

AC Transit Fuel Cell Bus Longevity Study

JULY 2020

FTA Report No. 0169
Federal Transit Administration

PREPARED BY

Niki Rinaldi El-Abd
Jaimie Levin

Center for Transportation and the Environment



COVER PHOTO

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1200 New Jersey Avenue, SE
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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft³	cubic feet	0.028	cubic meters	m ³
yd³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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ABSTRACT

The Center for Transportation and the Environment (CTE) led a team from AC Transit in the extended monitoring of 13 fuel cell electric buses (FCEBs) as a part of the Federal Transit Administration's (FTA) National Fuel Cell Bus Program (NFCBP), working with AC Transit, UTC Power, EnerDel, Van Hool, Siemens Industries, and Dynetek Industries in this endeavor. The extended monitoring demonstrated the exceptional durability of this technology, as the buses were still exceeding their expected performance in 2019, well beyond expected operations through 2016. The data show that these buses are durable and reliable and met or exceeded many of the performance targets identified by FTA and the U.S. Department of Energy (DOE) for determining the readiness of the technology for widespread commercialization.

EXECUTIVE SUMMARY

The Federal Transit Administration (FTA) started the NFCBP in 2006 with the overarching goal of facilitating the advancement of fuel cell technology in buses and pushing the concept to the market. The NFCBP has provided \$65 million in funding to 31 projects in the since the program began, matched with 50–50 cost sharing.

Objectives of the NFCBP include:

- Facilitating the development of commercially-viable fuel cell bus technologies
- Improving transit bus efficiency and reducing petroleum consumption
- Reducing transit bus emissions
- Establishing a globally-competitive U.S. industry for fuel cell bus technologies
- Increasing public awareness and acceptance of fuel cell vehicles

The Center for Transportation and the Environment (CTE) managed extended performance testing for Alameda-Contra Costa (AC) Transit's Van Hool fuel cell electric buses (FCEBs) as they performed routine service and received regular maintenance. This document covers project performance and results for extended maintenance and support of fuel cells, traction batteries, and hybrid-drive components of the FCEBs. FTA has sponsored this project since 2014 as part of the National Fuel Cell Bus Program.

The report contains an overview of the continued maintenance and performance of these buses and includes a summary of work completed, involved partners, difficulties encountered, data results, lessons learned, advancements made, and recommendations for future research.

Two of the 13 fuel cells installed in these buses were built in 2002 with an expected design life of 5,000 hours. One of the two continued in service until 32,134 hours; the other was retired at 25,969 hours. The remaining fuel cells were built in 2008 and 2009 and came with a 10,000-hour warranty; the average number of hours of these newer fuel cells is 25,974. Between January 1, 2014, and December 31, 2019, the fleet traveled a total of 2,363,480 miles. Over the lifetime of the buses, they have traveled more than 3,022,530 miles and logged 369,793 fuel cell hours.

This extended study was meant to provide data about FCEBs and their operating performance, fleet availability, reliability, fuel economy, infrastructure support and maintenance costs, with the goal of demonstrating their ability to meet or exceed the needs of the transit agency. Ultimately, the project showed that this technology is capable of exceptional performance in a transit setting, as the buses continually met or exceeded the needs of AC Transit.

Despite the technology still being in a state considered not commercially technology-ready, these buses were able to exceed targets set by the DOE and FTA for durability and reliability and demonstrated the potential for fuel cells in the transit industry.

This document will serve as a source of information to be used by organizations in the industry for future projects.

Introduction

The Center for Transportation and the Environment (CTE) led a team in the extended monitoring of 13 Fuel Cell Electric Buses (FCEBs) as a part of the Federal Transit Administration's (FTA) National Fuel Cell Bus Program (NFCBP). CTE worked with Alameda-Contra Costa (AC) Transit in California, UTC Power, EnerDel, Van Hool, Siemens Industries, and Dynetek Industries in this endeavor. This report summarizes the project, including the results of monitoring the buses as they operated within the AC Transit service area.

National Fuel Cell Bus Program

The Federal Transit Administration (FTA) started the NFCBP in 2006 with the overarching goal of facilitating the advancement of fuel cell technology in buses and pushing the concept to the market. The NFCBP has provided \$65 million in funding to 31 projects in the since the program began, matched with 50–50 cost sharing.

The objectives of the NFCBP include:

- Facilitating the development of commercially viable fuel cell bus technologies
- Improving transit bus efficiency and reducing petroleum consumption
- Reducing transit bus emissions
- Establishing a globally competitive U.S. industry for fuel cell bus technologies
- Increasing public awareness and acceptance of fuel cell vehicles

Congress authorized the NFCBP in 2006, and the first round of awards were announced in November 2006. FTA competitively selected three non-profit organizations—the Center for Transportation and the Environment (CTE), the Northeast Advanced Vehicle Consortium (NAVC), and CalStart—to administer projects under the program. The 14 original NFCBP projects featured multiple drive technologies and configurations as well as various methods of energy storage, such as batteries and ultracapacitors. They also implemented a variety of different fuel cell stacks from different manufacturers.

Since its initial round of funding in 2006, FTA has had second and third rounds of funding. This additional funding has expanded the original effort, adding new projects and bringing the total number of NFCBP projects to 38. These projects include development and demonstration projects, component development projects, education and outreach projects, and projects enhancing existing demonstrations.

