U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

2018 Fuel Cell Electric Buses: Progress Toward Meeting Technical Targets

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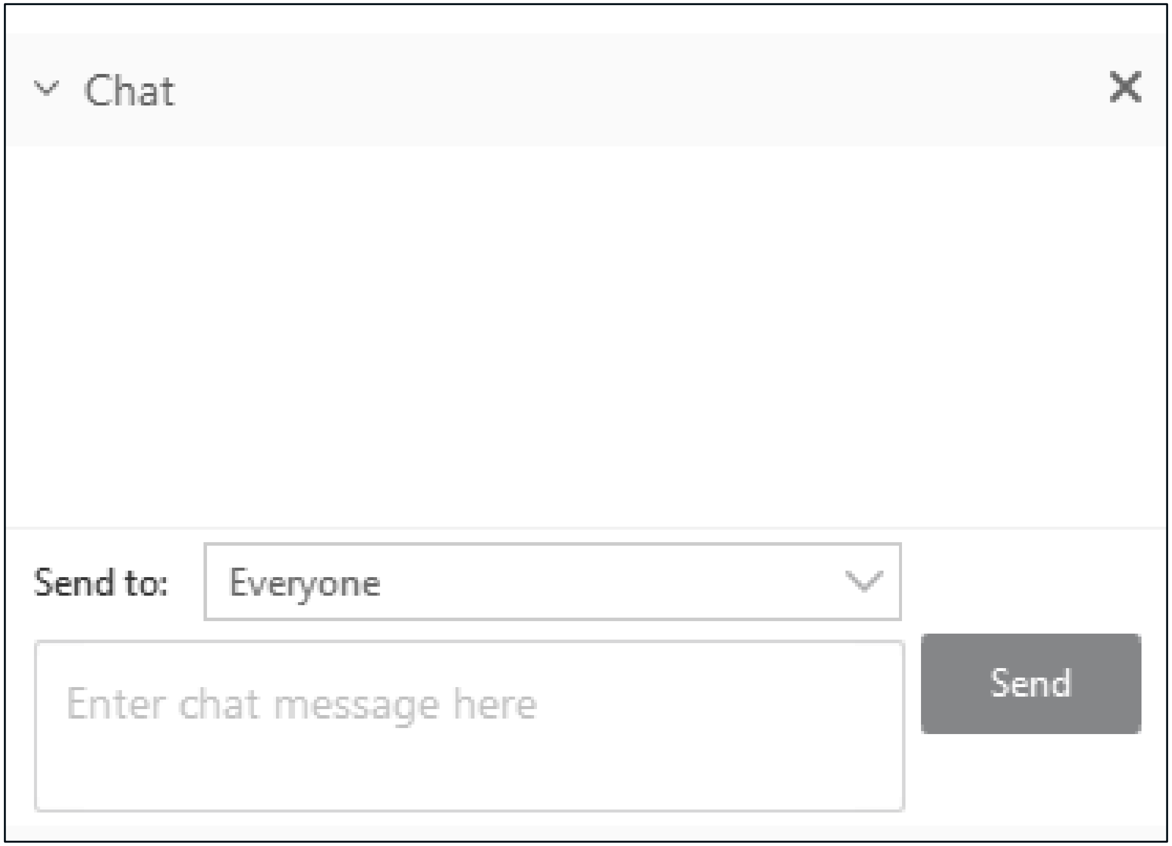
Fuel Cell Technologies Office Webinar

May 17, 2018

Question and Answer

- Please type your questions to the chat box. **<u>Send to: (HOST)</u>**



Evaluation Objectives and DOE-DOT Targets

- 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
- Evaluation funding from DOE and the Federal Transit Administration (FTA)

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

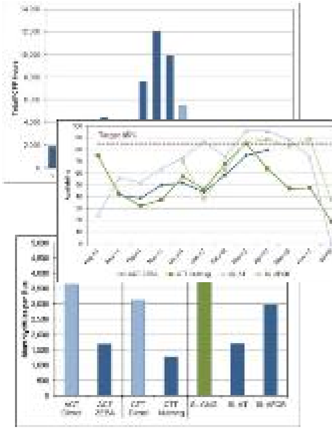
Data collection/Analysis

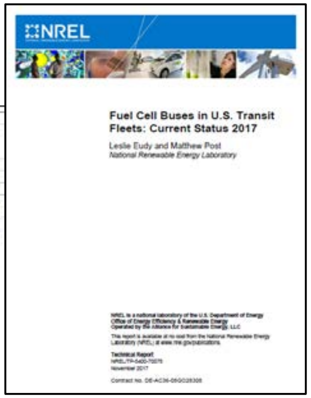
- NREL uses a standard protocol for collecting existing data from transit partners
- Provides a third-party analysis
- Includes comparisons to conventional-technology buses in similar service (diesel, CNG, diesel hybrid)

