VII.A.2 Technology Validation: Fuel Cell Bus Evaluations

Leslie Eudy (Primary Contact), Matthew Post, Matthew Jeffers
National Renewable Energy Laboratory (NREL)
15013 Denver West Parkway
Golden, CO 80401
Phone: (303) 275-4412
Email: Leslie.Eudy@nrel.gov

DOE Manager: James Alkire
Phone: (720) 356-1426
Email: James.Alkire@ee.doe.gov

Project Start Date: March 2001
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Validate fuel cell electric bus (FCEB) performance and cost compared to DOE and U.S. Department of Transportation targets and conventional technologies.
- Coordinate with the U.S. Department of Transportation Federal Transit Administration (FTA) on the data collection for the National Fuel Cell Bus Program and with international work groups to harmonize data collection methods and enable the comparison of a wider set of vehicles.

Fiscal Year (FY) 2017 Objectives

- Document performance results from each current FCEB demonstration site.
- Complete an annual status report comparing results from the different demonstrations.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

(A) Lack of Fuel Cell Electric Vehicle and Fuel Cell Bus Performance and Durability Data

(D) Lack of Hydrogen Fueling Infrastructure Performance and Availability Data

Contribution to Achievement of DOE Technology Validation Milestones

This project has contributed to achievement of the following DOE milestone from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration Plan.

- *Milestone 2.3: Validate fuel cell electric vehicles achieving 5,000-hour durability (service life of vehicle) and a driving range of 300 miles between fuelings. (4Q, 2019)* Through FY 2017, NREL collected data on 18 FCEBs. NREL documented 12 fuel cell power plants (FCPP) with operation hours in excess of 16,000 h. One of these systems has logged more than 24,800 h in service and five additional systems have surpassed 20,000 h. Bus fuel economy is dependent on duty cycle. Based on in-service fuel economies of 6.5 mi/kg, the hybrid FCEBs currently in service can achieve a range of approximately 245 mi per fill.

FY 2017 Accomplishments

- Published reports on performance and operational data covering 17 full-size FCEBs in revenue service in the United States.
- Documented more than 24,800 h on a single FCPP.

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INTRODUCTION

Transit agencies continue to aid the FCEB industry in developing and optimizing fuel cells for buses. These in-service demonstration programs are vital to validate the performance of fuel cell systems in buses and to determine issues that require resolution. Using fuel cells in a transit application can help accelerate the learning curve for the technology because of the high mileage accumulated in short periods of time. During the last year, the project teams have made progress in transitioning training to transit staff and improving the ability to troubleshoot issues. More work is still needed to improve reliability, lower capital and operating costs, and improve parts availability.

APPROACH

NREL uses a standard evaluation protocol to provide:

- Comprehensive, unbiased evaluation results of advanced technology vehicle development and operations.

- Evaluations of hydrogen infrastructure development and operation.
- Descriptions of facility modifications required for the safe operation of FCEBs.
- Detailed FCEB performance and durability results to validate status against technical targets, educate key stakeholders, and further DOE goals.

The evaluation protocol includes collecting operation and maintenance data on the bus and infrastructure. The analysis, which consists of economic, technical, and safety factors, focuses on performance and use, including progress over time and experience with vehicle systems and supporting infrastructure. The data are compared to DOE and FTA technical targets and to conventional baseline buses in similar service.

RESULTS

During FY 2017, NREL collected and analyzed data on the following FCEB demonstrations at two U.S. transit agencies and one university transit system.

- Zero Emission Bay Area (ZEBA) Demonstration—Five Bay Area transit agencies led by AC Transit (Oakland, California) are demonstrating thirteen 40-ft Van Hool buses with 120 kW fuel cells in a Siemens hybrid system. The hybrid system was integrated by Van Hool and uses lithium ion batteries from EnerDel.
- American Fuel Cell Bus (AFCB) Project—SunLine Transit Agency (Thousand Palms, California) is operating four ElDorado National 40-ft buses with a BAE Systems hybrid propulsion system using Ballard Power Systems fuel cells and lithium batteries.
- University of California, Irvine (UCI)—UCI operates one AFCB in its fleet that is the same design as the SunLine buses.

