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: Jason Marcinkoski
Phone: (202) 586-7466
Email: Jason.Marcinkoski@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) 2016 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 Refueling 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)

FY 2016 Accomplishments

Through FY 2016, NREL collected data on 17 FCEBs.

- Documented 11 fuel cell power plants (FCPPs) with operation hours in excess of 12,000 hours. One of these systems has logged more than 22,600 hours in service, and three additional systems have surpassed 16,000 hours.
- Bus fuel economy is dependent on duty cycle. Based on in-service fuel economy of 6.8 mi/kg, the hybrid FCEBs currently in service can achieve a range of approximately 270 miles per fill.
- Published reports on performance and operational data covering 17 full-size FCEBs in revenue service in the United States.

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 improving fuel cell durability, availability, and reliability. More work is still needed to meet the performance needs of transit, lower capital and operating costs, and transition the maintenance to transit staff.

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 2016, NREL collected and analyzed data on the following FCEB demonstrations at two transit agencies in the United States:

- Zero Emission Bay Area (ZEBA) Demonstration—Five Bay Area transit agencies led by AC Transit (Oakland, California) are demonstrating thirteen 40-foot Van Hool buses with US Hybrid 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—In December 2012 SunLine began operating an ElDorado National 40-foot bus with a BAE Systems hybrid propulsion system using Ballard Power Systems fuel cells and lithium batteries. This project is part of FTA's National Fuel Cell Bus Program. SunLine added two more AFCBs in 2014 and a third in 2015. NREL collected data on all four buses.

These projects involve fuel-cell-dominant hybrid buses. NREL's evaluations of these projects were funded by DOE. 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 and 2 provide a summary of the reported results from the operation at each agency, including data from the baseline buses.

One performance target set by DOE and FTA is for an FCPP durability of 4–6 years (or 25,000 hours), 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 17 FCPPs. Figure 1 shows the total hours accumulated on individual FCPPs for the current projects tracked by NREL. The average of 12,217 h is shown on the graph as a dashed line. The 2016 and ultimate targets are included on the graph. As of May 2016, the highest-hour

TABLE 1. 2016 Summary Data Results for ZEBA FCEBs

Vehicle data	FCEB	Diesel
Number of buses	13	10
Data period (month, year)	Sep 2011 – Mar 2016	Jul 2013 – Mar 2016
Number of months	47	33
Total fleet miles	1,320,920	1,534,138
Average miles per month	2,334	4,649
Total FC hours	153,853	–
Fuel economy (mi/kg)	6.03	–
Fuel economy (mi/diesel gal equivalent)	6.82	3.91
Average speed (mph)	8.8	–
Availability (%)	74	88

FC – Fuel cell

TABLE 2. 2016 Summary Data Results for SunLine FCEBs

Vehicle data	AFCB	CNG
Number of buses	4	5
Data period (month, year)	Mar 2012 – Apr 2016	Mar 2012 – Apr 2016
Number of months	50	50
Total fleet miles	258,370	1,157,589
Average miles per month	2,514	5,008
Total FC hours	18,107	–
Fuel economy (mi/kg)	5.84	–
Fuel economy (mi/diesel gal equivalent)	6.34	2.94
Average speed (mph)	14.3	16.3
Availability (%)	74	86

CNG – Compressed natural gas

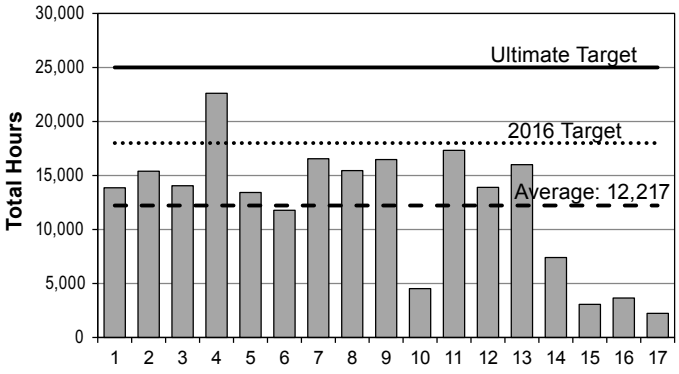

FIGURE 1. Total fuel cell hours accumulated on each FCPP

FCPP had reached 22,600 h, surpassing the 2016 target of 18,000 hours. Of the 17 total FCPPs included in the graph, 61% (11) have surpassed 13,000 h of operation. (The FCPPs with the lowest hours accumulated are newer buses.) This shows significant improvement in durability toward meeting the 25,000-hour target.