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-DOT targets

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

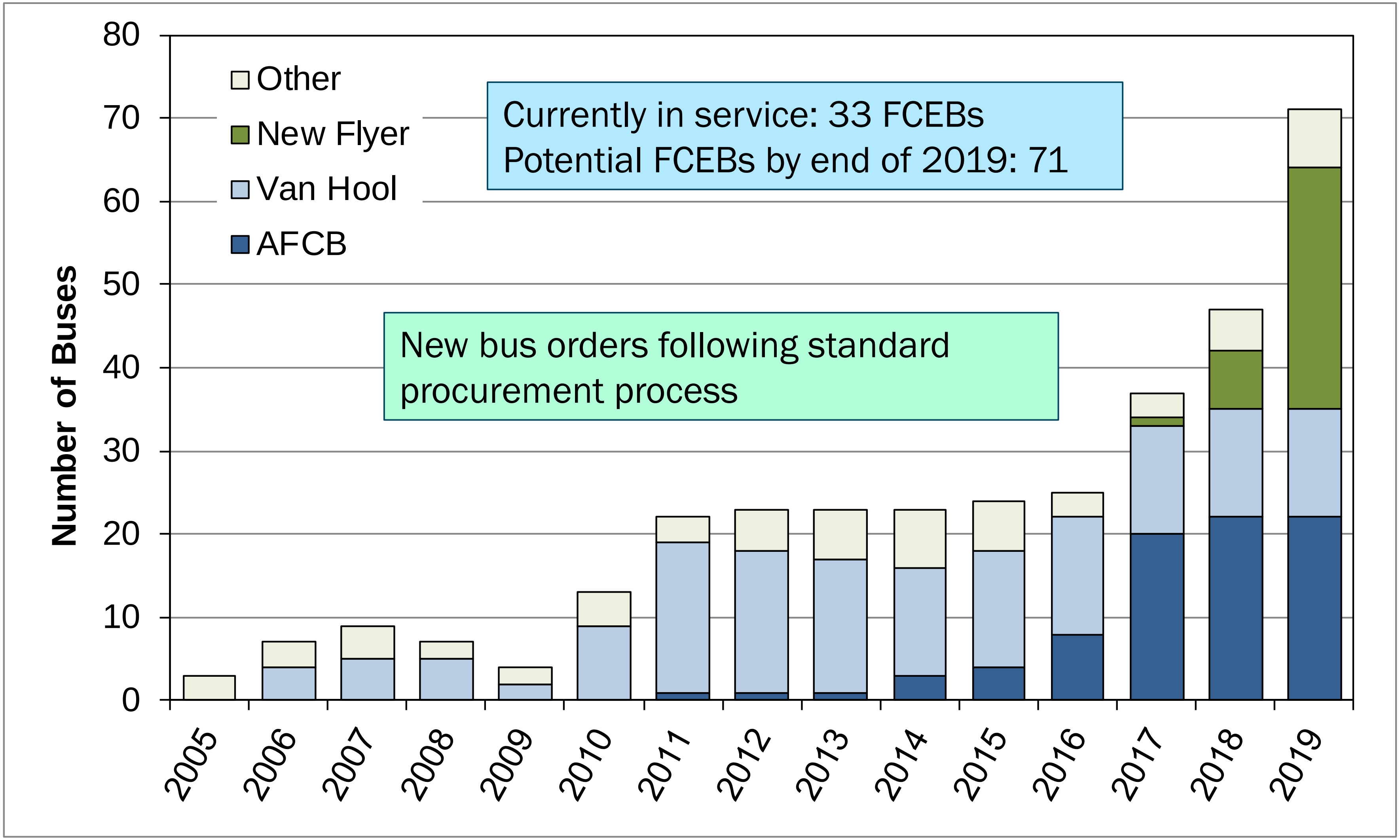
Data Summary for 2018

FCEB fleets included in data summary

Transit Agency	Abbreviation	Location	Bus Type	# Buses	Data Included
AC Transit [1]	ACT	Oakland, CA	Van Hool	13	Fuel cell hours, fueling records, reliability
SunLine Transit Agency [1]	SL	Thousand Palms, CA	AFCB	4	All
Orange County Transportation Authority [2]	OCTA	Santa Ana, CA	AFCB	1	All
Stark Area Regional Transit Authority [2]	SARTA	Canton, OH	AFCB	5	Fuel cell hours only
Massachusetts Bay Transportation Authority [2]	MBTA	Boston, MA	AFCB	1	Fuel cell hours and fueling records
University of California at Irvine [1]	UCI	Irvine, CA	AFCB	1	All

