# 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 U.S. Department of Transportation targets and conventional technologies.
- Coordinate with the U.S. Department of Transportation Federal Transit Administration (FTA) on the data collection for the National Fuel Cell Bus Program to harmonize data-collection methods and enable the comparison of a wider set of vehicles.

## Fiscal Year (FY) 2019 Objectives

- Document performance results from each current FCEB demonstration site.
- Present status at the DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting 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[1]:

- (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.

## Technical Targets

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).* Through FY 2019, NREL collected data on 32 FCEBs. NREL documented 10 fuel cell power plants (FCPPs) with operation hours in excess of 25,000 hours, which is the ultimate target for FCEBs. One of these systems logged more than 32,000 hours in service before being retired. Based on in-service fuel economy (which is dependent on duty cycle) of 6.2 miles per kilogram, the hybrid FCEBs currently in service can achieve a range of approximately 290 miles per fill

## FY 2019 Accomplishments

- Published reports on performance and operational data covering 32 full-size FCEBs in revenue service in the United States.
- Documented more than 32,000 hours on a single FCPP.

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

## INTRODUCTION

Transit agencies continue to aid the FCEB industry in developing and optimizing fuel cells for buses. These in-service demonstration programs are vital 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 successfully transitioned training to transit staff and are improving the ability to troubleshoot issues. More work is still needed to improve reliability, lower capital and operating costs, and improve parts availability. Newer designs are entering the market that are expected to show improved range and performance.

## 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 FCEB performance and durability results to validate status against technical targets, educate key stakeholders, and further DOE goals

The evaluation protocol includes collecting operation and maintenance data on the buses and infrastructure. 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 data are compared to DOE and FTA technical targets and to conventional baseline buses in similar service.

## RESULTS

During FY 2019, NREL collected and analyzed data on the following FCEB demonstrations at four U.S. transit agencies:

- American Fuel Cell Bus (AFCB) Project—SunLine Transit Agency (Thousand Palms, California) is operating nine ElDorado National 40-foot buses with a BAE Systems hybrid propulsion system using Ballard Power Systems fuel cells and lithium batteries.
- Orange County Transportation Authority AFCB—Orange County Transportation Authority is operating an AFCB in Southern California.
- Stark Area Regional Transit Authority AFCB Project—Stark Area Regional Transit Authority is operating five AFCBs in Canton, Ohio.
- Zero Emission Bay Area Demonstration—five Bay Area transit agencies led by AC Transit (Oakland, California) are demonstrating thirteen 40-foot Van Hool buses with 120-kW fuel cells in a Siemens hybrid system. The hybrid system was integrated by Van Hool and uses lithium ion batteries from EnerDel. NREL has ended the full evaluation of this fleet. Current data collection is limited to fuel cell hours

These projects involve fuel-cell-dominant hybrid buses. A summary of selected results is included in this report. The results are also compared to technical targets for FCEB performance established by DOE and FTA and published in a Fuel Cell Technologies Program Record in September 2012 [1].

One performance target set by DOE and FTA is for a FCPP durability of 4–6 years (or 25,000 hours), 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. Over the last year, NREL collected data on 32 FCPPs including seven new buses at two different agencies. Figure 1 shows the total hours accumulated on individual FCPPs for the current projects tracked by NREL. The 2016 and ultimate targets are included on the graph as

lines along with the average hours for the group. The first two FCPPs on the graph (orange bars), both of which surpassed the ultimate target, were retired during 2019. One of these FCPPs reached a record number of hours at 32,110 before being retired in May 2019. The agency reported that these FCPPs were retired because they could no longer provide the required power to meet service.

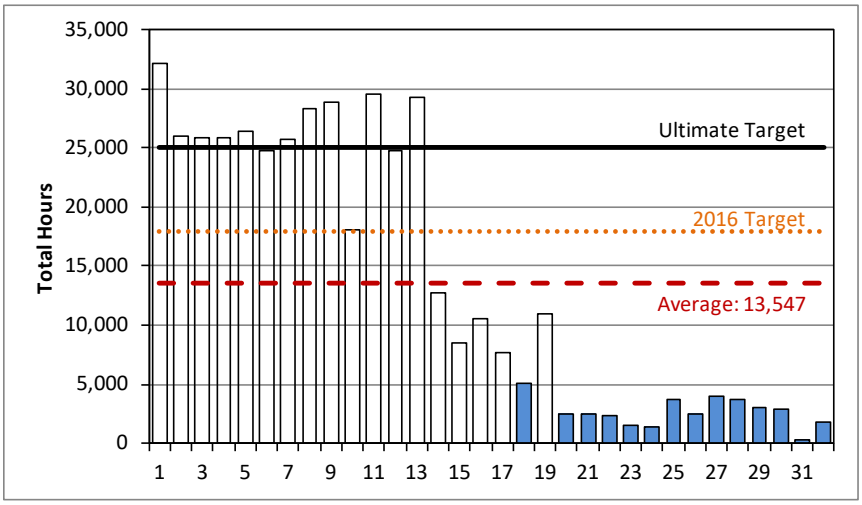


Figure 1. Total fuel cell hours accumulated on each FCPP

Thirteen FCPPs have surpassed the 2016 target of 18,000 hours. Of those FCPPs, ten have surpassed the ultimate target of 25,000 hours. The overall average of 13,547 hours is lower than that reported last year because of the addition of newer buses. The average for the FCPPs that are six years old or older is 23,592 hours. Agencies report that the FCPPs are proving reliable and that issues with the system are typically attributed to balance of plant components.

The transit industry measures reliability as mean distance between failures, also known as miles between roadcall (MBRC). Figure 2 tracks the MBRC over time for the three demonstrations and includes the MBRC for the bus as a whole and MBRC for the fuel cell system. The targets for each category are included on the chart. Bus MBRC has remained steady over time, averaging around the ultimate target of 4,000. Fuel cell system MBRC has steadily increased over the last two years averaging just under the ultimate target. Roadcalls due to bus-related issues—such as problems with doors and air conditioning—made up 49% of the total failures. Fuel-cell-related issues made up approximately 20% of the roadcalls during the period.

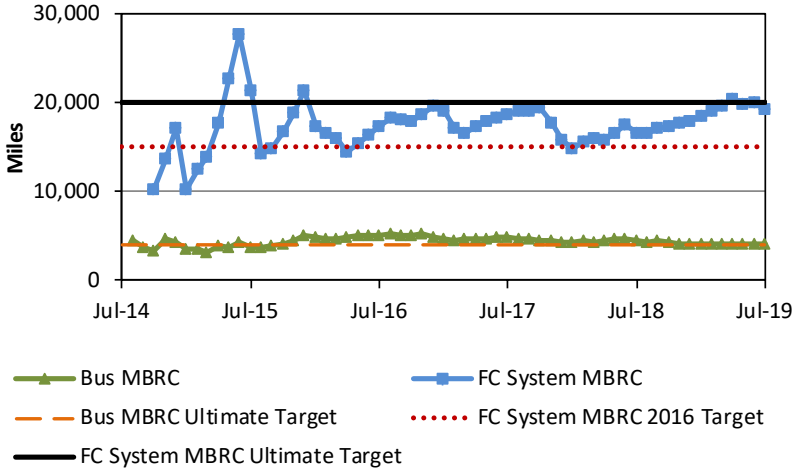


Figure 2. Miles between roadcall

Comparing cost trends over time as the buses age can provide insight into future costs for advanced technology buses compared to conventional technology. NREL has worked with transit agencies deploying FCEBs since 2000 and has gathered maintenance cost data for multiple years on both FCEB and baseline fleets. Figure 3 traces the cumulative maintenance cost for the combined fleet of FCEBs, a diesel bus fleet, a battery electric bus (BEB) fleet, and two fleets of compressed natural gas (CNG) buses—one that was model year 2008 and the other 2016. The fleets are aligned to match up the start of service when the buses are of similar age. Diesel and CNG buses are conventional technologies with well-established maintenance practices. The cost trends for these fleets follow a similar path, with lower costs in the early years when the buses are under warranty and rising costs as the warranty ends and the buses age. The BEB fleet cost is lower during the first two years because on-site original equipment manufacturer staff handled most of the maintenance. Over time, this cost has trended up as the transit staff took over all maintenance and parts costs were included after the end of the warranty. For the FCEBs, the transit agencies handled much of the maintenance in the early years with assistance of the original equipment manufacturers as needed. The buses were under warranty, so costs were driven primarily by labor hours and miles of operation. The costs dropped as staff became more familiar with the technology and troubleshooting issues. Costs began to rise as some of the buses passed the end of the warranty period, stabilizing at a slightly higher cost than that of the baseline CNG buses.

