VII.1 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 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) 2013 Objectives

- Document performance results from each current FCEB demonstration site.
- Complete 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)* By the end of May 2013, NREL had documented four FCEB fuel cell systems with operation in excess of 5,000 hours. One of these systems has logged more than 13,000 hours in service, and a second system has surpassed 10,600 hours. Bus fuel economy is dependent on duty-cycle. Based on in-service fuel economy values between 5 and 7 miles per kilogram, the hybrid FCEBs currently in service can achieve a range between 200 and 320 miles per fill.

FY 2013 Accomplishments

- Published reports on performance and operational data covering 18 full-size FCEBs in revenue service in the United States.
- Documented more than 13,000 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 performance and durability results of FCEBs to validate status against technical targets, educate key stakeholders, and further DOE goals.

The evaluation protocol includes two levels of data: operation and maintenance data on the bus and infrastructure, and more detailed data on the fuel cell, system, and components. The first set of data is considered non-sensitive and is obtained mainly from the transit fleet. 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 detailed data are collected with cooperation from the bus and fuel cell system manufacturers and are considered highly sensitive. Results include aggregate data products that protect each manufacturer's specific data. To date, NREL has collected this type of data from two fuel cell manufacturers. Aggregate results will be published if and when enough data are available to protect each company's identity and source data.

RESULTS

During FY 2013, NREL collected and analyzed data on the following four FCEB demonstrations at three transit agencies in the United States:

- Zero Emission Bay Area (ZEBA) Demonstration – five Bay Area transit agencies led by Alameda-Contra Costa Transit (AC Transit in Oakland, California) are demonstrating twelve 40-foot Van Hool buses with ClearEdge Power fuel cells in a Siemens hybrid system. The hybrid system was integrated by Van Hool and uses lithium-ion batteries from EnerDel.
- Advanced Technology FCEB Project (AT FCEB) – SunLine (Coachella Valley area, California) is operating one New Flyer 40-foot bus with a Bluways hybrid system and Ballard fuel cell. This bus was the pilot bus from a fleet of 20 buses operating in Whistler, British Columbia, Canada.
- American Fuel Cell Bus Project (AFCB) – in December 2012 SunLine began operating an ElDorado 40-foot bus with a BAE Systems hybrid propulsion system using Ballard fuel cells and lithium batteries. This project is part of FTA's NFCBP.
- 'Nutmeg' Fuel Cell Electric Bus Demonstration – named for Connecticut's state nickname, the Nutmeg project is also part of the NFCBP. The four buses, which are identical to the 12 ZEBA buses, were operated by Connecticut Transit (CTTRANSIT) in Hartford, Connecticut. One bus was moved to Flint, Michigan, for at least one year of demonstration.

All of these buses are fuel cell dominant hybrid buses. The first two of these evaluations were funded by DOE, and the other evaluations were covered by funding from FTA. NREL published results from each of these demonstrations. A summary of selected results is included in this report.

NREL completed reports on operational and performance data from these FCEBs and conventional baseline buses at each agency. The results are also compared to technical targets for FCEB performance established by DOE/DOT and published in a Fuel Cell Technologies Record in September 2012. 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. 2013 Summary Data Results for ZEBA FCEBs

Vehicle data	FCEB	Diesel
Number of buses	12	3
Data period (month, year)	Sep 11 – Apr 12	Sep 11 – Apr 12
Number of months	8	8
Total fleet miles	147,069	82,098
Average miles per month	1,690	3,635
Total fuel cell hours	17,619	
Fuel economy (mi/kg)	6.68	
Fuel economy (mi/diesel gallon equivalent)	7.55	4.00
Average speed (mph)	8.3	N/A
Availability (%)	56	77

TABLE 2. 2013 Summary Data Results for Nutmeg FCEBs

Vehicle data	FCEB	Diesel
Number of buses	4	3
Data period (month, year)	Aug 11 – Jan 13	Aug 11 – Jul 12
Number of months	18	12
Total fleet miles	83,996	112,308
Average miles per month	1,235	3,120
Total fuel cell hours	7,305	
Fuel economy (mi/kg)	6.42	
Fuel economy (mi/diesel gallon equivalent)	7.24	3.79
Average speed (mph)	13.2	N/A
Availability (%)	53	85

TABLE 3. 2013 Summary Data Results for SunLine FCEBs

Vehicle data	AFCB	AT FCEB	CNG
Number of buses	1	1	5
Data period (month, year)	Mar 12 – Jan 13	Aug 11 – Jan 13	Aug 11 – Jan 13
Number of months	11	18	18
Total fleet miles	37,896	27,970	377,318
Average miles per month	3,445	1,554	4,192
Total fuel cell hours	2,422	2,399	
Fuel economy (mi/kg)	6.45	5.34	
Fuel economy (mi/diesel gallon equivalent)	7.29	6.03	3.23
Average speed (mph)	15.6	11.7	15.7
Availability (%)	84	60	80

CNG – compressed natural gas

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 87% to 126% compared to conventional buses, depending on duty-cycle. Figure 1 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 about two times those of the baseline buses. The chart also includes data on hybrid buses at CTTRANSIT.

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 10,000. These FCPPs have continued to accumulate hours in service. Figure 2 shows the hours accumulated on the FCPPs by fleet over the last few years. As of May 2013, the highest-hour FCPP had surpassed 13,000 hours. Several other FCPPs have accumulated significant hours, the highest of which have achieved 10,686; 8,770; and 5,300 hours. This shows significant improvement in durability toward meeting the 25,000 hour target.

Another 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. While the current status for MBRC has risen over the last year, there are still improvements to be made to meet the targets. The highest percentage of roadcalls was due to bus-related

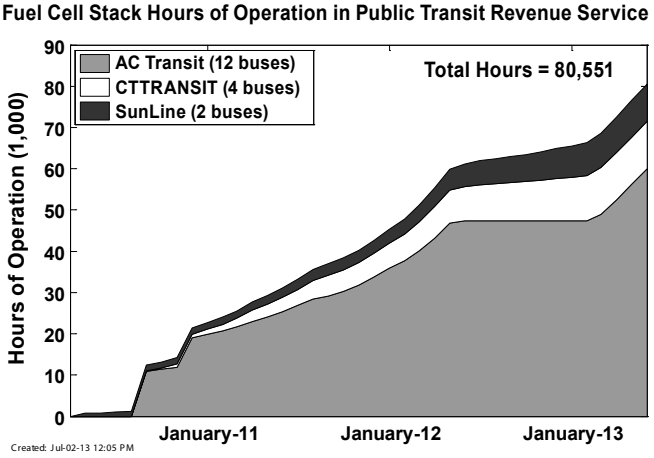

FIGURE 2. Total FCPP Hours Accumulated by Fleet

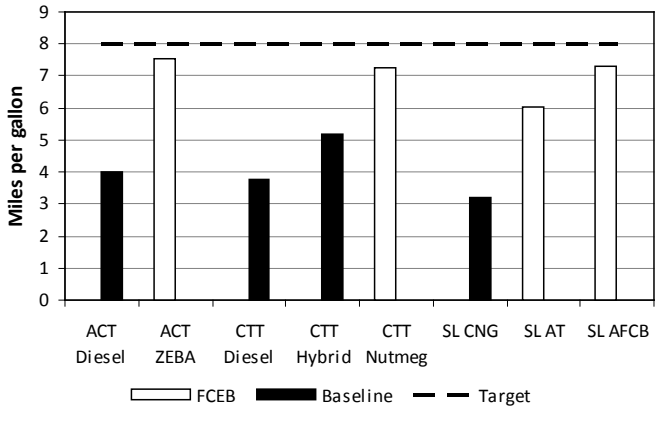

FIGURE 1. Fuel Economy Comparison by Fleet (Diesel Equivalent)

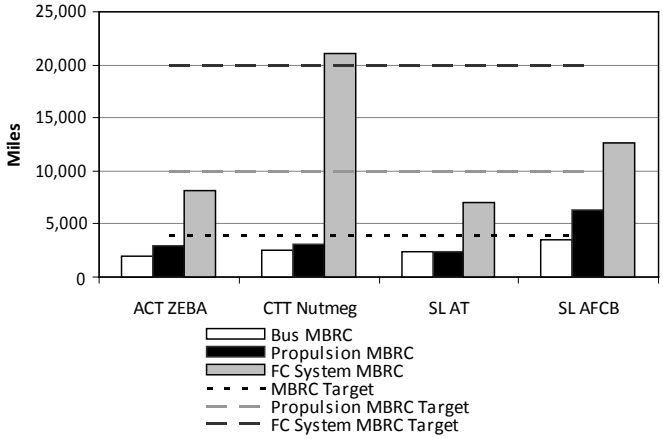

FIGURE 3. Miles between Roadcall Comparisons by Fleet

issues such as problems with doors, air conditioning, and windshield wipers. Fuel cell-related issues made up approximately 22% of the roadcalls 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 already meets fuel economy targets and is showing promise to exceed the fuel cell durability target. 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. These include:

- 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.

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
  - City of Burbank
  - 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 2013 PUBLICATIONS/PRESENTATIONS

1. L. Eudy, K. Chandler, 2013, *SunLine Transit Agency Advanced Technology Fuel Cell Bus Evaluation: Fourth Results Report*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5600-57560, January.

2. L. Eudy, K. Chandler, C. Gikakis, 2012, *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2012*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5600-52927, November.

3. K. Chandler, L. Eudy, 2012, *Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: Second Results Report*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-5600-55367, July.

4. L. Eudy, K. Chandler, 2012, *Connecticut Nutmeg Fuel Cell Bus Project: First Analysis Report*, Federal Transit Administration, Washington, DC, FTA Report No. 0020, July.

5. L. Eudy, 2012, *Fuel Cell Electric Bus Evaluations: Recent Results*, Presentation at the California Fuel Cell Partnership Bus Team Meeting, June.

6. L. Eudy, 2012, *Technology Validation: Fuel Cell Bus Evaluations*, Presentation at the DOE Hydrogen and Fuel Cells Program Annual Merit Review, Arlington, VA, May.

REFERENCES

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

TABLE 4. 2013 Summary of Progress Toward Meeting DOE/DOT Targets [1]

	Units	2013 Status	2016 Target	Ultimate Target
Bus lifetime	Years/miles	5/100,000	12/500,000	12/500,000
Power plant lifetime	Hours	1,000–13,000	18,000	25,000
Bus availability	%	53–84	85	90
Bus Roadcall Frequency	Miles between road call	2,000–3,500	3,500	4,000
Fuel Cell System Roadcall Frequency	Miles between road call	7,000–20,000	15,000	20,000
Operation time	Hours per day/days per week	19/7	20/7	20/7
Maintenance cost	$/mile	0.39–1.30	0.75	0.40
Fuel economy	Miles per diesel gallon equivalent	6–7.5	8	8
Range	Miles	220–325	300	300