1 DOE funded
2 FTA funded

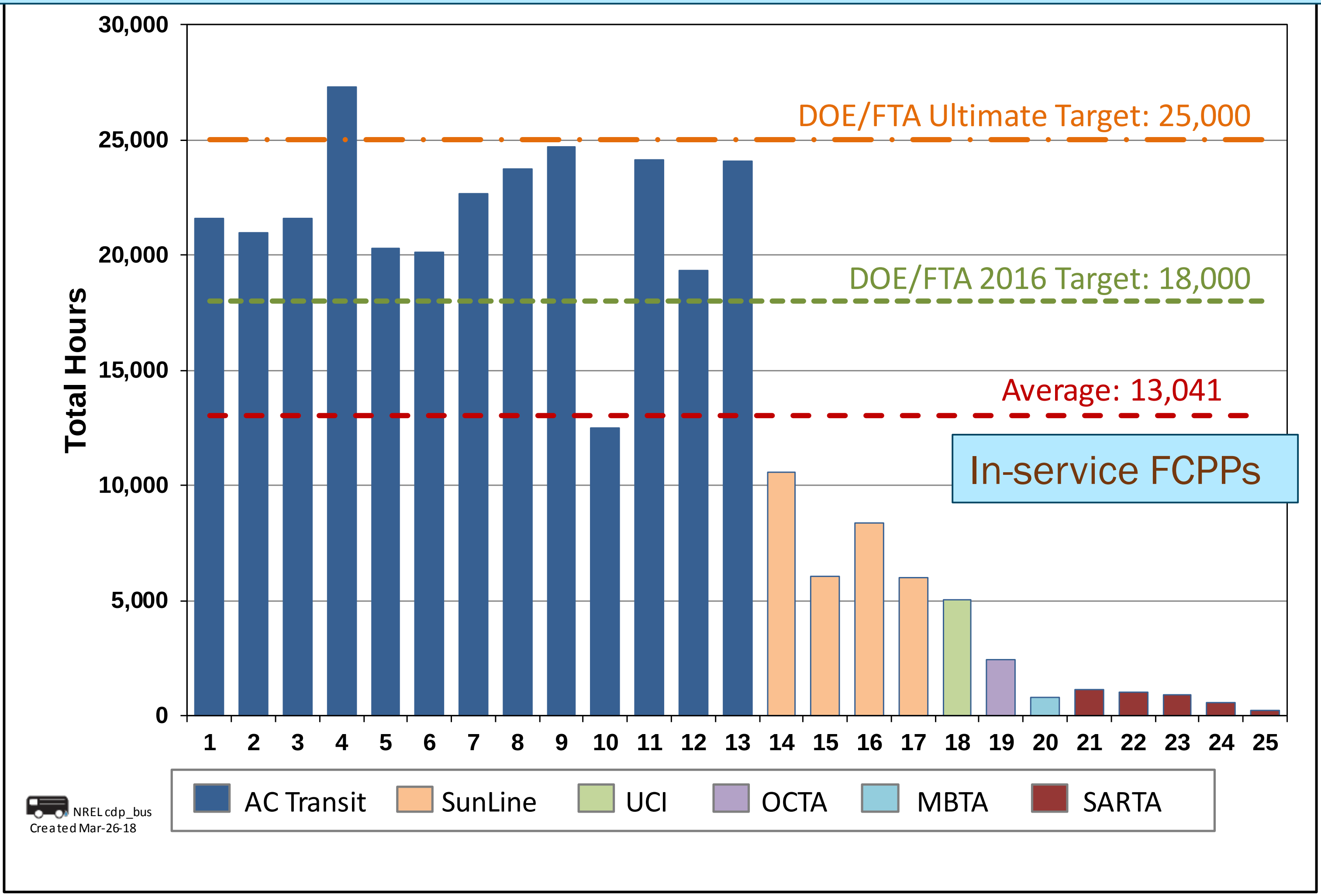
FCEB Numbers Expected to Grow



