VII.3 Technology Validation: Fuel Cell Bus Evaluations

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Project End Date: Project continuation and direction determined annually by DOE

Fiscal Year (FY) 2012 Objectives

- Determine the status of fuel cell electric bus (FCEB) 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 (NFCBP) 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 Electric Vehicle and Fuel Cell Bus Performance and Durability Data

(C) Lack of H_2 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 Program 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 April 2012, NREL had documented three FCEB fuel cell systems with operation in excess of 7,000 hours with no major repairs. One of these systems has logged more than 12,000 hours in service. Bus fuel economy is dependent on duty-cycle. Based on in-service fuel economies between 5 and 7 miles per kilogram, the hybrid FCEBs currently in service can achieve a range between 200 and 280 miles per fill.

FY 2012 Accomplishments

- Published reports on 2nd-generation performance and operational data on 13 full-size FCEBs in revenue service in the United States.
- Began data collection on FCEBs in revenue service at two additional transit agencies.

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Introduction

Transit agencies continue to aid the FCEB 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 resolution. The evaluations conducted to date have included two generations of FCEB design. 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, 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 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 call 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 2012, NREL collected and analyzed data on several 2nd-generation FCEB demonstrations at three transit agencies in the United States: SunLine Transit Agency in Thousand Palms, California; AC Transit in Oakland, California; and Connecticut Transit (CTTRANSIT) in Hartford, Connecticut. The first two of these evaluations were funded by DOE, and the third evaluation was covered by funding from FTA. NREL published results from each of these demonstrations. A summary of selected results is included in this report, followed by an overview of the newest FCEBs being evaluated. Under FTA funding, NREL began collecting data on two additional FCEBs, one at SunLine and one at Capital Metro in Austin, Texas.

In the demonstrations reported here, the 2nd-generation FCEBs are fuel cell dominant hybrid buses:

- Zero Emission Bay Area (ZEBA) Demonstration – five Bay Area transit agencies led by AC Transit are demonstrating twelve 40-foot Van Hool buses with UTC Power fuel cells in a Siemens hybrid system. The hybrid system was integrated by Van Hool and uses lithium ion batteries from EnerDel.
- 'Nutmeg' Fuel Cell Electric Bus Demonstration – named for Connecticut's state nickname, the Nutmeg project is part of FTA's NFCBP. The four buses, which are identical to the 12 ZEBA buses, were operated by CTTRANSIT in Hartford, Connecticut.
- Advanced Technology FCEB Project – SunLine 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.

NREL completed reports on operational and performance data on these FCEBs and conventional baseline buses at each agency. Table 1 provides a summary of the reported results from the operation at each agency, including data from the baseline buses.

One of the performance targets for FCEBs is to demonstrate fuel economy that is two times that of conventional bus technology. The 1st-generation FCEBs showed fuel economy improvements ranging from 48% to nearly 150% compared to conventional buses, depending on duty-cycle. Figure 1 shows the fuel economy of the 2nd-generation buses at each of the three transit agencies in miles per diesel gallon equivalent. (Note that the baseline buses at SunLine are CNG buses.) These data show that the 2nd-generation FCEBs are demonstrating fuel economies about two times that of the baseline buses, thus meeting the target.

Comparing FCEBs to competing technologies is valuable if the data are available. One such competing technology is

TABLE 1. Summary Data Results for 2nd-Generation FCEBs

	AC Transit		CTTRANSIT		SunLine	
Vehicle data	**FCEB**	**Diesel**	**FCEB**	**Diesel**	**FCEB**	**CNG1**
Number of buses	12	3	4	3	1	5
Data period (year, month)	Sep 11 – Apr 12	Sep 11 – Apr 12	Oct 10 – May 12	Oct 10 – May 12	May 10 – Jan 12	May 10 – Jan 12
Number of months	8	8	20	20	21	21
Total fleet miles	147,007	83,599	100,390	183,497	31,857	483,237
Average miles per month	1,598	3,635	1,385	3,219	1,517	4,602
Total fuel cell hours	17,619		7,305		2,591	
Fuel economy (mi/kg)	6.68		6.89		5.75	2.98
Fuel economy (mi/diesel gal eq.)	7.55	4.00	7.78	3.93	6.5	3.49
Average speed (mph)	9.4	N/A	13.8	N/A	13.1	13.9
Availability (%)	56	77	52	85	62	88

[1] CNG = compressed natural gas

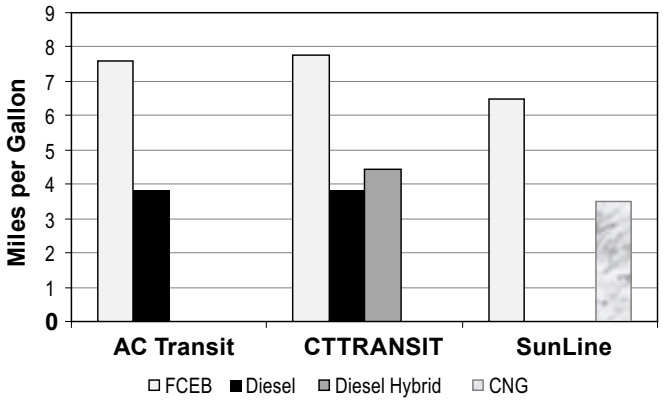

FIGURE 1. Fuel economy comparison by fleet (diesel equivalent)

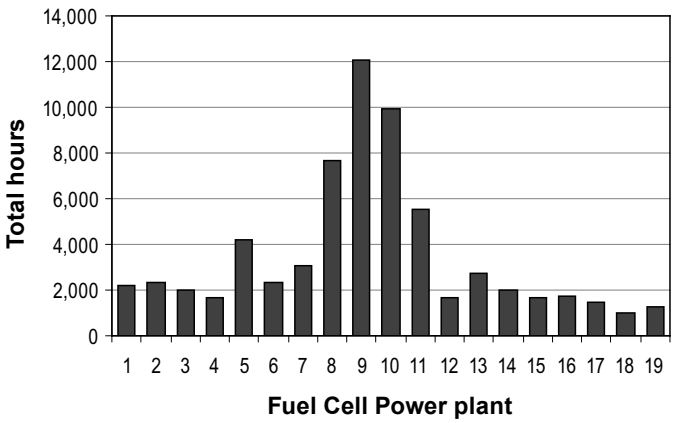

FIGURE 2. Hours accumulated on each fuel cell power plant

diesel hybrid buses. The primary challenge for adding these data to the evaluations is the fact that few of the agencies demonstrating FCEBs also operate similar diesel hybrid buses. Fuel economy is highly variable based on duty-cycle—the most accurate comparisons require similarly sized buses operated in the same service. Over the past year, NREL has begun to collect data on new hybrid buses at CTTRANSIT (included in Figure 1); however the hybrids of similar size to the FCEBs operate out of a different division. The hybrid buses have a more challenging duty-cycle than that of the FCEBs, characterized by more stops (buses operated out of this division typically have a 2% to 3% lower fuel economy). This fact should be noted when comparing the results presented in the table; however, this indicates that the duty-cycles are reasonably similar enough to compare.

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. Because transit agencies typically rebuild the diesel engines at approximately mid-life, a fuel cell power plant (FCPP) should be able to operate for at least half the life of the bus. DOE and FTA have set an early FCPP performance target of 4–6 years (or 25,000 hours) durability for the fuel cell propulsion system. Since NREL first began collecting data on the technology in 2002, FCEBs are now demonstrating some of the highest hours in service. These high-hour FCPPs are operating in the new ZEBA buses at AC Transit. At the time the first new bus bodies were delivered, three FCPPs from the 1st-generation demonstration were reaching very high hours without significant degradation. To further test this FCPP version, the manufacturers installed the three older FCPPs into the new ZEBA buses being delivered. Those three FCPPs continue to operate and accumulate hours in service. The top FCPP has now achieved more than 12,000 hours without major repair or cell replacements. The second FCPP is nearing 10,000 hours and the third is just under 8,000 hours. The manufacturer (UTC Power) reports that these FCPPs continue to provide the rated power of 120 kW. This is a significant achievement toward meeting the 25,000 hour target. The FCPPs in the Nutmeg buses are of the same version and are also expected to reach in excess of 10,000 hours in service. Figure 2 shows the total hours accumulated on each of the 2nd-generation buses.

NREL began collecting data on other types of fuel cell buses at the following transit agencies:

- City of Burbank – one battery dominant, plug-in hybrid FCEB developed by Proterra using Hydrogenics fuel cells and lithium titanate batteries.
- Capital Metro, Austin, Texas – one battery dominant, plug-in hybrid FCEB developed by Proterra using Hydrogenics fuel cells and lithium titanate batteries. This is the prototype bus to the Burbank bus and is funded under the NFCBP.
- SunLine, American Fuel Cell Bus – one fuel cell dominant ElDorado 40-foot bus with a BAE Systems hybrid drive using Ballard fuel cells and lithium ion batteries. This project is also part of the NFCBP.

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. There are still challenges to overcome before fuel cell buses can match the current standard of diesel bus performance. These include:

- Continue 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.
- Lowering the costs of purchasing, operating, and maintaining buses and infrastructure
- Transferring all maintenance work to transit personnel.

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 2012 Publications/Presentations

1. L. Eudy, K. Chandler. (2012). *SunLine Transit Agency Advanced Technology Fuel Cell Bus Evaluation: Third Results Report*. NREL/TP-5600-54427. National Renewable Energy Laboratory, Golden, CO, May.

2. K. Chandler, L. Eudy. (2012). *FTA Fuel Cell Bus Program: Research Accomplishments through 2011*. FTA Report No. 0014. Federal Transit Administration, Washington, DC, March.

3. L. Eudy. (2012). *American Fuel Cell Bus Project: Developing and Demonstrating the Next-Generation Fuel Cell Bus Made in America*. Fact Sheet: NFCBP-FS4-Feb12. Federal Transit Administration, Washington, DC, March.

4. L. Eudy. (2011). *Monitoring Ionic Compressor at AC Transit, Emeryville Station.* Presentation to the Hydrogen Delivery Tech Team, January.

5. L. Eudy, K. Chandler, C. Gikakis. (2011). *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2011*. NREL/TP-5600-52927. National Renewable Energy Laboratory, Golden, CO, November.

6. L. Eudy. (2011). *Fuel Cell Electric Bus Evaluations: Recent Results.* Presentation at the California Transit Assoc. Annual Conference, San Jose, CA, November.

7. L. Eudy, K. Chandler. (2011). *SunLine Transit Agency Advanced Technology Fuel Cell Bus Evaluation: Second Results Report and Appendices*. NREL/TP-5600-52349-1 and NREL/TP-5600-52349-2. National Renewable Energy Laboratory, Golden, CO, October.

8. L. Eudy. (2011). *2011 Status of Fuel Cell Electric Buses in U.S. Transit.* Presentation at the National Fuel Cell Bus Workshop, New Orleans, LA, October.

9. L. Eudy, K. Chandler. (2011). *National Fuel Cell Bus Program: Proterra Fuel Cell Hybrid Bus Report, Columbia Demonstration*. FTA Report No. 0003. Federal Transit Administration, Washington, DC, October.

10. K. Chandler, L. Eudy. (2011). *Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: First Results Report*. NREL/TP-5600-52015. National Renewable Energy Laboratory, Golden, CO, August.

11. L. Eudy. (2011). *Connecticut Nutmeg Fuel Cell Bus Project: Demonstrating Advanced-Design Hybrid Fuel Cell Buses in Connecticut.* Fact Sheet: NFCBP-FS3-Jul11. Federal Transit Administration, Washington, DC, July.

12. L. Eudy. (2011). *Compound Fuel Cell Hybrid Bus Hits the Streets of San Francisco: San Francisco Hosts National Fuel Cell Bus Program Demonstration*. Fact Sheet: NFCBP-FS2-Jul11. Federal Transit Administration, Washington, DC, July.

13. L. Eudy. (2011). *Fuel Cell Electric Buses Demonstrate Early Market Progress.* Presentation at the APTA Bus Conference, Memphis, TN, May.

14. L. Eudy. (2011). *Technology Validation: Fuel Cell Bus Evaluations.* Presentation at the DOE Hydrogen Program Annual Merit Review, Arlington, VA, May.