The transit industry measures reliability as mean distance between failures, also known as miles between road call (MBRC). Figure 2 tracks the MBRC over time for the ZEBA and SunLine 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 3 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. Road calls due to bus-related issues—such as problems with doors and air conditioning—made up 40% of the total failures. Fuel cell-related issues made up approximately 15% of the road calls during the period.

CONCLUSIONS AND FUTURE DIRECTION

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 road call frequency of both the overall bus and fuel cell system. The fuel cell system on one bus has surpassed the 2016 target for power plant lifetime. Table 4 summarizes the current status compared to the DOE and FTA performance targets. 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.
- 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
  - University of California, Irvine
  - Massachusetts Bay Transportation Authority, Boston
  - Additional sites as funding allows
- Investigating reliability, durability, and life cycle 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.

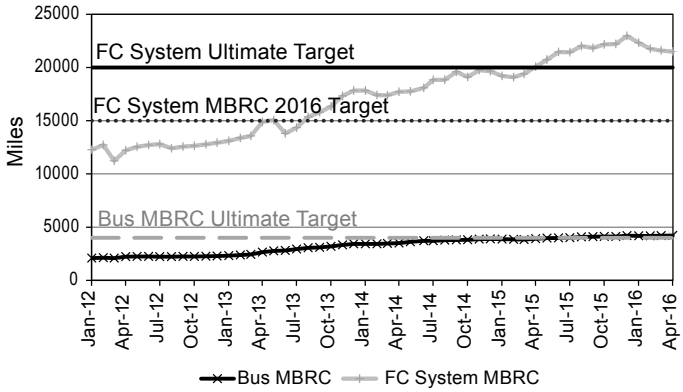

FIGURE 2. Miles between road call

TABLE 3. MBRC by Year through May 2016

	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
% improvement from 2012 to 2016	89	76

FY 2016 PUBLICATIONS/PRESENTATIONS

1. L. Eudy, M. Post, *Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fifth Report*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-66039, June 2016.

2. L. Eudy, *Technology Validation: Fuel Cell Bus Evaluations*, Presentation at the DOE Hydrogen and Fuel Cells Program Annual Merit Review, Washington, D.C., June 2016.

3. L. Eudy, *U.S. Zero Emission Bus Evaluation Results and Status*, Presentation at the American Public Transit Association Annual Bus and Paratransit Conference, May 2016.

4. L. Eudy, *U.S. Zero Emission Bus Evaluation Results and Status*, Presentation at the California Air Resources Board Advanced Clean Transit Technology Symposium, February 2016.

TABLE 4. 2016 Summary of Progress Toward Meeting DOE and FTA Targets

	Units	2016 Status	2016 Target	Ultimate Target
Bus lifetime	Years/miles	5.6/150,000[a]	12/500,000	12/500,000
Power plant lifetime	Hours	2,200–22,200[a]	18,000	25,000
Bus availability	%	74	85	90
Road call frequency (Bus/fuel cell system)	Miles between road call	4,300/ 21,500	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	0.50–2.11	0.75	0.40
Fuel economy	Miles per diesel gallon equivalent	5.5–7.4	8	8
Range	Miles	230–300	300	300

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

5. L. Eudy, *Technology Validation: FCEB Evaluations*, Presentation for the California Fuel Cell Partnership Bus Team meeting, December 2015.

6. L. Eudy, M. Post, C. Gikakis, *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2015*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-64974, December 2015.

7. L. Eudy, M. Post, *American Fuel Cell Bus Project Evaluation: Second Report*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-64344, December 2015.

8. L. Eudy, *U.S. Fuel Cell Electric Bus Evaluation Results*, Presentation at the 2015 Fuel Cell Seminar, November 2015.

REFERENCES

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