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

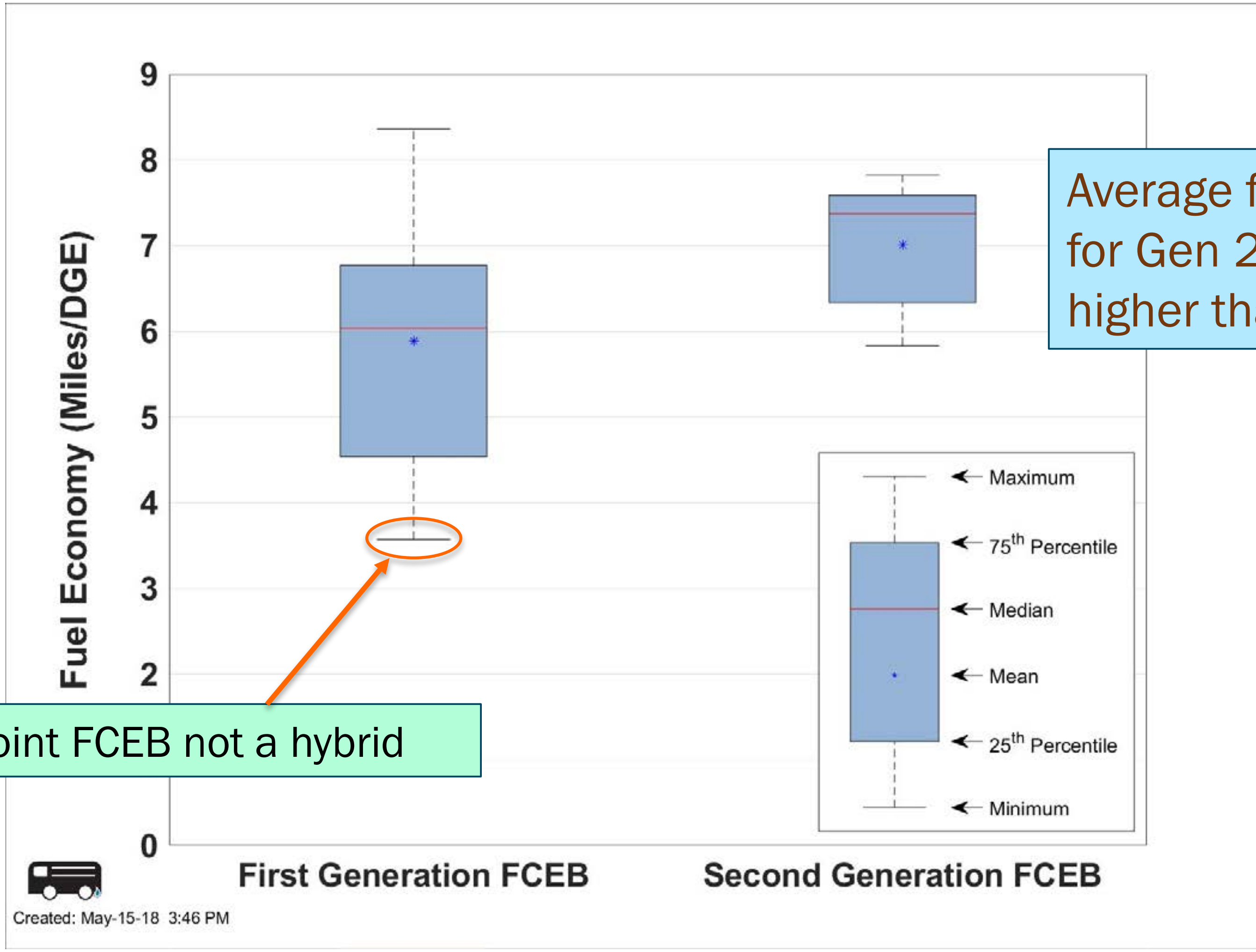
Top Fuel Cell Powerplant Exceeds 27,000 Hours

