VII.1 Technology Validation: Fuel Cell Bus Evaluations

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Project Start Date: 2003
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's 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) 2014 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)

  By the end of May 2014, NREL had documented 24 FCEB fuel cell systems with operation in excess of 8,000 hours. One of these systems has logged more than 16,800 hours in service, and a second system has surpassed 11,900 hours. Bus fuel economy is dependent on duty cycle. Based on in-service fuel economy values between 4 and 6.5 miles per kilogram, the hybrid FCEBs currently in service can achieve a range between 200 and 310 miles per fill.

FY 2014 Accomplishments

- Published reports on performance and operational data covering 24 full-size FCEBs in revenue service in the United States and Canada.
- Documented more than 16,800 hours on a single fuel cell power plant.

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INTRODUCTION

Transit agencies continue to aid the FCEB industry in developing and optimizing advanced transportation technologies. These in-service demonstration programs are a vital part of the process 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 agencies, 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/FTA technical targets and to conventional-technology baseline buses in similar service.

RESULTS

During FY 2014, NREL collected and analyzed data on the following four FCEB demonstrations at three transit agencies in the United States 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[1] fuel cells in a Siemens hybrid system. The hybrid system was integrated by Van Hool and uses lithium ion batteries from EnerDel.
- Advanced Technology (AT) FCEB Project—SunLine (Coachella Valley area, California) is operating one New Flyer 40-foot bus with Blueways hybrid system, Ballard fuel cell, and lithium phosphate batteries from Valence. This bus was the pilot bus from the BC Transit demonstration.
- American Fuel Cell Bus (AFCB) Project—in December 2012 SunLine began operating an ElDorado 40-foot bus with a BAE Systems hybrid propulsion system using Ballard fuel cells and lithium ion batteries from A123. This project is part of FTA's NFCBP.
- British Columbia Transit (BC Transit) Fuel Cell Bus Demonstration—BC Transit conducted a 5-year demonstration of a fleet of FCEBs in Whistler, Canada. The fleet consisted of 20 New Flyer 40-foot buses with Bluways hybrid systems, Ballard fuel cells, and lithium phosphate batteries from Valence.

All of these buses are fuel-cell-dominant hybrid buses. The first two of these evaluations were funded by DOE, the third was covered by funding from FTA, and the BC Transit evaluation was funded by the California Air Resources Board. NREL published results from each of these demonstrations. A summary of selected results is included in this report.

[1] In 2013 US Hybrid acquired all the transit fuel cell assets originally owned by UTC Power.

NREL completed reports on operational and performance data from these 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 through 3 provide a summary of the reported results from the operation at each agency, including data from the baseline buses.

TABLE 1. 2014 Summary Data Results for ZEBA FCEBs

Vehicle data	FCEB	Diesel
Number of buses	12	3
Data period (month, year)	Sep 11 – Dec 13	Sep 11 – Dec 13
Number of months	20	20
Total fleet miles	620,452	224,879
Average miles per month	2,095	4,249
Total fuel cell hours	69,407	–
Fuel economy (mi/kg)	6.46	–
Fuel economy (mi/diesel gal equivalent)	7.30	4.05
Average speed (mph)	8.9	–
Availability (%)	72	81

TABLE 2. 2014 Summary Data Results for BC Transit FCEBs

Vehicle data	FCEB	Diesel
Number of buses	20	–
Data period (month, year)	Apr 11 – Mar 14	–
Number of months	36	–
Total fleet miles	1,700,928	–
Average miles per month	2,612	–
Total fuel cell hours	150,556	–
Fuel economy (mi/kg)	3.97	–
Fuel economy (mi/diesel gal equivalent)	4.48	4.28
Average speed (mph)	14.2	–
Availability (%)	64	–

One key challenge for the fuel cell bus industry is 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. DOE and FTA have set an early fuel cell power plant (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. Last year, NREL reported on FCPPs that had accumulated hours in excess of 13,000. These FCPPs have continued to accumulate hours in service. The addition of BC Transit to the analysis provides data on an additional 22 FCPPs (20 FCPPs plus

