# VIII.7 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 Technology Development Manager:
John Garbak
Phone: 202-586-1723
E-mail: John.Garbak@ee.doe.gov

Subcontractor:
Kevin Chandler, Battelle, Columbus, OH


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## 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's Multi-Year Research, Development, and Demonstration Plan:

(A) Lack of Fuel Cell Vehicle Performance and Durability Data
(C) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data
(D) Maintenance and Training Facilities

## Contribution to Achievement of DOE Technology Validation Milestones

**Milestone 18: Validate fuel cell durability of 3,500 hours, 300+ mile range and fuel cell stack power density of 1.5kW/L. (4Qtr 2012)** Two of the five current-generation FCBs evaluated in this project have achieved more than 6,000 hours on the fuel cell system with no major repairs. One of these systems has logged more than 7,000 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 transit buses 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.

## Accomplishments

- Completed collection and analysis of current-generation performance and operational data on five full-size hybrid FCBs in revenue service in the United States.
- Began data collection on next-generation fuel cell system in revenue service at three transit agencies.

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## Introduction

Transit agencies continue to aid the FCB industry in developing and optimizing advanced transportation technologies. These in-service demonstrations are necessary to validate the performance of the current generation of fuel cell systems and to determine issues that require further development. 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 has been 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 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 Fiscal Year 2010, NREL collected data 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 of the next-generation FCBs being evaluated.

The current-generation FCBs in service at AC Transit, CTTRANSIT, and SunLine are all of the same basic design: Van Hool 40-foot buses with ISE Corp. hybrid-electric drives and UTC Power fuel cell power systems. During the early demonstration period, the manufacturer partners used the 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 fuel cell buses. 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.

**TABLE 1.** Summary Data Results

| | AC Transit | | CTTRANSIT | | SunLine | |
|---|---|---|---|---|---|---|
| Vehicle data | FCB | Diesel | FCB | Diesel | FCB | CNG |
| Number of buses | 3 | 6 | 1 | 3 | 1 | 5 |
| Data period | Dec 07 - Jan 10 | Jan - Dec 07 | Jan 08 - Jan 10 | Aug 07 - Oct 09 | Apr 08 - Jan 10 | Nov 08 - Jan 10 |
| Number of months | ~26 | 12 | 25 | 27 | 22 | 15 |
| Total fleet miles | 151,950 | 266,337 | 35,690 | 259,547 | 39,236 | 362,259 |
| Average miles per month | 2,082 | 3,699 | 1,428 | 3,204 | 1,783 | 4,830 |
| Total FC hours | 16,058 | -- | 5,424 | -- | 2,937 | -- |
| Fuel economy (mi/kg) | 6.03 | -- | 4.80 | -- | 7.09 | 3.21 |
| Fuel economy (mi/diesel eq. gal) | 6.82 | 4.20 | 5.43 | 3.68 | 8.01 | 3.59 |
| Average speed (mph) | 9.77 | | 6.58 | | 13.36 | |
| Availability | 66% | 85% | 68% | 85% | 65% | 94% |

FC - fuel cell

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 123% when compared to diesel and compressed natural gas baseline buses. This figure also illustrates the variability of the results from fleet to fleet. The results are affected by several factors,

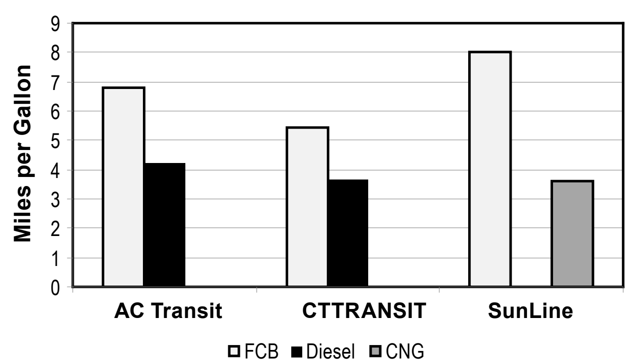


**FIGURE 1.** Fuel Economy Comparison by Fleet (Diesel Equivalent)

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 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 monthly 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. The average fuel cell system MBRC shows an upward trend and has increased by 21% with the newer version system. In fact, two of these fuel cell systems accumulated significant hours without any major repairs (one is over 7,000 hours and a second is over 6,000 hours).

Another measure of reliability for the transit industry is availability–the percentage of days a bus is planned for service compared to the percentage of days the bus is actually available. When a bus is unavailable, NREL reports the cause by one of several categories. To show the improvement in fuel cell system reliability over time, Figure 3 tracks the percentage of time by month that the buses are unavailable because of the fuel cell system. As in Figure 2, the shaded area denotes the

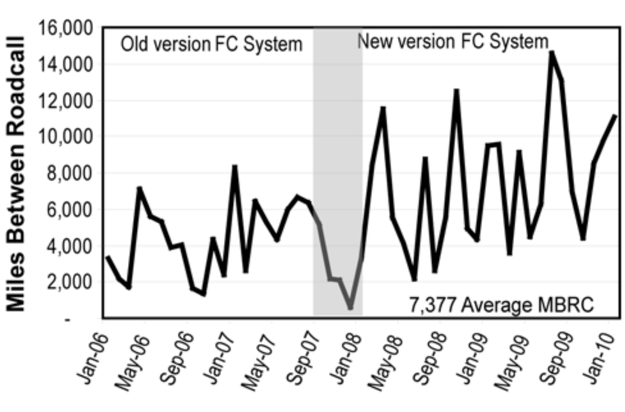


**FIGURE 2.** Monthly Miles between Roadcall for the Fuel Cell Propulsion System

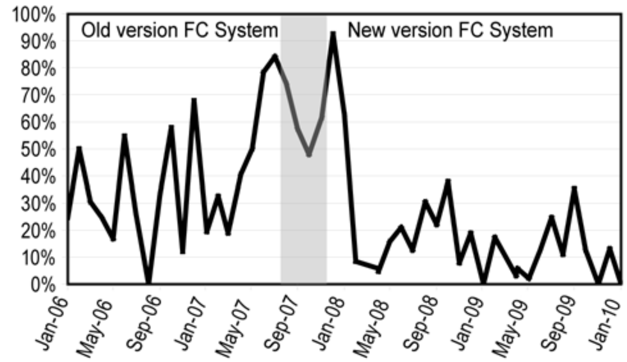


**FIGURE 3.** Percentage of Time Unavailability was Caused by the Fuel Cell System, by Month

period of time when the newer version fuel cells were installed. The chart shows a marked improvement for the new fuel cell systems.

NREL began collecting data on several next-generation FCBs at the following three transit agencies:

- City of Burbank – one battery dominant, plug-in hybrid FCB developed by Proterra using Hydrogenics fuel cells and lithium titanate batteries.
- SunLine – one New Flyer 40-ft FCB with an ISE hybrid system, Ballard fuel cells, and lithium ion batteries.
- AC Transit – 12 next-generation Van Hool FCBs with a hybrid system integrated by Van Hool and UTC Power fuel cell power system.

NREL also began data collection on another Proterra FCB in Columbia, South Carolina, under the FTA project.

## Conclusions and Future Direction

Over the last two years, first-generation fuel cell propulsion systems in buses have shown progress, although they are still considered prototypes in the early stages of technological development. Manufacturers have learned from the results of these first-generation demonstrations and have incorporated design improvements into next-generation fuel cell systems that are now beginning field demonstrations. There are still challenges to overcome, and more data are needed on these new systems just being introduced. Remaining challenges 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 2010 Publications/Presentations

**1.** Eudy, L. (2009). *U.S. Fuel Cell Bus Results*. Presentation at the HFC2009 Conference, Vancouver, BC, Canada, June.

**2.** Eudy, L.; Chandler, K. (2009). *SunLine Transit Agency, Fuel Cell Transit Bus: Fifth Evaluation Report and Appendices.* NREL/TP-560-46346-1 & NREL/TP-560-46346-2, NREL, Golden, CO, Aug.

**3.** Eudy, L.; Chandler, K.; Gikakis, C. (2009). *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2009.* NREL/TP-560-46490, NREL, Golden, CO, Oct.

**4.** Eudy, L. (2009). *Overview of U.S. FCB Technology Validation Activity*. Presentation at the Joint 12th IPHE ILC & SC Meeting, Washington, DC, Dec.

**5.** Eudy, L. (2009). *Overview of U.S. FCB Technology Validation Activity.* Presentation at the CaFCP Working Group Meeting, Sacramento, CA, Dec.

**6.** Chandler, K.; Eudy, L. (2010). *CTTRANSIT, Fuel Cell Transit Bus: Third Evaluation Report and Appendices*. NREL/TP-560-47334-1 & NREL/TP-560-47334-2, NREL, Golden, CO, Jan.

**7.** Eudy, L. (2010). *Fuel Cell Bus Takes a Starring Role in the BurbankBus Fleet.* DOE/GO-102010-3035, NREL, Golden, CO, May.

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