VI.G.3 Technology Validation: Fuel Cell Bus Evaluations

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

Objectives

- Determine the status of fuel cell bus (FCB) technologies in transit buses by evaluating them in real-world service.
- Coordinate with the Federal Transit Administration (FTA) and international FCB demonstration programs to harmonize data collection methods and enable comparison of a wider set of vehicles.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section (3.5.4.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Vehicles
(B) Storage
(C) Hydrogen Fueling Infrastructure
(D) Maintenance and Training Facilities
(E) Codes and Standards

Contribution to Achievement of DOE Technology Validation Technical Targets

- **Milestone 2: Demonstrate fuel cell vehicles (FCVs) that achieve 50% higher fuel economy than gasoline vehicles.** We are demonstrating nine heavy-duty fuel cell vehicles of various configurations and comparing them to baseline diesel or compressed natural gas (CNG) vehicles. Fuel economy results to date show that non-hybrid FCBs have 13% lower fuel economy in comparison to diesel buses. Although the evaluation of four hybridized FCBs has just begun, early results show up to two times greater fuel economy than a 40-ft diesel bus in the same service.
- **Milestone 5: Validate fuel cell demonstration vehicle range of ~200 miles and durability of ~1,000 hours.** To date, testing of three 40-foot, non-hybrid FCBs has resulted in a range of around 140 miles. In-service testing on the three buses for the first eight months resulted in 561 hours of operation for the highest mileage bus. The buses are on target to achieve over 1,000 hours each by the end of the demonstration. The hybrid FCBs went into service in early 2006, and will be reported on after at least six months of operation.

Accomplishments

- Collected, analyzed, and reported the first eight months of performance and operational data on three full-size, non-hybrid FCBs in revenue service in the United States.
- Illustrated the positive effect on fuel economy by adding a small fuel cell to a hydrogen fueled internal combustion engine (ICE) transit vehicle – model/simulation work with TIAX.
- Gained agreement from international FCB demonstration partners to share specific data on bus and infrastructure performance.

Introduction

The transit industry has become an excellent "test-bed" for developing and optimizing advanced transportation technologies. Demonstrations of FCBs are being conducted in transit applications all over the world. Although progress has been made, more work is needed to improve reliability and durability of fuel cell systems to meet the needs of transit agencies.

Demonstration programs are necessary to validate the performance of the current generation of fuel cell systems. Lessons learned in evaluating buses in revenue service will help assess the status of FCB technology and determine issues that require further development. Evaluations of early prototype FCBs have demonstrated

improved performance characteristics over conventional buses in transit applications. Improved characteristics include faster acceleration, lower noise, and no tailpipe emissions. Barriers to using fuel cells in transportation applications need to be surmounted, however, before these technologies can be commercialized. Future evaluations should help address these issues, which include extending the life of a fuel cell, improving reliability and durability of the systems, and lowering vehicle and infrastructure costs.

Coordinating with demonstration programs worldwide is important for gathering and comparing data from a larger statistical set of vehicles and for leveraging resources without duplicating efforts. The progress made in developing fuel cell propulsion systems for buses can also carry over to other applications, including light-duty passenger vehicles.

Approach

The National Renewable Energy Laboratory (NREL) and Battelle researchers have developed an evaluation protocol to provide:

- Comprehensive, unbiased evaluation results of advanced technology vehicle development and operations.
- Evaluations of hydrogen infrastructure development and operations.
- Descriptions of facility modifications required for safe operation of FCVs.

These evaluations include economic, technical, environmental, and safety factors and are conducted in collaboration with the transit fleet, the vehicle and fuel cell manufacturers, and applicable government partners.

The evaluation project has three major goals:

- To yield credible data and evaluations that go beyond the "proof of concept" of FCBs and infrastructure, to inform the transit bus and fuel cell industries.
- To create results that focus on performance and use, including progress over time and experience from integrating vehicle systems, operations, and facilities for FCBs and supporting infrastructure.
- To collect detailed results on fuel cell systems for buses and the requisite hydrogen infrastructure, to complement the light-duty vehicle demonstrations and further DOE goals.

Results

Bus Evaluations

NREL is collecting data from several fleets demonstrating FCBs in the United States. One of those fleets, Santa Clara Valley Transportation Authority (VTA), has been operating three FCBs in service since March 2005. The buses were manufactured by Gillig Corporation, and have a non-hybrid, fuel cell system developed by Ballard Power Systems (see Figure 1). NREL is collecting performance and operational data for the three FCBs and five standard diesel buses in the same service (to provide a baseline for comparison). The fuel cell buses at VTA are considered prototype technology, and the analysis and comparison discussions with standard diesel buses reflect this status. During FY 2006, NREL published the results of the first eight months of in-service data (March–October 2005) for the demonstration. The remainder of this section summarizes some of the results presented in the report.

Bus Usage

Bus usage is intended as an indicator of reliability and availability for bus service. The lack of bus usage may indicate downtime for maintenance or purposeful reduction of planned work for the buses. The diesel buses at VTA are randomly dispatched on all routes from a depot and operate seven days a week. The FCBs at VTA have been restricted in several ways to allow for potential service interruptions if a bus needs maintenance or is scheduled for an event. Events may include training sessions for fleet staff or first responders and educational activities to increase public awareness. Restrictions for use of the FCBs include:

- Used for extra service instead of replacing existing diesel buses (placed between regularly scheduled buses on a route).
- Two of the buses are in service and one is kept as a spare.
- Weekday operation only, when trained drivers and mechanics are available.

These restrictions result in lower mileage accumulation for the FCBs compared to the diesel buses. Table 1 summarizes the usage of the buses. Although the total fuel cell miles accumulated seems low in comparison to the diesel buses, the total fuel cell hours on the FCBs exceeded 1,300 hours. Figure 2 shows the

FIGURE 1. The Buses at VTA use a Non-Hybrid Fuel Cell System Developed by Ballard Power Systems

cumulative miles and fuel cell hours for the three FCBs. The buses are all on track to achieve well over 1,000 hours by the end of the demonstration.

TABLE 1. Summary of Bus Use

Bus	Total Mileage	Monthly Average Mileage	Fuel Cell Module Hours
4001	6,498	812	561
4002	4,822	689	402
4003	5,388	674	413
Fuel Cell	**16,708**	**726**	**1,376**
2229	30,408	3,801	n/a
2230	36,915	4,614	n/a
2231	36,434	4,554	n/a
2232	34,864	4,358	n/a
2233	32,738	4,092	n/a
Diesel	**171,359**	**4,284**	**n/a**

Fuel Economy and Costs

The fuel cell buses averaged 3.05 miles per kg of hydrogen, which translates into 3.45 miles per diesel equivalent gallons (mpg). This fuel economy includes all hydrogen fuel added to the buses even if there was some venting for maintenance or testing during the evaluation period. The diesel study group had a fuel economy of 3.95 mpg. With diesel fuel as the baseline, the fuel cell buses had a fuel economy that was 13% lower on an energy equivalent basis. Figure 3 shows average monthly energy equivalent fuel economies throughout the evaluation period for the fuel cell and diesel buses. These results show a need for hybridization in order to meet the DOE target of 50% increase in fuel economy. The range of the FCBs in operation at VTA has been around 140 miles. VTA's diesel buses typically have a range of 400 miles.

The average cost of hydrogen during the evaluation period was $8.56 per kg of hydrogen and the average cost of diesel fuel during the evaluation period was $2.02 per gallon. These average fuel costs translate into a fuel cost per mile of $2.80 for the fuel cell buses and $0.51 per mile for the diesel buses.

Hydrogen Fueling

The infrastructure at VTA is a liquid hydrogen storage and compression system designed, built, and maintained by Air Products. As with the FCBs, some of the technology used in the hydrogen dispensing station is in early deployment and use. During initial use of the station, there were some significant challenges and problems that had to be overcome. These include an incident with a thermocouple failure, followed by several false alarms, which caused the local fire officials to temporarily stop the operation of the hydrogen fueling facility until corrections were made and issues were resolved. This prevented the fuel cell buses from being fueled with hydrogen for several months. Significant progress and improvements have been made to the hydrogen dispensing station as a result of the early issues. The system has been in operation in earnest since February 2005.

The station is capable of filling a bus in 10 minutes, with fill times averaging between 10 and 14 minutes. DOE's target fill-rate for light-duty vehicles is one kg per minute. For the FCBs, which hold over 50 kg of useful fuel, the fill rate must be much higher to meet transit agency requirements. Figure 4 shows the cumulative fueling rates for the station at VTA. The average fueling rate during the evaluation period was 2.03 kg/min, but rates have been as high as 4.12 kg/min.

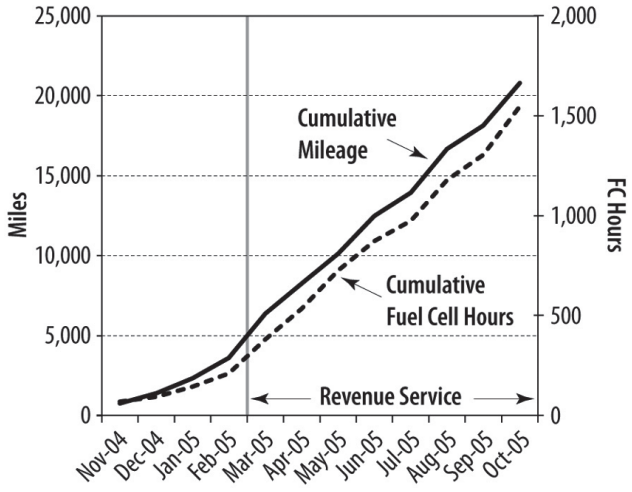

FIGURE 2. Cumulative Miles and Fuel Cell Hours for the three FCBs

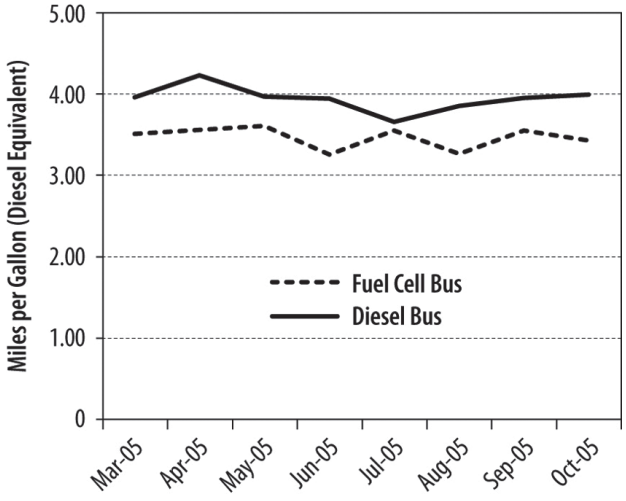

FIGURE 3. Average Fuel Economy by Month

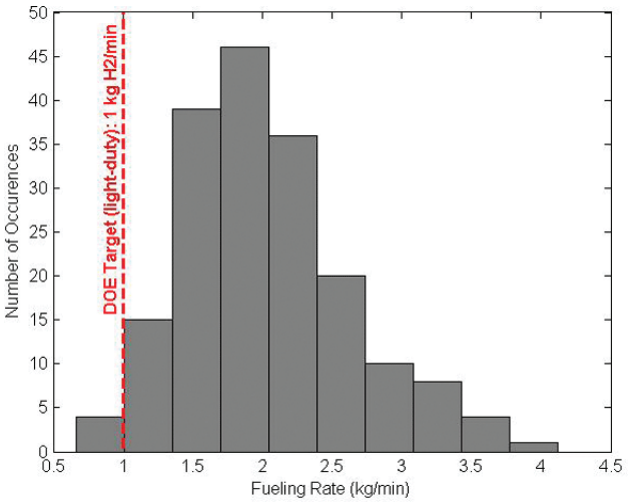

FIGURE 4. Cumulative Fueling Rate Histogram: VTA Station

International FCB Coordination

NREL continues to work with international groups to collaborate among FCB demonstrations worldwide. A core group of agencies–including NREL, FTA, EDTA, the European Commission, and the Flemish Institute for Technological Studies–coordinated the third International Fuel Cell Bus Workshop in Vancouver, BC, in December 2005.

The goals of the workshop were to

- Enhance information sharing on FCB demonstrations worldwide.
- Develop a standard set of data elements on the performance of FCBs and hydrogen infrastructure to collect and share.
- Investigate the potential for further collaboration and coordination of future FCB demonstrations.

The structure of this meeting was changed compared to the two previous workshops. In addition to updates on current demonstration programs, the workshop included facilitated breakout groups to discuss the topics of data sharing sensitivities, the business/policy case for FCBs, and early lessons learned with hydrogen infrastructure. Summaries of the discussions follow.

- Data Sharing Sensitivities – A list of data elements needed to fully understand the status of fuel cell technology in buses was drafted. The data was broken into categories:
  - High level – For government and regulatory agencies to use when setting policy.
  - Medium level – For end-users to understand the costs of operating and maintaining FCBs.
  - Detailed data – For bus manufacturers, system integrators, and fuel cell manufacturers to understand how the systems are working and make necessary modification or optimizations and for some government and regulatory agencies to aid in refocusing R&D funding.
- Standardized Definitions – The group agreed that standardized definitions of terms are essential to allow comparison between programs. Sensitive data should be reported in an aggregate form to protect individual technology companies. Topics for further discussion included establishing what organization should be responsible for collection/analysis of the data and the process needed to determine what results can be shared publicly and how.
- Business/Policy Case for FCBs – participants discussed the reasons for investing in fuel cell technology in buses and the barriers to address to bring the technology to commercialization. Reasons included energy security, lower emissions, and new business opportunities. Barriers included high costs of buses and infrastructure, operational performance, the need to determine life-cycle costs, and safety codes and standards.
- H2 infrastructure – lessons learned and technical issues to be resolved were discussed.

This workshop afforded participants the opportunity to further discuss coordination with the Clean Urban Transport for Europe (CUTE) Program and other FCB demonstrations.

Conclusions and Future Directions

Fuel cell propulsion systems, such as those used in the demonstration buses, are prototypes in the early stages of technological development. The evaluations of these prototype buses will result in opportunities to record experiences with FCBs and hydrogen infrastructure technologies, show the progress of these technologies, and facilitate understanding of the work that remains to be done to make the technologies viable and to meet DOE technical targets. Key FY 2006 accomplishments include:

- Collected and analyzed eight months of data on FCBs in real-world service.
- Achieved over 500 hours of operation in-service for a fuel cell bus; on-track to accumulate over 1,000 by the end of the demonstration period.
- Showed that hybridization of FCB systems is needed to meet fuel economy targets.
- Began to establish a baseline for conventional technology buses in the same duty cycle to help measure the progress of FCBs.
- Successfully demonstrated fueling rates averaging over 2 kg/min.

- Documented the fleet's experience with hydrogen-fueled buses and accompanying infrastructure.
- Shared informational data on FCB demonstrations with other world-wide partners, and began the process of harmonizing performance and operational data collection.

Future work includes:

- Collect, analyze, and report on performance data of nine hydrogen fueled vehicles in service at the following sites:
  - Santa Clara Valley Transportation Authority: three FCBs.
  - Hickam Air Force Base: one battery-dominant FCB, one fuel-cell-dominant shuttle van.
  - AC Transit District: three hybrid FCBs.
  - SunLine Transit Agency: one hybrid FCB, one hybrid hydrogen-fueled internal-combustion-engine bus.
- Investigate reliability, durability, and life cycle of FCBs as a part of ongoing evaluations. These efforts complement the DOE light-duty fuel cell vehicle demonstrations.
- Coordinate with FTA to ensure harmonized data collection efforts for the National Fuel Cell Bus Program.
- Coordinate with FTA to plan the fourth International Fuel Cell Bus Workshop in Yokohama, Japan, in October 2006.

FY 2006 Publications/Presentations

1. Eudy, L. (2005). FCB Data Sharing Sensitivities. Presented at Third International Fuel Cell Bus Workshop, Vancouver, BC, Canada, December.

2. Chandler, K., and Eudy, L. (2006). *Santa Clara Valley Transportation and San Mateo County Transit District, Fuel Cell Transit Buses: Preliminary Evaluation Results.* NREL/TP-540-39365, NREL, Golden, CO, March.

3. Eudy, L. (2006). Preliminary Data on FCB Evaluations. Presented at American Public Transportation Association Bus Conference, Anaheim, CA, May.

4. Eudy, L. (2006). Technology Validation: Fuel Cell Bus Evaluations. Poster Presentation at the 2006 Annual Merit Review, Arlington, VA, May.