

Fuel Cell Bus Evaluations

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DOE Hydrogen Program
2022 Annual Merit Review and Peer Evaluation Meeting

Project ID: ta013

Project Goal

- Validate fuel cell electric bus (FCEB) performance and cost
 - Determine status toward meeting DOE/DOT technical targets
 - Compare to conventional technologies in similar service
- Document progress on implementing FCEBs in transit operations
 - Share early adopter lessons learned
 - Address barriers to market acceptance
 - Publish results for widespread industry and stakeholder use
- Assess future research needs to increase durability and reliability

Overview

Timeline and Budget

- Project start date: 09/01/2003
- FY21 DOE funding (if applicable): \$150K
- FY22 planned DOE funding (if applicable): \$150K
- Total DOE funds received to date*: \$4.725M

* Since the project started

Partners

- Matthew Post (PI, NREL)
- Partner organizations
 - Transit fleets: Operational data, fleet experience
 - Manufacturers: Vehicle specs, data, and review
 - Fuel providers: Fueling data and review

Relevance/Potential Impact

With industry input, DOE and DOT established technical targets that FCEBs need to meet to reach commercial viability.

Data collected are used to assess the progress toward meeting those targets and to provide feedback to DOE on what research is needed.

Selected Targets from DOE/DOT Program Record

Metric ^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

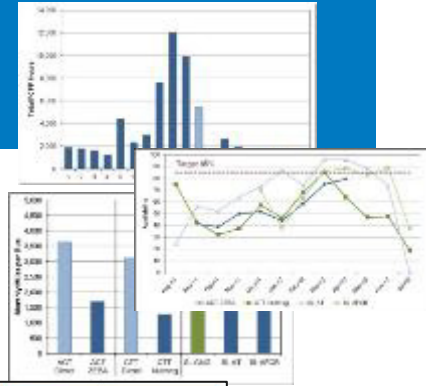
- Standard protocol, uses existing data from transit agencies
- Third-party analysis with comparisons to conventional technology

Individual Reports

- Document performance by transit site
- Builds database of results
- Reports posted on NREL website for industry access

Annual Status Report

- Analysis comparing results for all sites
- Assess progress toward meeting technical and cost targets
- Provide input to DOE for future R&D needs



Approach – Data Summary for 2022

FCEB Fleets Included in Data Summary

Transit Agency	Location	Bus OEM	# Buses	Data Included
AC Transit	Oakland, CA	New Flyer	10	All
SunLine Transit Agency	Thousand Palms, CA	New Flyer	5	All
Orange County Transportation Authority (OCTA)	Santa Ana, CA	New Flyer	10	All



