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Fuel Cell Buses in U.S. Transit Fleets: Current Status 2009

Technical Report
NREL/TP-560-46490
October 2009

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Federal Transit Administration

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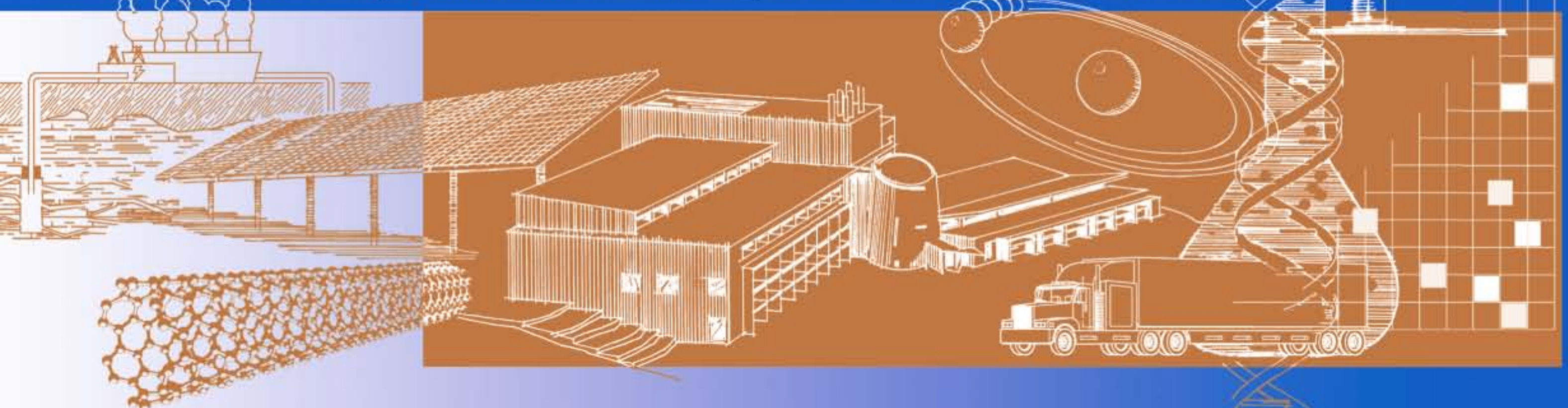

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Acronyms and Abbreviations

AC Transit	Alameda-Contra Costa Transit District
APTA	American Public Transportation Association
BAAQMD	Bay Area Air Quality Management District
BC	British Columbia
CARB	California Air Resources Board
CATA	Centre Area Transportation Authority
CNG	compressed natural gas
CTE	Center for Transportation and the Environment
CTTRANSIT	Connecticut Transit
CUTE	Clean Urban Transport for Europe
DGE	diesel gallon equivalent
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EDSP	Electric Drive Strategic Plan
EDTA	Electric Drive Transportation Association
FC	fuel cell
FCB	fuel cell bus
ft	feet
FTA	Federal Transit Administration
GEF	Global Environmental Facility
GGT	Golden Gate Transit
GVWR	gross vehicular weight rating
HCNG	hydrogen and compressed natural gas
HHICE	hydrogen hybrid internal combustion engine
HICE	hydrogen internal combustion engine
hp	horsepower
ICE	internal combustion engine
in	inches
kg	kilogram
kW	kilowatts
kWh	kilowatt-hours
lb	pounds
MBRC	miles between road calls
mpg	miles per gallon
mph	miles per hour
MTC	Metropolitan Transportation Commission
NAVC	Northeastern Advanced Vehicle Consortium
NFCBP	National Fuel Cell Bus Program
NREL	National Renewable Energy Laboratory
NYCT	New York City Transit
OEM	original equipment manufacturer
PEM	proton exchange membrane
psi	pounds per square inch
RC	road call

rpm	revolutions per minute
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SamTrans	San Mateo County Transit District
SFMTA	San Francisco Municipal Transportation Agency
SOC	state of charge
UNDP	United Nations Development Program
VTA	Santa Clara Valley Transportation Authority
WMATA	Washington Metropolitan Area Transit Authority
ZEB	zero-emission bus
ZEBA	Zero Emission Bay Area

Executive Summary

This report documents progress in meeting the technological challenges of fuel cell propulsion for transportation based on current fuel cell transit bus demonstrations and plans for more fuel cell transit buses and hydrogen infrastructure. Introducing new types of buses into the transit world is a well-understood, if sometimes challenging, process involving testing, demonstration, and limited production using increasingly greater numbers of vehicles. The three steps to introduce transit buses with fuel cell propulsion technology are:

Step 1. Operational field testing and design shakedown (one to three vehicles)

Step 2. Full-scale operational demonstration and fleet-ready reliability testing (five to twenty vehicles at several locations)

Step 3. Limited production and full operation (50 to 100 vehicles at a small number of locations)

Based on the number of buses in operation (currently 10 fuel cell buses in six locations in the United States), fuel cell transit bus introduction in North America is currently in step one. However, current plans in the United States and Canada will change this status from step one to step two within the next year. Three major programs are driving this progression:

- **Federal Transit Administration's (FTA) National Fuel Cell Bus Program (NFCBP)—**This $49 million, multi-year, cost-share research program for developing and demonstrating commercially viable fuel cell technology for transit buses provides for 11 new fuel cell buses. The NFCBP includes developing the new buses, expanding the fuel cell manufacturers beyond Ballard and UTC Power to include Hydrogenics and Nuvera, and exploring multiple bus sizes and hybrid propulsion designs. The demonstration of these buses completes much of the research needed for step one for the introduction of fuel cell propulsion technology into transit.
- **Zero Emission Bay Area (ZEBA) Group Demonstration—**This San Francisco Bay-area demonstration includes 12 next-generation fuel cell transit buses with redesigned Van Hool chassis, the newest UTC Power fuel cell power system, and fully integrated hybrid propulsion system. The ZEBA group demonstration is led and hosted by AC Transit and includes Santa Clara VTA, Sam Trans, Golden Gate Transit, and San Francisco Municipal Transportation Agency. This demonstration of 12 fuel cell buses represents progress toward step two in introducing transit buses with fuel cell propulsion technology.
- **BC Transit Fuel Cell Bus Demonstration**—This demonstration includes 20 fuel cell buses that will operate before, during, and after the 2010 Olympic Winter Games in Whistler, BC, Canada. The demonstration will comprise the world's largest fleet of fuel cell buses and hydrogen fueling in one transit location. The buses are from New Flyer, use Ballard fuel cells, and have hybrid propulsion from ISE/Siemens. This demonstration also represents progress to step two in introducing transit buses with fuel cell propulsion technology.

By the end of 2010, fuel cell transit buses in North America will include 10 buses currently in service, 43 new buses in three programs (NFCBP, ZEBA, and BC Transit), and 8 additional buses from other programs. When AC Transit receives its 12 new buses, it will remove its 3 existing buses from service and send them to UTC Power, adding a net of 9 buses, making a total of 58 fuel cell transit buses in operation in North America within the next two years.

This status report also provides an analysis of the combined results from three fuel cell transit bus demonstrations (AC Transit, Connecticut Transit, and SunLine) evaluated by the U.S. Department of Energy (DOE) National Renewable Energy Laboratory (NREL) using data from August 2008 through July 2009. Individual evaluation reports for each of the three demonstrations are listed in the "References" section and are provided at www.nrel.gov/hydrogen/proj_fc_bus_eval.html.

