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 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) 2018 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[1]:

(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 2018, NREL collected data on 27 FCEBs. NREL documented 12 fuel cell power plants (FCPPs) with operation hours in excess of 20,000 hours. One of these systems has logged more than 29,000 hours in service, and four additional systems have surpassed 25,000 hours. Bus fuel economy is dependent on duty cycle. Based on in-service fuel economies of 5.6 miles per kilogram, the hybrid FCEBs currently in service can achieve a range of approximately 260 miles per fill.

FY 2018 Accomplishments

- Published reports on performance and operational data covering 27 full-size FCEBs in revenue service in the United States.
- Documented more than 29,000 hours on a single FCPP.

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

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 buses 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 2018, NREL collected and analyzed data on the following FCEB demonstrations at four U.S. transit agencies and one university transit system:

- American Fuel Cell Bus (AFCB) Project—SunLine Transit Agency (Thousand Palms, California) is operating four ElDorado National 40-foot 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.
- Orange County Transportation Authority (OCTA) AFCB—Orange County Transportation Authority is operating an AFCB in Southern California.
- Stark Area Regional Transit Authority (SARTA) AFCB Project—SARTA is operating five AFCBs in Canton, Ohio.
- 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 120 kW fuel cells in a Siemens hybrid system. The hybrid system was integrated by Van Hool and uses lithium ion batteries from EnerDel. NREL has ended the full evaluation of this fleet. Current data collection is limited to fuel cell hours, mileage, and miles between roadcall analysis.

These projects involve fuel-cell-dominant hybrid buses. A summary of selected results is included in this report. 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 through 5 provide a summary of the reported results from the operation at each agency, including data from the baseline buses.

Table 1. FY 2018 Summary Data Results for SunLine

Vehicle Data	AFCB	CNG
Number of buses	7	5
Data period	Mar 2012–Jul 2018	Jan 2017–Jul 2018
Number of months	77	19
Total fleet miles	506,496	516,105
Average miles per month	2,323	5,433
Total FC hours	38,304	–
Fuel economy (mi/kg or gge)	5.59	3.44
Fuel economy (mi/dge)	6.31	3.84
Average speed (mph)	15.1	16.8
Availability (%)	74	88

FC – fuel cell
CNG – compressed natural gas
gge – gasoline gallon equivalent
dge – diesel gallon equivalent

Table 2. FY 2018 Summary Data Results for UCI

Vehicle Data	AFCB
Number of buses	1
Data period	Jan 2016–Jul 2018
Number of months	31
Total fleet miles	52,065
Average miles per month	1,680
Total FC hours	5,917
Fuel economy (mi/kg)	5.20
Fuel economy (mi/dge)	5.88
Average speed (mph)	9.2
Availability (%)	78

Table 3. FY 2018 Summary Data Results for OCTA

Vehicle Data	AFCB	CNG
Number of buses	1	10
Data period	Jun 2016–Jul 2018	Jun 2016–Jun 2018
Number of months	26	26
Total fleet miles	36,808	857,036
Average miles per month	1,416	3,296
Total FC hours	3,027	–
Fuel economy (mi/kg or gge)	6.49	3.56
Fuel economy (mi/dge)	7.33	3.98
Average speed (mph)	14.8	17.0
Availability (%)	55	85

Table 4. FY 2018 Summary Data Results for SARTA

Vehicle Data	AFCB	CNG	Diesel Hybrid
Number of buses	5	4	3
Data period	Oct 2017–Jul 2018	Oct 2017–Jul 2018	Oct 2017–Jul 2018
Number of months	10	10	10
Total fleet miles	92,524	182,536	88,453
Average miles per month	2,056	4,563	3,402
Total FC hours	6,786	–	–
Fuel economy (mi/kg or gge)	4.83	4.15	–
Fuel economy (mi/dge)	5.46	4.64	4.71
Average speed (mph)	13.6	N/A	N/A
Availability (%)	65	77	86

Table 5. FY 2018 Summary Data Results for ZEBA

Vehicle Data	FCEB	Diesel
Number of buses	13	10
Data period	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	–

One performance target set by DOE and FTA is for a 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 27 FCPPs including eight new buses at two different agencies. Figure 1 shows the total hours accumulated on individual FCPPs for the current projects tracked by NREL. The 2016 and ultimate targets are included on the graph as lines along with the average of 21,023 hours. As of July 2018, the highest-hour FCPP had reached 29,028 hours. Twelve FCPPs have surpassed the 2016 target of 18,000 hours. Of those FCPPs, five have surpassed the ultimate target of 25,000 hours. Agencies report that the FCPPs are proving reliable and that issues with the system are typically attributed to balance of plant components.

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 all five 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. Reliability has shown a steady 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 45% of the total failures. Fuel-cell-related issues made up approximately 22% of the roadcalls during the period.

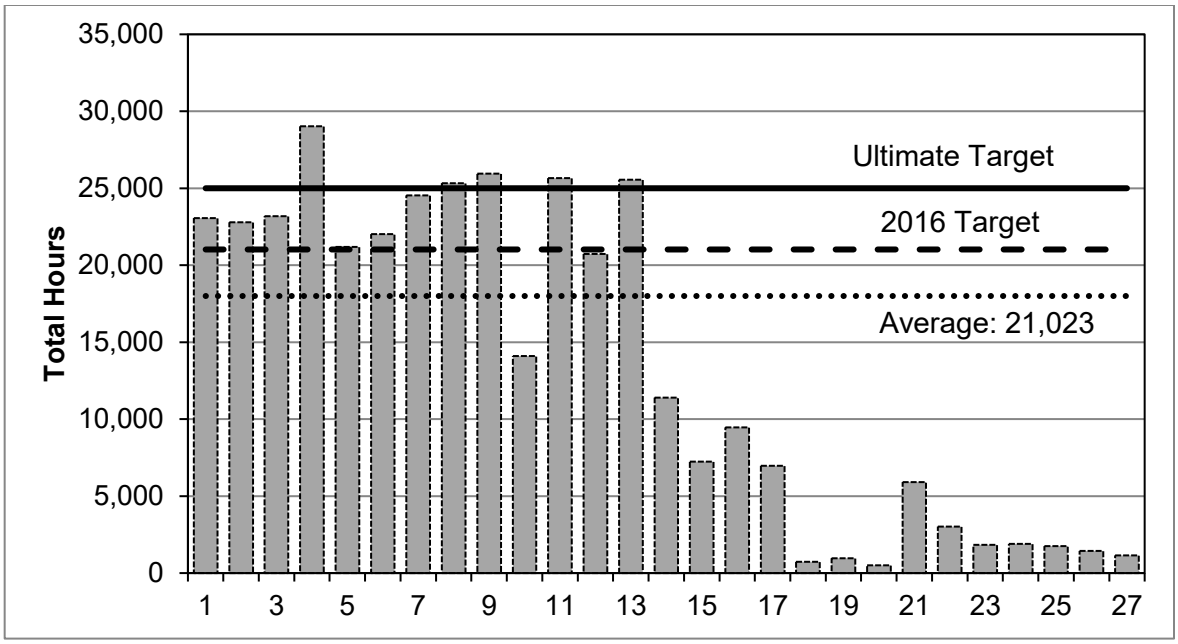

Figure 1. Total fuel cell hours accumulated on each FCPP

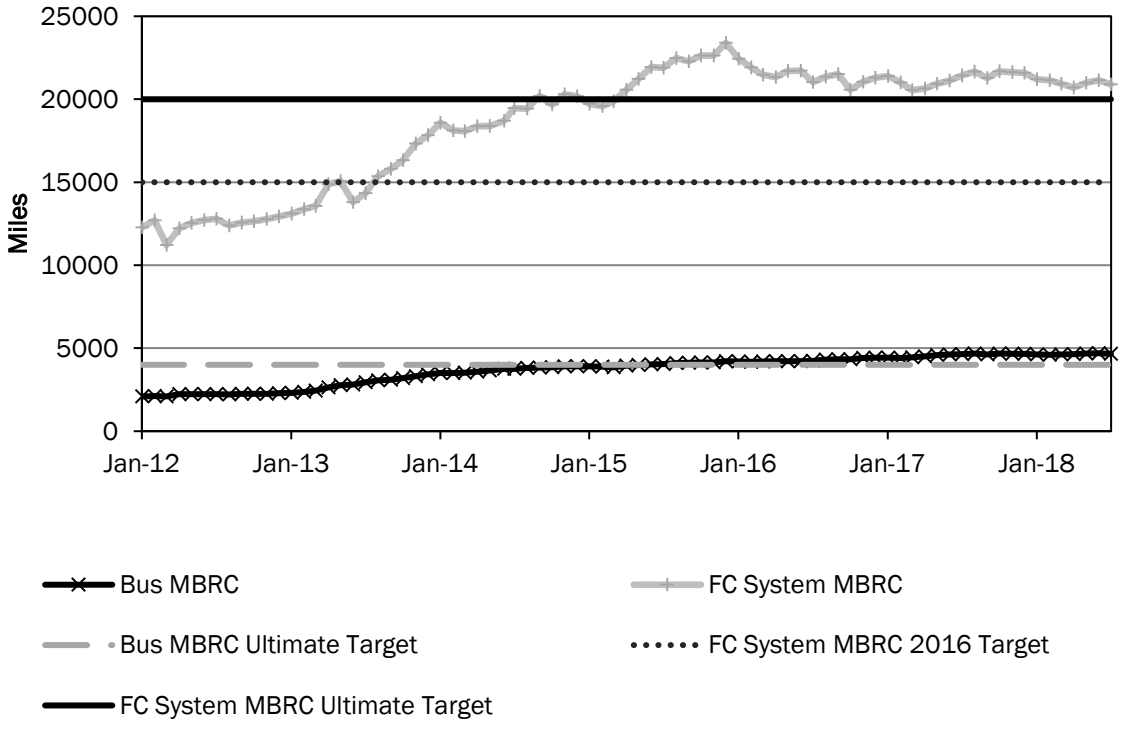

Figure 2. Miles between roadcall

CONCLUSIONS AND UPCOMING ACTIVITIES

Fuel cell propulsion systems in buses have continued to show progress, with increasing 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 systems on five buses have surpassed the ultimate target for power plant lifetime and six additional fuel cell systems have surpassed the 2016 target. Table 6 summarizes the current status compared to the DOE and FTA performance targets. Transit agencies have made major progress over the last 2 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
- 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.

Table 6. FY 2018 Summary of Progress Toward Meeting DOE and FTA Targets

	Units	2018 Status (Range)	2016 Target	Ultimate Target
Bus lifetime	Years/miles	0.2–8/ 500–222,000[a]	12/500,000	12/500,000
Power plant lifetime	Hours	500–29,000[a]	18,000	25,000
Bus availability	%	55–88	85	90