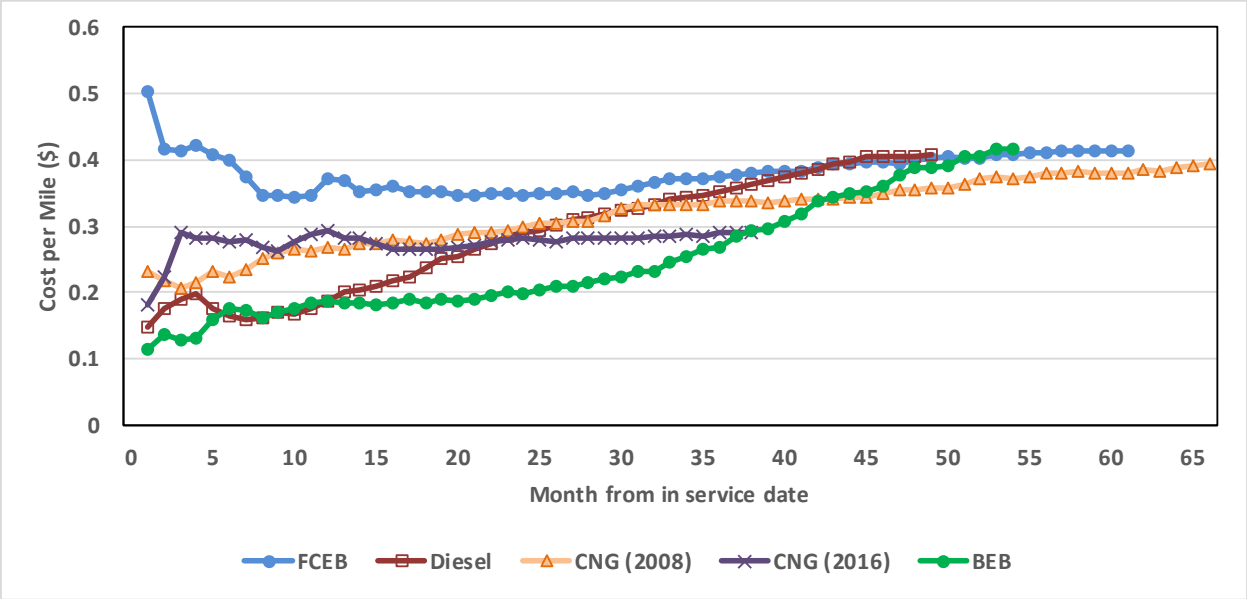


Figure 3. Cumulative maintenance cost per mile

## CONCLUSIONS AND UPCOMING ACTIVITIES

Fuel cell propulsion systems in buses have continued to show progress, with increasing durability and reliability of FCEBs and the primary components. The current technology meets the ultimate reliability target for roadcall frequency of the overall bus and is nearing the ultimate target for the fuel cell system. Ten fuel cell systems have surpassed the ultimate target for power plant lifetime. Table 1 summarizes the current status compared to the DOE and FTA performance targets. New FCEB designs are being introduced that are expected to show improved performance. 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
- Lowering the costs of purchasing, operating, and maintaining buses and infrastructure
- Scaling up the introduction and operation of larger numbers of FCEBs.

Table 1. FY 2019 Summary of Progress toward Meeting DOE and FTA Targets

| | Units | 2019 Status (Range) | Average | 2016 Target | Ultimate Target |
|---|---|---|---|---|---|
| Bus lifetime | years/miles | 0.3–9/ 3,100–257,000[a] | 4.9 | 12/500,000 | 12/500,000 |
| Power plant lifetime | hours | 343–32,110[a] | 13,547 | 18,000 | 25,000 |
| Bus availability | % | 42–89 | 73 | 85 | 90 |
| Roadcall frequency (bus/ fuel cell system) | MBRC | 2,200–5,700/ 13,000–36,800 | 4,000/19,000 | 3,500/15,000 | 4,000/20,000 |
| Operation time | hours per day/ days per week | 7–21/5–7 | 7–21/5–7 | 20/7 | 20/7 |
| Maintenance cost | $/mile | 0.29–0.53 | 0.42 | 0.75 | 0.40 |
| Fuel economy | miles per dge | 5.8–7.8 | 7.0 | 8 | 8 |
| Range | Miles | 277–357 | 300 | 300 | 300 |

[a] Accumulation of miles and hours to date—not end of life.
dge – diesel gallon equivalent

Future work by NREL includes:

- Initiating data collection, analysis, and reporting on performance data for the newest design FCEBs in service at the following sites:
    - SunLine
    - AC Transit
    - Orange County Transportation Authority
    - Additional sites as funding allows.
- Investigating reliability, durability, and life cycle of FCEBs as a part of ongoing evaluations

## FY 2019 PUBLICATIONS/PRESENTATIONS

1. L. Eudy, "Summary of Fuel/Energy Costs for NREL Evaluation Projects," Presentation at the ZEB Technology Showcase and Symposium, February 2019.
2. L. Eudy and M. Post, "Zero Emission Bus Evaluation Results: Orange County Transportation Authority Fuel Cell Electric Bus," FTA Report No. 0134 (Washington, DC: Federal Transit Administration, May 2019).
3. L. Eudy, "Technology Validation: Fuel Cell Bus Evaluations," Presentation at the DOE Hydrogen and Fuel Cells Program Annual Merit Review, Washington, DC, June 2019

## REFERENCES

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