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

Fuel Economy



Average fuel economy for Gen 2 designs 19% higher than Gen 1

Low point FCEB not a hybrid

- 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

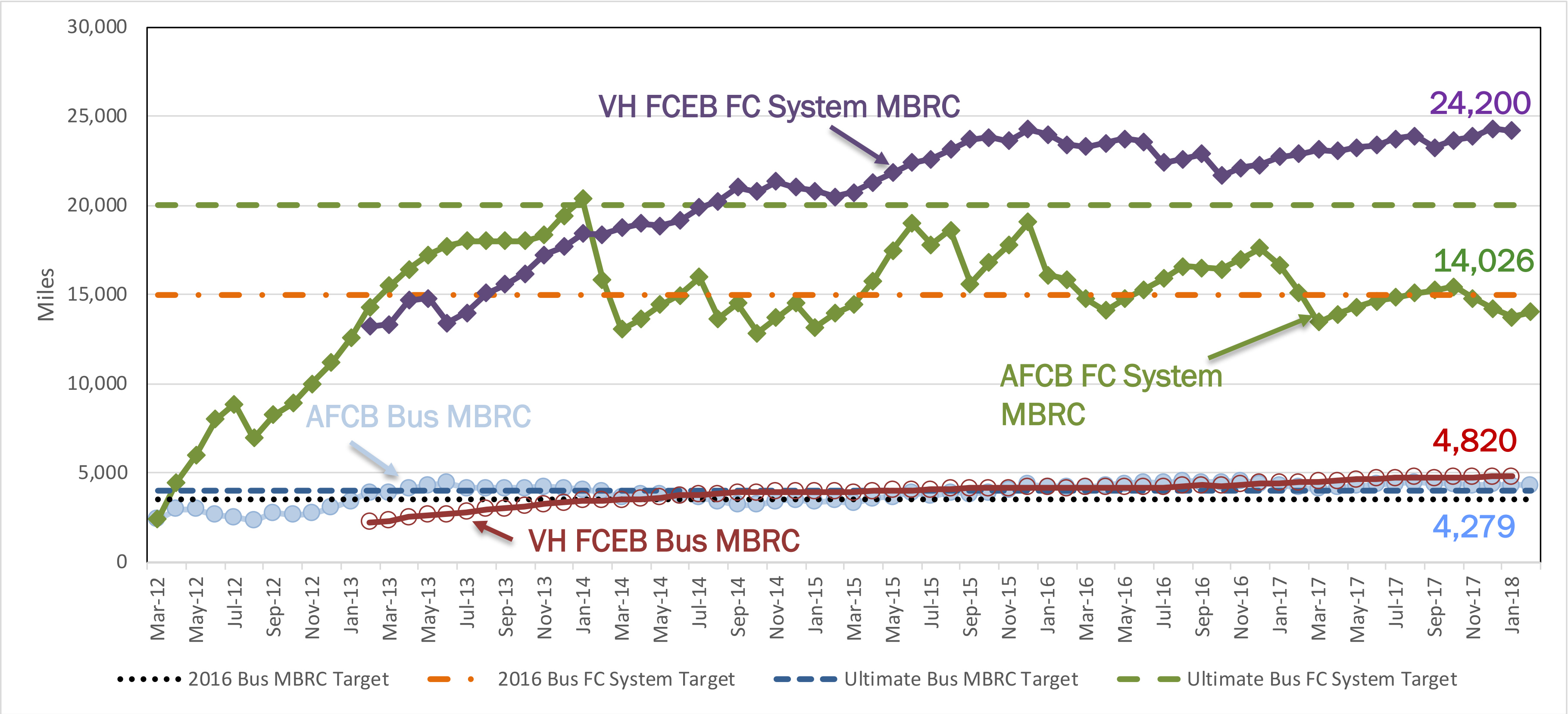
Fueling Data Summary

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

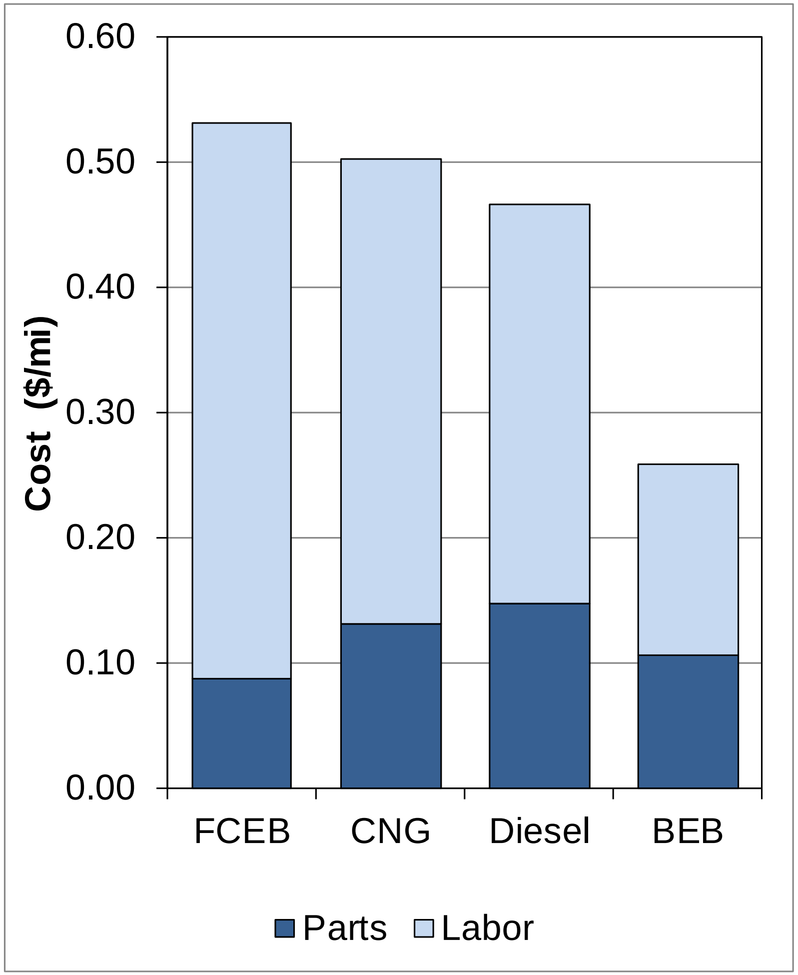
- Transit agencies typically fill the buses every day during a 6–8-hour window after the end of service
- Stations must be capable of back-to-back fueling of up to 40 kg per fill, although the average fill is 21 kg
- Agency goal of fueling in less than 10 minutes

