VII.5 Technology Validation: Fuel Cell Bus Evaluations

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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 (DOT) targets and conventional technologies
- Coordinate with the DOT Federal Transit Administration (FTA) on the data collection for the National Fuel Cell Bus Program (NFCBP) and with international work groups to harmonize data collection methods and enable the comparison of a wider set of vehicles

Fiscal Year (FY) 2015 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 (MYRDD) 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 MYRDD 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 2015, NREL collected data on 18 FCEBs. NREL documented nine fuel cell power plants (FCPP) with operation hours in excess of 10,000 hours. One of these systems has logged more than 19,500 hours in service and a second system has surpassed 12,900 hours. Bus fuel economy is dependent on duty cycle. Based on in-service fuel economies of 6.3 miles per kilogram, the hybrid FCEBs currently in service can achieve a range of approximately 270 miles per fill.

FY 2015 Accomplishments

- Published reports on performance and operational data covering 18 full-size FCEBs in revenue service in the U.S.
- Documented more than 19,500 hours on a single fuel cell power plant

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 the following.

- 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/FTA technical targets and to conventional baseline buses in similar service.

RESULTS

During FY 2015, NREL collected and analyzed data on the following four FCEB demonstrations at three transit agencies in the U.S. and Canada:

- Zero Emission Bay Area (ZEBA) Demonstration—five Bay Area transit agencies led by AC Transit (Oakland, California) are demonstrating twelve 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 NFCBP. SunLine added two more AFCBs in 2014 and a third in 2015. NREL collected data on all four buses.
- Birmingham Fuel Cell Bus Project—Demonstration of one 30-foot EVAmerica bus with an Embedded Power Labs battery-dominant hybrid propulsion system using lithium titanate batteries and a Ballard fuel cell. The bus is being operated by Birmingham-Jefferson County Transit Authority.
- Advanced Composite Fuel Cell Bus: Demonstration of one next-generation battery-dominant Proterra FCEB in Austin, TX, and Washington, DC. The 35-foot bus has a hybrid system from Proterra, lithium titanate batteries, and a Ballard fuel cell power system.

The first two projects involve fuel cell-dominant hybrid buses. NREL's evaluations of these projects were funded by DOE. The remaining two projects involve battery-dominant hybrid buses and were covered by funding from FTA. NREL published results from the first two of these demonstrations. A summary of selected results is included in this report.

The Birmingham bus experienced some issues during the early portion of the demonstration and was not in service for a significant period of time. The Proterra bus went into service in early 2015. NREL will report on these buses once sufficient data are collected.

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/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.

TABLE 1. 2015 Summary Data Results for ZEBA FCEBs

Vehicle data	FCEB	Diesel (Van Hool)	Diesel (Gillig)
Number of buses	12	3	10
Data period (month, year)	Sept. 2011 – Apr. 2015	Sept. 2011 – Apr. 2015	July 2013 – Apr. 2015
Number of months	36	36	22
Total fleet miles	962,124	490,693	1,030,102
Average miles per month	2,248	4,055	4,682
Total FC hours	112,363	–	–
Fuel economy (mi/kg)	6.36	–	–
Fuel economy (mi/diesel gal equivalent)	7.19	3.92	4.28
Average speed (mph)	8.6	–	–
Availability (%)	74	79	87

FC – fuel cell

TABLE 2. 2015 Summary Data Results for SunLine FCEBs

Vehicle data	AFCB	CNG
Number of buses	4	5
Data period (month, year)	Mar. 2012 – June 2015	Mar. 2012 – June 2015
Number of months	47	47
Total fleet miles	151,935	898,670
Average miles per month	2,491	4,493
Total FC hours	10,297	–
Fuel economy (mi/kg)	6.11	–
Fuel economy (mi/diesel gal equivalent)	6.72	3.20
Average speed (mph)	14.8	16.3
Availability (%)	70	85

CNG – compressed natural gas

Increasing the durability and reliability of the fuel cell system to meet FTA life cycle requirements for a full-size

bus—12 years or 500,000 miles—continues to be a challenge for the fuel cell bus industry. DOE and FTA have set an early FCPP performance target of 4–6 years (or 25,000 hours) durability for the fuel cell propulsion system, 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 8,980 hours is shown on the graph as a dashed line. The 2016 and ultimate targets are included on the graph. As of May 2015, the highest-hour FCPP had reached 19,500 hours, surpassing the 2016 target of 18,000 hours. Of the 18 total FCPPs included in the graph, 67% (12) have surpassed 9,000 hours of operation. The FCPPs with the lowest hours accumulated are either newer buses or spare FCPPs that are used periodically. 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 FC system MBRC. Road calls due to bus-related issues—such as problems with doors, and air conditioning—made up

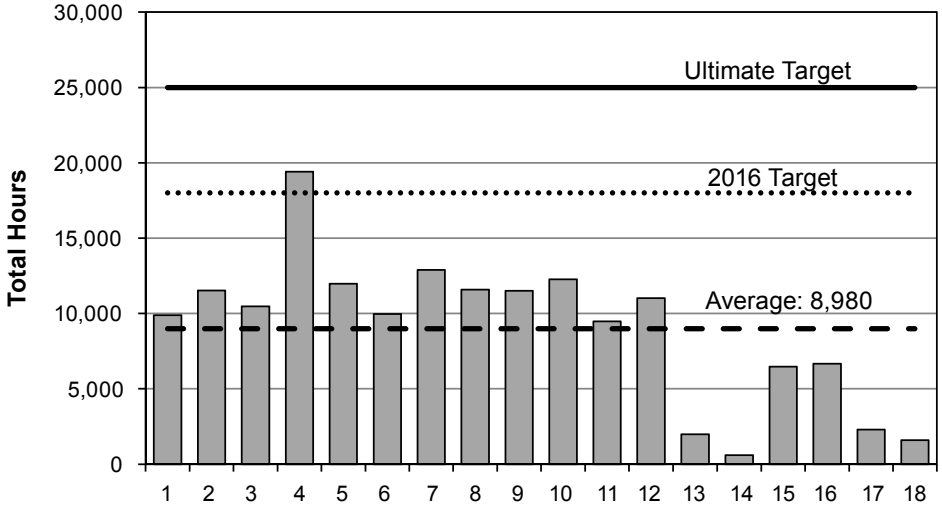

FIGURE 1. Total fuel cell hours accumulated on each FCPP

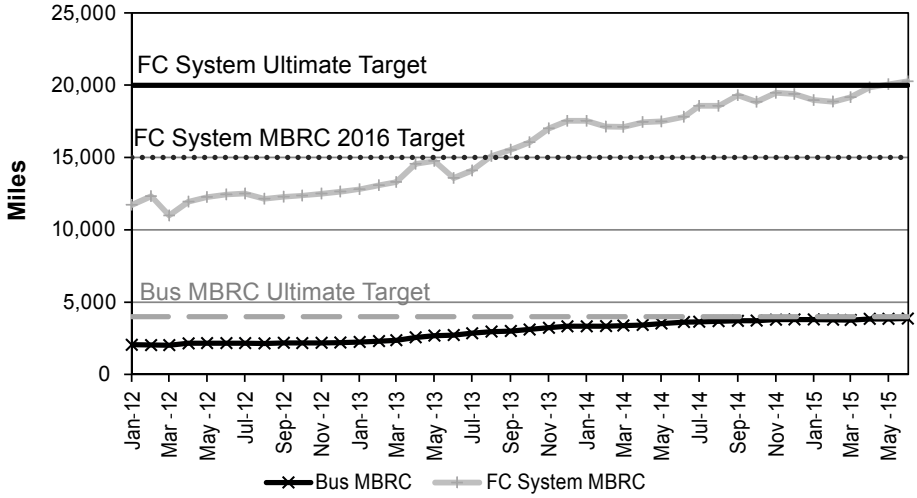

FIGURE 2. Miles between road call

39% of the total failures. Fuel cell-related issues made up approximately 19% of the road calls during the period.

TABLE 3. MBRC by Year through June 2015

	Bus MBRC	FC System MBRC
June 2012	2,160	12,507
June 13	2,730	13,572
June 14	3,625	17,816
June 15	3,873	20,269
% improvement from 2012 to 2015	79	62

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 already meets fuel economy targets and has now exceeded the fuel cell durability targets. Table 4 summarizes the current status compared to the DOE/DOT performance targets. There are still challenges to overcome before fuel cell buses can match the current performance standard of diesel buses.

- Continuing operation to validate durability and reliability of the fuel cell systems and other components to match transit needs
- Transferring all maintenance work to transit personnel
- Lowering the costs of purchasing, operating, and maintaining buses and infrastructure
- Integrating hydrogen fueling procedures into the existing fueling process
- Transferring the lead role for FC system integration to transit bus builders

Future work by NREL includes the following.

- 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
  - Birmingham-Jefferson County Transit Authority in Birmingham, Alabama
  - Capital Metro, Austin, Texas
  - University of California, Irvine
  - 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 NFCBP
- Coordinating with national and international FCEB demonstration sites

FY 2015 PUBLICATIONS/PRESENTATIONS

1. L. Eudy, M. Post, *Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: Fourth Results Report*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-63719, July 2015.

2. L. Eudy, *Technology Validation: Fuel Cell Bus Evaluations*, Presentation at the DOE Hydrogen and Fuel Cells Program Annual Merit Review, Washington, DC, June 2015.

3. L. Eudy, *U.S. Fuel Cell Bus Performance*, Presentation at the 9th International Fuel Cell Bus Workshop, February 2015.

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

TABLE 4. 2015 Summary of Progress toward Meeting DOE/DOT Targets

	Units	2015 Status	2016 Target	Ultimate Target
Bus lifetime	Years / miles	5/100,000[a]	12/500,000	12/500,000
Power plant lifetime	Hours	600–19,500[a]	18,000	25,000
Bus availability	%	70–74	85	90
Road call frequency (Bus / fuel cell system)	Miles between road call	3,400–4,000 / 17,500–21,300	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	0.54–1.33	0.75	0.40
Fuel economy	Miles per diesel gallon equivalent	6.7–7.2	8	8
Range	Miles	220–300	300	300

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

5. L. Eudy, C. Gikakis, *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2014*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-62383, December 2014.

REFERENCES

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