VII.5 Technology Validation: Fuel Cell Bus Evaluations

Leslie Eudy
National Renewable Energy Laboratory (NREL)
1617 Cole Blvd.
Golden, CO 80401
Phone: (303) 275-4412
E-mail: leslie.eudy@nrel.gov

DOE Manager
HQ: John Garbak
Phone: (202) 586-1723
E-mail: John.Garbak@ee.doe.gov

Subcontractor:
Kevin Chandler, Battelle, Columbus, OH

Start Date: March 2001
Projected End Date: Projected continuation and direction determined annually by DOE

Fiscal Year (FY) 2011 Objectives

- Determine the status of fuel cell bus (FCB) technologies in transit applications by evaluating them in real-world service.
- Coordinate with the Department of Transportation's 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.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Program Multi-Year Research, Development, and Demonstration Plan:

(A) Lack of Fuel Cell Vehicle Performance and Durability Data

(C) Lack of H_2 Fueling Infrastructure Performance snd Availability Data

(D) Maintenance and Training Facilities

Technical Targets

Milestone 18: Validate fuel cell durability of 3,500 hours, 300+ mile range and fuel cell stack power density of 1.5 kW/L. (4Qtr 2012) By the end of April 2011, NREL had documented three FCB fuel cell systems with operation in excess of 6,000 hours with no major repairs. One of these systems has logged more than 9,000 hours in service. Based on in-service fuel economies between 5 and 7 miles per kilogram, hybrid FCBs can achieve a range between 250 and 350 miles per fill. This efficiency depends on duty-cycle. There are no major issues with lost cargo/passenger space on FCBs because the tanks are typically mounted on the roof; however, the added weight of the system limits the number of standing passengers allowed on the buses.

FY 2011 Accomplishments

- Published final reports on current-generation performance and operational data on five full-size hybrid FCBs in revenue service in the United States.
- Published first report on next-generation FCB in service in Palm Springs, CA.
- Began data collection on next-generation fuel cell system in revenue service at two additional transit agencies.

Introduction

Transit agencies continue to aid the FCB industry in developing and optimizing advanced transportation technologies. These in-service demonstration programs are necessary to validate the performance of the current generation of fuel cell systems 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 accumulation in short periods of time. During the last year, major progress was made in improving fuel cell durability; however, more work is needed to improve reliability, increase durability to meet the 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 FCBs.
- Detailed results on fuel cell systems for buses and the requisite hydrogen infrastructure to complement the light-duty demonstrations 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/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 2011, NREL completed data collection and analysis on current-generation FCB demonstrations at three transit agencies in the United States: SunLine Transit Agency in Thousand Palms, California; Connecticut Transit (CTTRANSIT) in Hartford, Connecticut; and AC Transit in Oakland, California. The first two of these evaluations were funded by DOE, and the third evaluation was covered by funding from FTA. Under DOE funding, NREL also began collecting data on next-generation FCBs at three agencies: City of Burbank, California; AC Transit; and SunLine. NREL published results from the current-generation FCBs. A summary of selected results is included in this report, followed by an overview and early results of the next-generation FCBs being evaluated.

The current-generation FCBs in service at AC Transit, CTTRANSIT, and SunLine were all of the same basic design: Van Hool 40-ft buses with ISE Corp. hybrid-electric drives and UTC Power fuel cell power systems. As reported in the previous annual report, the manufacturer partners used the early performance data to validate the systems and further develop the product and components. Beginning in November 2007, UTC Power replaced the fuel cell power systems in each of the five buses with newer versions that were developed incorporating many of the lessons learned from the previous operation of these FCBs. NREL collected operational and performance data on these FCBs and conventional baseline buses at each agency. Table 1 provides a summary of results from the operation at each agency after the new fuel cells were installed. Data from the baseline buses are included in the table. Note that the data from the buses at AC Transit ended in September 2010. These three buses were retired during that year; however, two of the fuel cell power systems were transferred into the bodies of the next generation buses and continue to accumulate hours.