NREL kicked off two additional evaluations during FY 2017 funded by FTA. Once there are enough data from these evaluations, they will be included in future reports. The evaluations are:

- Massachusetts AFCB—Massachusetts Bay Transportation Authority is operating another AFCB, adding data on the bus design in a cold climate.
- Orange County Transportation Authority AFCB—Orange County Transportation Authority is operating an AFCB in southern California.

These projects involve fuel-cell-dominant hybrid buses. A summary of selected results is included in this report. NREL completed reports on operational and performance data from the FCEBs and from conventional baseline buses at each agency. The results are also compared to technical targets for FCEB performance established by DOE and FTA and published in a Fuel Cell Technologies Program Record in September 2012 [1]. Tables 1, 2, and 3 provide a summary of the reported results from the operation at each agency, including data from the baseline buses.

TABLE 1. FY 2017 Summary Data Results for ZEBA FCEBs

Vehicle data	FCEB	Diesel
Number of buses	13	10
Data period (month, year)	Sep 2011 – Mar 2017	Jul 2013 – Mar 2017
Number of months	59	45
Total fleet miles	1,773,305	2,029,503
Average miles per month	2,456	4,510
Total FC hours	204,639	–
Fuel economy (mi/kg)	5.81	–
Fuel economy (mi/diesel gal equivalent)	6.56	4.29
Average speed (mph)	8.8	–
Availability (%)	77	89

FC – fuel cell; gal – gallon

TABLE 2. FY 2017 Summary Data Results for SunLine FCEBs

Vehicle data	AFCB	CNG
Number of buses	4	5
Data period (month, year)	Mar 2012 – May 2017	Mar 2012 – Dec 2016
Number of months	63	58
Total fleet miles	374,104	1,369,822
Average miles per month	2,539	4,724
Total FC hours	27,341	–
Fuel economy (mi/kg)	5.67	–
Fuel economy (mi/diesel gal equivalent)	6.41	3.21
Average speed (mph)	13.7	16.3
Availability (%)	78	87

CNG – compressed natural gas

TABLE 3. FY 2017 Summary Data Results for UCI FCEB

Vehicle data	AFCB
Number of buses	1
Data period (month, year)	Jan 2016 – May 2017
Number of months	17
Total fleet miles	40,725
Average miles per month	2,407
Total FC hours	4,676
Fuel economy (mi/kg)	5.13
Fuel economy (mi/diesel gal equivalent)	5.79
Average speed (mph)	10.2
Availability (%)	90

One performance target set by DOE and FTA is for an FCPP durability of 4–6 yr (or 25,000 h), which would be approximately half the life of the bus. The FCPP would be rebuilt or replaced at that time, similar to what transit agencies typically do for diesel engines. Over the last year, NREL collected data on 18 FCPPs. Figure 1 shows the total hours accumulated on individual FCPPs for the current projects tracked by NREL. The average of 16,149 h is shown on the graph as a dashed line. The 2016 and ultimate targets are included on the graph. As of May 2017, the highest-hour FCPP had reached 24,800 h, nearing the ultimate target of 25,000 h. Eight FCPPs have surpassed the 2016 target of 18,000 h. Of the 18 total FCPPs included in the graph, 67% (12) have surpassed 16,000 h of operation. (The FCPPs with the lowest hours accumulated are newer buses.) This shows significant improvement in durability toward meeting the 25,000-h target.

The transit industry measures reliability as mean distance between failures, also known as miles between roadcall (MBRC). Figure 2 tracks the MBRC over time for the ZEBA, SunLine, and UCI FCEB demonstrations and includes the MBRC for the bus as a whole and MBRC for the fuel cell system. The targets for each category are included on the chart. Table 4 provides the MBRC by year since 2012. Reliability has shown a marked increase over time, reaching the ultimate targets for both bus MBRC and fuel cell system MBRC. Roadcalls due to bus-related issues, such as problems with doors and air conditioning, made up 41% of the total failures. Although still over the ultimate target, the fuel cell system MBRC dropped over the last year as a result of several fuel cell system roadcalls. Fuel-cell-related issues made up approximately 22% of the roadcalls during the period.