In the next few years, the United States will progress through stage-one introduction of fuel cell transit buses. Planned demonstrations will continue to address the following areas:

- **Bus performance**—The purpose of step-one demonstrations of fuel cell transit buses is to prove reliability and begin assessing fuel cell power systems and related components for durability. Hybrid/fuel cell systems must also be optimized for reliability and durability. Newer/next-generation fuel cell buses are optimizing on-board hydrogen storage and packaging. Step one is nearing completion in North America with larger orders of fuel cell buses for the ZEBA and BC Transit demonstrations.
- **Fueling stations and hydrogen source**—Providing wider and better fuel availability and optimizing fueling station sizes for multiple vehicles requires more hydrogen fueling stations. Scaling of hydrogen fueling stations will also be needed as larger fleets of fuel cell buses are demonstrated. In addition, it is important to prove that fuel can be clean and "green" at the same time for hydrogen produced and delivered at dispensing stations.
- **Preparation for market introduction**—Demonstration of larger numbers of hydrogen fuel cell transit buses requires market preparation, including assessing the availability of technologies and products; training fleet personnel and the public; developing codes and standards; and continuing data collection, analysis, and reporting.
- **Cost reduction**—Considering their current high capital cost, a priority regarding fuel cell transit buses is cost reduction. Cost reduction sufficient to make fuel cell buses competitive in the marketplace must be validated. However, purchase price has little relevance if the buses cannot meet performance standards. After fuel cell bus designs have proven performance and durability, the industry can investigate ways to reduce the cost of buses and replacement components. As with all developmental technologies, larger-quantity orders can help manufacturers develop low-cost manufacturing techniques. The industry also needs to investigate ways to lower operational costs.

With current and new funding, including funding under the American Reinvestment and Recovery Act of 2009 and a new or extended surface transportation authorization, additional opportunities for fuel cell bus introductions are possible.

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Introduction

This status report is the third in a series of annual status reports from the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL).[1] It summarizes progress and accomplishments from demonstrations of fuel cell transit buses in the United States. The U.S. Department of Transportation's (DOT) Federal Transit Administration (FTA) funds the transit bus demonstrations. Since 2000, DOE has funded NREL's evaluation of hydrogen and fuel cell bus demonstrations; including buses, infrastructure, and each transit agency's implementation experience. More recently, as described in a joint evaluation plan,[2] FTA has also funded NREL's evaluation of additional demonstrations.

Scope and Purpose

This annual status report discusses the status and challenges of fuel cell propulsion for transportation and summarizes the introduction of fuel cell transit buses in North America. It provides an analysis of the combined results from fuel cell transit bus demonstrations evaluated by NREL with a focus on data from August 2008 through July 2009. NREL also periodically evaluates the operating experience and costs of these demonstrations individually, and posts the individual reports at http://www.nrel.gov/hydrogen/proj_fc_bus_eval.html. The "References" section lists these reports, each of which is an unbiased assessment of a transit agency's experience implementing fuel cell bus operations.

Because this report combines results for fuel cell transit bus demonstrations across the United States and discusses the path forward for commercial viability of fuel cell transit buses, this report is useful to inform DOE and FTA decision makers regarding research and funding; state and local government agencies that fund new propulsion technology transit buses, such as the California Air Resources Board (CARB); and interested transit agencies and industry manufacturers.

Organization

This report is organized in seven sections. The section "Fuel Cell Propulsion for Transportation" discusses the status and challenges of fuel cell propulsion for transportation. The section "Introduction of Fuel Cell Transit Buses" describes the status of fuel cell transit bus introduction in the United States and across the world. It summarizes existing demonstrations and lessons learned in the United States; provides an overview of FTA's National Fuel Cell Bus Program (NFCBP); describes two new North American fuel cell transit bus demonstrations; and briefly summarizes a few demonstrations in Europe, Asia, and South America.

The section "Update of Evaluation Results, August 2008 – July 2009" presents the results of the most recent NREL evaluations of three fuel cell transit bus demonstrations with comparisons for availability, fuel economy, and roadcalls. The section "Progress and Needs" discusses the United States' progress in introducing fuel cell transit buses in commercial service with specific attention to bus performance, hydrogen sources and fueling stations, and cost reduction. The

[1] Previous reports are *Fuel Cell Buses in U.S. Transit Fleets: Summary of Experiences and Current Status*, September 2007, NREL/TP-560-41967; and *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2008, December 2008*, NREL/TP-560-44133.

[2] *Hydrogen and Fuel Cell Transit Bus Evaluations, Joint Evaluation Plan for the U.S. Department of Energy and the Federal Transit Administration*, 2008, NREL/MP-560-42781

section “Future Funding for Fuel Cell Bus Demonstrations in the United States” reviews potential funding for future research and expanded fuel cell transit bus demonstrations. The “References” section provides references for NREL’s periodic evaluations of the individual fuel cell bus demonstrations.

Fuel Cell Propulsion for Transportation

The U.S. government funds a great deal of research to develop clean and “green” energy sources and energy-efficient technologies, and to address atmospheric pollution and climate change. Fuel cells have high potential to address both energy and environmental concerns.

Fuel cells are already successfully proven in applications such as back-up power, stationary power generation, and material handling equipment. These markets offer high-value propositions with few technical barriers, which means business cases can be achieved in the near term. Developing fuel cells for transportation applications is more complicated because of varied and rigorous operating environments and packaging challenges. Although progress has been made, challenges still exist to widespread introductions in the transportation market. Proving fuel cell durability and reliability; optimizing hybrid–fuel cell system designs, including energy storage (specifically batteries); building hydrogen fueling stations; determining the best sources for hydrogen; and lowering costs are just a few of these challenges.

This report examines and documents the progress toward meeting the technological challenges of fuel cell propulsion for transportation based on real fuel cell transit bus implementation experience and plans for additional fuel cell transit buses and hydrogen infrastructure. Centralized fueling, fixed route service, professional operation and maintenance, and greater exposure to raise public awareness make transit buses an excellent platform for continued testing of fuel cell propulsion for transportation.

Introduction of Fuel Cell Transit Buses

Introducing new types of buses into the transit industry is a well-understood, if sometimes challenging, process involving testing, demonstration, and limited production using increasingly greater numbers of vehicles. The three steps to introducing transit buses with fuel cell propulsion technology are:

Step 1. Operational field testing and design shakedown (one to three vehicles)

Step 2. Full-scale operational demonstration and fleet-ready reliability testing (five to twenty vehicles at several locations)

Step 3. Limited production and full operation (50 to 100 vehicles at a small number of locations)

Based on the number of buses in operation, fuel cell transit bus introduction in North America is currently in step one. However, current plans in the United States and Canada will change this status from step one to step two within the next year.

This section discusses the status of fuel cell buses planned and in operation in North America and the world. It summarizes existing demonstrations and lessons learned; provides an overview of FTA's National Fuel Cell Bus Program (NFCBP); describes two new North American fuel cell transit bus demonstrations; and briefly summarizes several demonstrations in Europe, Asia, and South America. FTA also reported on these and other fuel cell bus demonstrations in *A Report on Hydrogen Bus Demonstrations Worldwide, 2002-2007.*[3]

Fuel Cell Buses in Operation in the United States

Table 1 lists current fuel cell transit bus demonstrations in the United States. These demonstrations focus on identifying improvements to optimize reliability and durability. As of August 2009, ten fuel cell buses were in service at six locations in the United States. See the "References" section for details on the reports discussed.