Center for Transportation and the Environment

CTE is one of three non-profit consortia selected to manage NFCBP projects. It specializes in facilitating the rapid development, commercialization, public understanding, and acceptance of advanced transportation technologies and alternative fuels to implement solutions to achieve energy and environmental sustainability. CTE has worked with various organizations to develop and demonstrate economically-feasible sustainable transportation technologies.

SECTION

2

Project Description

This project involved an extension of maintenance and support that was expected to allow operation of the AC Transit fuel cell bus fleet until December 31, 2016. This goal was far exceeded, as the buses continued to operate well beyond December 31, 2019. In total, 11 of the agency's 13 FCEBs remained in daily service at the time of this report. The first 12 buses included in this study were put into service in September 2010, and the last entered service in November 2011; the 13th was added in 2016.

AC Transit's fleet is the keystone example of both U.S. and international FCEB activity due to the extensive performance and cost data provided for the industry and government. The buses are 40-ft Van Hool transit buses powered by 120 kW UTC Power PureMotion fuel cell systems. The series hybrid architecture includes EnerDel lithium ion batteries (rated at between 76 kW to 125 kW of power and 21 kWh of energy storage) and Siemens ELFA Drive System with two 85 kW AC traction motors.

This project included performance monitoring of the technology and provided critical operational and maintenance cost data on performance over time, and fuel cell, battery, and drive system durability.

During the first 5.5 years of extended support, the U.S. Department of Energy (DOE) and DOE's National Renewable Energy Laboratory (NREL) collected important performance data on AC Transit's FCEB fleet. NREL uses a standard data-collection and analysis protocol to evaluate fuel cell bus technology readiness originally developed for DOE heavy-duty vehicle evaluations.

As a part of NREL's work, the performance of AC Transit's FCEBs, along with the FCEBs of several other agencies, were compared to performance criteria meant to measure the progress of the technology towards widespread commercialization. The performance of AC Transit's buses against these standards is discussed in Section 3. In addition to NREL's data collection, AC Transit also installed a data collection system on each bus to facilitate efficient data collection from the vehicles in passenger service. These data were summarized in quarterly reports submitted to FTA; a summary of the data is also discussed in Section 3.

SECTION

3

Performance Analysis

Extended Service Performance

The extended service performance of the AC Transit FCEBs was monitored based on several variables, including mileage, road calls, miles between road calls, fuel cell hours, and availability. The performance of these FCEBs also was compared to FTA targets for commercialization.

Mileage

The first performance criterion was the fleet's overall mileage over time. Between January 1, 2014, and December 31, 2019, the fleet traveled a total of 2,363,480 miles. Over the lifetime of the buses, they have traveled more than 3,022,530 miles. The average fleet miles gradually increased between January 2014 and March 2018, with the highest monthly mileage of 46,975 miles in March 2018 (Figures 3-1 and 3-2). After that, the monthly fleet mileage began to decline, which resulted in the overall mileage of the fleet showing a declining trend over time. Annually, however, fleet mileage increased between 2014 and 2019, decreasing only between 2018 and 2019. This decrease was caused primarily by power plant degradation, which resulted in the buses requiring more fuel and a decrease in range. The average monthly fleet mileage for 2016, 2017 and 2018, however, was well above 35,000 miles.

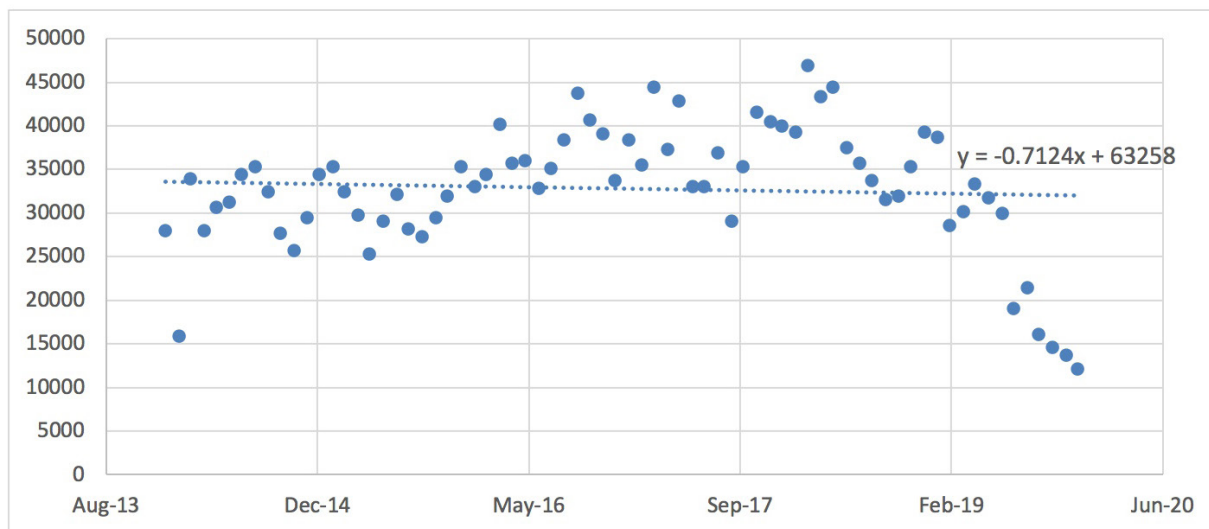


Figure 3-1

Fleet miles over time

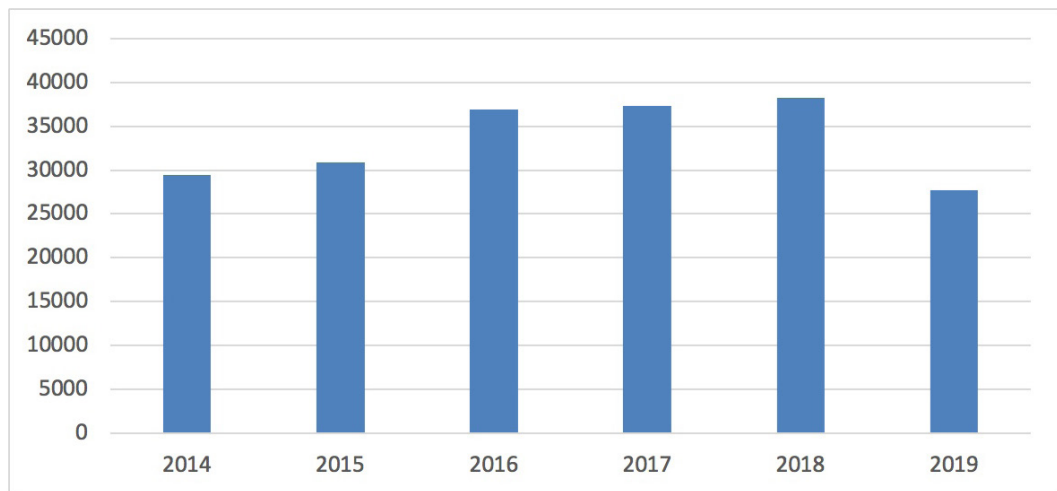


Figure 3-2

Average monthly fleet miles by year

Road Calls

Another important performance criterion that was monitored throughout this study was the number of reported road calls. Road calls are the result of the failure of one or more of the systems needed to operate the bus that prevent the bus from operating as scheduled; these are an important consideration in evaluating overall performance. When a bus is out of service for six minutes or more, it is considered a road call regardless of whether the problem can be fixed while on the route or if the bus must be taken back to the maintenance division.

Over time, there was a slight increase in the number of road calls for the fleet, although these were not all due to the fuel cell system. For the monthly average annually, the number of road calls was near or below 8 for all years except 2019, which exceeded an average of 10 road calls per month (Figures 3-3 and 3-4). As with the decrease in fleet mileage, the increase in road calls was likely due to degradation of the power plants with age and degradation of the high voltage batteries, which made them unable to keep up with demand. Figure 3-5 shows that the fuel cell system was the source of the issue in only a fraction of the calls. These data were available only for 2018, but the trend can be assumed to be the case for the entirety of the project.

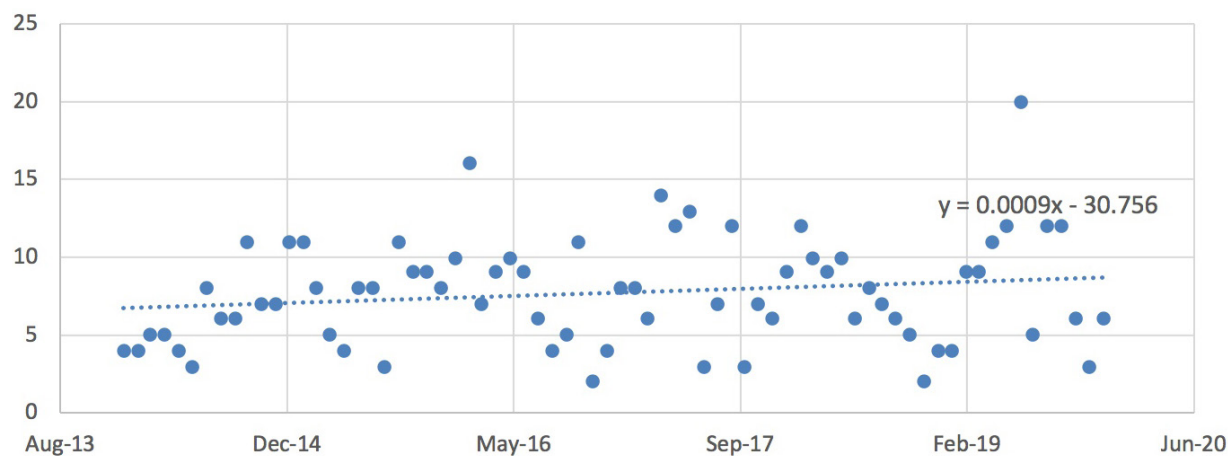


Figure 3-3
Number of road calls over time

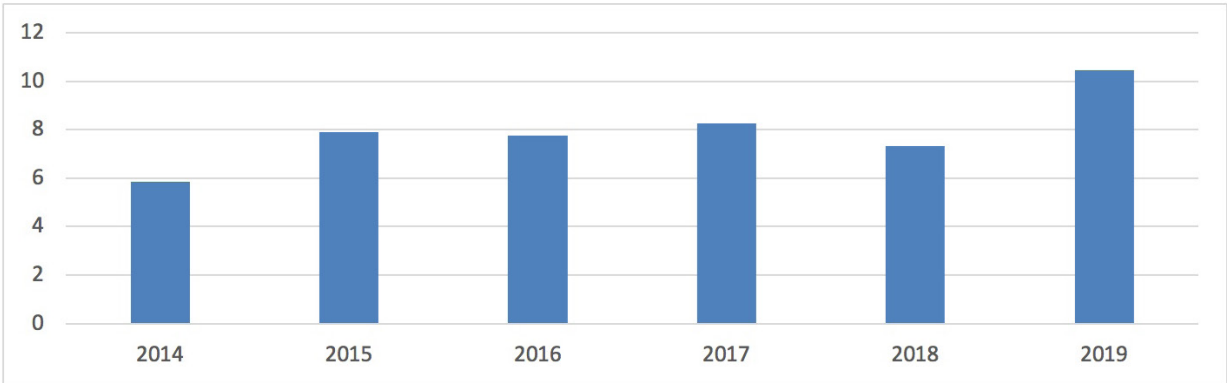


Figure 3-4
Average number of road calls by year

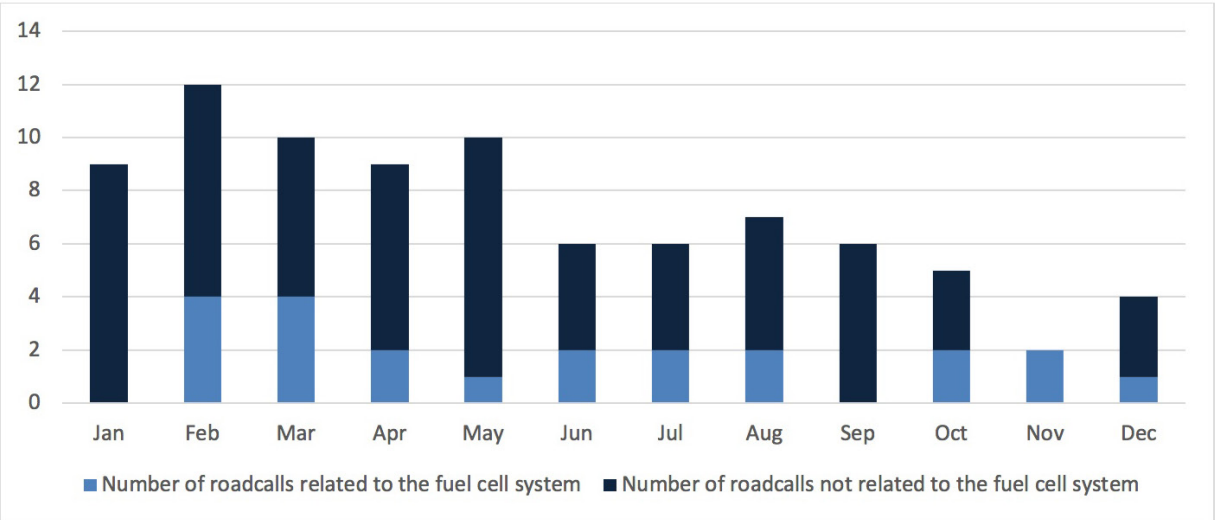


Figure 3-5
Number of road calls by month in 2018 related to fuel cell system and overall

Miles Between Roadcalls

In addition to the overall trend of road calls over time, it is also important to consider the number of miles the buses traveled between road calls. The miles between road calls (MBRCs) reported here were averaged across the fleet and represent a per-bus average. The maximum reported MBRC for a single bus was 18,862. The trend over time shows a slight decline in that number over time. In 2016 and 2018, the average monthly MBRC exceeded 6,000 miles, with the lowest average number in 2019, an average of less than 4,000 miles (Figures 3-6 and 3-7). This decrease was likely due to the same issues related to the age of the system that caused the increase in road call frequency in 2019—power plant and battery degradation.

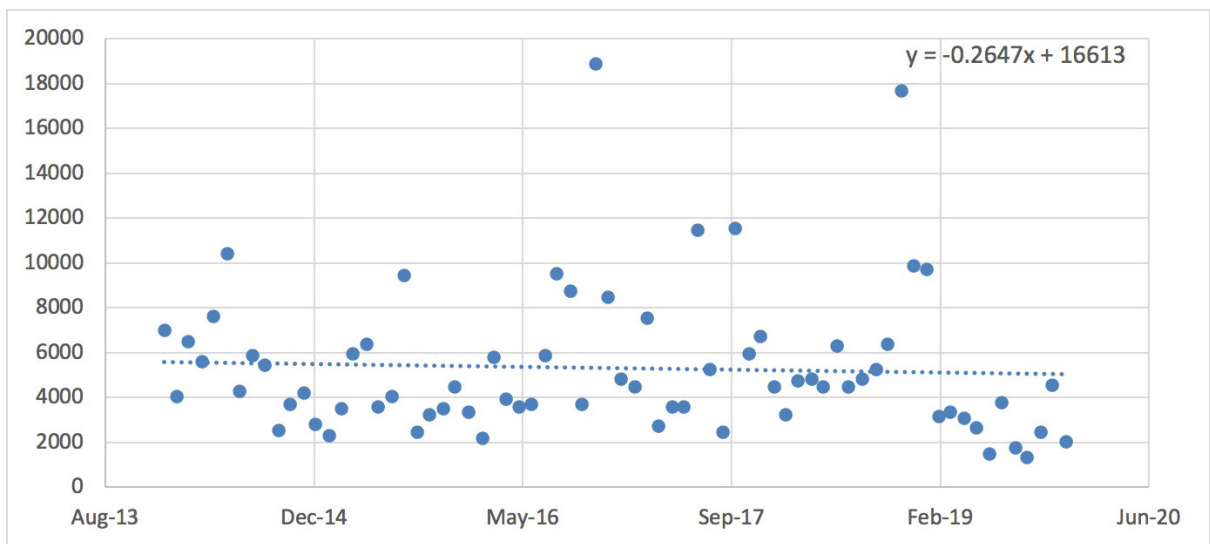


Figure 3-6

MBRC over time

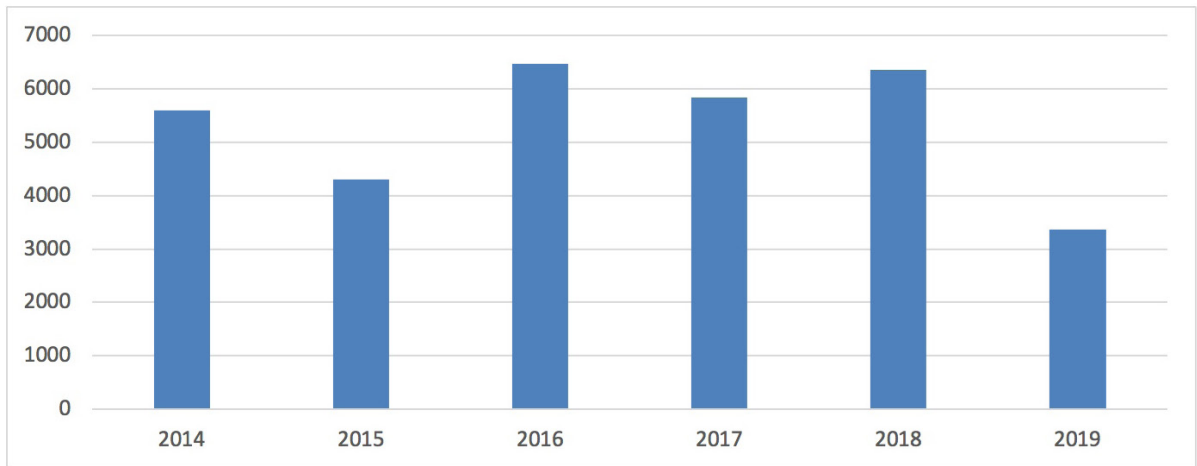


Figure 3-7

Average MBRC by year

Isolating the systems that resulted in the road calls also revealed that only a portion of the calls were related to fuel cell performance, whereas many of the other calls were due to systems that exist in any bus. Comparing the MBRC for the propulsion vs. fuel cell systems, for example, showed that the buses traveled further between road calls linked to the fuel cell system than between issues with the propulsion system, which suggests that the propulsion system was more likely to cause a debilitating problem for the buses in service than was the fuel cell system (Figures 3-8 and 3-9). These data were available only for selected periods between September 2011 and July 2017 because the buses were included in several NREL reports related to FCEB commercialization and the data were extracted from those reports. The increase in 2016/2017 in MBRC related to the propulsion system was due to repairs to the system in two of the FCEBs, which increased the average performance of the system.

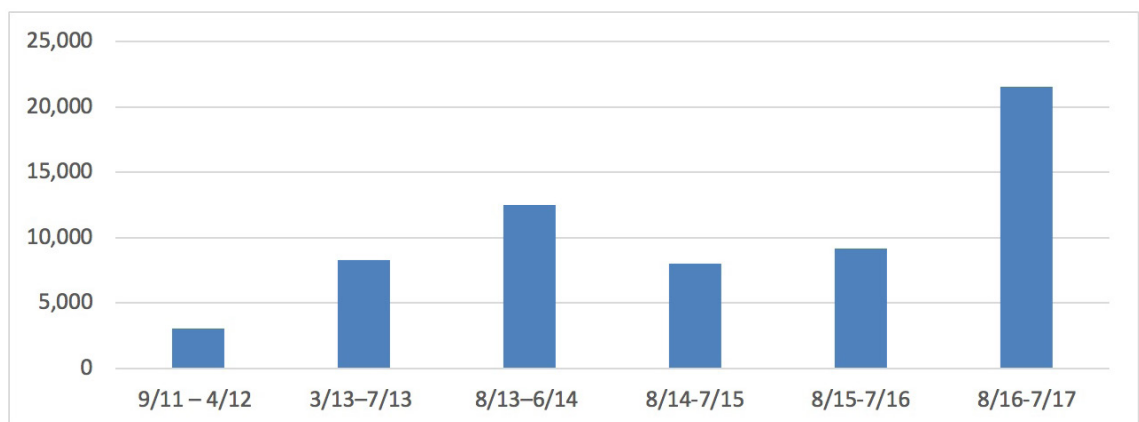


Figure 3-8

MBRC related to propulsion system for periods of time included in NREL reports

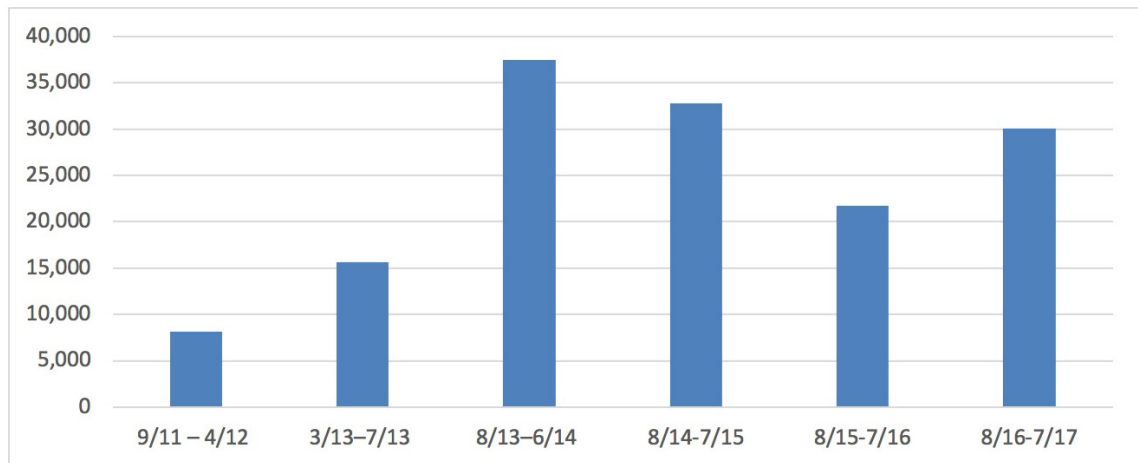


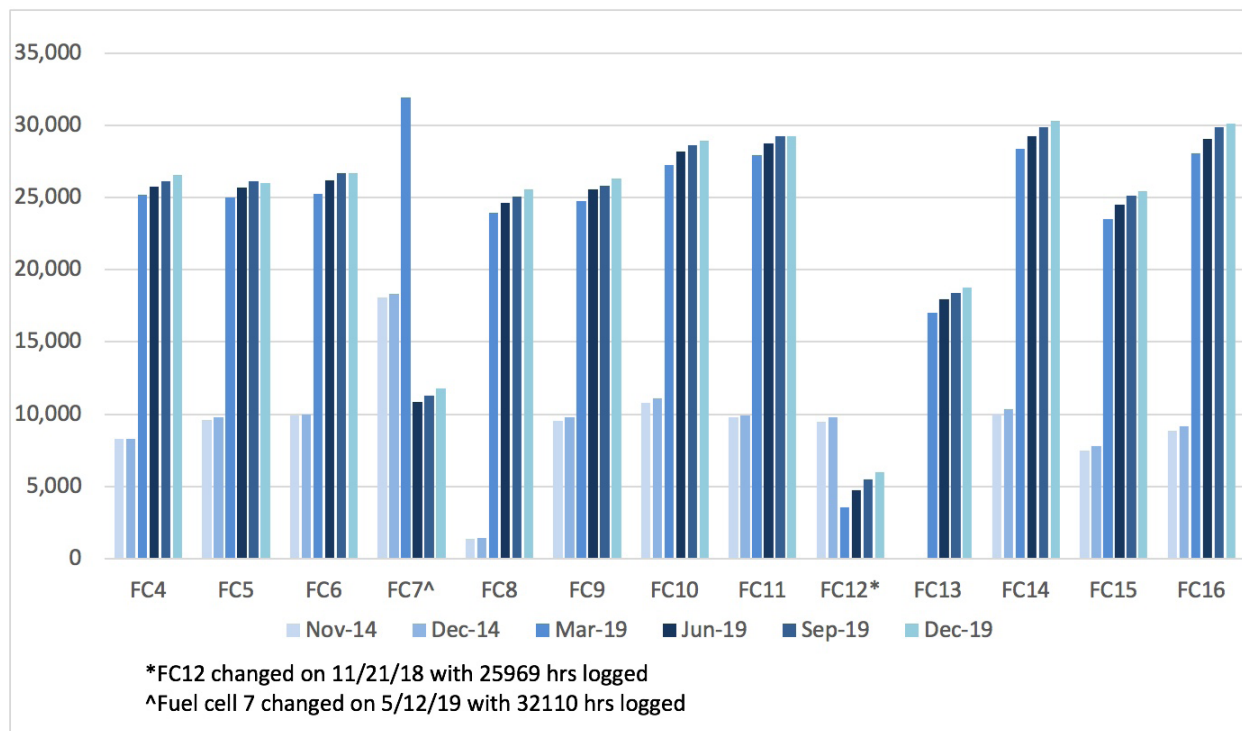
Figure 3-9

MBRC related to fuel cell system for periods of time included in NREL reports

Fuel Cell Hours Over Time

The number of hours fuel cells can operate before they become too degraded to be operational is also an important consideration for this technology. The durability of the fuel cell and its performance over time are crucial to the success of the technology, but real-world data regarding the number of hours a fuel cell can operate before reaching these performance limits has been limited, which is why the data from AC Transit are so crucial.

FTA set the performance goal for these early systems at between 20,000 and 30,000 hours. Since 2014, three fuel cells have exceeded the upper limit of 30,000 hours and 12 have exceeded the lower range of 20,000 hours (Figure 3-10 and Table 3-1). It should also be noted that the warranty on two of the older fuel cells (built in 2002) was 4,000 hours; the newer fuel cells built in 2008 and 2009 came with a 10,000-hour warranty. The fact that these FCEBs are still operating is a testament to how far they have exceeded expectations of performance.

**Figure 3-10**

Fuel cell hours over time for FCEB fleet

Table 3-1

*Life-to-Date Mileage
and Fuel Cell Hours
for FCEB Fleet by Bus*

Bus Number	Life-to-Date Miles	Life to Date Fuel Cell Hours
FC4	244,810	26,567
FC5	252,632	26,002
FC6	218,737	26,695
FC7	234,164	11,806^
FC8	185,715	25,545
FC9	228,341	26,286
FC10	262,746	28,906
FC11	258,380	29,275
FC12	251,557	5,964*
FC13	181,302	18,763
FC14	255,551	30,306
FC15	211,297	25,434
FC16	237,298	30,141
Total	3,022,530	311,690
Average	232,502	25,974

^FC7: fuel cell replaced at 32,134 hours

*FC12: fuel cell replaced at 25,969 hours

Two fuel cells, including FC7, which operated for more than 30,000 hours, were replaced because their outputs dropped below the threshold of 80–85KW required for the buses to complete their routes (FC7 was replaced at 78KW, and FC12 was replaced at 79KW). Also, two buses (FC6 and FC11) were retired in the fourth quarter of 2019, with final hours of 26,695 and 29,275 and final outputs of 77.4KW and 82.4KW, respectively. These buses were retired because they could no longer reliably run their routes and will be either scrapped or auctioned. At the time of this report, the other 11 buses are still in regular operation.

Availability

A final measure of performance is availability—a bus is considered available if it is ready for pullout at 7:00 AM and is presented as a percentage for the fleet.

The data for 2018 are shown in Figure 3-11. This year is presented in isolation because it represents the year that availability peaked and is the year with the most constant data available. Availability in March 2018 was 89%, which is the highest availability during this period. The minimum availability percentage during this period was 74% in October.

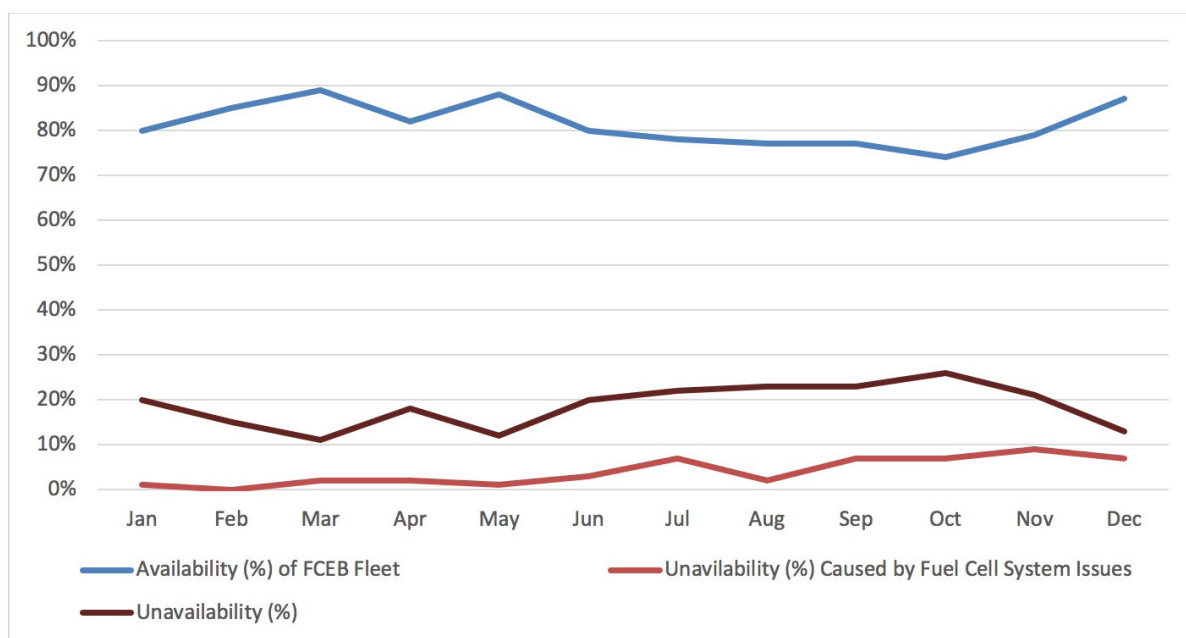


Figure 3-11

Fleet availability by month and unavailability overall and related to fuel cell system

Figure 3-11 also illustrates that the fuel cell system was the cause of unavailability for only a fraction of the unavailability occurrences. Other causes of unavailability include general repair issues, the drive system, training, issues with the fueling station, and inspections. As with many of the other statistics monitored, availability began dropping in 2019 due to issues related to bus age and degradation of the powerplant and battery. The average bus availability overall was 81%, which compared favorably to AC Transit's diesel fleet availability of 85%.

Performance Against FTA Targets

Several targets were set by DOE and FTA for FCEBs related to the goal of commercialization. Table 3-2 summarizes how the FCEBs included in this study compared to the goals for the technology set by these agencies. Several of these ultimate targets have already been met, including the powerplant lifetime, road call frequency, and MBRC, and shows that this technology is nearing commercial viability. Future improvements in the technology should bring the technology over the thresholds that remain to be crossed.

Table 3-2
*Comparison of AC
Transit FCEB Fleet
Performance to FTA/
DOE Guidelines
for Commercialization
Readiness*

	Units	AC Transit Status	2016 Target	Ultimate Target
Bus lifetime	Yrs/mi	9/232,502 (to date)	12/500,000	12/500,000
Power plant lifetime	Hrs	25,969–32,110	18,000	25,000
Bus availability	%	81% (max)	85	90
Fuel fills	Per day	1 (<10 min)	1 (<10 min)	1 (<10 min)
Bus cost	\$	\$2,500,000	1,000,000	600,000
Power plant cost	\$	8,300\$/kw	450,000	200,000
Hydrogen storage cost	\$	Inclusive	75,000	50,000
Road call frequency (bus/fuel cell system)	Miles between road calls (MBRC)	5,323.67/24,318 (2011–2017)	3,500/15,000	4,000/20,000
Operation time	Hrs per day/ per wk	20/7	20/7	20/7
Range	Miles	220	300	300
Fuel economy	Mi per gallon diesel equivalent (MPGDE)	6.8 (2011–2017)	8	8

Challenges and Setbacks

Although the performance of AC Transit's Van Hool FCEBs show that the technology is already meeting or exceeding several of the performance targets set by FTA, including powerplant lifetime hours, fuel fills per day, fueling speed, and MBRC (for the bus overall and for the fuel cell system specifically), the technology is still very costly because manufacturing volumes are very small and the supply chain is not well developed to provide significant cost savings for component systems. With future innovation, it is very likely that these remaining barriers to widespread commercialization of the technology will be overcome.

AC Transit is blazing a trail for this technology, so it could not seek input from other agencies when it ran into challenges. It supported development of the technology by providing performance data to FTA and NREL to help the industry learn, but it often was agency the first to overcome certain challenges, which is why this report is so important.

Lessons Learned from Extended Service

Fuel Cell Endurance

Several of AC Transit's fuel cells exceeded 30,000 hours of service, which demonstrates that fuel cell technology has the endurance necessary for transit applications and meeting the lifetime needed for the industry. Considering that the fuel cells were under warranty only for 10,000 hours, the fact that these buses have exceeded that amount three-fold should give agencies confidence in the reliability of the technology. This has significant implications for the technology, as it shows that fuel cell endurance is already at a level conducive to widespread commercialization.

Reliability

AC Transit's Van Hool buses showed that they are able to meet MBRC goals set by FTA. Although bus availability is, on average, still below the target, NREL has shown that fuel cell bus availability is improving with time and can be expected to meet the target in the near future. Availability also fluctuates, and for several months during the reporting period, the goal of 85% availability was exceeded, even reaching 89% availability in March 2018. The fact that the fuel cell system is comparable in reliability to other systems in terms of road call frequency and MBRC provides further evidence that this technology has great potential for use in the transit industry.

Comparison to Other Fuel Cell Projects

AC Transit's extended service included data on more buses than any other transit agency, making it the largest single source of FCEB information. It also has some of the longest-running FCEBs, which has provided invaluable information about the technology as it operates in service throughout the lifetime of both the buses and fuel cells.

Innovative Solutions

As AC Transit is one of the first agencies to employ FCEBs, it also has been the first to find many innovative solutions to issues with the technology. One example of this occurred when FC4's powerplant became weak and was experiencing low outlet power. With no known solution to this problem, the

initial thought was that the bus would have to be retired. AC Transit, however, had the idea to use a stack from FCII, which had already been retired, to replace the FC4's stacks; after repairs to one of FC4's other stacks, the bus was able to be put back into service and is still in service today.

Going Forward

Implications for Future Projects

Although the success of the FCEBs at AC Transit has helped pave the way for future developments in the technology, one of the largest limitations to the technology remains the discrepancy in price between fuel cell buses and their competitors. The cost of the infrastructure needed to support these buses and the cost of the buses themselves need to be addressed to allow this technology to reach its full commercialized potential. Initiatives that would help bring down the cost of FCEBs should be a priority in funding future projects of much larger scale, as increased volumes will be key to reducing costs and realizing the success of this zero-emission technology.

Opportunities for Further Study

AC Transit has already put the next generation of FCEBs (New Flyer 40-ft FCEBs with an 85-kW fuel cell and 100 kWh of batteries) into regular service that operate on many of the same routes as the Van Hool buses. The new buses are far exceeding the fuel efficiency of the Van Hool buses, achieving 9–10 miles/dge (diesel per gallon equivalent), compared to 6.6 miles/dge for the Van Hool buses. They have a range of 300 miles or more compared to 220 miles for the Van Hool buses.

Comparing the performance of these two FCEB types will provide an interesting opportunity to observe the progress of nearly 10 years of technology development. The Van Hool buses are also still being run daily, despite already having met or exceeded their expected lifespan. There will be a lot to learn from these buses as they continue to operate.

AC Transit will continue to monitor the performance of the Van Hool buses and compare them with its new fleet of New Flyer buses, as well as a small fleet of battery-electric buses. DOE has funded NREL to monitor and evaluate the New Flyer buses at AC Transit, Orange County Transportation Authority, and SunLine Transit.



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