TABLE 3. 2014 Summary Data Results for SunLine FCEBs

Vehicle data	AFCB	AT FCEB	CNG
Number of buses	1	1	5
Data period (month, year)	Mar 11 – Dec 13	May 10 – Dec 13	May 10 – Dec 13
Number of months	22	44	44
Total fleet miles	58,366	58,101	962,247
Average miles per month	2,653	1,320	4,374
Total FC hours	3,779	4,939	–
Fuel economy (mi/kg)	6.50	5.52	–
Fuel economy (mi/diesel gal equivalent)	7.34	6.24	3.22
Average speed (mph)	15.4	11.7	15.7
Availability (%)	66	55	85

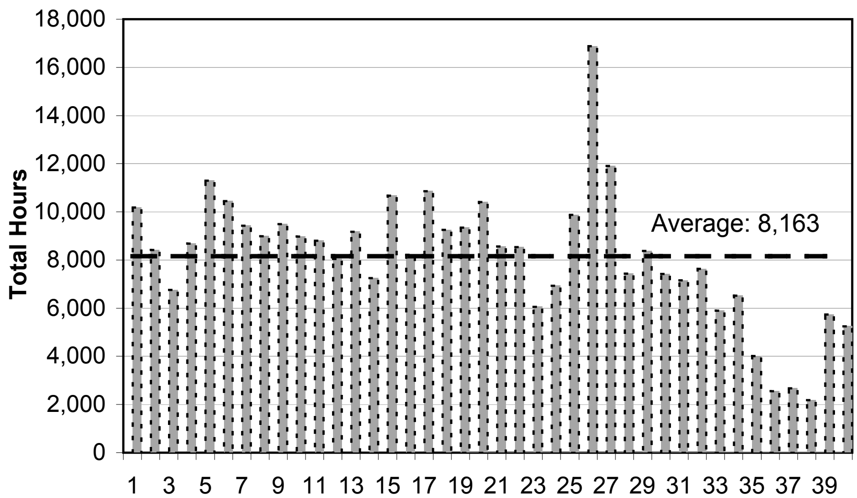

FIGURE 1. Total Fuel Cell Hours Accumulated on Each FCPP

2 spares). Figure 1 shows the total hours accumulated on individual FCPPs for the projects tracked by NREL since 2012. The average of 8,163 hours is shown on the graph as a dashed line. As of May 2014, the highest-hour FCPP had surpassed 16,800 hours. Of the 40 total FCPPs included in the graph, 60% (24) have surpassed 8,000 hours of operation. This shows significant improvement in durability toward meeting the 25,000-hour target.

One of the performance targets for FCEBs is to demonstrate fuel economy that is two times that of conventional bus technology. The FCEBs included in this report showed fuel economy improvements ranging from 5% to 128% compared to conventional buses, depending on duty cycle. Figure 2 shows the fuel economy of the buses at each of the three transit agencies in miles per diesel gallon equivalent. (Note that the baseline buses at SunLine are compressed natural gas [CNG] buses.) These data show that the FCEBs are demonstrating fuel economy values up to two times those of the baseline buses. The FCEBs at BC Transit demonstrated lower fuel economy than that typically shown at other locations. Several factors contribute to the lower numbers, including FCEB design strategy, an oversized heater, and a harsh duty cycle (extreme grades, seasonal crush loadings, cold temperatures, and wet conditions).

One measure of reliability for the transit industry is miles between roadcall (MBRC). Figure 3 provides a summary of MBRC for the four FCEB demonstrations and includes the MBRC for the bus as a whole, MBRC for the propulsion system, and MBRC for the fuel cell system. The targets for each category are included on the chart. For comparison, the MBRC results for two first-generation FCEB demonstrations are included on the graph.[2] Table 4 provides the average MBRC for the first- and second-

[2] 1st-gen 1: previous-generation Van Hool buses at AC Transit, SunLine, and Connecticut Transit; 1st-gen 2: non-hybrid Gillig/Ballard buses operated at Santa Clara Valley Transportation Authority in San Jose, California.

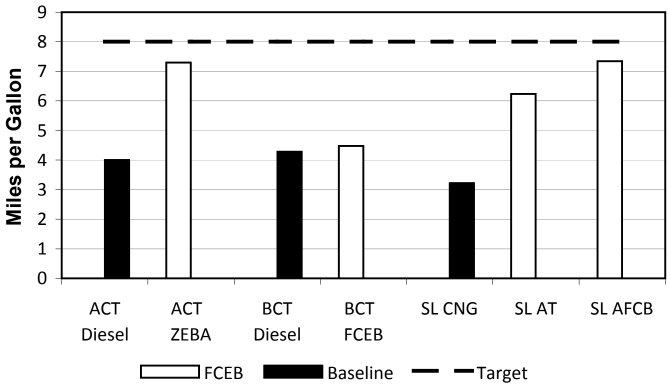

FIGURE 2. Fuel Economy Comparison by Fleet (Diesel Equivalent)

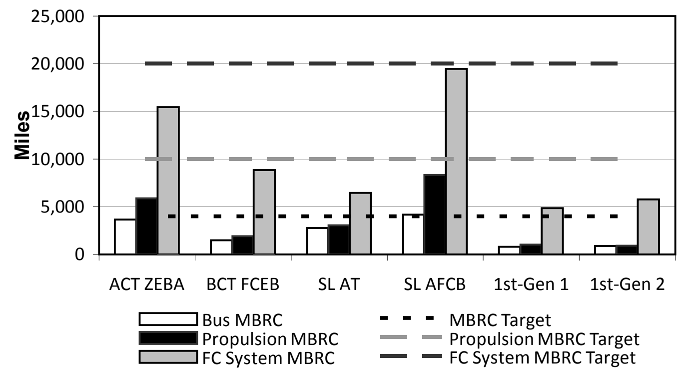

FIGURE 3. Miles Between Roadcall Comparisons by Fleet

generation FCEBs. Reliability has shown a marked increase over that of the earlier-generation buses; however, there are still improvements to be made to meet the targets. Roadcalls due to bus-related issues—such as problems with doors, air conditioning, and windshield wipers—made up 24% of the total failures. Fuel-cell-related issues made up approximately 17% of the roadcalls during the period.

TABLE 4. Comparison of Current MBRC to First-Generation FCEBs

	Total MBRC	Propulsion MBRC	FC System MBRC
1st-gen average	1,263	1,555	7,710
2nd-gen average	1,863	2,523	9,554
Percent improvement	48%	62%	24%

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 is showing promise to exceed the fuel cell durability target. Table 5 summarizes the current status compared to the DOE/DOT performance targets. For fuel cell buses to match the current performance standard of diesel buses, the following needs to happen:

- Continuing operation to validate durability and reliability of the fuel cell systems and other components to match transit needs
- Optimizing the propulsion system to maximize operation and resolve integration issues
- 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 fuel cell system integration to transit bus builders.

TABLE 5. 2013 Summary of Progress Toward Meeting DOE/DOT Targets

	Units	2014 Status	2016 Target	Ultimate Target
Bus lifetime	Years/miles	5/100,000[a]	12/500,000	12/500,000
Power plant lifetime	Hours	1,000–16,500[a]	18,000	25,000
Bus availability	%	55–72	85	90
Roadcall frequency (Bus / fuel cell system)	Miles between road call	1,500–4,000 / 6,000–19,000	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	0.39–1.60	0.75	0.40
Fuel economy	Miles per diesel gallon equivalent	4.5–7.3	8	8
Range	Miles	220–310	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:
  - ZEBA FCEB demonstration led by AC Transit
  - SunLine
  - Birmingham-Jefferson County Transit Authority in Birmingham, Alabama
  - Capital Metro, Austin, Texas
  - 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 2014 PUBLICATIONS/PRESENTATIONS

1. L. Eudy, *Technology Validation: Fuel Cell Bus Evaluations*, Presentation at the DOE Hydrogen and Fuel Cells Program Annual Merit Review, Washington, DC, June 2014.

2. L. Eudy, M. Post, *Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: Third Results Report*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-60527, May 2014.

3. L. Eudy, M. Post, *BC Transit Fuel Cell Bus Project Evaluation Results: Second Report*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-62317, September 2014.

4. L. Eudy, C. Gikakis, *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2013*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5400-60490, December 2013.

5. L. Eudy, K. Chandler, *American Fuel Cell Bus Project: First Analysis Report*, Federal Transit Administration, Washington, DC, FTA Report No. 0047, December 2013.

6. L. Eudy, *FCEB Validation: Overview and Status*, Presentation for the California Fuel Cell Partnership Bus Team meeting, December 2013.

7. L. Eudy, *Technology Validation of Zero-Emission Buses*, Presentation at the California Air Resources Board ZBus Workshop, September 2013.

REFERENCES

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