AC Transit, New Flyer

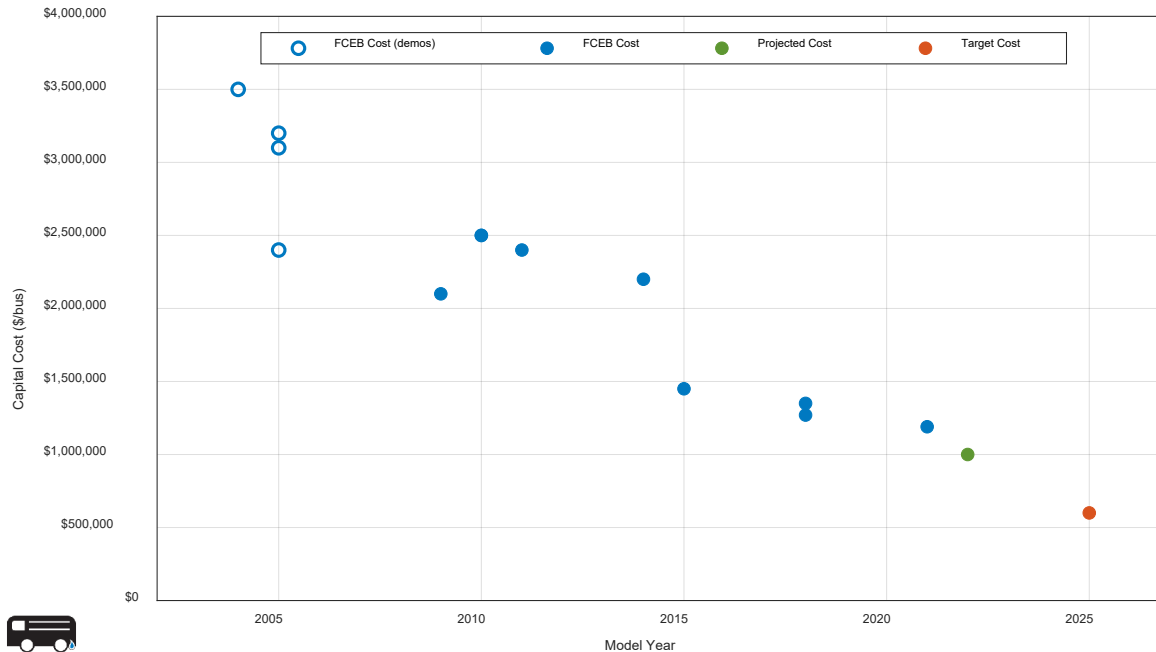


OCTA, New Flyer



SunLine, New Flyer

Accomplishments and Progress: FCEB Cost

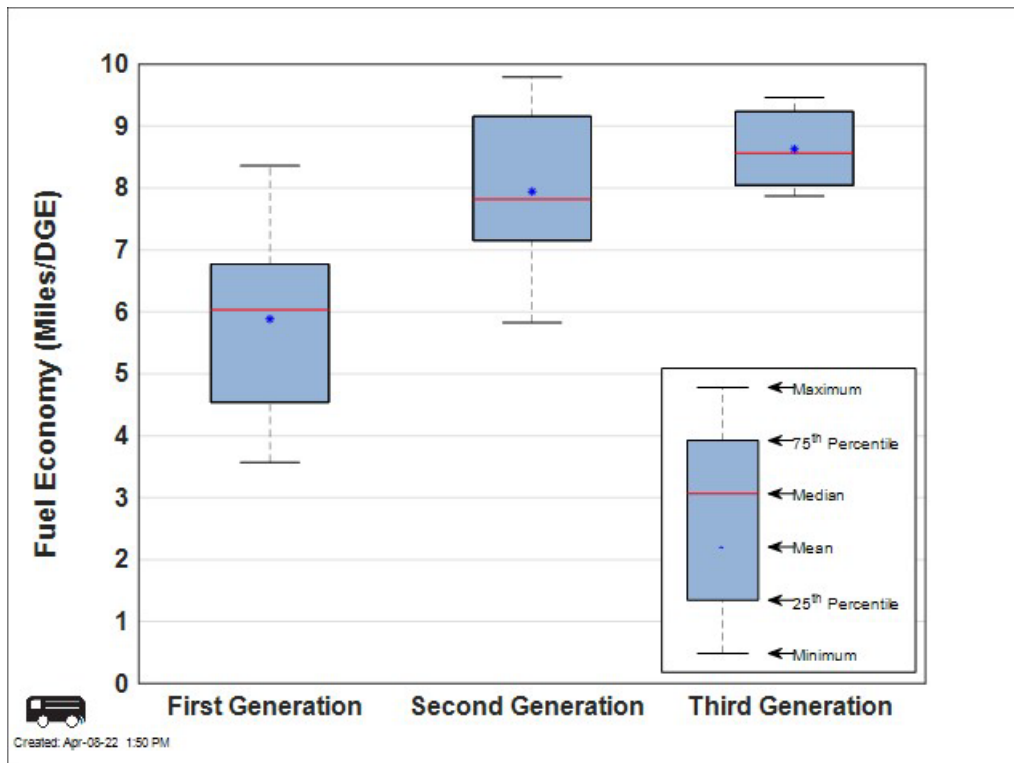


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FCEB cost is still about twice the ultimate target

- FCEB cost continues to trend downward
- Ultimate target has not yet been met
- Larger volume orders have not yet been made in order to make significant cost reductions