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

Maintenance Cost: Parts and Labor

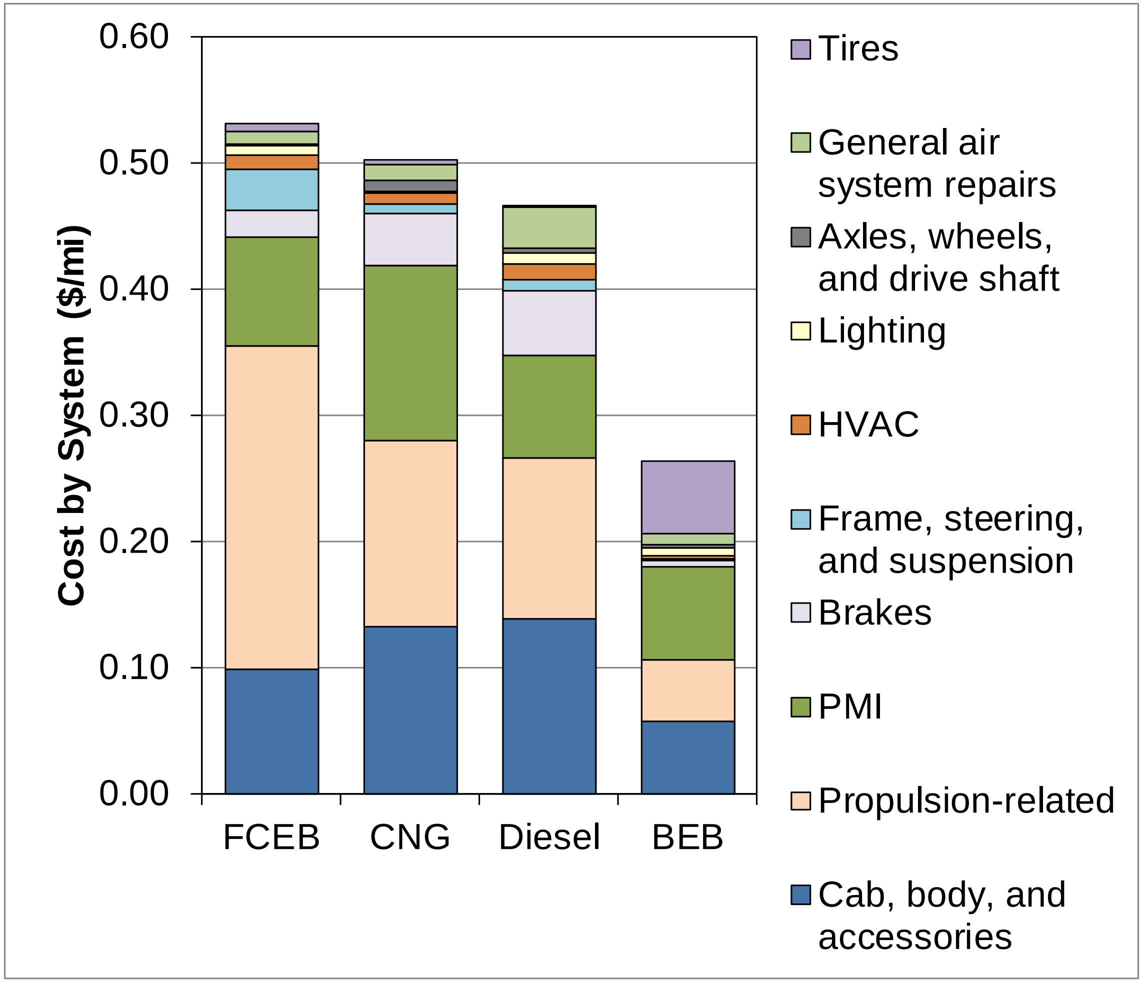


- Majority of FCEB cost is from labor— troubleshooting and training increase labor hours
- Parts costs are low while the buses are under warranty
- Cost per mile calculation sensitive to number of buses in each fleet—
  5 FCEBs, 10 diesel buses,
  10 CNG buses, 12 BEBs

