DOE Hydrogen and Fuel Cell Technologies Program Record	
Record #: 20008	**Date:** September 15, 2020
Title: On-Road Transit Bus Fuel Cell Stack Durability	
Originator: Elliot Padgett	
Peer Reviewed By: Jason Marcinkoski (HFTO), Leslie Eudy and Jen Kurtz (NREL), Chris Durant (AC Transit), Jaimie Levin (CTE)	
Approved by: Dimitrios Papageorgopoulos Sunita Satyapal	**Date:** April 14, 2021

Item

Fuel cell electric bus (FCEB) durability was determined to be 17,000 hours with less than 20% degradation (8,500 hours with less than 10% degradation), approaching the DOE/DOT interim fuel cell bus target of 18,000 hours (with less than 20% degradation).[1] This status is based on real-world fuel cell bus data collected between 2011 and 2017, and newer FCEB power plants currently undergoing evaluation are expected to be more durable. A nearly 50% increase in durability is required to meet the ultimate target of 25,000 hours.

Supporting Information

On-Road Operating Time

The ultimate durability performance target set by the DOE and the Department of Transportation's Federal Transit Administration (DOT FTA) is 4 - 6 years (or 25,000 hours) for the fuel cell propulsion system, with an interim target of 18,000 hours.[1] To track progress toward these targets, the National Fuel Cell Technology Evaluation Center (NFCTEC) evaluates the durability of FCEBs and fuel cell power plants (FCPPs) through demonstrations taking place at transit agencies.[2]

Figure 1 summarizes the operational hours accumulated by 15 FCPPs included in a fleet operated by Alameda-Contra Costa Transit District (AC Transit). A total of twelve systems have surpassed 25,000 hours and 13 have surpassed 18,000 hours of operation.[3] Four of these FCPPs have been retired from service because they no longer provided the power necessary to meet service requirements, including one that operated for over 32,000 hours. The remaining FCPPs have continued service.

[1] U.S. Department of Energy. "Fuel Cell Bus Targets". DOE Hydrogen and Fuel Cell Technologies Program Record #12012. March 2, 2012: https://www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf
[2] For more information on NFCTEC and its fuel cell bus evaluations, see https://www.nrel.gov/hydrogen/nfctec.html and https://www.nrel.gov/hydrogen/fuel-cell-bus-evaluation.html.
[3] L. Eudy, M. Post, "Fuel Cell Buses in U.S. Transit Fleets: Current Status 2020", National Renewable Energy Laboratory, NREL/TP-5400- 75583, (2021). https://www.nrel.gov/docs/fy21osti/75583.pdf