Figure 1 shows the fuel economy of the buses at each location in miles per diesel gallon equivalent. (Note that the baseline buses at SunLine are compressed natural gas [CNG] buses – SunLine does not operate diesel buses.) The FCBs at the three locations showed fuel economy improvement ranging from 48% to 133% when compared to diesel and CNG baseline buses. This figure also illustrates the variability of the results from fleet to fleet. The results are affected by several factors, including duty-cycle characteristics (average number of stops, average speed, and idle time). Also, the diesel buses at AC Transit do not have air conditioning, but the fuel cell buses do. The CTTRANSIT diesel buses operate at twice the average speed of the FCB operating on the Star Shuttle Route, which causes significantly lower fuel economy for the FCB compared to the fuel economies at the other two agencies.

One measure of reliability for the transit industry is miles between roadcall (MBRC). A roadcall is the failure of an in-service bus that causes the bus to be replaced on route

TABLE 1. Summary Data Results for Early Generation FCBs

	AC Transit		CTTRANSIT		SunLine	
Vehicle data	FCB	Diesel	FCB	Diesel	FCB	CNG
Number of buses	3	6	1	3	1	5
Data period	Nov 07 - Sep 10	Jan - Dec 07	Jan 08 - Jan 11	Aug 07 - Oct 09	Apr 08 - Jan 11	Nov 08 - Jan 11
Number of months	~34	12	37	27	34	15
Total fleet miles	194,288	266,337	46,558	259,547	67,553	636,954
Average miles per month	2,136	3,699	1,258	3,204	1,987	4,718
Total FC hours	19,802	--	7,187	--	9,448	--
Fuel economy (mi/kg)	5.93	--	4.83	--	7.15	3.11
Fuel economy (mi/diesel eq. gal)	6.70	4.20	5.46	3.68	8.08	3.47
Average speed (mph)	9.8	not available	6.5	not available	13.0	not available
Availability	66%	85%	62%	85%	70%	92%

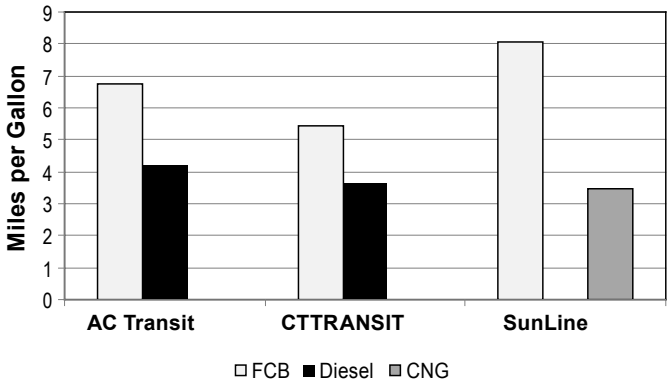

FIGURE 1. Fuel Economy Comparison by Fleet (Diesel Equivalent)

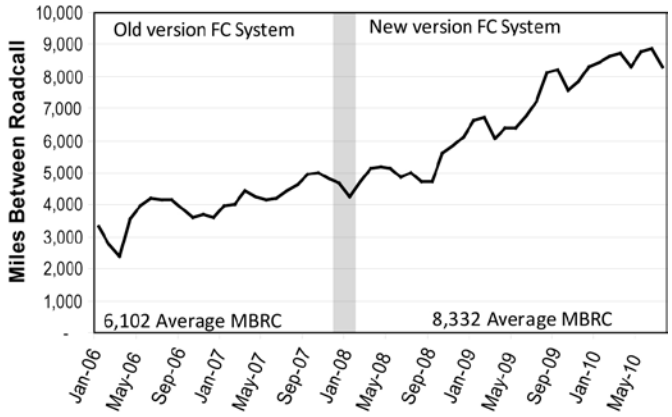

FIGURE 2. Miles between Roadcall for the Fuel Cell Propulsion System (12-Month Rolling Average)

or causes a significant delay in schedule. NREL typically reports MBRC for the entire bus and for the propulsion system separately to show the reliability of the FCBs. Over time, these FCBs have been shown to have propulsion system MBRCs that are much lower than MBRCs for the baseline buses. This is not necessarily due to the fuel cell power system, but instead has mostly been because of traction battery issues. To illustrate the improvement in reliability of the fuel cell power system in the buses, Figure 2 tracks the combined fuel cell system MBRC since the buses went into service. The shading in the middle of the chart marks the time during which all five FCBs had the newer version fuel cell systems installed. In the 2010 annual report, NREL reported this upward trend for the average fuel cell system MBRC. The trend has continued to show improvement; increasing from 21% to 37% with the newer version system. The two leading fuel cell systems have accumulated significant hours without any major repairs (one is over 9,000 hours and a second is over 8,000 hours).

NREL began collecting data on several next-generation FCBs during the year. Figure 3 shows the newest fuel cell bus in service at SunLine. This bus is a New Flyer 40-ft. bus with a Bluways hybrid system, Ballard fuel cells, and lithium ion batteries. NREL completed its first report on this bus in service at SunLine. As of November 2010, the bus had accumulated more than 9,000 miles and 818 hours on the fuel cell with an average fuel economy of 5.75 miles per kg. This is nearly two times higher than the fuel economy for the baseline CNG buses.

NREL began collecting data on other next generation fuel cell buses at the following transit agencies:

- City of Burbank – one battery dominant, plug-in hybrid FCB developed by Proterra using Hydrogenics fuel cells and lithium titanate batteries.
- AC Transit – 12 next-generation Van Hool FCBs with a hybrid system integrated by Van Hool and UTC Power fuel cell power system.
- Additional sites funded by the FTA include four buses at CTTRANSIT and a bus in service in Columbia, SC.

FIGURE 3. SunLine's Newest Fuel Cell Bus

Conclusions and Future Direction

First-generation fuel cell propulsion systems in buses have continued to show progress in fuel economy and longer durability. Changes incorporated into the design based on early lessons learned have resulted in fuel cells that are nearing a target of 10,000 hours. While this is encouraging, there are still challenges to overcome before fuel cell buses can match the current standard of diesel bus performance. These include:

- Lowering costs of purchasing, operating, and maintaining buses and infrastructure.
- Increasing durability/reliability of the fuel cell systems and other components to match transit needs.
- Transferring all maintenance to transit personnel.

Future work by NREL includes:

- Collecting, analyzing, and reporting on performance data for next-generation hydrogen-fueled vehicles in service at the following sites:

  - Bay Area FCB Demonstration led by AC Transit
  - SunLine
  - City of Burbank
  - Additional sites as funding allows
- Investigating reliability, durability, and life cycle of FCBs as a part of ongoing evaluations; these efforts complement the DOE light-duty fuel cell electric vehicle demonstrations.
- Coordinating with FTA to ensure harmonized data-collection efforts for the National Fuel Cell Bus Program.
- Coordinating with national and international FCB demonstration sites.

FY 2011 Publications/Presentations

1. L. Eudy. (2010). *Fuel Cell Bus Takes a Starring Role in BurbankBus Fleet.* Fact Sheet: NREL/TP-560-47893. National Renewable Energy Laboratory, Golden, CO, May.

2. K. Chandler, L. Eudy. (2010). *National Fuel Cell Bus Program: Accelerated Testing Evaluation Report # 2 and Appendices.* NREL/TP-560-48106-1 & 48106-2. Federal Transit Administration, Washington, DC, June.

3. L. Eudy, (2010). *Technology Validation: Fuel Cell Bus Evaluations.* Poster Presentation at the DOE Hydrogen Program Annual Merit Review, Arlington, VA, June.

4. L. Eudy. (2010). *Bay Area Transit Agencies Propel Fuel Cell Buses Toward Commercialization.* Fact Sheet: NREL/TP-560-48115. National Renewable Energy Laboratory, Golden, CO, July.

5. L. Eudy, K. Chandler. (2010). *Fuel Cell Bus Evaluation: Joint Evaluation Plan for the Dept. of Energy and Federal Transit Admin. and Appendices*. NREL/TP-560-49342-1 & 49342-2. National Renewable Energy Laboratory, Golden, CO, November.

6. L. Eudy, K. Chandler, C. Gikakis. (2010). *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2010*. NREL/TP-560-49379. National Renewable Energy Laboratory, Golden, CO, November.

7. L. Eudy. (2011). *SunLine Leads the Way in Demonstrating Hydrogen-Fueled Bus Technologies.* Brochure: NREL/TP-5600-49673. National Renewable Energy Laboratory, Golden, CO, January.

8. L. Eudy. (2011). *Fuel Cell Electric Buses Demonstrate Early Market Progress*. Presentation at the Fuel Cell & Hydrogen Energy Conference, Washington, DC, February.

9. L. Eudy, K. Chandler. (2011). *SunLine Transit Agency Advanced Technology Fuel Cell Bus Evaluation: First Results Report.* NREL/TP-5600-50500. National Renewable Energy Laboratory, Golden, CO, March.