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

BEB = battery electric bus

Maintenance Cost by System



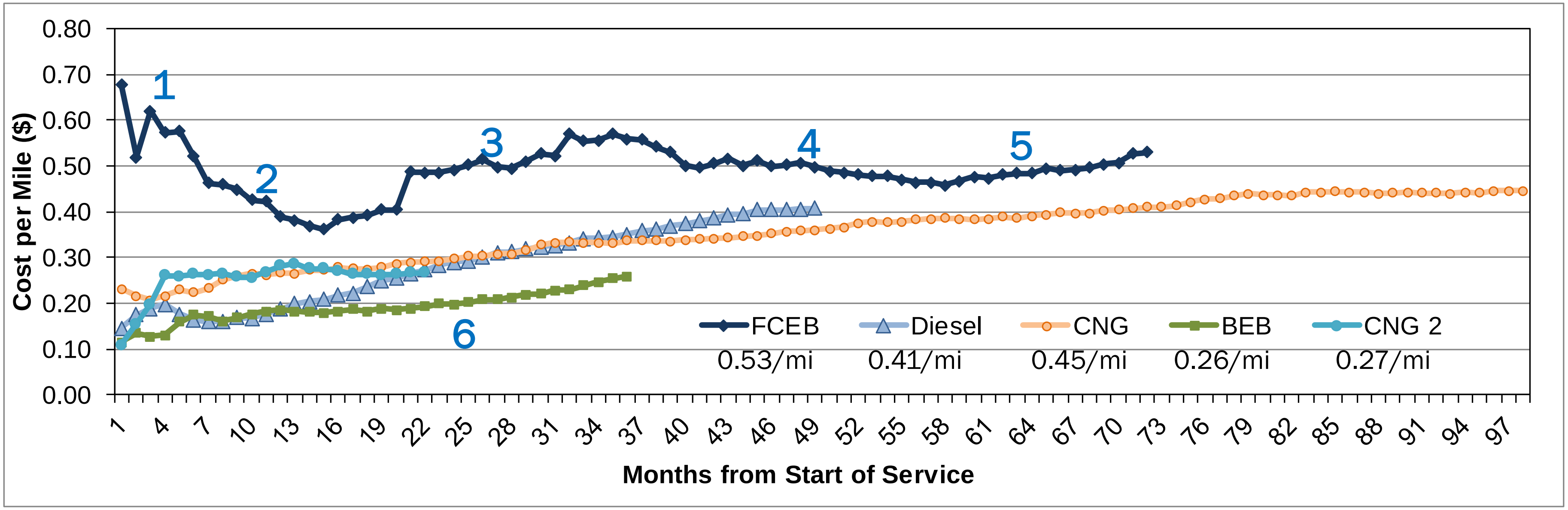
- Cost for propulsion system repairs highest for FCEBs
- Propulsion issues include:
  - Cooling system leaks
  - Low-voltage electrical
  - Low-voltage batteries
  - Fuel cell BOP
- Other issues:
  - Air compressor
  - Suspension