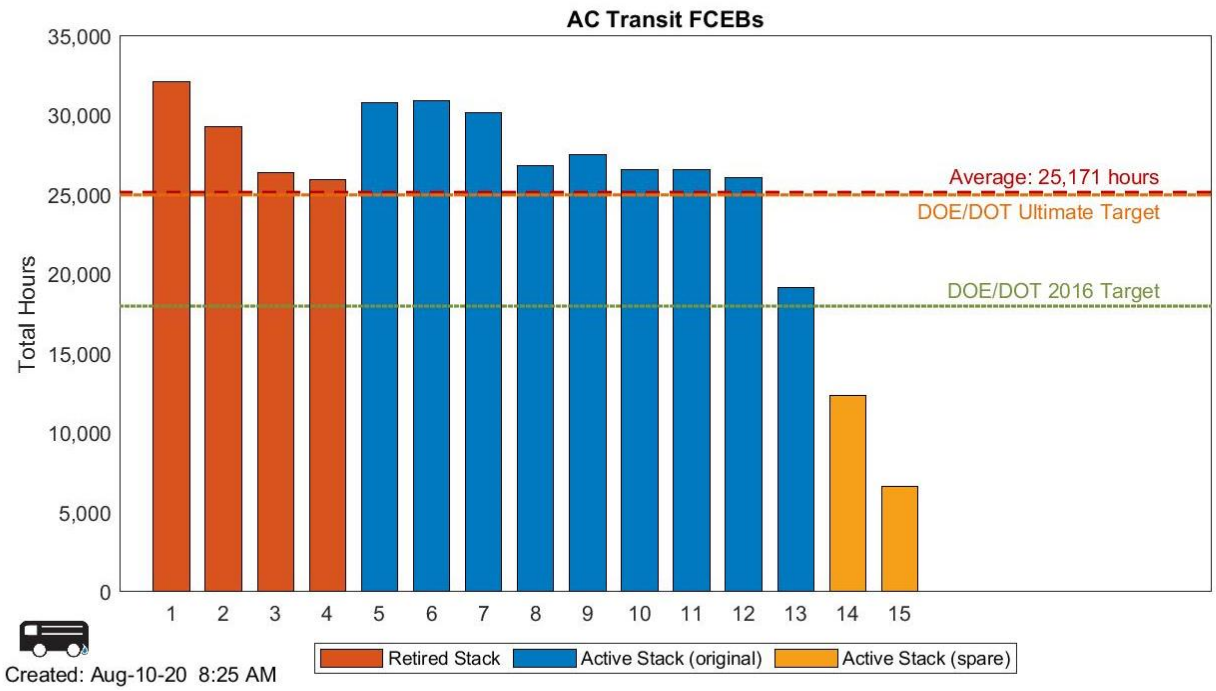

Figure 1: Total hours accumulated on each FCPP through July 2020.

<u>On-Road Durability</u>

In addition to the operational lifetime of FCEB power systems, it is important to track the loss of performance resulting from degradation of the fuel cell system. DOE durability targets were set at no more than 20% fuel cell voltage degradation based on stakeholder feedback and end user expectations.[4] Fuel cell voltage degradation leads to a loss of power performance, potentially limiting the ability to complete routes including hills, and leads to declining fuel economy, which increases operating costs. While fuel cell system diagnostics are not available as part of this study, changes in the recorded fuel economy can serve as a proxy for the performance of the fuel cell system. The fuel economy of a fuel cell vehicle depends on the efficiency of the fuel cell system at the different power levels and operating conditions that it experiences during the vehicle's operation. The average fuel economy over a period of time will reflect a weighted average of the fuel cell voltage at its different operating conditions. Therefore, fuel cell voltage degradation leads directly to degradation of fuel economy for fuel cell-powered vehicles.

Some assumptions are required to estimate the relationship between fuel economy degradation and fuel cell performance decay. Fuel cells for FCEBs or other medium/heavy duty vehicle applications typically use significantly higher platinum catalyst loadings than state-of-the-art fuel cells for light duty vehicles and are less likely to use alloy catalysts. Consequently, gradual voltage degradation is expected to be primarily caused by kinetic losses from catalyst mass activity degradation, rather than by ohmic or mass transport losses.[5] Such kinetic losses lead to similar voltage decay at all operating powers, and therefore the average fuel economy loss is expected to be roughly proportional to the voltage loss at rated power. As such, relative

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[4] The targeted 20% degradation does not necessarily reflect FCEB end-of-life, but enables the FCEB to maintain relatively high performance, fuel efficiency across its lifetime.

[5] If significant ohmic or mass transport degradation also occurs the voltage decay will be more severe for higher power operation. Consequently, the average fuel economy decay may underestimate the decay in voltage at rated power.

degradation in fuel economy is a useful approximation for the voltage degradation at rated power, and can be used to indicate the status of FCEB durability.

NFCTEC provided fuel economy records for 13 FCEBs operated by AC Transit, collected from September 2011 to July 2017 and reported monthly. The buses operated on different routes and were not necessarily maintained on the same route for the entire period. These buses were manufactured by Van Hool with 120 kW_{net} fuel cell systems supplied by UTC power and 21 kWh Li-ion batteries in a fuel-cell dominant architecture.[3,6] The fuel economy records (illustrated for four FCPPs in Figure 2) show that the fuel economy in these transit buses fluctuated seasonally, but decayed steadily over time due to fuel cell degradation. By examining a time period long enough to average out seasonal variations, the average rate of degradation can be calculated using a linear fit, as shown in Figure 2, with the intercept indicating the initial fuel economy and the slope indicating the degradation rate.

