Results:

TBD: Bus recently delivered to AC Transit in Oakland, CA for a 2 year demonstration

xcelsior CHARGE H2™ 40-foot

Altoona Range @ SLW

	Manhattan	OCBC	UDDS	Average
Power Consumption [kWh/mile]	8.57	1.83	0.94	3.78
Fuel Consumption [miles/kg]	5.32	6.91	8.33	6.86
Fuel Cell Range [miles]	191.52	248.76	299.88	246.96
Battery Range [miles]	7.00	32.79	63.83	15.87
Total Range [miles]	**198.52**	**281.55**	**363.71**	**262.83**

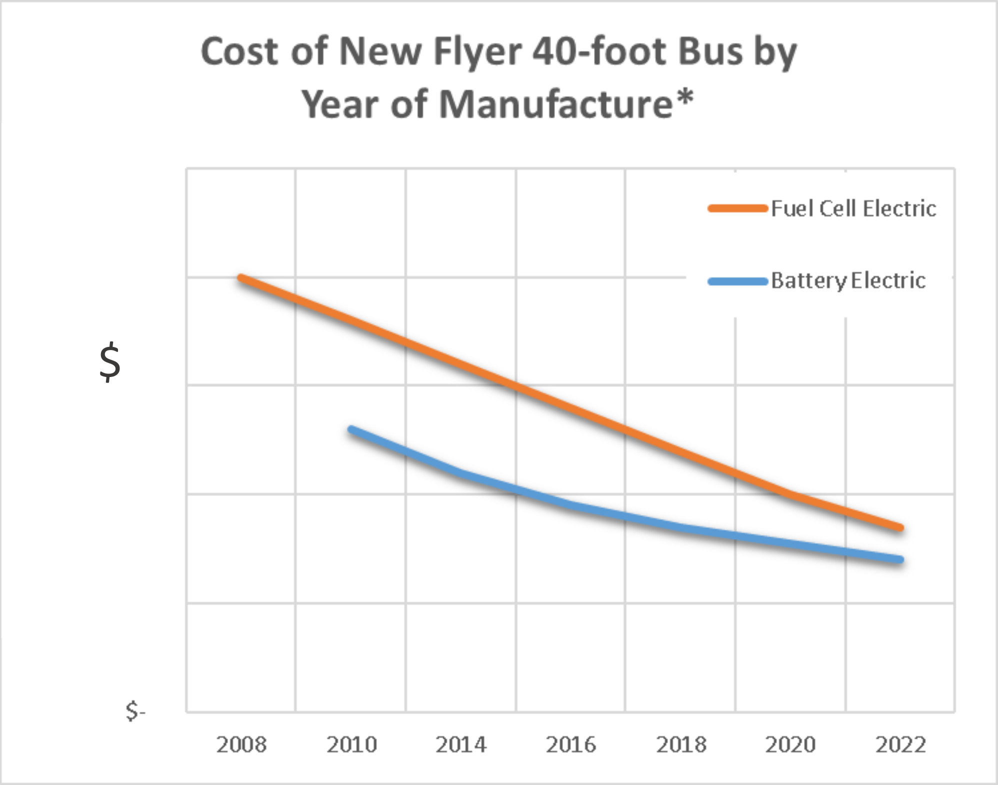
Real Life Results:

350 miles (560 km) on a single fill validated during testing in Orange County

- 9.16 miles/kg (14.66 km/kg)
- 330 miles (480 km) fuel only
- 20 miles (32 km) extended battery range

Fuel Cell-Electric Bus Price Trends

- Decrease in fuel cell cost
- Decrease in battery cost
- Improved design for manufacture and assembly
  - Mass production optimization
  - Standardization between FC electric and battery electric
  - Reduced complexity and highly repeatable assembly
- Expanded supply chain with increased competition
- Manufacturing volume will reduce cost



*Note: Actual bus price will vary based on battery capacity and customer options

Questions?

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newflyer.com/chargeH2

Fuel Cell Electric Bus Evaluation Results

Leslie Eudy
National Renewable Energy Laboratory

NREL Role in ZEB Evaluation

- 3rd party evaluation of advanced technology in real-world service
  - Established evaluation protocol provides consistent data collection and reliable analysis
  - Unbiased results in common format
  - Comparison to baseline conventional technology and technical targets

Transit Agencies

Share information with the transit industry that will aid in advanced technology purchase decisions & fleet operations

Government

Provide feedback to federal, state and local government to understand technology status and prioritize funding for necessary R&D

OEMs

Collaborate with tech providers to understand status and share performance results for ZEB and baseline buses

Data Collection Process

NREL works closely with the transit agencies and other partners to gather data including:

- Fueling records – cost and efficiency calculations
- Maintenance records – cost per mile by system
- Daily bus use & availability – reliability
- Roadcalls – reliability
- Fleet experience – lessons learned

Results Summary

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

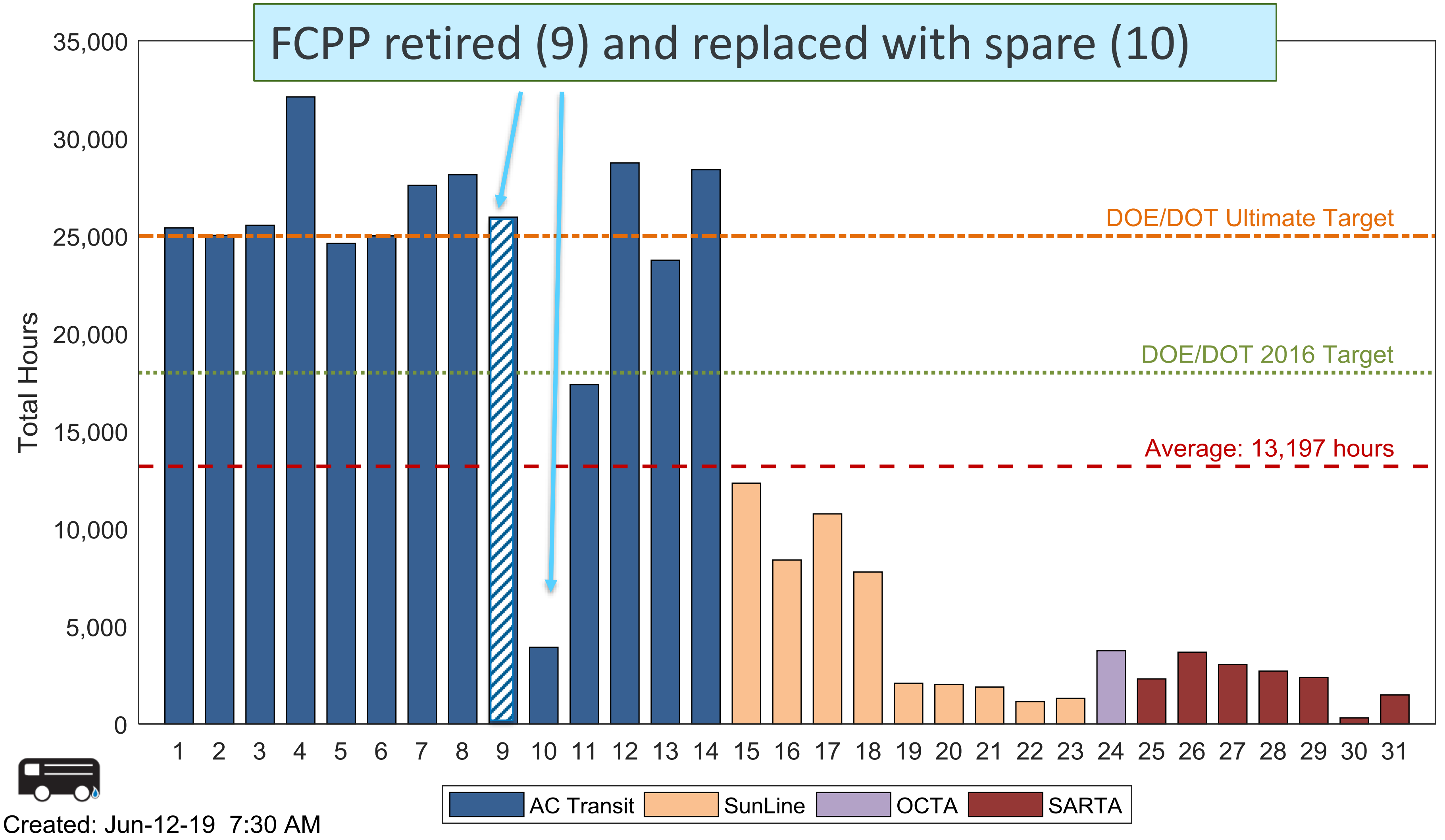
SunLine

OCTA

SARTA

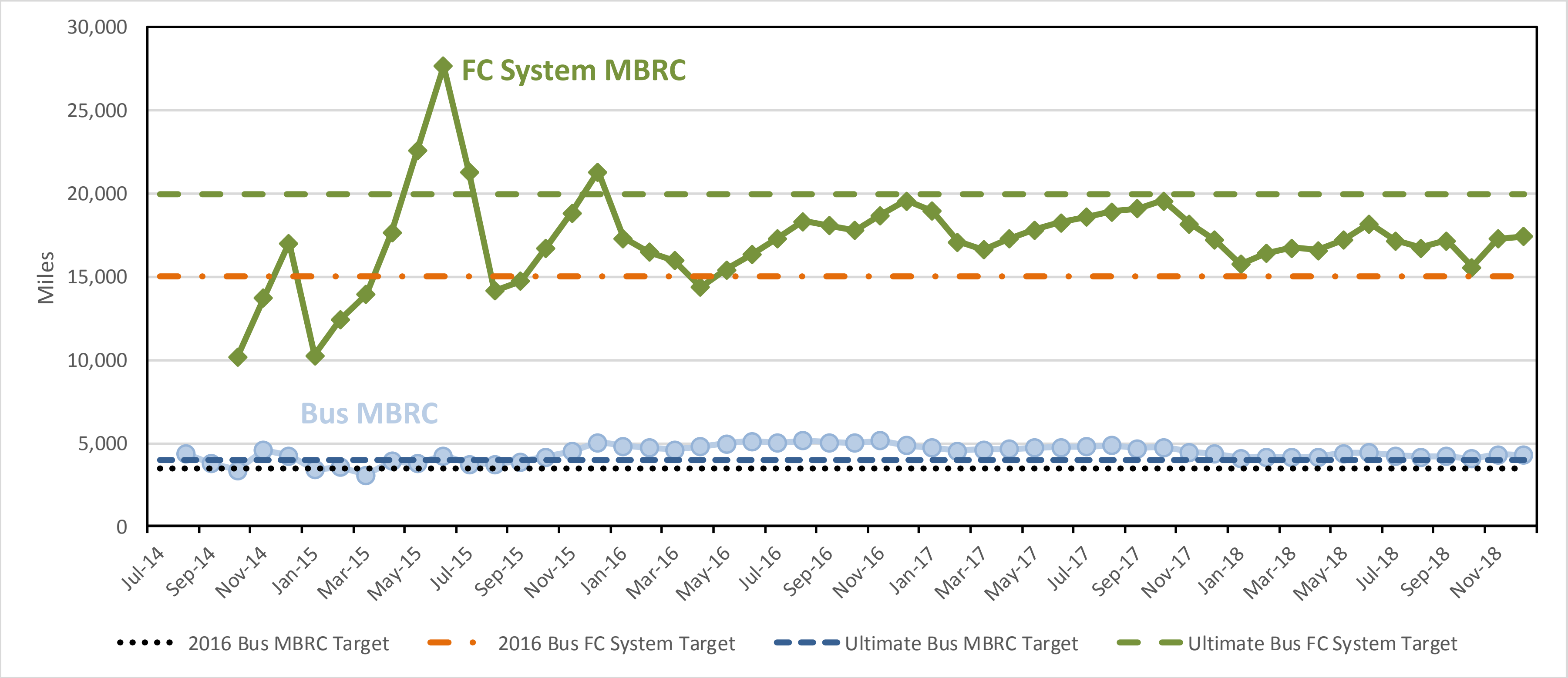
Top Fuel Cell Powerplant Exceeds 32,000 Hours

- Top fuel cell powerplant (FCPP) >32,100 hours
- Ten FCPPs have surpassed DOE/DOT ultimate target



Total hours accumulated on each FCPP as of 4/30/19

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

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

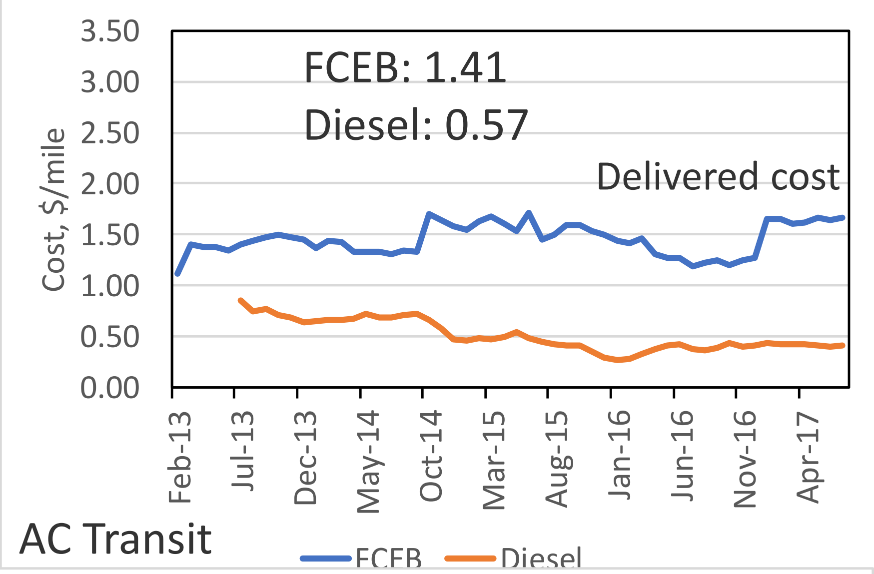
[a] Delivered cost

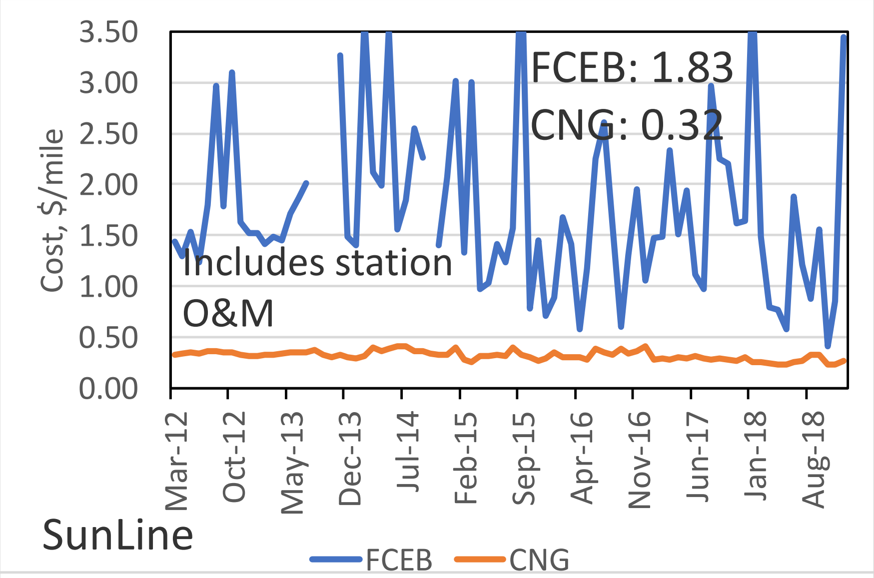
[b] Includes station operating and maintenance (O&M) costs

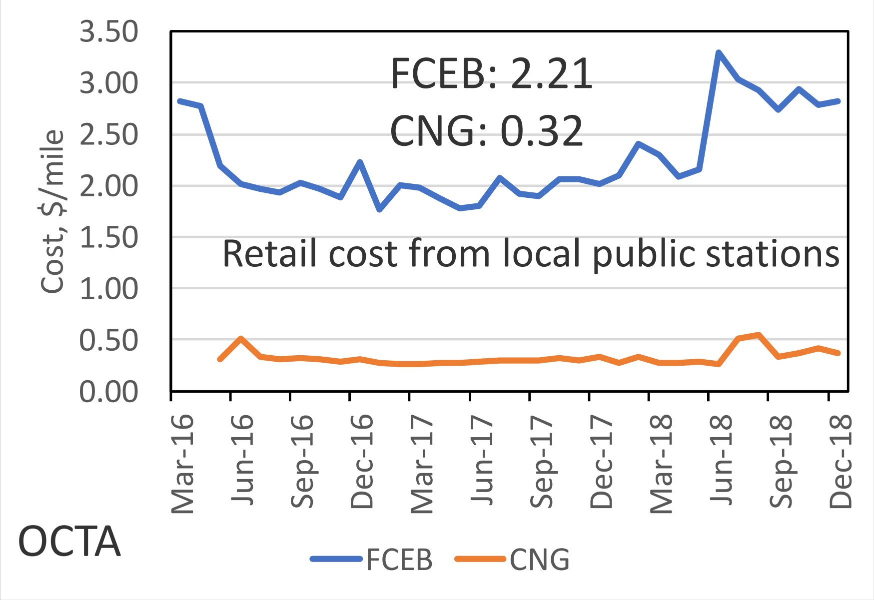
[c] Retail cost from local public stations

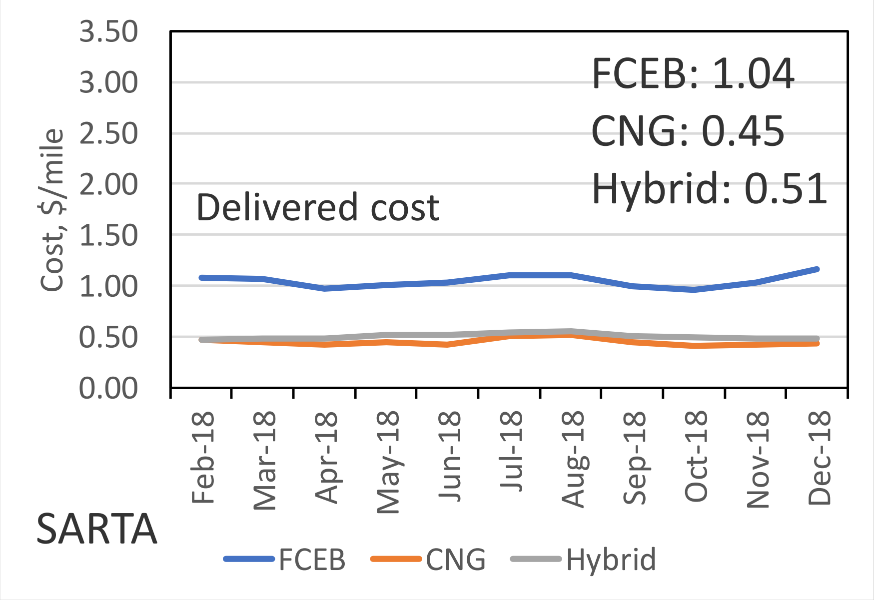
[d] Delivered cost

Fueling Cost Data Summary, $/mi

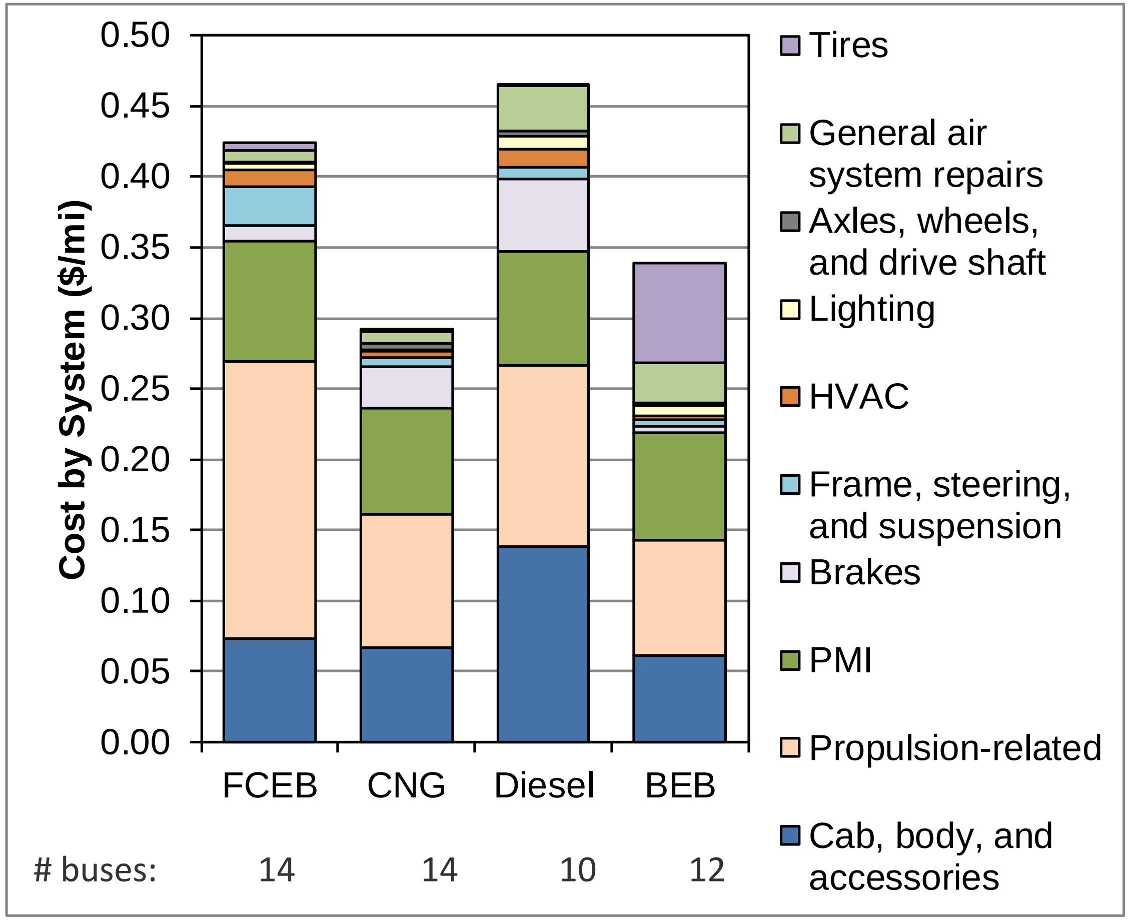








Maintenance Cost by System



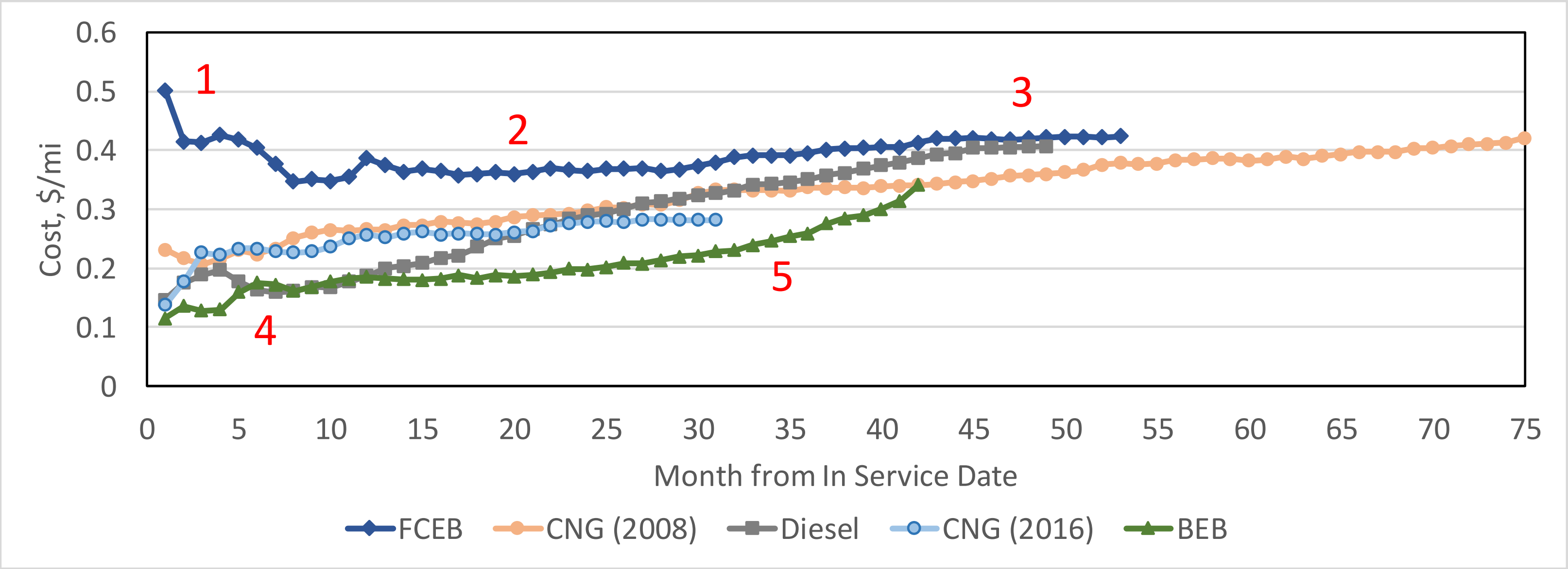
- Cumulative cost from in-service date
- Labor @ $50/h

- 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

Remaining Challenges and Barriers

For industry to fully 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

Questions?

www.nrel.gov

Leslie Eudy

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Web site: https://www.nrel.gov/hydrogen/fuel-cell-bus-evaluation.html

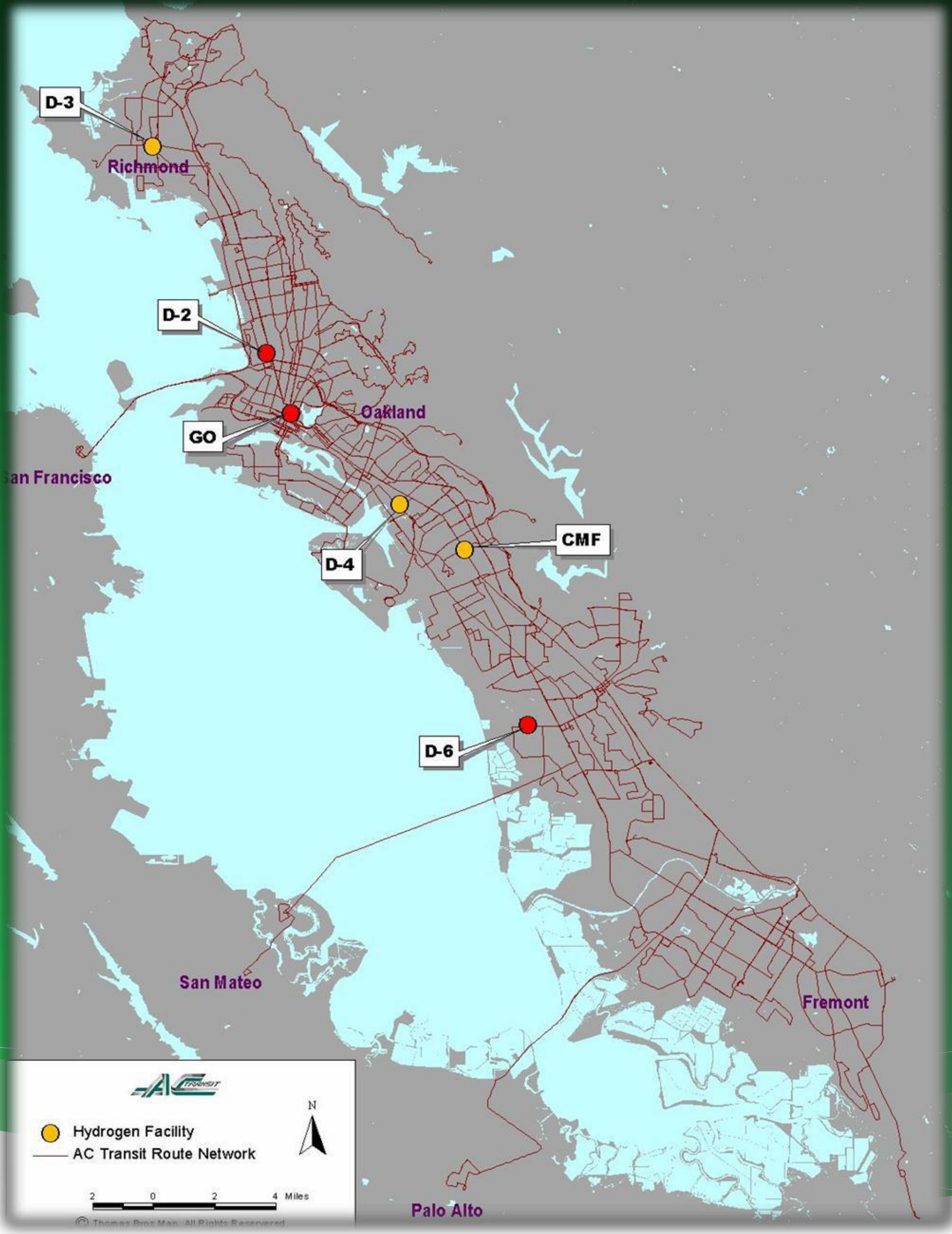
NREL
Transforming ENERGY

Alameda-Contra Costa Transit District
Fuel Cell Bus Program

Fuel Cell Electric Bus Technology: Technical Capabilities and Experience

June 13, 2019

- 7 member, publicly elected Board of Directors
- Michael Hursh, General Manager
- Serving 1.5 million people
- 364 square mile service area
- 152 lines (31 Transbay)
- 20.4 million annual service miles
- 637 buses (14 – ZEB)
- 6 facilities in the East Bay
- 2,243 employees



Zero-Emission Bay Area (ZEBA) Advance Demonstration Program

- CARB Fuel Path Mandate
  - Three bus demonstration program
  - Twelve bus advanced demonstration program
- Consortium Agencies in ZEBA Program
  - Funding support for AC Transit program
  - Requirement to operate buses in revenue service

Program Advancement

2003-2006

- 1 FC Buses
- 30'Thor
- 60kW UTC PEM
- 48, 12v Panasonic
- batteries
- 25kg H2 storage
- 175-200 mile range

2006-2010

- 3 FC Buses
- 40' VanHool A330
- 120kW UTC PEM
- Zebra 90 kWh battery system
- 50kg H2 storage
- 250-300 mile range

2010-Present

- 13 FC Buses
- 40' VanHool A300
- 120kW UTC PEM
- EnerDel 21kWh battery system
- 40kg H2 storage
- 200-220 mile range

2019

- 10 FC Buses
- 40' New Flyer
- 85kW Ballard
- A123 100kWh battery system
- 37.5 kg H2 storage
- 300 mile range

Future ZEB Programs

New Flyer Xcelsior XHE60

- 60-foot fuel cell transit bus
- Target range of 250 miles

(10) Xcelsior XHE40 (FCEB)

(5) Xcelsior XE40 (BEB)

True side-by-side comparison

- Same Agency
- Same Service Environment
- Same OEM
- CTE – Performance Report

Fuel Cell Fleet Advancements

	Units	This Report[a]	2016 Target	Ultimate Target
Bus lifetime	years/miles	5.3/ 8,300–131,900[b]	12/500,000	12/500,000
Power plant lifetime[c]	hours	4,000–21,400[d]	18,000	25,000
Bus availability	%	74	85	90
Fuel fills[e]	per day	1	1 (<10 min)	1 (<10 min)
Bus cost[f]	$	2,500,000[g]	1,000,000	600,000
Power plant cost[c,f]	$	N/A[h]	450,000	200,000
Hydrogen storage cost	$	N/A[h]	75,000	50,000
Roadcall frequency (bus/fuel cell system)	miles between roadcalls	4,500/ 23,200	3,500/ 15,000	4,000/ 20,000
Operation time	hours per day/days per week	7–14/ 5–7	20/7	20/7
Scheduled and unscheduled maintenance cost[i]	$/mile	1.15	0.75	0.40
Range	miles	235[j]	300	300
Fuel economy	miles per diesel gallon equivalent	6.18	8	8

- 5 fuel cells met the 2016 target in Oct 2016, 11 by 2017
- **FC7 achieved "Ultimate Target" of 25K hrs in June 2017 & reached over 32K hrs**
- **10 fuel cells have met the "Ultimate Target"**
- **Over 356,490 combined hours!**
- **More than 3.2 million clean zero emissions miles!**

ZEB Study Results

Beginning-of-Life (BOL) & End-of-Life (EOL) batteries by bus length & route

Bus Length (feet)	Energy Storage (kWh)	BoL Service Energy (kWh)	EoL Service Energy (kWh)	Route Category	Nominal Range BoL (miles)	Nominal Range EoL (miles)	Strenuous Range BoL (miles)	Strenuous Range EoL (miles)
26	100	70	46	Flat	50	33	33	22
26	100	70	46	Hilly	47	31	32	21
26	100	70	46	Transbay	54	35	41	27
30	300	230	158	Flat	153	105	105	72
30	300	230	158	Hilly	144	99	100	69
30	300	230	158	Transbay	153	105	121	83
40	450	350	242	Flat	184	127	130	90
40	450	350	242	Hilly	184	127	121	83
40	450	350	242	Transbay	194	134	152	105
45	450	350	242	Flat	159	110	109	76
45	450	350	242	Hilly	140	97	100	69
45	450	350	242	Transbay	159	110	130	90
60	450	350	242	Flat	121	83	85	59
60	450	350	242	Hilly	135	93	83	58
60	450	350	242	Transbay	140	97	117	81

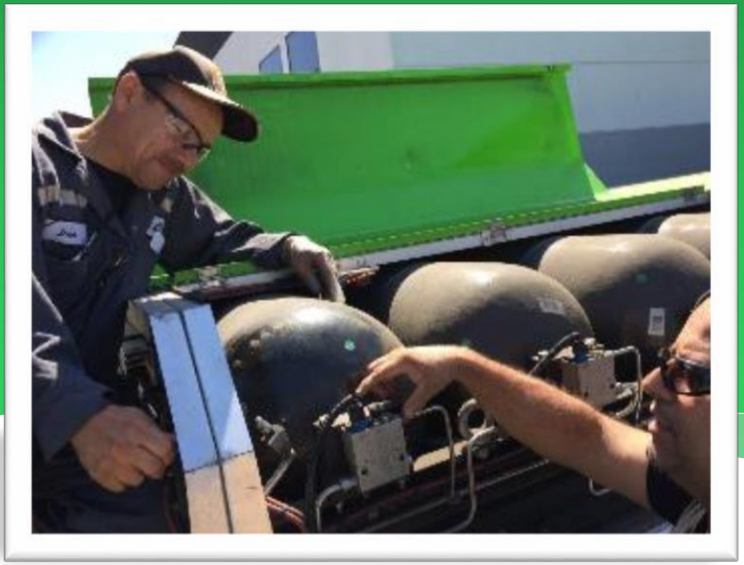
Route, charge, and rate modeling to assess energy efficiency and energy consumption.

20% of AC Transit blocks could be replaced with BEBs on a 1:1 basis with a single overnight charge.

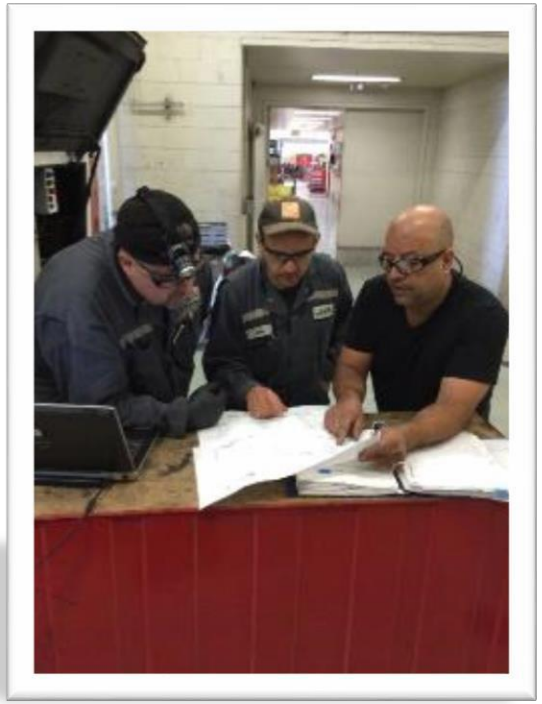
95% of all blocks can be served by FCEBs on a 1:1 replacement basis.

ZEB Training Initiatives

- H2 Fuel Cell Safety & Familiarization
- Lithium Ion Battery Safety
- Fuel Cell Power Plant
- Siemens Drive System



Hands-on Technical Experience



5 week program
- Basic P.M.I.
- Basic Diagnostics & Repair
- Advanced Diagnostics & Repair

Training Provided:
- **343 Mechanics**
- **16,560 Hours**
- Every Bus Operator

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Director of Capital Projects
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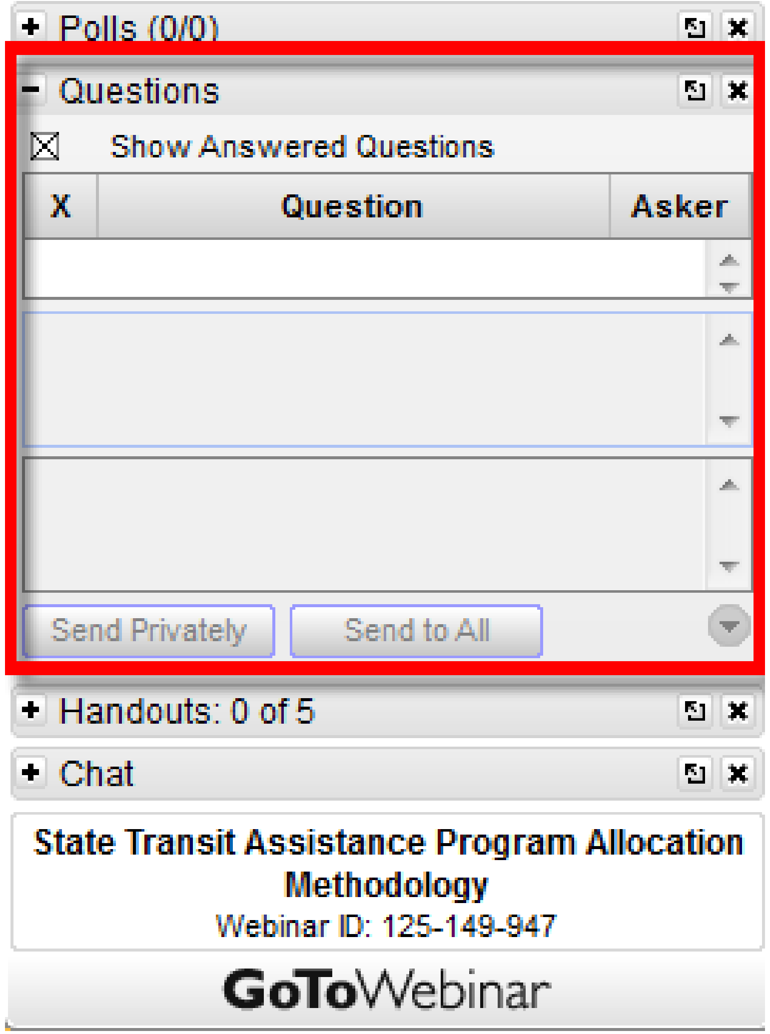

Remember to Register!

- Hydrogen Infrastructure: Scalability and Technical Considerations (6/20)
- Fund the Fleet: Funding Mechanisms to Assist and Accelerate ZEB Deployment (6/27)

Contact Us

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