Accomplishments and Progress: Initial Fuel Economy by FCEB Generation



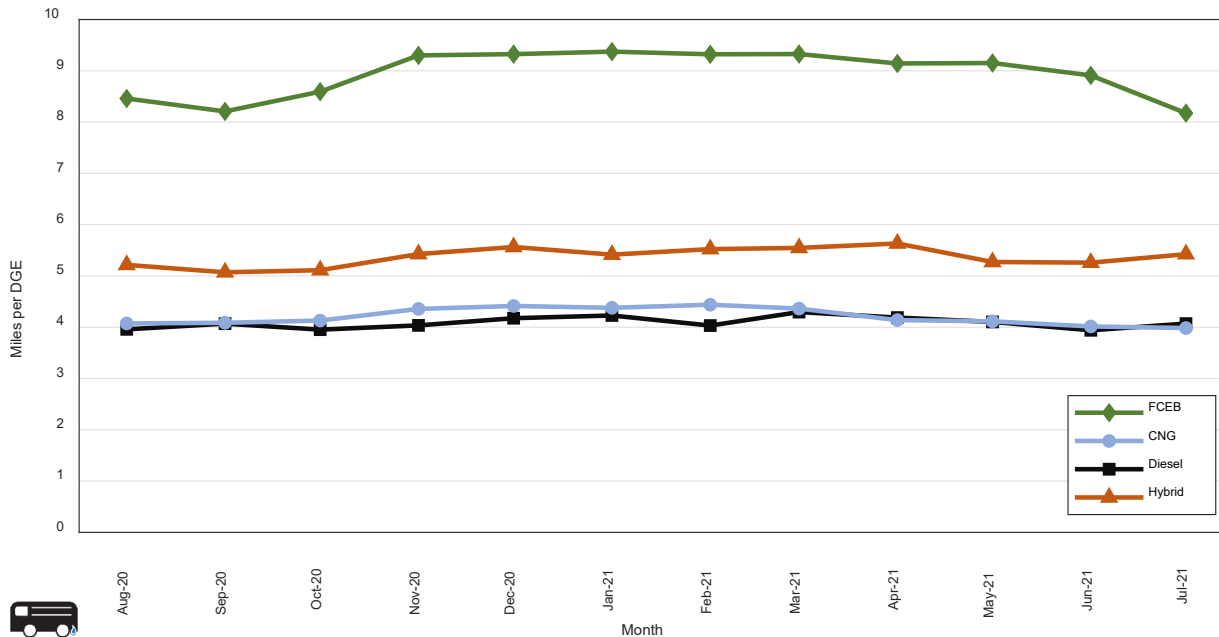
Current generation FCEB average fuel economy has exceeded the ultimate target of 8 Miles/DGE

- The New Flyer FCEBs in this evaluation are their second generation, but considered an overall third generation after lessons learned from previous manufacturers
- Initial Fuel Economy is defined as the fleet average of the first full year in service



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Accomplishments and Progress: Fuel Economy Continues to Surpass Target



Bus type	mpdgc
FCEB	8.95
CNG	4.20
Diesel	4.09
Hybrid	5.37

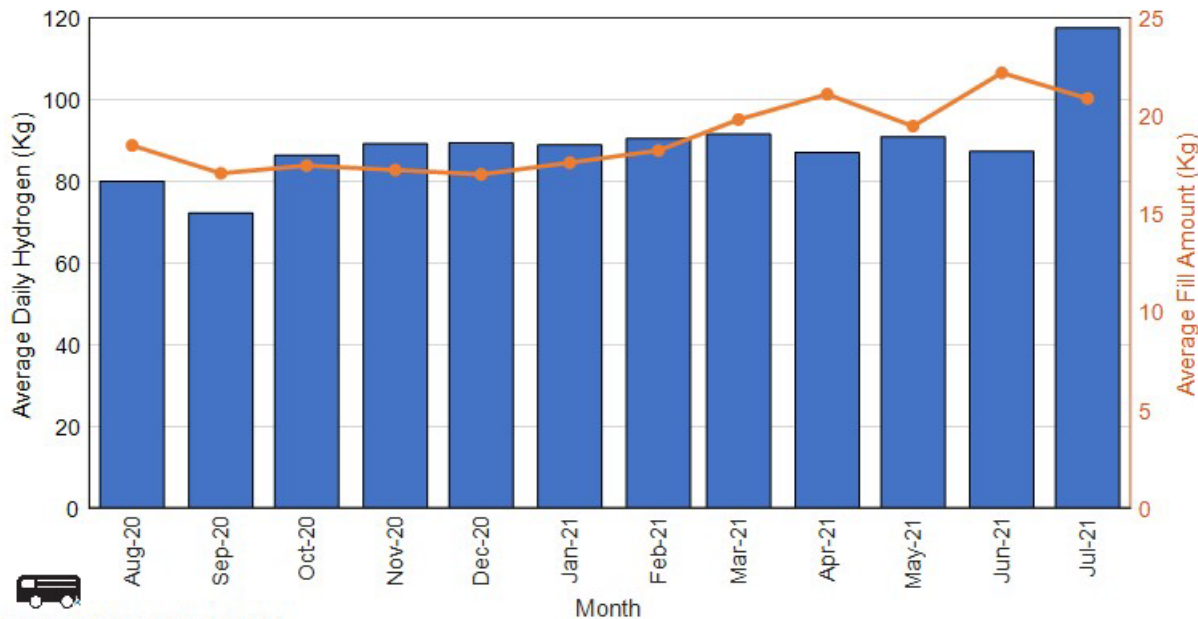
FCEB fuel economy continued to be >2 times that of CNG and diesel buses and >1.6 times that of hybrid buses



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FCEB fuel economy stayed above target all seasons

Accomplishments and Progress: Hydrogen Usage

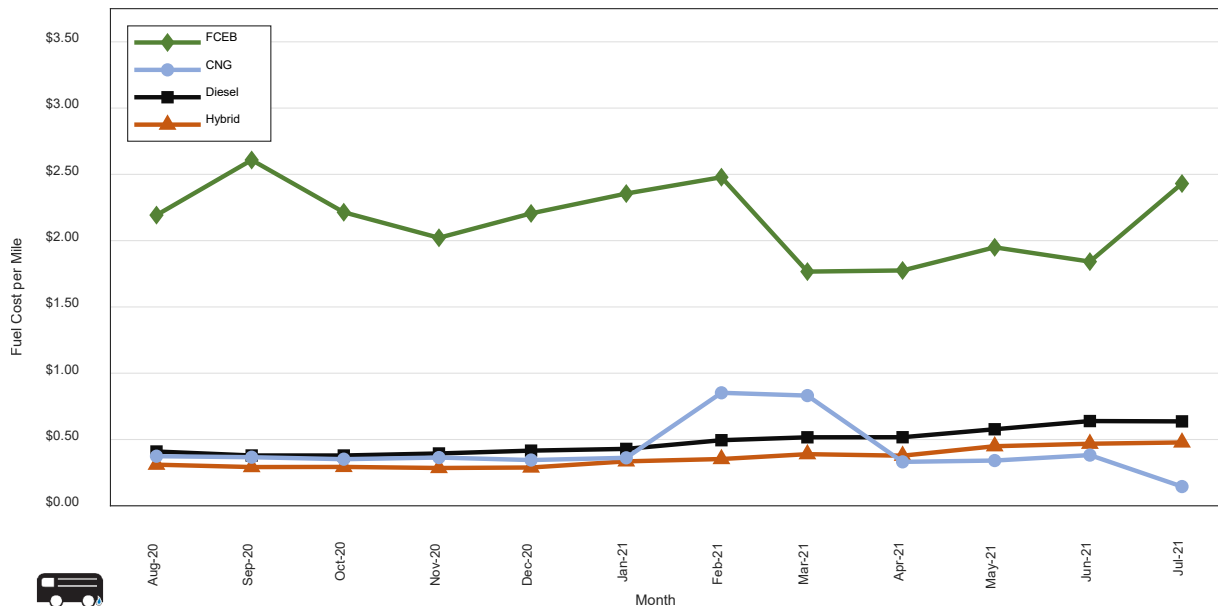


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- Current model FCEBs have a capacity of 37.5 kg hydrogen
- Average fill amount is <20 kg, so the buses are capable of further range
- The pandemic may have influenced the average daily hydrogen used

Transit agencies are using about half the H₂ capacity of the FCEB

Accomplishments and Progress: Fuel Cost per Mile



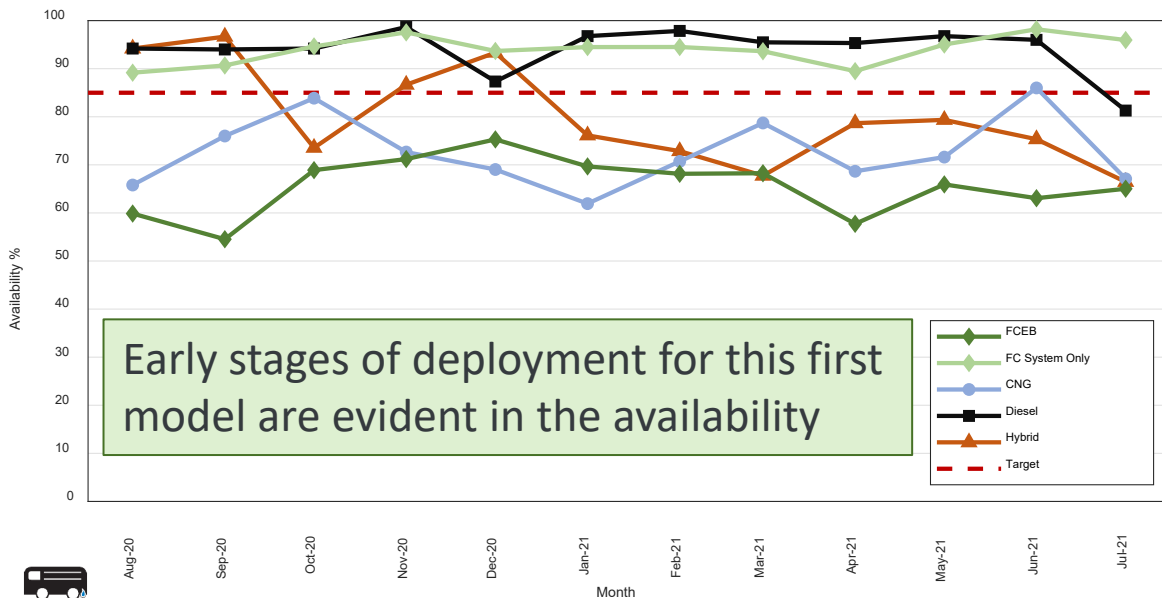
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- The cost per mile of hydrogen is more than 4 times higher than diesel and CNG
- Early market supply issues cause instability observed in the FCEB cost per mile

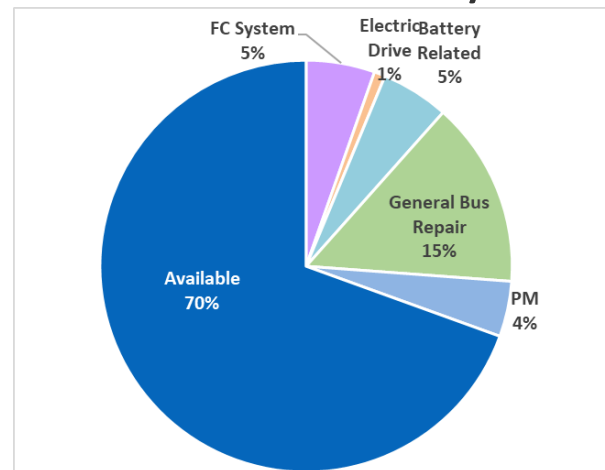
Hydrogen cost per mile is still more than 4 times that of other fuel

Accomplishments and Progress: FCEB Availability

Availability by Month



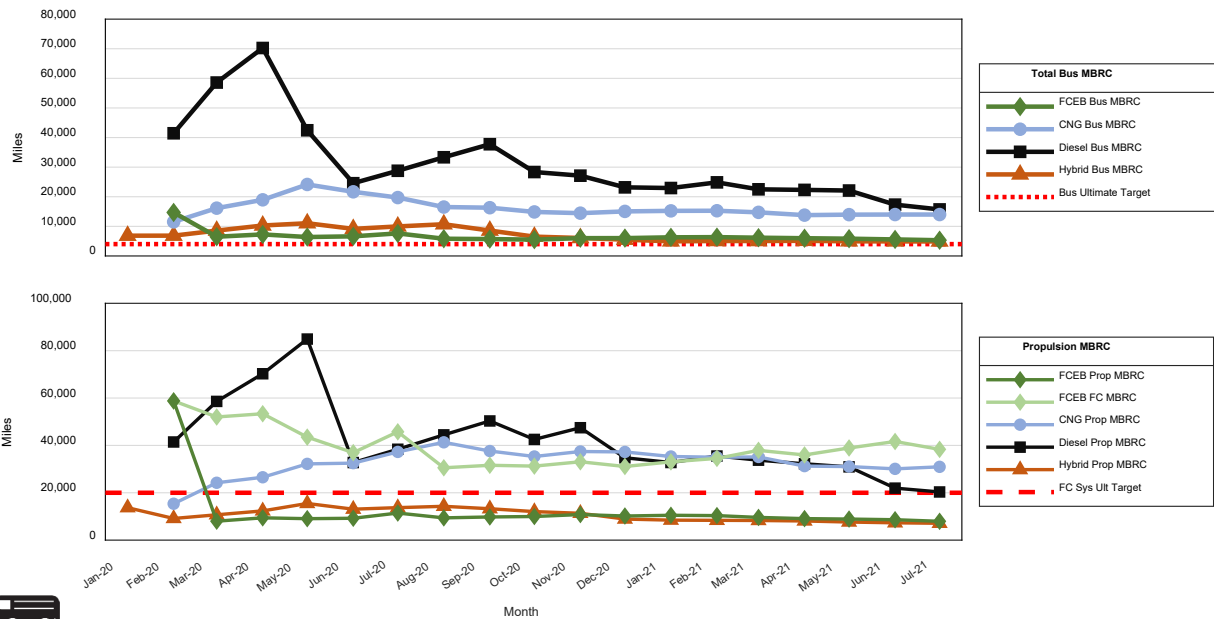
FCEB Reasons for Unavailability



General bus repair continues to be the largest issue



Accomplishments and Progress: Cumulative Monthly Miles Between Road Call (MBRC)



- Total MBRC for FCEBs stayed above the target
- Propulsion MBRC dropped below target due to balance of plant
- Fuel Cell MBRC shows the fuel cell had fewer issues



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FCEB and Hybrid Bus MBRC are lower than established technologies

Accomplishments and Progress: Response to Previous Year Reviewers' Comments

- This project was not reviewed in the previous year AMR.

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. Current FCEBs OEMs:
 - Bus OEM: New Flyer
 - Fuel cell OEM: Ballard
 - Hybrid system OEM: New Flyer
- 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:
 - Data collection requirements expire with grant timeline
 - Finding additional transit agencies willing to add to the data set
 - Incorporating findings into future cross-cutting analyses
- 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 2022
 - Finalize analysis on new designs of three fleets:
 - SunLine, 5 New Flyer FCEBs
 - OCTA, 10 New Flyer FCEBs
 - AC Transit, 10 New Flyer FCEBs
 - Complete the following data analyses/reports:
 - Individual Reports for each Transit Agency listed above
 - Annual Status Report combining the above findings
 - Work with OEMs to determine what detailed data can be collected
- FY 2023
 - Implement data collection process for new OEMs with FCEB fleets
 - Complete annual crosscutting analysis across sites

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

Summary

- Project uses existing data primarily from transit agencies to assess the progress of FCEB technology toward commercialization
- Collected & analyzed data on newest FCEB design at three agencies
- Collected data on three baseline technologies for comparison: CNG, diesel, and diesel hybrid
- Documented progress toward meeting DOE/DOT targets:
 - Fuel economy/range: 8 mpg/300 miles
 - New bus model meets fuel economy target at 8.95 mpdge
 - Range based on 95% useful fuel capacity (37.5 kg tank) is 280 miles
 - Road Call Frequency
 - FCEBs have met this measure of durability
- Published reports to aid other transit agencies considering FCEBs

Thank You

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Technical Backup and Additional Information

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

Publications and Presentations

- Eudy, L., Fuel Cell Bus Evaluations, Presentation for the 2021 DOE Annual Merit Review
- Post, M., (2021), Fuel Cell Bus Evaluations, 2021 Zero Emissions Bus Conference, September 16, 2021