Roadcall frequency (bus/FC system)	Miles between roadcall	2,500–5,700/ 13,000–36,800	3,500/15,000	4,000/20,000
Operation time	Hours per day/days per week	7–21/5–7	20/7	20/7
Maintenance cost	$/mile	0.22–0.73	0.75	0.40
Fuel economy	Miles per dge	5.8–7.8	8	8
Range	Miles	199–348	300	300

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

Future work by NREL includes:

- Continuing data collection, analysis, and reporting on performance data for FCEBs in service at the following sites:
  - SunLine
  - UCI
  - AC Transit ZEBA FCEB demonstration (limited parameters)
  - 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.

FY 2018 PUBLICATIONS/PRESENTATIONS

1. L. Eudy, "Fuel Cell Electric Buses: Progress Toward Meeting Technical Targets," Presentation at a Denver Regional Transportation District Meeting, August 2018.
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 2018.
3. L. Eudy, "Fuel Cell Electric Buses: Progress Toward Meeting Technical Targets," Presentation for a DOE Webinar, May 2018.
4. L. Eudy, M. Post, and M. Jeffers, "Fuel Cell Buses in U.S. Transit Fleets: Current Status 2017," National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-70075, November 2017.
5. L. Eudy, M. Post, and M. Jeffers, "Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Sixth Report," National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-68413, September 2017.

REFERENCES

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