NREL evaluated the first four demonstrations in Table 1. NREL has not evaluated the University of Delaware or University of Texas demonstrations, which, to date have not released technical results to the public.

- **Alameda-Contra Costa Transit District (AC Transit)**—Demonstration of three Van Hool buses with UTC Power fuel cell power system in a hybrid propulsion system. Data collection began in March 2006. NREL completed three evaluation reports for DOE with operations data through December 2007 and one evaluation report for FTA with operations data through October 2008. NREL will complete a second evaluation for FTA with operations data through October 2009.

- **Connecticut Transit (CTTRANSIT)—**Demonstration of one Van Hool bus with UTC Power fuel cell power system in a hybrid propulsion system. Data collection began in April 2007. NREL completed two evaluation reports for DOE with operations data

[3] Curtin, S., L. Jerram, and L. Justice. 2009. *A Report on Hydrogen Bus Demonstrations Worldwide, 2002-2007*. FTA-GA-04-7001-2009.01

through February 2009. NREL will complete a third report for DOE with operations data through November 2009.

- **SunLine Transit Agency—**Demonstration of one Van Hool bus with UTC Power fuel cell power system in a hybrid propulsion system. Data collection began in January 2006. NREL completed five evaluation reports for DOE for operations data through June 2009 and will continue to evaluate this demonstration.

- **Santa Clara Valley Transportation Authority (VTA)—**Demonstration of three Gillig buses with Ballard fuel cell stacks in a non-hybrid propulsion system. NREL completed two evaluation reports for DOE with operations data from March 2005 through July 2006. Two of the three fuel cell buses are still operational although not in scheduled service.

This report does not discuss the VTA demonstration further. The section "Update of Evaluation Results, August 2008 – July 2009" provides the most recent evaluation results for the three ongoing demonstrations at AC Transit, **CT**TRANSIT, and SunLine.

Table 1. Current Fuel Cell Transit Bus Demonstrations in the United States

Bus Operator	Location	Total Buses	Active Buses	Technology Description
AC Transit	Oakland, CA	3	3	Van Hool bus with UTC Power fuel cell system, ISE hybrid system
CTTRANSIT	Hartford, CT	1	1	Van Hool bus with UTC Power fuel cell system, ISE hybrid system
SunLine Transit Agency	Thousand Palms, CA	1	1	Van Hool bus with UTC Power fuel cell system, ISE hybrid system
Santa Clara Valley Transportation Authority	San Jose, CA	3	2	Gillig bus with Ballard fuel cell stacks (non-hybrid)
University of Delaware (Phase 1 & 2)	Newark, DE	2	2	Ebus battery dominant plug-in hybrid using Ballard fuel cells (22-ft)
University of Texas	Austin, TX	1	1	Ebus battery dominant plug-in hybrid using Ballard fuel cells (22-ft)
	Total	**11**	**10**	

National Fuel Cell Bus Program (NFCBP)

In 2007, following the implementation of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU),[4] FTA initiated the National Fuel Cell Bus Program (NFCBP), a $49 million, multi-year, cost-share research program for developing and demonstrating commercially viable fuel cell technology for transit buses. The program included eight demonstration, two component, and four outreach projects.

The outreach projects are now underway, and the two component research projects (an integrated auxiliary module and a bi-directional converter, each for a fuel cell bus) are complete. The

[4] Signed into law in August 2005, SAFETEA-LU governs United States federal surface transportation spending.

demonstration teams are currently completing the design and early construction phases of the buses. Because not all of the demonstrations received funding during the first year, the bus designs and development are in different stages.

The demonstrations under FTA's NFCBP include developing new buses; expanding the fuel cell manufacturers beyond Ballard and UTC Power to include Hydrogenics and Nuvera; and exploring multiple bus sizes and hybrid propulsion designs. Table 2 lists the 11 new buses planned for 7 demonstrations. The demonstration of these individual buses completes much of the research needed for step one for the introduction of fuel cell propulsion technology into transit.

Table 2. New Fuel Cell Transit Buses Planned for the FTA NFCBP

Project	Location	Total Buses	Technology Description
American FCB – SunLine (NFCBP – CALSTART)	Thousand Palms, CA	1	Next-generation advanced design to meet 'Buy America' requirements
Compound FCB for 2010 (NFCBP – CALSTART)	San Francisco, CA	1	Daimler/BAE diesel hybrid with Hydrogenics fuel cell APU
Hydrogen Hybrid FCB (NFCBP – CTE)	Columbia, SC	1+2[a]	Proterra battery-dominant, plug-in hybrid with Hydrogenics fuel cells
Lightweight FCB Demo (NFCBP – NAVC)	Albany, NY	1	Lightweight bus with a hybrid system using advanced batteries and a Hydrogenics fuel cell
Massachusetts FCB Demo (NFCBP – NAVC)	Boston, MA	1	Hybrid bus using Nuvera fuel cells and an advanced battery system
New York Power Authority FCB Demo (NFCBP – NAVC)	NY	2	Advanced hybrid fuel cell bus
Connecticut 'Nutmeg' FCB Demo (NFCBP – NAVC)	Hartford, CT	4+1[b]	Van Hool hybrid FCB with new design UTC Power fuel cell
NFCBP Total New Buses		**11**	

a – Proterra also plans deliveries of this bus design to the City of Burbank in California and Ft. Lewis in Tacoma, WA.
b – **CT**TRANSIT intends to order an additional Van Hool fuel cell bus not part of the NFCBP.

The eighth NFCBP demonstration is a follow-on to the existing operation of three fuel cell buses at AC Transit. NFCBP funded AC Transit and UTC Power to accelerate testing of the three existing buses and to study root causes of failures or problems with the fuel cell power systems. This demonstration is underway, and NREL has already reported evaluation results. NREL plans a second report with operational data through October 2009. This three-bus demonstration will eventually transition into AC Transit's demonstration of 12 new fuel cell buses (see "Zero Emission Bay Area (ZEBA) Group Demonstration" below).

The Compound Fuel Cell Bus for 2010 demonstration with BAE Systems is underway. The fuel cell system and associated components are being procured, tested, and installed on a diesel hybrid bus with BAE Systems' hybrid drive system. The hybrid bus includes an integrated starter generator, electric accessories, and lithium ion batteries for energy storage. The bus is planned for demonstration at San Francisco Municipal Transportation Agency (SFMTA).

Proterra is a new bus manufacturer. The first Proterra fuel cell bus was delivered as part of the NFCBP in August 2009 to Central Midlands Regional Transit Authority (CMRTA) in Columbia, SC. CMRTA will share operation of the bus with the University of South Carolina. Two more Proterra fuel cell buses are planned for delivery to the City of Burbank in California and to Ft. Lewis in Tacoma, WA. These buses are not part of the FTA NFCBP. NREL will evaluate the Columbia bus as part of the NFCBP. A project by the California Air Resources Board (CARB) provided most of the funding for the City of Burbank's bus. NREL will evaluate this bus as part of its DOE evaluations. NREL will also evaluate the Ft. Lewis bus through funding from the U.S. Department of Defense (DOD).

The Connecticut "Nutmeg" project with UTC Power is part of the next-generation Van Hool fuel cell buses with UTC Power fuel cell power systems that are planned for demonstration at AC Transit. The Nutmeg project includes four Van Hool buses that will operate primarily at **CT**TRANSIT. **CT**TRANSIT is also purchasing a fifth bus, which is not part of the NFCBP. The first Nutmeg bus is planned for delivery early in 2010, and the fifth bus is planned for delivery in mid-2010.

Beyond the NFCBP, FTA funds fuel cell bus research at several universities and transit agencies around the country.

- Georgetown University is developing a methanol reformer and fuel cell system on a 30-foot transit bus.
- University of Delaware research includes several fuel cell buses, the first two of which are already in service on campus. These buses are Ebus 22-ft shuttles powered by a battery-dominant system and a Ballard fuel cell. Future research will upgrade the system for a larger 30-foot bus platform (two buses planned).
- University of Texas FCB research also involves a 22-foot Ebus shuttle with a Ballard fuel cell system.
- The University of Alabama is developing a battery-dominant hybrid fuel cell system on one 30-foot bus body produced by EVAmerica. Hydrogenics is providing the fuel cell.
- SunLine is planning an Advanced Technology fuel cell bus. Manufacturers and schedule were not available at the time of this report.

Zero Emission Bay Area (ZEBA) Group Demonstration

Based on lessons learned from early demonstration, the manufacturers of the fuel cell buses in operation at AC Transit, SunLine, and **CT**TRANSIT improved their bus design and will soon field the next generation ZEBA 12-bus demonstration in Northern California. With more than three buses being deployed in one location, this demonstration, led by AC Transit, represents progress to step two in introducing transit buses with fuel cell propulsion technology.

The ZEBA demonstration grew out of CARB's 2000 "Fleet Rule for Transit Agencies" urban bus requirements,[5] which set more stringent emission standards for new urban bus engines and promoted advances in the cleanest technologies, specifically, zero-emission buses (ZEBs). Under

[5] Fact Sheet at http://www.arb.ca.gov/msprog/bus/ub/ubfactsheet.pdf.

the rule, agencies with more than 200 buses must include ZEBs as 15% of new bus purchases beginning in 2011. *Fuel Cell Buses in U.S. Transit Fleets: Summary of Experiences and Current Status*[6] describes the requirements of this rule in detail. Affected transit agencies on the "diesel fuel path" are required to participate in an advanced ZEB demonstration.

Currently, five agencies located in the San Francisco Bay area (AC Transit, Golden Gate Transit, VTA, SamTrans, and SFMTA[7]) are affected by the rule. These five Bay-area agencies joined to form the ZEBA demonstration group. These agencies, led by AC Transit, will demonstrate a minimum of 12 ZEBs.

Scheduled for delivery beginning in December 2009, the ZEBs are the next generation of fuel cell buses at AC Transit with a redesigned Van Hool chassis and the newest UTC Power fuel cell power system. The new hybrid system is now fully integrated by Van Hool using a Siemens ELFA 2 system and a lithium ion energy storage system by EnerDel. This advanced demonstration will continue the momentum of technology development and allow transit agency staff to gain more experience with the buses.

Besides AC Transit, all transit agencies in the ZEBA demonstration group will provide funding, participate in training activities, and periodically operate buses as part of the demonstration. Another focus of the ZEBA group demonstration is to prove hydrogen production that is more "green."

The ZEBA demonstration group is supported through funding and planning by the Metropolitan Transportation Commission (MTC), the Bay Area Air Quality Management District (BAAQMD), CARB, and the FTA NFCBP. This support includes purchase of 12 new fuel cell buses and two new hydrogen fueling facilities to expand fueling capability up to 420 kg/day. (AC Transit will replace the existing hydrogen station with a new one.)

The ZEBA demonstration was originally scheduled to begin by January 2009, and CARB staff was scheduled to report the early demonstration results to the Board by July 2009. However, because the procurement, design, and development of the fuel cell buses took longer than anticipated, no results were available in July. Instead, staff provided the Board with an informational report on the status of Zero-Emission Bus Regulation implementation and recommended the following actions:

- Delay the 15% purchase requirement to give staff time to gather at least one year of data on the next-generation fuel cell buses
- Continue the Advanced ZEB Demonstration of 12 buses in the Bay Area
- Develop performance criteria that the technology must meet before the purchase requirement is triggered
- Include a greenhouse gas reduction goal in the Transit Bus Rule.

[6] *Fuel Cell Buses in U.S. Transit Fleets: Summary of Experiences and Current Status*, September 2007, NREL/TP-560-41967, pages 10-11
[7] SFMTA already meets the requirements for ZEB with electric trolley buses. However, the agency has expressed interest in participation in the demonstration.

The Board agreed with staff recommendations and directed them to report back to the Board no later than December 2012 with any proposed modifications. For more information on the ruling, see www.arb.ca.gov/msprog/bus/zeb/zeb.htm.

The primary drawback of the ZEBA group demonstration for advanced fuel cell buses is that data from only one technology will become available. Participation from more manufacturers is needed to truly understand the status of the industry and allow CARB staff to make informed recommendations to the Board. To compensate, CARB staff will need to gather information from other demonstrations such as FTA's NFCBP and the BC Transit demonstration.

BC Transit Fuel Cell Bus Demonstration

As part of several environmental initiatives in British Columbia (BC), Canada, BC Transit plans a fuel cell bus demonstration of 20 buses to operate before, during, and after the 2010 Winter Games in Whistler, BC. The demonstration will comprise the world's largest fleet of fuel cell buses and hydrogen fueling in one transit location. The 20 new fuel cell buses are scheduled to arrive from September through December 2009. With more than three buses being deployed in one location, this demonstration also represents progress to step two in introducing transit buses with fuel cell propulsion technology.

This demonstration includes a four-year (2010-2014) evaluation of cost, performance, and service availability of New Flyer, low-floor, 40-foot buses with hybrid propulsion from ISE/Siemens; Valence lithium phosphate batteries for energy storage; Ballard, HD6 module, 150-kW fuel cell power systems; and Dynetek on-board hydrogen fuel storage that will store compressed hydrogen up to 5,000 psi.

The main hydrogen fueling will be from electrolyzers using hydro power with supplemental hydrogen gas recovered from waste gases. One permanent fueling station, located at Whistler, will include 1,000 kg/day of hydrogen capacity with liquid storage. The demonstration will also test a mobile fueler. Preproduction testing was completed in October 2008 and the first bus entered service in October 2009.

Fuel Cell Bus Demonstrations Outside North America

Many countries worldwide are investing in fuel cell bus technology and are funding demonstration projects to commercialize the technology. Knowledge of the major demonstrations outside North America facilitates our understanding of how the technology is progressing worldwide. Although this report focuses on U.S. projects, several international demonstrations are of interest:

- **Hamburg, Germany**—Hamburg is proactive on hydrogen vehicles and has operated a small fleet of Clean Urban Transport for Europe (CUTE) fuel cell buses for six years, since September 2003. As follow-on to the CUTE and HyFLEET:CUTE projects, EvoBus, a division of Daimler, has developed a next-generation hybrid fuel cell bus. The bus design incorporates the latest version fuel cell stacks from Ballard. EvoBus will demonstrate approximately 30 buses in several locations with at least 10 operating in Hamburg. Hamburg's fleet experience with fuel cell technology makes it an excellent partner for demonstrating the new buses.

- **London—**Transport for London will demonstrate a fleet of hybrid fuel cell buses in the city beginning around 2010. The current contract includes five fuel cell buses. In addition, the agency is investigating potential funding sources for three more buses.[8] The buses are an ISE hybrid design with a Ballard fuel cell system on a Wrightbus chassis. Because of traffic congestion, buses in London operate at very slow speeds and experience high passenger loads.

- **China**—Phase II of a United Nations Development Program (UNDP) Global Environmental Facility (GEF)-funded project will deploy six fuel cell buses in Shanghai. Selected under a competitive bid process, Shanghai Automotive Industry Corporation will provide the buses.

- **Brazil**—In 2009, the first fuel cell bus in South America was introduced for demonstration in São Paulo, Brazil. São Paulo expects delivery of four more buses in early 2010 and will place them in service along a metropolitan corridor. The characteristics of the bus service in São Paulo make this demonstration particularly interesting: 33 km (20.5 mi) of dedicated bus lanes with an average speed of 25 km to 27 km per hour (15 to 17 miles per hour) and heavy passenger loads of about 270,000 per day.

- **Korea**—Hyundai demonstrated several fuel cell buses as employee shuttles between its facilities around Seoul. Hyundai is now developing a second-generation bus for a follow-on demonstration.

[8] See www.tfl.gov.uk/corporate/projectsandschemes/environment/8444.aspx

Update of Evaluation Results, August 2008 – July 2009

Unless otherwise noted, the data presented below represent one year of bus operation, August 2008 through July 2009. Because the evaluation of AC Transit diesel baseline buses concluded in December 2007, data for these buses are from January 2007 through December 2007. For comparison, data are included from the earlier fuel cell system and from the entire data-collection period after the new fuel cell systems were installed. Appendix A summarizes information by demonstration location.

Prototype Demonstrations—The fuel cell transit buses presented in this section are prototype designs in the early demonstration and testing phase of development. The primary objective of fuel cell bus demonstrations is to learn from operational experience and incorporate the lessons learned into future designs. Demonstrations of prototype buses in real-world service are essential to validate technologies and identify modifications needed to increase reliability and durability for future commercial products. All manufacturers analyzed data from their particular designs and incorporated lessons learned into the next generation fuel cell bus designs.

Lessons learned following almost four years of operation of the five Van Hool/UTC Power fuel cell buses at AC Transit, **CT**TRANSIT, and SunLine include:

- The demonstrations focused on proving that fuel cell transit buses can function in standard revenue transit service. The Van Hool/UTC Power fuel cell buses continue to be in standard revenue service since early 2006.

- The fuel cell power system manufacturer iterated its design, components, and implementation to explore reliability improvements, and is implementing these improvements in its new products.

- The energy storage and amount of on-board hydrogen fuel storage selected for these demonstrations were not optimal. Energy storage was problematic because implementation was not optimized with the hybrid propulsion system, and manufacturing quality control and shipping requirements were lacking. Also, the amount of hydrogen onboard was more than needed. The next-generation bus will use lithium ion batteries and carry less hydrogen onboard. These changes will reduce the weight of the bus by 6,000 lbs. The next-generation bus will be only 2,000 lbs heavier than a standard diesel bus.

- Demonstration participants expended great effort to educate the public about hydrogen and fuel cell propulsion in the locations where fuel cell transit buses were deployed. Two of the three locations surveyed their passengers to enhance public awareness of the buses and to obtain public impressions. Occasionally, the buses were provided to other locations for public events.

- Hydrogen fuel production and dispensing infrastructure has worked well for the three locations. However, scaling up for larger demonstrations and “greening” hydrogen production and delivery will require additional research and testing.

As it places new buses into service, AC Transit will remove its three buses with Van Hool/UTC Power fuel cells from service and send them to UTC Power. The fuel cell buses at SunLine and **CT**TRANSIT will continue in their current service so long as their existing fuel cell power systems are operational. Operational data from these buses will allow UTC Power to continue assessing reliability and durability. Whether UTC Power will replace the power systems on these two buses after their end of useful life is undetermined at this time.

Bus Service Schedules—At the time of the 2008 status report, UTC Power had just completed installation of a new version of its fuel cell system in fuel cell buses at AC Transit, **CT**TRANSIT, and SunLine. After the installation, the transit agencies increased usage of their fuel cell buses. The accelerated service concluded during the data-reporting period for this report. By the end of the reporting period, the three transit agencies were using their buses at about 50% of average conventional transit bus use.

Total Miles and Hours—Table 3 shows miles, hours, average speed, and average monthly miles per bus for the fuel cell buses at AC Transit, **CT**TRANSIT, and SunLine. At 13.8 mph, the SunLine bus averaged the highest speed. AC Transit buses averaged 9.6 mph, and the **CT**TRANSIT bus averaged 6.9 mph. AC Transit fuel cell buses have the highest average monthly usage, about 2,300 miles per month. Compared to previous evaluation periods, all three transit agencies show increased monthly mileage accumulation.

Table 3. Miles and Hours for the Fuel Cell Buses

Site	Period	Months	No. of Buses	Miles	Hours	Avg. Speed (mph)	Avg. Monthly Miles
Early FC System Results							
AC Transit	4/06-10/07	19	3	60,198	5,499	10.9	1,023
SunLine	1/06-3/08	27	1	52,336	4,027	13.0	1,886
CTTRANSIT	4/07-12/07	10	1	4,554	886	5.6	516
New FC System Results							
AC Transit	11/07- 7/09	~19	3	112,210	11,452	9.8	2,044
SunLine	4/08-7-09	16	1	27,778	2,053	13.5	1,736
CTTRANSIT	1/08-7/09	19	1	28,631	4,272	6.7	1,507
Report Results Period							
AC Transit	8/08-7/09	12	3	83,156	8,636	9.6	2,310
SunLine	8/08-7/09	12	1	21,556	1,559	13.8	1,796
CTTRANSIT	8/08-7/09	12	1	18,900	2,738	6.9	1,575

Bus Use—Figure 1 shows the average monthly bus use for the fuel cell buses and their respective baseline buses. The three transit agencies continue to operate their fuel cell buses fewer miles than they operate their baseline buses. However, operation increased over time as the transit agencies worked to accelerate testing.

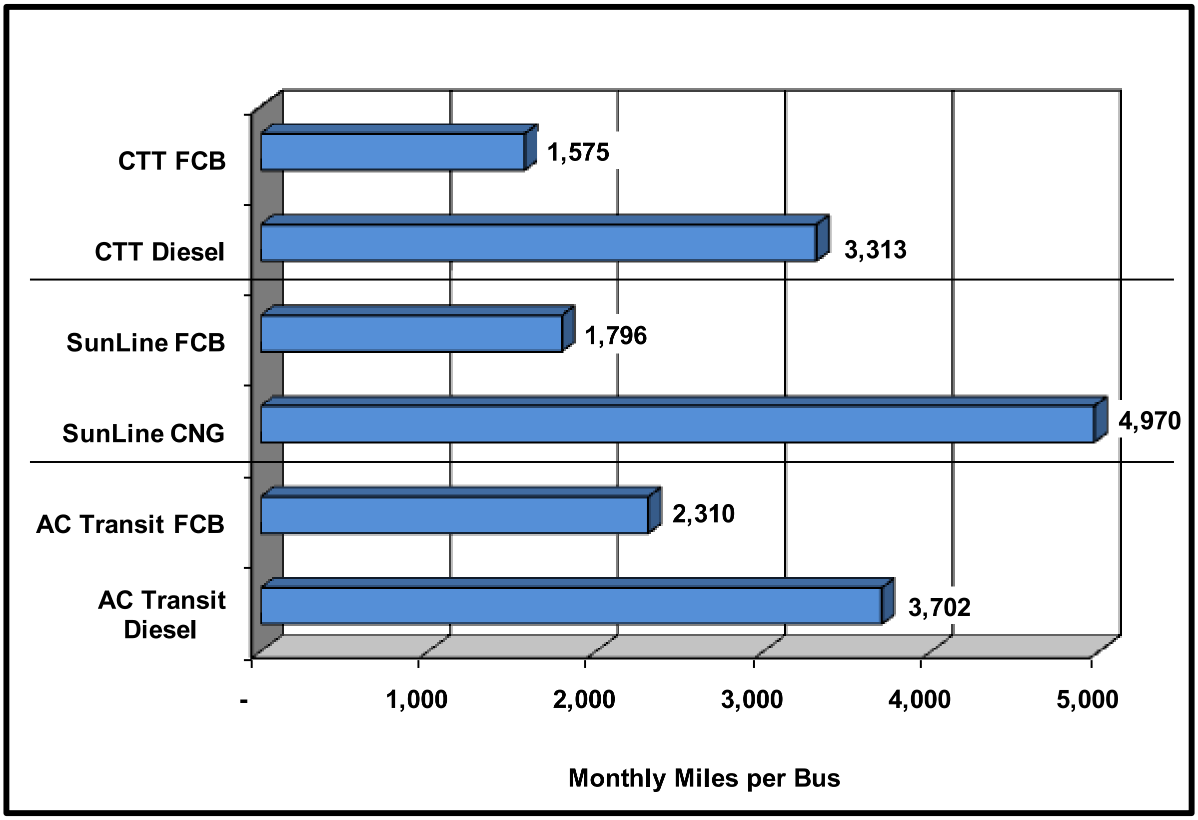

Figure 1. Average monthly miles per fuel cell and baseline buses

Availability—Availability is the percent of days that buses are planned for operation compared to the percent of days the buses are actually available. Table 4 summarizes the availability of the fuel cell buses at each transit agency. For this evaluation period, the fuel cell buses at AC Transit were available 69% of the time, the fuel cell bus at SunLine was available 63% of the time, and the fuel cell bus at **CT**TRANSIT was available 68% of the time. Figure 2 categorizes by transit agency the reasons that the buses were not available.

AC Transit's fuel cell buses were not available mostly due to transit-related repairs. Repairs were higher than last year for this location because several accidents required downtime for body work. AC Transit also had problems with the hybrid propulsion systems, primarily because of the batteries. Both SunLine's and **CT**TRANSIT's fuel cell buses had significant problems with the hybrid propulsion system and the traction batteries (both included in the hybrid propulsion category). SunLine also had a fueling station problem that kept its bus out of service for about a month.

Table 4. Availability for the Fuel Cell Buses

Site	Period	Months	No. of Buses	Planned Days	Days Avail.	% Avail.
Early FC System Results						
AC Transit	4/06-10/07	19	3	1,246	720	58
SunLine	1/06-3/08	27	1	653	432	66
CTTRANSIT	4/07-12/07	10	1	192	87	45
New FC System Results						
AC Transit	11/07- 7/09	~19	3	1,463	868	59
SunLine	4/08-7-09	16	1	419	274	65
CTTRANSIT	1/08-7/09	19	1	452	313	69
Report Results Period						
AC Transit	8/08-7/09	12	3	878	602	69
SunLine	8/08-7/09	12	1	310	195	63
CTTRANSIT	8/08-7/09	12	1	290	198	68

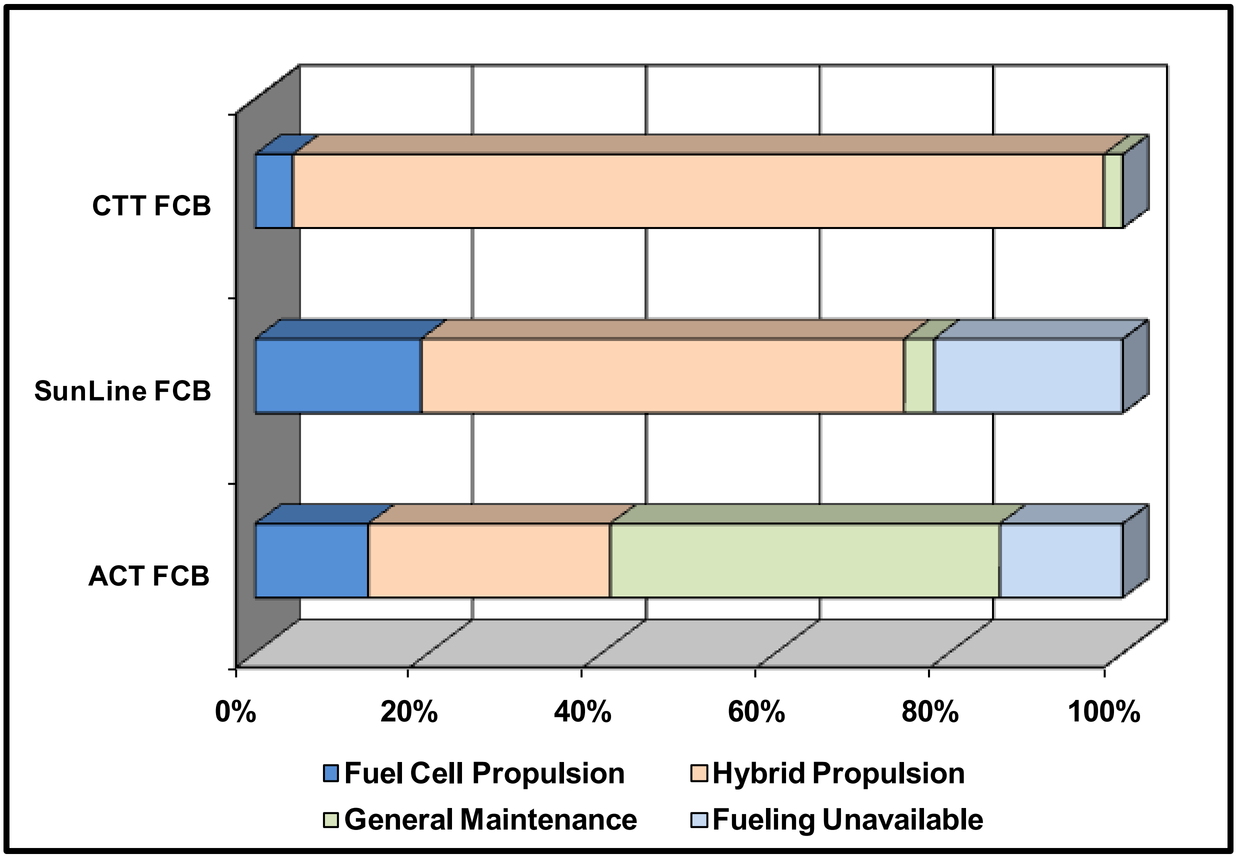

Figure 2. Reasons for unavailability of the fuel cell buses

Fuel Economy—Figure 3 shows the fuel economy in diesel energy equivalent gallons (DGE) for the fuel cell and baseline buses evaluated in this report. The fuel cell buses at the three locations showed fuel economy improvement ranging from 59% to 141% when compared to CNG and diesel baseline buses. The fuel economy results from agency to agency are affected by several factors including duty-cycle characteristics (average speed, number of stops, idle time). Also note that the diesel buses at AC Transit do not have air conditioning and the fuel cell buses do. The **CT**TRANSIT diesel buses operate at twice the average speed as the fuel cell bus operating on the Star Route, which causes significantly lower fuel economy for the fuel cell bus compared to the fuel economies at the other two transit agencies.

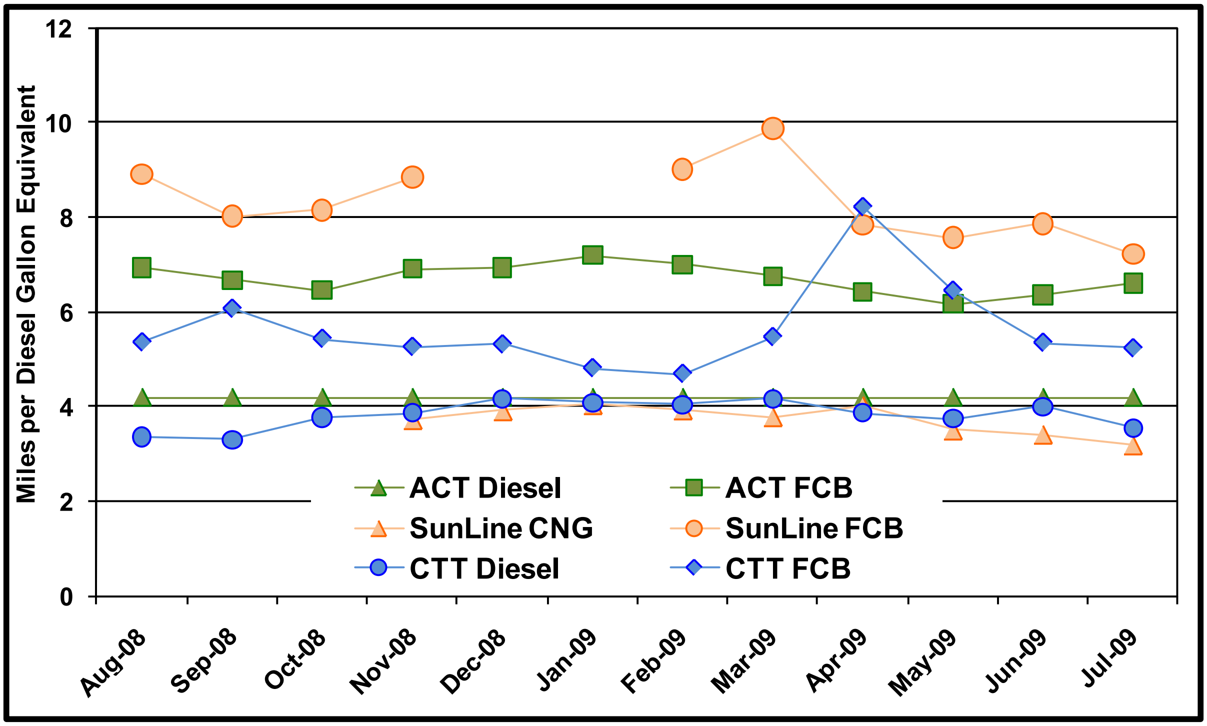

Figure 3. Fuel economy for fuel cell and baseline buses[9]

Roadcalls—A roadcall (RC) or revenue vehicle system failure (see National Transit Database) is a failure of an in-service bus that causes the bus to be replaced on route or causes a significant delay in schedule. If the bus is repaired during a layover and the schedule is maintained, then no RC is recorded. Figure 4 shows miles between roadcalls (MBRC) for all RCs, for propulsion-related-only RCs, and for fuel-cell-system-only RCs for the fuel cell and baseline bus groups at AC Transit, SunLine, and **CT**TRANSIT.

MBRC rates for the fuel cell buses are significantly lower than the MBRC rates for the baseline buses. Clearly, fuel cell buses need improvement in reliability. Manufacturers and transit agencies are working to resolve the problems causing these low rates. Traction battery and hybrid propulsion control software problems accounted for more than half the propulsion-related RCs (67%) across the five fuel cell buses evaluated. In addition, problems with UTC Power fuel cell systems made up 27% of propulsion-related RCs.

[9] Because the data collection on AC Transit's diesel baseline buses was completed previously, the chart includes the average fuel economy for one year of service.

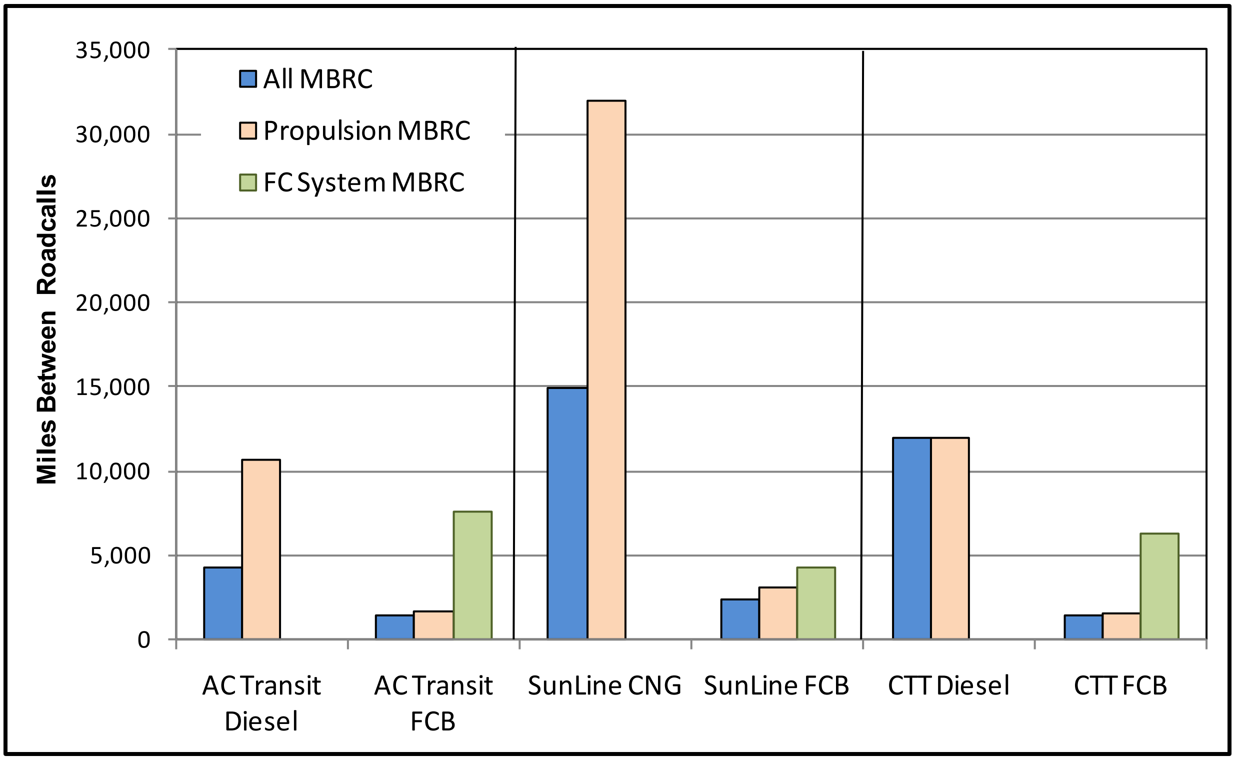

Figure 4. MBRC rates for fuel cell and baseline buses

Hydrogen Fueling—The fuel cell buses at these three transit agencies have been fueled with more than 60,000 kg of hydrogen (including a hydrogen internal-combustion engine hybrid bus at SunLine) over nearly four years with no fueling safety incidents. The fueling at each site is as follows:

- AC Transit—30,369 kg (March 2006 through July 2009)
- **CT**TRANSIT—7,029 kg (April 2007 through July 2009)
- SunLine—27,213 kg (December 2005 through July 2009).

Progress and Needs

In the next few years, the United States will progress through stage-one introduction of fuel cell transit buses. Planned demonstrations will continue to address the following areas:

- **Bus performance**—The purpose of step-one demonstrations of fuel cell transit buses is to prove reliability and begin assessing fuel cell power systems and related components for durability. Hybrid/fuel cell systems must also be optimized for reliability and durability. Newer/next-generation fuel cell buses are optimizing on-board hydrogen storage and packaging. Step one is nearing completion in North America with larger orders of fuel cell buses for the ZEBA and BC Transit demonstrations.

- **Fueling stations and hydrogen source**—Providing wider and better fuel availability and optimizing fueling station sizes for multiple vehicles requires more hydrogen fueling stations. Scaling of hydrogen fueling stations will also be needed as larger fleets of fuel cell buses are demonstrated. In addition, it is important to prove that fuel can be clean and "green" at the same time for hydrogen produced and delivered at dispensing stations.

- **Preparation for market introduction**—Demonstration of larger numbers of hydrogen fuel cell transit buses requires market preparation, including assessing the availability of technologies and products; training fleet personnel and the public; developing codes and standards; and continuing data collection, analysis, and reporting.

- **Cost reduction**—Considering their current high capital cost, a priority regarding fuel cell transit buses is cost reduction. Cost reduction sufficient to make fuel cell buses competitive in the marketplace must be validated. However, purchase price has little relevance if the buses cannot meet performance standards. After fuel cell bus designs have proven performance and durability, the industry can investigate ways to reduce the cost of the buses and replacement components. As with all developmental technologies, larger-quantity orders can help manufacturers develop low-cost manufacturing techniques. The industry also needs to investigate ways to lower operational costs.

Future Funding for Fuel Cell Bus Demonstrations in the United States

Over the past year, substantial new funding has become available for transportation construction and implementation projects.

Most new funding for capital projects has come through appropriations from the American Recovery and Reinvestment Act of 2009 (ARRA). For example, the Transportation Investment Generating Economic Recovery (TIGER) program included $1.5 billion in discretionary grant funding for major capital transportation infrastructure improvements, and the Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) program included $100 million in discretionary grant funding to support transit capital projects to reduce greenhouse gases and energy use. Forty-three projects were awarded grants under the TIGGER program.[10] AC Transit received a grant to install photovoltaic capacity for hydrogen production at one of its facilities.

DOE Clean Cities annually funds cost-share projects submitted by its coalitions' public-private partnerships. This year, DOE Clean Cities selected 25 projects that will be funded with nearly $300 million from the ARRA. Among the recipients, the Greater New Haven Clean Cities Coalition, Inc., received $13,195,000 for the Connecticut Clean Cities Future Fuels Project. As part of this project, **CT**TRANSIT will build a new hydrogen station capable of dispensing 30 kg/day of hydrogen onsite in Hartford, Connecticut.

The current federal surface transportation authorization (SAFETEA-LU), signed into law in 2005, was set to expire on September 30, 2009. Congress has extended the authorization and may extend it another 6- to 12-months or pass a new surface transportation authorization. In either case, significant funding will likely become available for capital projects in transit that could be applied to hydrogen and fuel cell bus demonstrations.

In order to move the technology introduction into step three, more buses (perhaps 50 to 100) must be deployed and demonstrated in a few selected locations. This will allow manufacturers and the transit industry to explore larger-scale implementation and potential cost reductions of this technology.

[10] See www.dot.gov/affairs/2009/fta2209.htm

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Appendix A: Summary Statistics

Table A-1: AC Transit Data Summary

	Early FC Version	New FC Version	Past Year
Data period	4/06 – 10/07	11/07 – 7/09	8/07 – 7/09
Number of buses	3	3	3
Number of months	19	~19	12
Total miles	60,198	112,210	83,156
Total FC hours	5,499	11,452	8,636
Average speed (mph)	10.9	9.8	9.6
Average miles per month	1,023	2,044	2,310
Availability	58%	65%	69%
Fuel economy (mi/kg)	6.22	6.17	5.92
Fuel economy (mpdeg)	7.03	6.97	6.69
All MBRC	1,281	1,336	1,434
Propulsion-only MBRC	1,505	1,516	1,631
FC system-only MBRC	5,017	7,481	7,560
Total hydrogen used (kg)	9,683	18,468	13,730

Table A-2: SunLine Data Summary

	Early FC Version	New FC Version	Past Year
Data period	1/06 – 3/08	4/08 – 7/09	8/07 – 7/09
Number of buses	1	1	1
Number of months	27	16	12
Total miles	52,336	27,778	21,556
Total FC hours	4,027	2,053	1,559
Average speed (mph)	13.0	13.5	13.8
Average miles per month	1,886	1,736	1,796
Availability	67%	65%	63%
Fuel economy (mi/kg)	7.20	7.07	7.05
Fuel economy (mpdeg)	8.14	7.99	7.96
All MBRC	1,495	2,142	2,402
Propulsion-only MBRC	1,636	3,094	3,089
FC system-only MBRC	7,477	3,978	4,324
Total hydrogen used (kg)	7,265	3,930	3,059

Table A-3: CTTRANSIT Data Summary

	Early FC Version	New FC Version	Past Year
Data period	4/07 – 12/07	1/08 – 7/09	8/08 – 7/09
Number of buses	1	1	1
Number of months	10	19	12
Total miles	4,554	28,631	18,900
Total FC hours	886	4,272	2,738
Average speed (mph)	5.6	6.7	6.9
Average miles per month	516	1,507	1,575
Availability	45%	69%	68%
Fuel economy (mi/kg)	4.82	4.74	4.78
Fuel economy (mpdeg)	5.44	5.36	5.40
All MBRC	573	1,030	1,454
Propulsion-only MBRC	737	1,154	1,575
FC system-only MBRC	5,157	5,770	6,300
Total hydrogen used (kg)	944	6,041	3,952

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This report documents progress in meeting the technological challenges of fuel cell propulsion for transportation based on current fuel cell transit bus demonstrations and plans for more fuel cell transit buses and hydrogen infrastructure.

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