TABLE 4. MBRC by Year through April 2017

	Bus MBRC	FC System MBRC
April 2012	2,230	12,215
April 2013	2,644	14,884
April 2014	3,510	17,714
April 2015	3,910	20,082
April 2016	4,210	21,482
April 2017	4,531	20,737
% improvement from 2012 to 2017	103	70

CONCLUSIONS AND UPCOMING ACTIVITIES

Fuel cell propulsion systems in buses have continued to show progress in increasing the durability and reliability of FCEBs and the primary components. The current technology meets the ultimate reliability target for roadcall frequency of both the overall bus and the fuel cell system. The fuel cell system on one bus is nearing the ultimate target for power plant lifetime and seven additional fuel cell systems have surpassed the 2016 target. Table 5 summarizes the current status compared to the DOE and FTA performance targets. Transit agencies have made major progress over the last two years toward transitioning maintenance to staff. There are still challenges to overcome before fuel cell buses can match the current performance standard of diesel buses. These include:

- Continuing operation to validate durability and reliability of the fuel cell systems and other components to match transit needs.

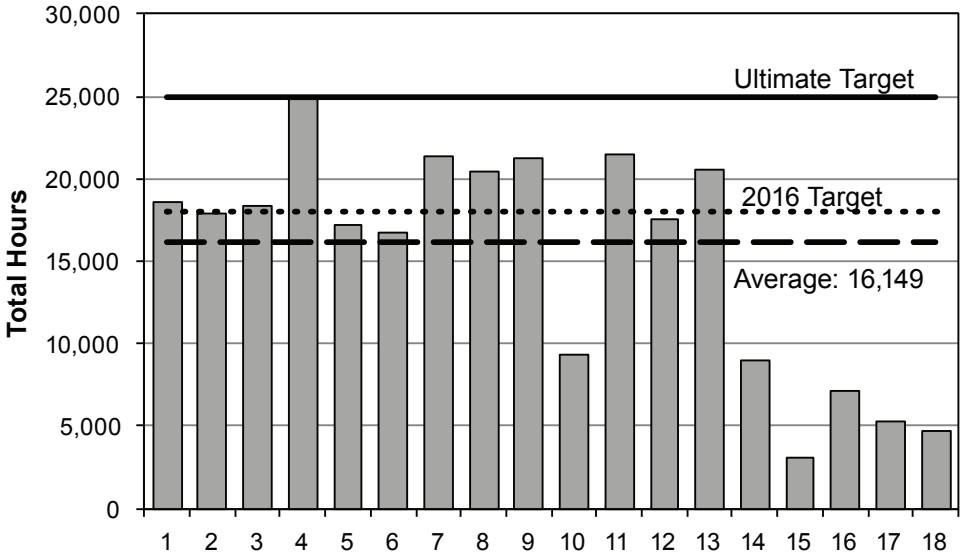

FIGURE 1. Total fuel cell hours accumulated on each FCPP

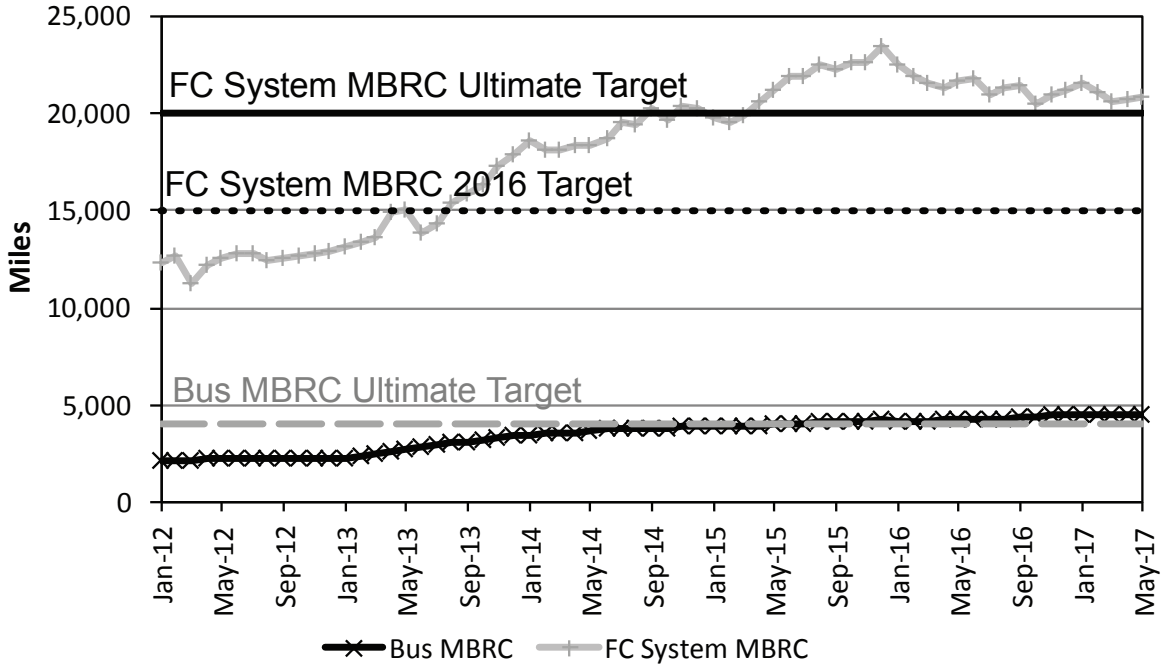

FIGURE 2. Miles between roadcall

- Completing the transfer of all maintenance work to transit personnel.
- Lowering the costs of purchasing, operating, and maintaining buses and infrastructure.
- Scaling up the introduction and operation of larger numbers of FCEBs.

Future work by NREL includes:

- Continuing data collection, analysis, and reporting on performance data for FCEBs in service at the following sites:
  - ZEBA FCEB demonstration led by AC Transit
  - SunLine
  - UCI
  - Additional sites as funding allows
- Investigating reliability, durability, and lifecycle of FCEBs as a part of ongoing evaluations.