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

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 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

Technical Issues Affecting Cost

Understanding technical issues helps guide early R&D needs

- 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

Remaining Challenges and Barriers

For industry to fully 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

Current and Potential Evaluations

<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>ZEBA Demonstration</td><td>CA</td><td>Oakland</td><td>40</td><td>13</td><td colspan="4">AC Transit</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<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 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>SunLine FCEB & H2 generation</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></td><td></td><td></td><td colspan="4">SunLine</td></tr>
<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>
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Color coded by Technology:
- Fuel cell dominant electric
- 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

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.

Acknowledgements

Funding for the FCEB evaluations provided by

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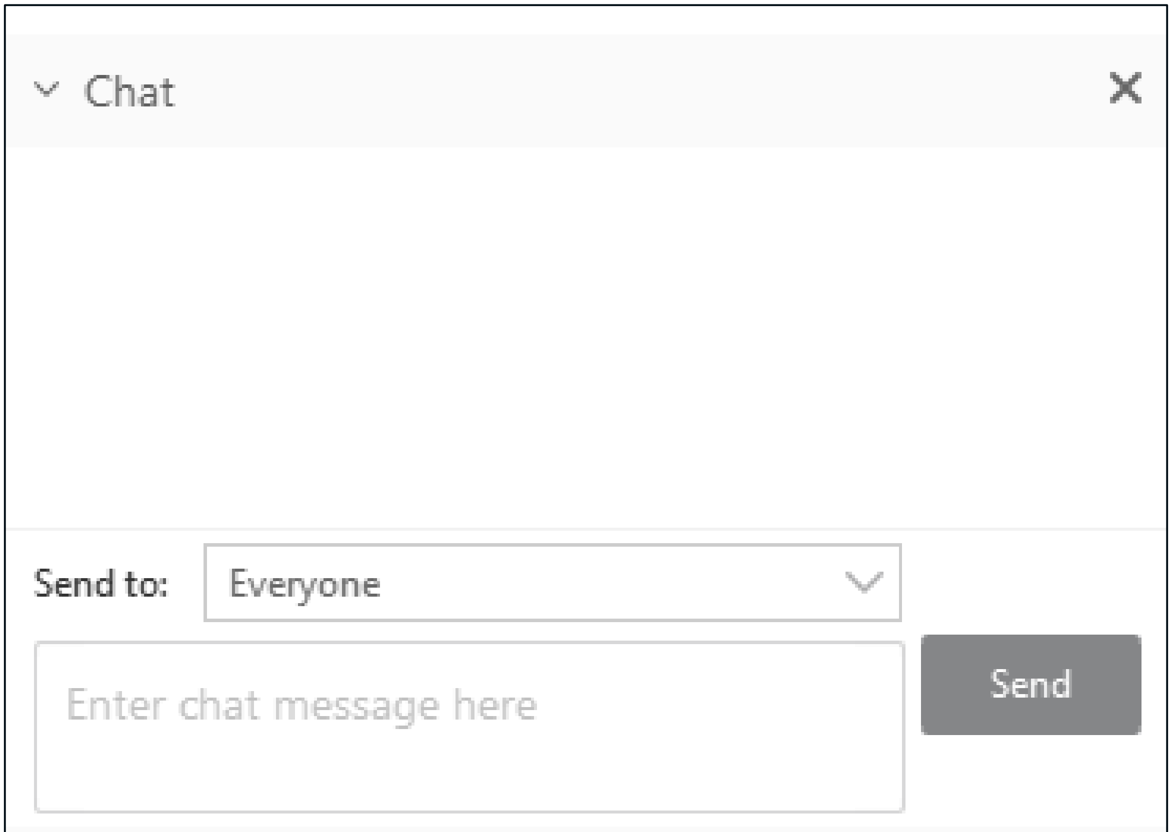

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Thank you

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