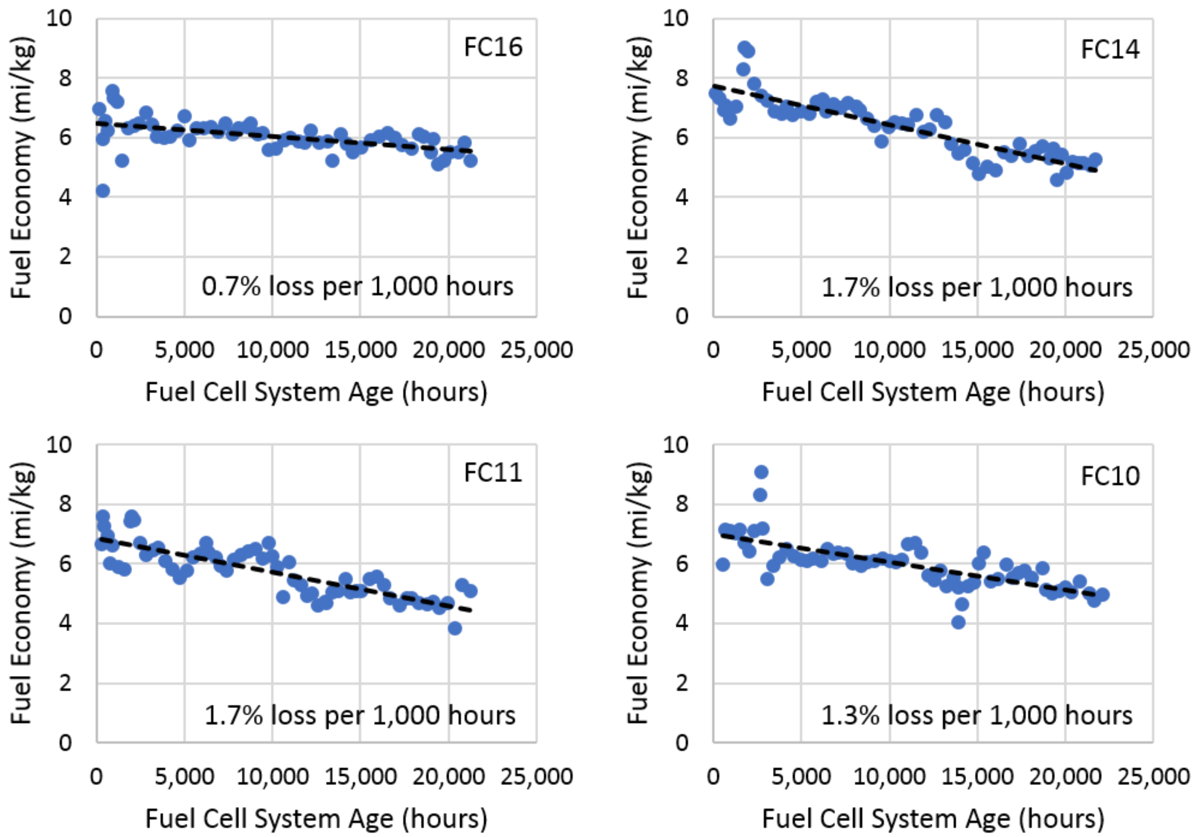

Figure 2: Recorded fuel economy of four representative FCEBs, with linear fits used to determine the average rate of fuel economy loss.

Using this approach, degradation rates were measured for 9 FCPPs with fuel economy records spanning at least 15,000 hours with no major gaps. These buses had an average fuel economy decay rate of 1.3% per 1,000 hours, and lost 20% of their initial fuel economy after 17,000 hours on average (and 10% after 8,500 hours). There was significant variation between the buses, with a standard deviation of 0.4% per 1,000 hours in the fuel economy decay rate and 6,500 hours in the time to 20% loss. The longest operating bus in this data set (with over 32,000 hours) is projected to have 20% degradation after 11,300 hours and 57% degradation at its end of life. The

[6] L. Eudy and M. Post, "Fuel Cell Buses in U.S. Transit Fleets: Current Status 2018," National Renewable Energy Laboratory (2018). https://www.nrel.gov/docs/fy19osti/72208.pdf.

slowest degrading bus has projected time of 30,500 hours to 20% degradation. However, this bus had only operated 21,000 hours in the fuel economy records available to date.

Measured against the benchmark of 20% fuel economy degradation, the demonstrated 17,000 hour on-road durability of bus FCPPs falls short of the ultimate DOE and DOT FTA target of 25,000 hours. However, long-term, on-road durability data is only available for relatively old fuel cell technology.

Newer FCEB power plants, including others currently being evaluated by NFCTEC, are expected to be more durable although further validation is necessary to demonstrate this. While FCEBs may often be operated beyond 20% degradation, other heavy duty vehicle applications, such as trucks, have more stringent durability requirements and duty cycles that may exacerbate degradation.[7] Further advances in the durability of heavy-duty fuel cell systems are therefore required to enable fuel cells for these applications.

[7] U.S. Department of Energy. "Hydrogen Class 8 Long Haul Truck Targets". DOE Hydrogen and Fuel Cell Technologies Program Record #19006. December 12, 2019: https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf