FTA Report No. 0205

FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

National Fuel Cell Bus Program: Ohio Bus 2
Final Report

PREPARED BY

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CALSTART

U.S. Department of Transportation
Federal Transit Administration

NOVEMBER
2021

COVER PHOTO

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U.S. Department of Transportation
1200 New Jersey Avenue, SE
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AVAILABLE ONLINE
https://www.transit.dot.gov/about/research-innovation

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
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	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

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
November 2021	Final	

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
National Fuel Cell Bus Program: Ohio 2 Bus, Final Report	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROGRAM NUMBER
Bryan Lee	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSE(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
CALSTART 48 South Chester Avenue Pasadena, CA 91106	FTA Report No. 0205

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
U.S. Department of Transportation Federal Transit Administration Office of Research, Demonstration and Innovation 1200 New Jersey Avenue, SE, Washington, DC 20590	FTA
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12 . DISTRIBUTION/AVAILABILITY STATEMENT
Available from: National Technical Information Service (NTIS), Springfield, VA 22161; (703) 605-6000, Fax (703) 605-6900, email [orders@ntis.gov]; Distribution Code TRI-30

13. SUPPLEMENTARY NOTES [www.transit.dot.gov/research-innovation/fta-reports-and-publications] [https://www.transit.dot.gov/about/research-innovation] [https://doi.org/10.21949/1520691] Suggested citation: Federal Transit Administration. National Fuel Cell Bus Program: Ohio 2 Bus, Final Report. Washington, D.C.: United States Department of Transportation, 2021. https://doi.org/10.21949/1520691.

14. ABSTRACT

This report provides an overview of the "Ohio 2" fuel cell bus demonstrated at the Stark Area Regional Transit Authority (SARTA) under the Federal Transit Administration (FTA) National Fuel Cell Bus Program. The objective of this project was to develop and demonstrate next generation Buy America-compliant fuel cell buses in a large transit fleet environment and to operate the bus in cold climate conditions and accelerate the commercialization of this technology.

15. SUBJECT TERMS
National Fuel Cell Bus Program, fuel cell bus, SARTA

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	Unlimited	16	19b. TELEPHONE NUMBER

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Abstract

This report provides an overview of the “Ohio 2” fuel cell bus demonstrated at the Stark Area Regional Transit Authority (SARTA) under the Federal Transit Administration (FTA) National Fuel Cell Bus Program. The objective of this project was to develop and demonstrate next generation Buy America-compliant fuel cell buses in a large transit fleet environment and to operate the bus in cold climate conditions and accelerate the commercialization of this technology.

Executive Summary

This report provides an overview of the "Ohio 2" fuel cell bus demonstrated at the Stark Area Regional Transit Authority (SARTA) under the Federal Transit Administration (FTA) National Fuel Cell Bus Program. The objective of this project was to develop and demonstrate next generation Buy America-compliant fuel cell buses in a large transit fleet environment and to operate the bus in cold climate conditions and accelerate the commercialization of this technology.

Statement of Work

The fuel cell electric bus tested was manufactured by ElDorado National in partnership with FTA, CALSTART, BAE Systems, Ballard Power Systems, and SARTA. The bus is an FTA Buy America-compliant vehicle referred to as the "Ohio 2" bus operated by SARTA in the Canton, Ohio, region. The bus was demonstrated by SARTA and operated on local and regional routes. Hydrogen fueling infrastructure was constructed in parallel to this project. SARTA collected operating data throughout the testing period, allowing the project team to evaluate the performance and reliability of the Ohio 2 bus.

The bus was funded by the National Fuel Cell Bus Program (NFCBP), and the project started in 2011. The original fleet demonstration partner was the Chicago Transit Authority; SARTA later stepped in to serve as the fleet partner.

Project Goals

The objective of this project was to further the technological and commercial development of fuel cell buses and to understand their performance in real-world conditions. The demonstration allowed the project partners to demonstrate the bus, obtain real-world performance data, and continue to refine the bus design and maintainability.

This project also examined FCEBs and hydrogen fueling in cold climates. The goal of this aspect of the project was to investigate methods for improving cold weather performance of the bus and hydrogen fueling. This study focused on technologies that could improve the cold weather performance of the bus, including fuel cell waste heat capture, climate-controlled seating, hydrogen fuel-fired heaters, insulation and air curtains, and high-pressure 700-bar hydrogen fueling. This study is important because it examined the feasibility of implementing these technologies and can guide future technology demonstrations for confronting cold climate bus performance.

Section 1

Ohio 2 Bus History

The National Fuel Cell Bus project is intended to fund the development of FCEBs so they can pass Altoona testing and be demonstrated under real-world conditions at a transit agency.

The Ohio 2 bus was developed and arrived at Altoona in early April 2016. The bus was prepared to begin Altoona testing; however, the testing was delayed because there was no hydrogen fueling infrastructure onsite at Altoona. In March 2017, hydrogen fueling infrastructure was installed and testing began. Between December 2017 and February 2018, testing was delayed due to problems with obtaining usable data during the fuel economy test. In February 2018, a successful fuel economy test was completed. The bus completed Altoona testing in Q4 of 2018 and was sent to the Stark Area Regional Transit Authority (SARTA) to begin operations.

The bus entered transit service at SARTA in March 2019. In August 2019, the bus experienced problems with the air conditioning system and was removed from service until the system could be repaired; the bus returned to service in October 2019. In February 2020, there was a problem with the fuel cell that required repair, and the bus was temporarily removed from service. In April 2020, a stress fracture was discovered in the frame of the bus; the manufacturer conducted welding on the bus frame to fix the problem. The bus returned to service in June 2020. The bus was also taken out of service in August 2020 due to a problem with a hydrogen tank valve, which caused a fuel leak; the bus returned to service in October 2020.

In 2019, CALSTART requested a no-cost time extension until March 2021. This extension, which extended the time the bus was in service and allocated funding for a cold weather bus study, was approved by FTA.

Section 2

Engineering Overview

The Ohio 2 bus is a Buy America-compliant FCEB being demonstrated at SARTA. It was manufactured by ElDorado National in partnership with FTA, CALSTART, BAE Systems, Ballard Power Systems, and SARTA. The project leveraged technical expertise from all partners to develop this new-generation FCEB.

The Ohio 2 bus was built on the ElDorado National Axess 40-ft chassis, the same chassis used by ElDorado National's diesel and CNG buses. The bus employed Ballard Power's FCvelocity-HD6TM fuel cell, which was designed specifically for transit applications. This power plant is an advanced fuel cell that employs new technologies such as a robust Membrane Electrode Assembly and advanced balance-of-plant components. It is also scalable, and its output can be customized to the specific application it serves. The power plant on the Ohio 2 bus is 150 kW. This fuel cell powered the drivetrain, a HD200 Hybrid Drive Propulsion System manufactured by BAE Systems that provides power to batteries on the roof of the bus and the AC Traction Motor. The bus also has a regenerative braking system.

The Ohio 2 bus was manufactured at ElDorado National's plant in Riverside, California; it went through Altoona testing at Penn State before being sent to SARTA for revenue service.

Outreach

The Ohio 2 bus was loaned to other transit agencies through SARTA's Borrow-A-Bus program, which allows other transit agencies to borrow one of SARTA's FCEBs at no cost. The objective of the program is to allow transit agencies to demonstrate and gain hands-on experience with FCEBs.

Section 3

Bus Performance

The Ohio 2 bus entered service at SARTA on March 15, 2019, and has been operating since then. During the demonstration, on average, the bus was driven 1,610 miles and consumed 304 kg of hydrogen at a cost of $1,822 per month. The bus was used an average of 10 days per month. It is important to note that there were some major bus outages that affected these averages. Excluding the months in which the bus experienced major outages, the bus averaged 2,318 miles driven and 437 kg of hydrogen consumed per month at a cost of $2,620. The average days of service per month increased to 15. These adjusted averages better reflect normal service levels. The maximum number of miles the bus was driven in a month was 3,721 miles.

During the demonstration, there were a few problems that took the bus out of service. In August 2019, the air conditioning system on the bus became inoperable and the bus had to be removed from service until October 2019. In February 2020, there was a problem with the fuel cell and the bus had to be removed from service for repair. In April 2020, a crack was discovered on the frame, and the bus was sent to ElDorado National so the frame could be welded. The bus returned to service in June 2020. In August 2020, the bus experienced a fuel leak and had to be repaired; the bus returned to service in late November 2020.

The activities of the bus were also tracked over the duration of the demonstration, including number of days the bus was in service, undergoing maintenance, out of service due to a bus problem, or on loan through the Borrow-a-Bus program.

The majority of the days the bus was out of service were due to the major problems noted. With the exception of these issues, the bus was highly reliable and did not experience any other major problems. This is important because some of the problems, such as the stress fracture in the frame, were rare and unlikely to occur in the future. Most problems were in auxiliary equipment, the bus frame, or systems that support the drivetrain/fuel cell. The drivetrain was very reliable during this demonstration.

Month	Miles of Service	Kg of Hydrogen	Hydrogen Cost	Days of Service
March 2019	1,526	316.63	$1,899.78	10
April 2019	1,297	203.26	$1,220.16	8
May 2019	1,563	232.69	$1,396.14	10
June 2019	2,721	471.36	$2,828.16	15
July 2019	1,556	265.38	$1,592.28	11
August 2019	2,046	361.45	$2,168.70	14
September 2019	0	0	$0.00	0
October 2019	3,572	621.84	$3,731.04	22
November 2019	1,761	338.07	$2,028.42	15
December 2019	3,580	732.19	$4,393.14	24
January 2020	3,056	634.53	$3,807.18	24
February 2020	0	0	$0.00	0
March 2020	3,237	610	$3,660.00	19
April 2020	1,457	258.2	$1,549.20	8
May 2020	0	0	$0	0
June 2020	216	59.33	$355.98	3
July 2020	1,636	336.39	$2,018.34	9
August 2020	0	0	$0.00	0
September 2020	0	0	$0.00	0
October 2020	0	0	$0.00	0
November 2020	626	108.95	$653.70	3
December 2020	2,798	597.34	$3,584.04	17
January 2021	2,787	568.51	$3,411.06	16
February 2021	1,092	225.85	$1,355.10	8
March 2021	3,721	650.04	$3,900.24	19
Total	**40,248**	**7,592.00**	**$45,553**	**255**

Month	Days in Service	Days Conducting Maintenance/ PMI	Days of Outage Due to Bus Problem	Days on Loan (Borrow-a-Bus Program)
March 2019	10	1	0	0
April 2019	8	0	6	9
May 2019	10	5	1	0
June 2019	15	5	0	0
July 2019	11	5	8	0
August 2019	14	2	11	0
September 2019	0	0	23	0
October 2019	22	5	2	0
November 2019	15	6	0	2
December 2019	24	2	0	0
January 2020	24	4	0	0
February 2020	0	0	23	0
March 2020	19	0	4	0
April 2020	8	0	13	0
May 2020	0	0	25	0
June 2020	3	7	13	0
July 2020	9	2	16	0
August 2020	0	0	26	0
September 2020	0	0	24	0
October 2020	0	0	27	0
November 2020	3	3	17	0
December 2020	17	4	0	0
January 2021	16	6	0	0
February 2021	8	0	11	0
March 2021	19	5	0	0
Total	**255**	**62**	**250**	**11**

Cold Weather Bus Performance Study

CALSTART conducted a study to investigate technologies that can improve the cold climate performance of zero emission buses. HVAC and thermal management systems are responsible for a large portion of bus energy consumption during operation in cold climates. Buses also have unique HVAC needs because the bus doors open frequently, which leaks conditioned air out to the external environment. As a result, this study focused on investigating methods and technologies for reducing HVAC load and technologies such as fuel cell waste heat capture, heat pumps, hydrogen catalytic fuel-fired heaters, climate-controlled seating, insulation and air curtains, and 700-bar hydrogen

fueling. The study investigated the feasibility of integrating these technologies into the bus. Based on this information, technology demonstrations were proposed and research methodologies were developed for these demonstrations. The results of this study are included in a separate report.

Section 4

Conclusion

The demonstration of the Ohio 2 bus is valuable for SARTA and the transit industry. The development of the Ohio 2 bus helped to advance commercialization of FCEB technology. Through this demonstration, SARTA was able to gain valuable experience operating the latest generation of FCEBs and associated infrastructure. This project allowed SARTA to learn more about operating and maintaining the buses as well as planning for an FCEB fleet. This knowledge is important for deploying a larger fleet and eventually completing the transition to a 100% zero-emission fleet. Furthermore, through the Borrow-a-Bus program, SARTA helped other transit agencies learn more about deploying FCEBs. This project has also allowed SARTA to communicate best practices with fleets that are interested in demonstrating or purchasing FCEBs.

This demonstration allowed for the collection of valuable data about the buses. During the demonstration, there were a few problems that took the buses out of service for lengthy periods, which delayed the demonstration. However, they highlighted the need to budget additional time into future demonstrations to provide sufficient time to deal with problems that may arise. This demonstration also provided valuable insight into the type of problems an FCEB can experience. Although the problems that emerged took the bus out of service for substantial periods of time, many were related to non-drivetrain issues. During the demonstration, the systems that caused the longest outages occurred in the HVAC system, the bus frame, and in valves and balance-of-plant components. It is important to note that the drivetrain itself had few problems and proved to be very reliable.

The cold weather bus performance study is valuable for the industry. Zero-emission buses tend to perform poorly in cold weather because the HVAC system consumes large quantities of energy. This study examined technological solutions that have the potential to address this problem and the feasibility of integrating these technologies into a zero-emission bus. The study also proposed demonstrations and provided a research methodology that can be used to examine the performance of these technologies. The study can help to guide future research and demonstrations of cold weather bus technology, which will help industry overcome the cold weather bus problem.

After this demonstration, SARTA will continue to use the bus for the remainder of its 12 year/500,000 mile service life. This bus will join SARTA's fleet which, including the Ohio 2 bus, currently consists of 12 40-ft FCEBs and 5 fuel cell shuttle buses, making SARTA's fleet the largest FCEB fleet outside of California.

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