- Coordinating with FTA to collect data on the demonstrations funded under the National Fuel Cell Bus Program.
- Coordinating with national and international FCEB demonstration sites.

TABLE 5. FY 2017 Summary of Progress Toward Meeting DOE and FTA Targets

	Units	2017 Status	2016 Target	Ultimate Target
Bus lifetime	Years/miles	5.6/150,000[a]	12/500,000	12/500,000
Power plant lifetime	Hours	3,061–24,800[a]	18,000	25,000
Bus availability	%	75	85	90
Roadcall frequency (bus/FC system)	Miles between roadcall	4,500/20,700	3,500/15,000	4,000/20,000
Operation time	Hours per day/days per week	19/7	20/7	20/7
Maintenance cost	$/mile	0.46–2.28	0.75	0.40
Fuel economy	Miles per diesel gallon equivalent	5.8–6.6	8	8
Range	Miles	220–270	300	300

[a] Accumulation of miles and hours to date—not end of life.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. L. Eudy, "Technology Validation: Fuel Cell Bus Evaluations," Presentation at the DOE Hydrogen and Fuel Cells Program Annual Merit Review, Washington, D.C., June 2017.

2. L. Eudy, M. Post, M. Jeffers, *American Fuel Cell Bus Project Evaluation: Third Report*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-67209, May 2017.

3. M. Post, "Fuel Cell Electric Bus Evaluation Results," Presentation at the American Public Transit Association Annual Bus and Paratransit Conference, May 2017.

4. L. Eudy, "Guideline for Assessing Readiness Levels for Maintenance of ZEBs," Presentation at the American Public Transit Association Annual Bus and Paratransit Conference, May 2017.

5. L. Eudy, "U.S. Fuel Cell Electric Bus Evaluation Results," Presentation at the 10th International Fuel Cell Bus Workshop, December 2016.

6. L. Eudy, M. Post, M. Jeffers, *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2016*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-67097, December 2016.

REFERENCES

1. Fuel Cell Technologies Program Record #12012, September 2012, www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf.