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Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: Second Results Report

Leslie Eudy
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Technical Report
NREL/TP-5600-55367
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Prepared under Task No. H270.8150

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Acronyms and Abbreviations

Ah	amp-hours
BAAQMD	Bay Area Air Quality Management District
CARB	California Air Resources Board
CEC	California Energy Commission
CNG	compressed natural gas
DGE	diesel gallon equivalent
DOE	U.S. Department of Energy
FCEB	fuel cell electric bus
FCEV	fuel cell electric vehicle
FCPP	fuel cell power plant
ft	feet
FTA	Federal Transit Administration
GGT	Golden Gate Transit
GVWR	gross vehicle weight rating
hp	horsepower
HVAC	heating, ventilation, and air conditioning
in.	inches
kg	kilograms
kW	kilowatts
kWh	kilowatt hour
lb	pounds
MBRC	miles between roadcalls
mpDGE	miles per diesel gallon equivalent
mpg	miles per gallon
mph	miles per hour
MTC	Metropolitan Transportation Commission
NFCBP	National Fuel Cell Bus Program
NREL	National Renewable Energy Laboratory
PMI	preventive maintenance inspection
PRD	pressure relief device
psi	pounds per square inch
RC	roadcall
SamTrans	San Mateo County Transit District
SFMTA	San Francisco Municipal Transportation Agency
SI	International System of Units
TIGGER	Transit Investments for Greenhouse Gas and Energy Reduction
VTA	Santa Clara Valley Transportation Authority
ZEB	zero emission bus
ZEBA	Zero Emission Bay Area

Executive Summary

This report presents results of a demonstration of 12 new fuel cell electric buses (FCEB) operating in Oakland, California. The FCEBs have a fuel cell dominant hybrid electric propulsion system in a series configuration. The bus manufacturer—Van Hool— fully integrated the hybrid design, using a Siemens ELFA 2 hybrid system; UTC Power's newest-design fuel cell power system; and an advanced lithium-based energy storage system by EnerDel. The first results report[1] was published in August 2011, describing operation of these new FCEBs from September 2010 through May 2011. New results in this report provide an update through April 2012.

The 12 FCEBs operate as a part of the Zero Emission Bay Area (ZEBA) Demonstration, which also includes two new hydrogen fueling stations. This effort is the largest FCEB demonstration in the United States and involves five participating transit agencies. The ZEBA partners are collaborating with the U.S. Department of Energy (DOE) and DOE's National Renewable Energy Laboratory (NREL) to evaluate the buses in revenue service. NREL has been evaluating FCEBs under funding from DOE and the U.S. Department of Transportation's Federal Transit Administration (FTA). NREL uses a standard data-collection and analysis protocol originally developed for DOE heavy-duty vehicle evaluations[2].

Since the last report, there have been multiple accomplishments.

- The last three of the 12 FCEBs were delivered and began full revenue operation
- One of the two new hydrogen fuel stations opened (at Emeryville Division)
- AC Transit and its transit agency and manufacturer partners have been ramping up service of the new FCEBs, including troubleshooting, maintenance, and training for all involved (as shown in the report with increasing availability and miles accumulated)
- The FCEBs have operated 272,968 miles and 29,039 hours on the fuel cell power systems, with an average speed of 9.4 mph, as well as use of 38,168 kg of hydrogen
- More than one million passengers have used the buses
- Three of the fuel cell power systems (from UTC Power) have accumulated significant hours of service without fuel cell stack maintenance or significant power degradation (more than 12,000 hours, 10,000 hours, and 7,500 hours)

This second results report provides data analysis summaries of FCEB operations beginning in September 2011, when the buses were moved to Emeryville Division, through April 2012. This data period focuses on operation from that Division and use of the new hydrogen fueling station, which was designed by Linde LLC and Jacob engineering, and constructed by a local Bay Area contractor. Linde supplied the hydrogen equipment and Proton Onsite supplied the electrolyzer.

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[1] Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: First Results Report, NREL/TP-5600-52015, August 2011, http://www.nrel.gov/hydrogen/pdfs/52015.pdf.

[2] Fuel Cell Transit Bus Evaluations: Joint Evaluation Plan for the U.S. Department of Energy and the Federal Transit Administration, NREL/MP-560-49342-1, November 2010, www.nrel.gov/hydrogen/pdfs/49342-1.pdf.

During this time period, several issues have been resolved, and the agency is increasing the service toward full operation.

The Emeryville Station is a combined facility for light-duty fuel cell electric vehicles (FCEV) and fuel cell buses. Hydrogen is provided from two sources: liquid hydrogen delivery and a solar-powered electrolyzer. Hydrogen from both sources feeds into high pressure gaseous storage tubes for fueling buses and autos. The electrolyzer is capable of producing 65 kg of hydrogen per day. When combined with the liquid hydrogen delivered, the station has the capacity to dispense up to 600 kg of hydrogen.

There was a safety incident at the station since it was commissioned. In early May 2012, a pressure relief device (PRD) valve on one of the high pressure storage tubes failed. There was a loud bang and escaping gas coming out of the vent tube ignited. The emergency systems worked as designed. There were no injuries or threats of injuries, and no damage occurred, except for minor singeing on a corrugated canopy roof on one side of the station. Emeryville FCEB operations have been suspended while this incident is fully investigated.

Once FCEB operations resume, Golden Gate Transit (GGT) plans to operate one of the FCEBs. The other transit agencies plan to operate the buses once the Oakland hydrogen station is complete and operational. This station is scheduled for completion in 2013.

Table ES-1. Summary of Evaluation Results

Data Item	Fuel Cell	Diesel
Number of Buses	12	3
Data Period	9/11 – 4/12	9/11 – 4/12
Number of Months	8	8
Total Mileage in Period	147,007	83,599
Average Monthly Mileage per Bus	1,598	3,635
Total Fuel Cell Operating Hours	17,619	N/A
Average Bus Operating Speed (mph)	9.4	N/A
Availability (85% is target)	56	77
Fuel Economy (miles/kg)	6.68	N/A
Fuel Economy (miles/DGE[a])	7.55	4.00
Miles between Roadcalls (MBRC) – All	2,014	2,117
MBRC – Propulsion Only	3,000[b]	3,629
Total Maintenance ($/mile)[c]	1.31	0.79
Maintenance – Propulsion Only ($/mile)	0.39	0.22

[a] Diesel gallon equivalent.
[b] For fuel cell propulsion only, MBRC was 8,174.
[c] Work order maintenance cost.

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Introduction

In May 2010, a group of transit agencies in the San Francisco Bay area began operating a fleet of 2nd-generation[3] fuel cell electric buses (FCEB). The Zero Emission Bay Area (ZEBA) demonstration includes 12 advanced design fuel cell buses and two new hydrogen fueling stations. This effort is the largest FCEB demonstration in the United States and includes five participating transit agencies:

- Alameda-Contra Costa Transit District (AC Transit) – lead transit agency for ZEBA
- Santa Clara Valley Transportation Authority (VTA)
- Golden Gate Transit (GGT)
- San Mateo County Transit District (SamTrans)
- San Francisco Municipal Transportation Agency (SFMTA)

The ZEBA partners are collaborating with the U.S. Department of Energy (DOE) and DOE's National Renewable Energy Laboratory (NREL) to evaluate the buses in revenue service. NREL has been evaluating FCEBs under funding from DOE and the U.S. Department of Transportation's Federal Transit Administration (FTA). NREL uses a standard data-collection and analysis protocol originally developed for DOE heavy-duty vehicle evaluations. This protocol was documented in a joint evaluation plan for transit bus evaluations.[4] The objectives of these evaluations are to provide comprehensive, unbiased evaluation results of fuel cell bus development and performance compared to conventional baseline vehicles. NREL published an earlier report[5] on this demonstration in August 2011 (covering data from September 2010 through May 2011). This report is an update to the previous report and focuses on data from August 2011 through April 2012.

Fuel Cell Buses in California

Transit agencies in California have been operating FCEBs in the state, primarily in response to the California Air Resources Board's (CARB) 2000 "Fleet Rule for Transit Agencies" urban bus requirements,[6] which set more stringent emission standards for new urban bus engines and promoted advances in the cleanest technologies, specifically, zero-emission buses (ZEBs). Under the rule, agencies with more than 200 buses must include ZEBs as 15% of new bus purchases. The effective date of this purchase requirement is currently under consideration by CARB and will take into account cost and performance data from this and other FCEB demonstrations.

The ZEBs demonstration requirements under the Fleet Rule for Transit Agencies led to two early-generation FCEB projects:

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[3] The FCEBs described in this report are considered a 2nd-generation Van Hool fuel cell electric bus design.
[4] Fuel Cell Transit Bus Evaluations: Joint Evaluation Plan for the U.S. Department of Energy and the Federal Transit Administration, NREL/MP-560-49342-1, November 2010, www.nrel.gov/hydrogen/pdfs/49342-1.pdf.
[5] Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: First Results Report, NREL/TP-5600-52015, August 2011, http://www.nrel.gov/hydrogen/pdfs/52015.pdf.
[6] Fact Sheet at http://www.arb.ca.gov/msprog/bus/ub/ubfactsheet.pdf.

- VTA and SamTrans teamed up to operate three Gillig 40-foot buses with Ballard fuel cells based at VTA in San Jose, California. The buses were operated from 2004 through 2009.[7]

- AC Transit and GGT teamed up to demonstrate three Van Hool 40-foot buses with UTC Power fuel cells at AC Transit in Oakland, California. This demonstration began in 2006 and operated into 2010.[8]

These two demonstrations provided valuable information to the industry and helped develop next-generation FCEBs on a clear path to commercialization.

ZEBA Fuel Cell Bus Demonstration

CARB updated the transit rule in 2006, adding a requirement for an advanced zero-emission bus demonstration for the larger California agencies. The five largest transit agencies in the San Francisco Bay Area formed the ZEBA demonstration group to respond to the rule. Of that group, SFMTA is a voluntary participant, since they already own and operate a large fleet of zero-emission electric trolley buses. The ZEBA partners' operating areas are shown in Figure 1.

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, the California Energy Commission (CEC), and the FTA (including early funding under the National Fuel Cell Bus Program). Besides AC Transit, four of the five transit agencies (excluding SFMTA) in the ZEBA demonstration group are providing funding, participating in training activities, and plan to periodically operate buses as part of the demonstration.

The goals for the ZEBA demonstration include the following:

- **Operating performance:** Demonstrate that FCEBs can fulfill or exceed the operating requirements and standards of baseline diesel buses from the perspective of drivers and passengers (i.e. schedule adherence, vehicle handling, and passenger acceptance).
- **Fleet availability:** Match the "A.M. Pullout" fleet availability percentages of baseline diesel buses with a minimum fleet size of 12 buses.
- **Fleet reliability:** Match the miles between roadcall (MBRC) of diesel buses for the bus as a whole and for the propulsion system category with a minimum fleet size of 12 buses.
- **Fuel economy:** Exceed the fuel economy of baseline diesel buses.
- **Infrastructure support:** Develop renewable sources of hydrogen, and demonstrate safe fueling systems and throughput (fueling speeds) equivalent to diesel fueling.

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[7] NREL evaluation results reported in Santa Clara Valley Transportation Authority and San Mateo County Transit District, Fuel Cell Transit Buses: Evaluation Results, 2006, NREL/TP-560-40615, http://www.nrel.gov/hydrogen/pdfs/40615.pdf.

[8] Last results report for this demonstration – National Fuel Cell Bus Program: Accelerated Testing Evaluation Report #2 and Appendices, FTA-CO-26-7004-2010.1, http://www.nrel.gov/hydrogen/pdfs/48106-1.pdf.

- **Maintenance costs:** Track labor and material costs to compare with baseline diesel buses across applicable expense categories.

Four additional FCEBs have been purchased from AC Transit's order by UTC Power for operation in Connecticut and other selected areas under the FTA's National Fuel Cell Bus Program (NFCBP). Together, this fleet of 16 FCEBs is the premier fuel cell bus program in the United States.

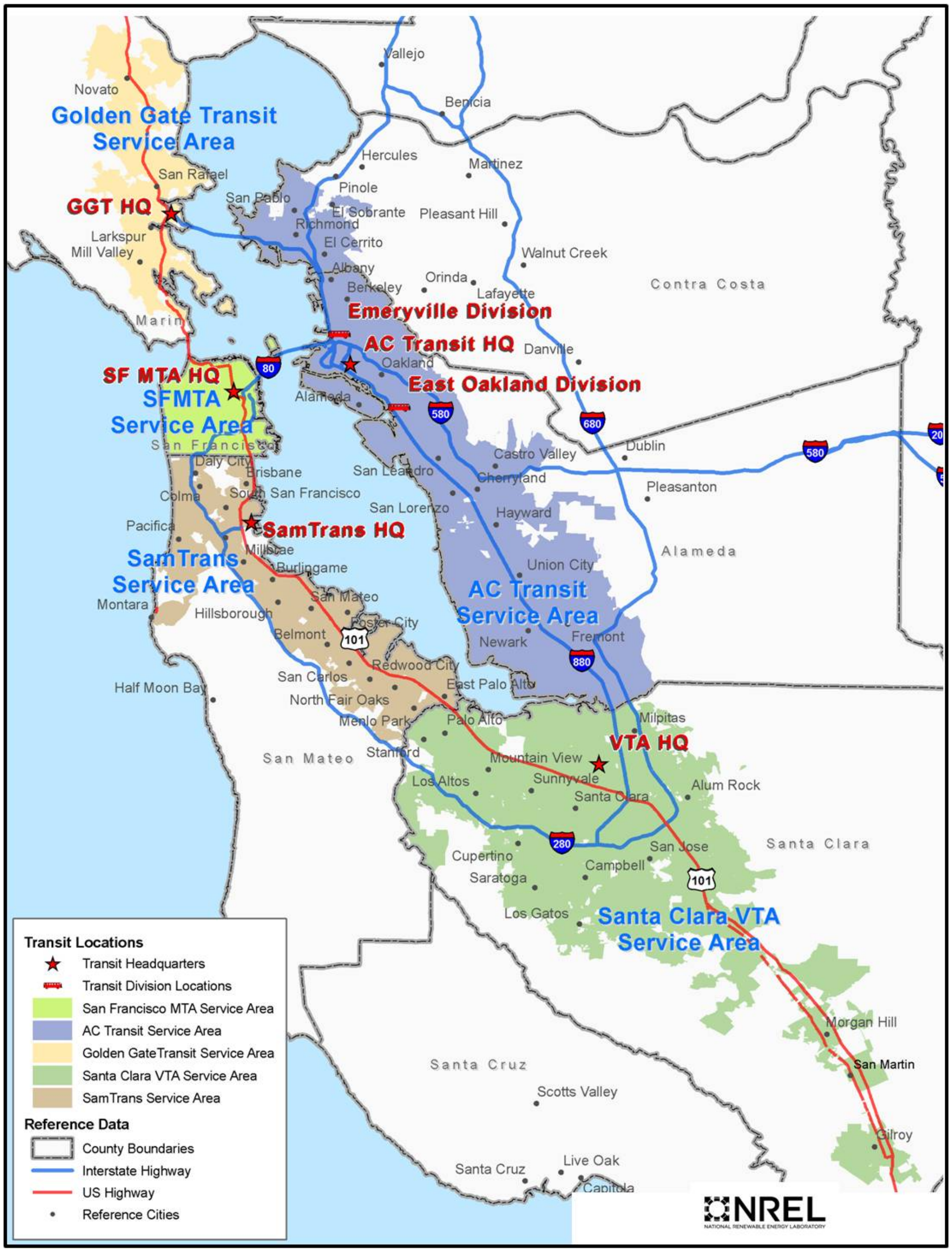

Figure 1. Map of ZEBA transit partner operating locations

Bus Technology Descriptions

Table 1 provides bus system descriptions for the fuel cell and diesel buses that were studied in this evaluation. The FCEBs in service primarily at AC Transit (Figure 2) are 40-foot, low-floor buses built by Van Hool with a hybrid electric propulsion system that includes a UTC Power fuel cell power system. In the evaluation of the three 1st-generation fuel cell buses at AC Transit, the diesel buses studied were not equipped with air conditioning. For this study/evaluation, three diesel buses that include air conditioning were selected. Figure 3 shows one of AC Transit's diesel buses. The fuel cell and diesel buses are controlled to operate on similar routes, and those routes are discussed later in this report.

Table 1. Fuel Cell and Diesel Bus System Descriptions

Vehicle System	Fuel Cell	Diesel
Number of buses	12	3
Bus manufacturer and model	Van Hool A300L FC low floor	Van Hool A300L low floor
Model year	2010	2009
Length/width/height	40 ft/102 in./136 in.	40 ft/102 in./121 in.
GVWR/curb weight	39,350 lb/31,400 lb	40,800 lb/27,800 lb
Wheelbase	269 in.	278 in.
Passenger capacity	33 seated or 29 seated plus 2 wheelchairs	31 seated or 28 seated plus 2 wheelchairs
Engine manufacturer and model	UTC Power PureMotion[9] 120 fuel cell power system	Cummins ISL
Rated power	Fuel cell power system: 120 kW	280 hp @ 2200 rpm
Accessories	Electrical	Mechanical
Emissions equipment	None	Diesel Oxidation Catalyst
Transmission/retarder	Seico Brake resistors Regenerative braking	Voith Integrated retarder
Fuel capacity	40 kg hydrogen	92 gal
Bus purchase cost	$2.5 million	$323,000

Table 2 provides a description of some of the electric propulsion systems for the fuel cell buses. The diesel baseline buses are not hybrids and do not have regenerative braking or energy storage for the drive system. The new FCEBs have a fuel cell-dominant hybrid-electric propulsion system in a series configuration. Van Hool fully integrated the hybrid design using a Siemens ELFA 2 hybrid system; UTC Power's newest-design fuel cell power system that includes lessons learned from previous operation; and an advanced lithium-based energy storage system by EnerDel.

[9] PureMotion is a registered trademark of UTC Power.

Figure 2. One of AC Transit's new fuel cell buses

Figure 3. One of AC Transit's diesel buses at Emeryville Division

Table 2. Additional Electric Propulsion System Descriptions

Propulsion Systems	Fuel Cell Bus
Integrator	Van Hool
Hybrid type	Series, charge sustaining
Drive system	Siemens ELFA
Propulsion motor	2-AC induction, 85 kW each
Energy storage	Battery: EnerDel, lithium ion, Rated energy: 21 kWh Rated capacity: 29 Ah Rated power: 76 to 125 kW
Fuel storage	Eight roof mounted, Dynetek, type 3 tanks; 5,000 psi rated
Regenerative braking	Yes

Fueling and Maintenance Facilities

As part of the ZEBA Program, AC Transit planned construction of two hydrogen stations: one at the Emeryville Division and a second station to replace the decommissioned station at the Oakland Division. In addition, the agency plans for modifying the garage at Emeryville to allow safe maintenance of hydrogen-fueled buses. The Oakland Division garage has already been modified. This section describes the station at Emeryville, outlines the plans for future construction, and provides a summary of fueling data from August 2011 through April 2012.

Emeryville Hydrogen Station

In 2012, AC Transit entered into a contract with Linde LLC to build the hydrogen fueling station at Emeryville. Funding to build the station came from several state and federal grants including:

- CARB Hydrogen Highway Grant - $2.7 million
- FTA Clean Fuels Grant - $4 million
- Bay Area Regional Grant - $2 million
- FTA TIGGER (Transit Investments for Greenhouse Gas and Energy Reduction) Grant for a solar system at the Central Maintenance Facility to offset hydrogen station energy needs - $6.4 million.

Construction on the station began in late December 2010 and was completed by the end of July 2011. Linde began the commissioning process in early August 2011 and was completing test fuels of the buses by mid-month. Figure 4 shows the completed station in the bus yard at the Emeryville Division. Linde and AC Transit's goals for the station were to:

- Prove out commercial viability of the station
- Design and construct the station to allow for scalability should the FCEB fleet increase
- Achieve fast fueling rates for buses – 5 to 6 minutes per fill
- Demonstrate ability to fuel 6 to 12 buses per day with back-to-back fuelings
- Achieve high station reliability
- Minimize hydrogen venting.

AC Transit has a maintenance contract with Linde for 3 years with options for extension.

Figure 4. The Linde hydrogen station at AC Transit's Emeryville Division

This station is a combined facility for light-duty fuel cell electric vehicles (FCEV) and FCEBs. Funding from the state of California made the light-duty FCEV fueling access possible – dispensers are available to fuel at 350 and 700 bar pressure. Figure 5 shows the FCEV fueling area and a close up photo of the dispenser. To enable access for outside fueling, AC Transit modified the exterior wall of the bus yard and added a drive-through lane. A security fence prevents the dispenser from being accessed by unauthorized users. The dispenser has a credit card interface to allow the user to pay for the fuel.

Figure 5. The light duty FCEV fueling access (left) and dispenser (right) at the Emeryville station

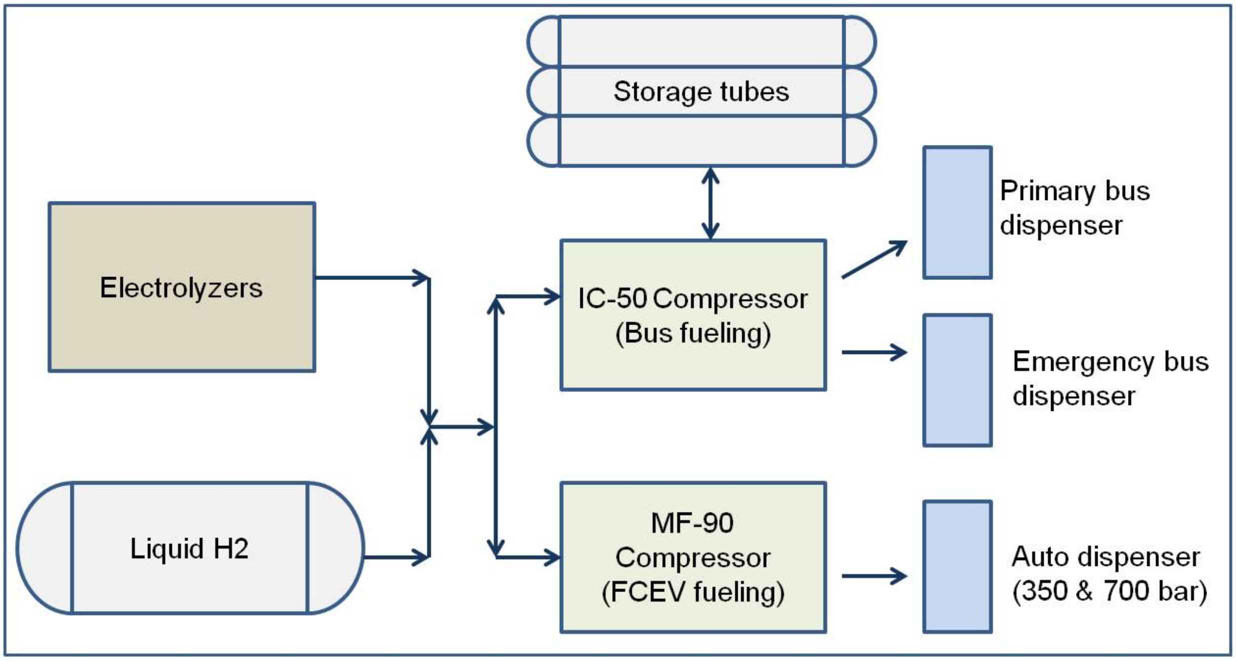

Figure 6. Block diagram of the Emeryville station

Figure 6 provides a simple block diagram of the station and primary components. Hydrogen is provided from two sources: liquid hydrogen delivery and a solar-powered electrolyzer. The liquid hydrogen tank and the electrolyzers are pictured in Figure 7. Hydrogen from both sources feeds into high-pressure gaseous storage tubes for fueling buses and autos. The electrolyzer is capable of producing 65 kg of hydrogen per day. When combined with the liquid hydrogen delivered, the station has the capacity to dispense up to 600 kg of hydrogen.

The station uses two compressors: one is a high-pressure mechanical compressor and the other is an ionic compressor. The mechanical compressor (MF-90) handles the FCEV side of the station and is capable of filling at both 350 and 700 bar. The MF-90, pictured in Figure 8, boosts the pressure to 700 bar for the FCEVs that operate at the higher pressure. The station can fully fuel a light-duty vehicle in 3 to 5 minutes depending on vehicle tank capacity.

Linde's ionic compressor (IC-50) handles the bus fueling side of the station. This compressor uses a proprietary ionic liquid in place of a mechanical piston. Ionic liquids are made up of organic salts that remain in a liquid state within a specific temperature range. Composed entirely of particles with negative and positive charges, the liquid is nearly incompressible and behaves like a solid material during compression. Using liquid instead of conventional metal pistons means fewer moving parts and no need for lubricants that could cause contamination. This also results in higher operating efficiency.[10] The buses can be fueled quickly – 30 kg in about 6 minutes. Figure 9 shows the bus fueling area and a picture of the primary bus dispenser. The station also has an emergency dispenser for the buses in case there are issues with the primary fueling dispenser.

[10] Linde Report on Science and Technology, Jan 2006, www.linde.com

Figure 7. Emeryville station liquid hydrogen tank (left) and electrolyzers (right)

Figure 8. The Linde MF-90 high pressure compressor at the Emeryville station

Figure 9. Bus fueling at the Emeryville hydrogen station: fueling area (left) and close up of the bus dispenser (right)

Oakland Seminary Division Hydrogen Fueling

AC Transit also contracted with Linde for the new station planned for the Seminary Division in Oakland. This station will be similar in design to the one at Emeryville. The primary differences are:

- Bus dispensers will be installed in-line with the diesel fueling island
- There will be no public access for light-duty FCEV fueling because the station is at the back of the property
- Hydrogen will be available at 350 bar pressure only
- The on-site electrolyzer will be powered by a solid-oxide fuel cell fueled with directed biogas.[11]

At the time of this report, the station is in the design phase. AC Transit's goal for completing the second station is by mid- to late-2013. This station location will be more convenient for use by ZEBA partner agencies VTA and SamTrans.

Maintenance Facilities

When AC Transit first began operating FCEBs, the agency converted one of the maintenance bays at the Oakland Seminary Division to accommodate hydrogen-fueled buses (as described in a previous report[12]). This bay is available for the new fleet; however, the fleet is currently operated out of Emeryville Division. To use this bay for maintenance requires shuttling the buses between the divisions and results in additional labor charges. The agency has plans to upgrade a bay at the Emeryville Division to make maintenance more convenient. Once the Seminary Division hydrogen station is operational, the buses will be split between the two locations.

Summary of Fueling Data

The Linde Emeryville station began fueling buses in mid-August 2011 and was fully commissioned by the end of the month. Figure 10 shows the average daily hydrogen dispensed (for days when hydrogen was dispensed, zero use days were excluded) by month for the data period beginning in September 2011 through April 2012. During this period, the buses were fueled 1,036 times for a total of 18,070 kg. The average amount per fueling was 17.4 kg.

[11] Directed biogas implies a process of purified biomethane (methane/natural gas developed from decaying organic matter) being injected into the natural gas pipeline. Designated customers of the biomethane do not use the identical biomethane, but can take credit for using the biomethane when using natural gas from the pipeline.

[12] AC Transit, Fuel Cell Transit Buses: Preliminary Evaluation Results, February 2007, NREL/TP-560-41041, http://www.nrel.gov/hydrogen/pdfs/41041.pdf

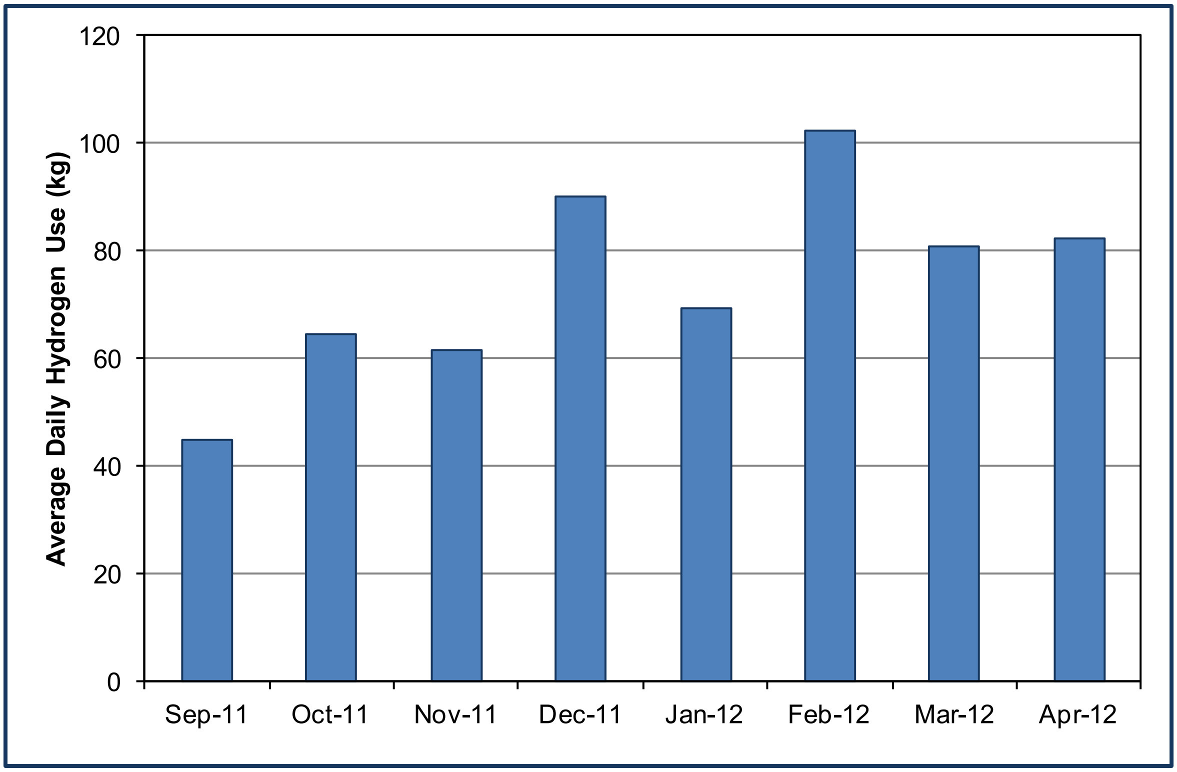

Figure 10. Average hydrogen dispensed per day at Emeryville Station (excluding 0 kg days)

Implementation Experience

The new FCEBs were built at the Van Hool plant in Belgium. The manufacturer had two fuel cell power plants on-site for testing the buses. Once each bus was completed and tested, the test fuel cell power plant was removed and the bus shipped to California. The bus was transported from the shipping port to AC Transit where maintenance staff and the UTC Power engineer installed another fuel cell power plant. By the end of September 2011, all 12 FCEBs had been delivered and, as of this report, were placed in revenue service as shown in Table 3. The manufacturers also delivered another four FCEBs to UTC Power/CTTRANSIT during this timeframe. While the delivery of the FCEBs took longer than originally anticipated, this was not a significant problem due to the delay in having the Emeryville fueling station available and the nine-bus limitation of the temporary fueling solution provided by Air Products until August 2011.

Table 3. Delivery and Start of Service for ZEBA Fuel Cell Buses

Bus Number	Arrived at AC Transit	Start of Passenger Service	Data Collection Start	Evaluation Period Start
FC4	5/26/2010	9/9/2010	Sep 2010	Sep 2011
FC5	8/19/2010	12/2/2010	Dec 2010	Sep 2011
FC6	7/7/2010	8/23/2010	Sep 2010	Sep 2011
FC7	8/17/2010	9/10/2010	Sep 2010	Sep 2011
FC8	10/27/2010	12/27/2010	Feb 2011	Sep 2011
FC9	2/11/2011	4/28/2011	May 2011	Sep 2011
FC10	2/28/2011	4/25/2011	May 2011	Sep 2011
FC11	4/27/2011	6/16/2011	July 2011	Sep 2011
FC12	5/4/2011	6/29/2011	July 2011	Sep 2011
FC14	8/15/2011	10/12/2011	Oct 2011	Oct 2011
FC15	8/10/2011	9/30/2011	Oct 2011	Oct 2011
FC16	9/21/2011	11/16/2011	Nov 2011	Nov 2011

NREL began collecting data on each bus as it was placed into service. The early results were documented in the first data report published in August 2011. The FCEB fleet has been going through a shakedown period during which the manufacturers work with the agency to further optimize the bus systems and make needed modifications. This is typical of all bus fleets regardless of the propulsion system; however, it can take additional time to accomplish this for advanced propulsion systems. Once the final changes are made, the demonstration team will select a ‘clean point’ for data collection. The clean point for the ZEBA demonstration has not been finalized. For this report, the evaluation period begins in September 2011 for the majority of the buses. The exception is the three final buses, which were not in service until a few months later.

One key challenge for FCEBs is increasing the durability and reliability of the fuel cell system to meet FTA life cycle requirements for a full size bus – 12 years or 500,000 miles. Because transit agencies typically rebuild the diesel engines at approximately mid-life, a fuel cell power system should be able to operate for at least half the life of the bus. FTA has set an early performance target of 4–6 years (or 20,000–30,000 hours) durability for the fuel cell propulsion system. The ZEBA buses are demonstrating some of the highest hours for FCEBs in service. The fuel cell power plants (FCPPs) were installed in each bus after they were delivered to AC Transit. At the time the first new bus bodies were delivered, three FCPPs from the first generation demonstration were reaching very high hours without significant degradation. To further test this FCPP version, the manufacturers installed them into the new FCEBs being delivered. In all, three older FCPPs were installed into the new buses; two from buses operated by AC Transit and the third from a bus previously operated in another location. Those three FCPPs continue to operate and accumulate hours in service. Table 4 outlines the total hours on each FCPP at the time it was installed into the new buses.

Table 4. Total Hours on Each FCPP at time of Installation

Bus number	Date of FCPP installation	FCPP Hours at installation
FC4	8/22/10	59
FC5	8/20/10	20
FC6	8/1/10	2,915
FC7	8/29/10	7,727
FC8	11/15/10	6,806
FC9	2/22/11	34
FC10	3/1/11	20
FC11	5/5/11	0
FC12	5/12/11	0
FC14	8/17/11	0
FC15	8/15/11	0
FC16	9/30/11	0

Figure 11 shows the total hours accumulated on each FCPP through April 2012. The top FCPP has now achieved more than 12,000 hours without major repair or cell replacements. The second FCPP is nearing 10,000 hours and the third is just under 8,000 hours. UTC Power reports that these FCPPs continue to provide the rated power of 120kW. This is a significant achievement toward meeting a target of 25,000 hours.

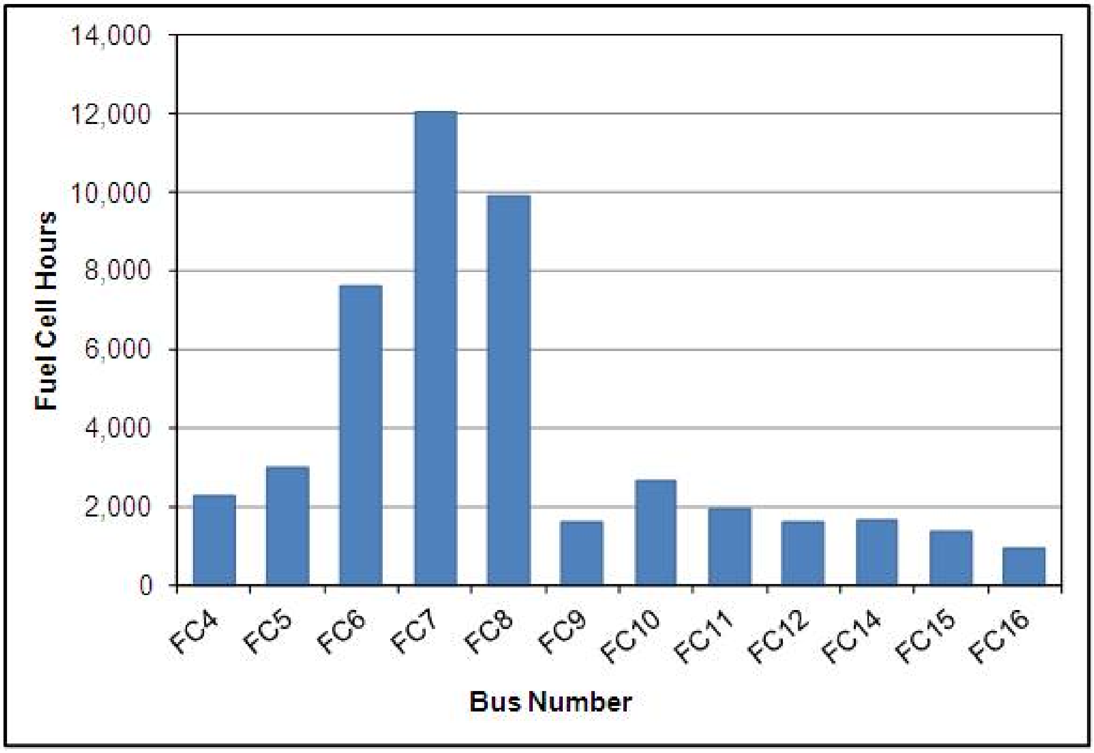

Figure 11. Total number of fuel cell power-plant hours on each bus

Operations Plan

All of the buses were delivered and moved from the Seminary Division to the Emeryville Division in August 2011 after the Emeryville station was completed. The entire FCEB fleet will operate from Emeryville until the new hydrogen fueling station at Seminary is completed (planned for late-2012). At that time, the fleet will be split – six buses operating out of Seminary and six out of Emeryville. The ZEBA partner agencies will be able to operate as many as two buses each in their respective service area at prearranged times. GGT will be the first of the agencies to operate the new buses, primarily because the Emeryville station is located in closer proximity to their service area than to the other agencies. GGT is currently planning that operation and is working with AC Transit to finalize logistics of getting the buses back to Emeryville for daily fueling.

The SamTrans and VTA service areas are closer to the Seminary Division. Once the new station is operational at Seminary division, those two partner agencies will explore the potential of operating FCEBs in their fleets.

Bus-Related Issues

All new transit buses typically have a few issues that need to be resolved after the first buses are delivered. These new FCEBs are no exception. A few of the issues and status of resolution are provided here.

- **Stalling issues and traction battery software** – the battery software has been updated to balance life of the batteries and maximize fuel economy. An integration problem was identified as an issue between the hybrid system and the batteries that now has been addressed. The communication problem would cause the bus to stall/shut down because of an unexpected condition.

- **Fueling nozzles** – the fueling connection on the FCEBs has been changed out to allow for faster hydrogen fueling. The station can now fuel as high as 4.5 kg/min, with an average rate of around 3 kg/min. As these changes in the flow rate were being made, this caused a problem with the mass flow meter for the station. This problem has been resolved, but did cause a disruption in fueling data for the operation and evaluation during March and April 2012.

- **On-board hydrogen fuel storage system** – there has been a problem with hydrogen leaking from the manual valve on the storage tanks. The manufacturer replaced the part that allowed the leak.

Station-Related Issues

Linde Station Incident – There has been one safety incident at the station since it was commissioned. In early May 2012, a pressure relief device (PRD) valve on one of the high-pressure storage tubes broke. There was a loud bang and escaping gas coming out of the vent tube ignited. The emergency system worked as it was designed, but the fire burned for about 2-1/2 hours before Linde technicians were allowed into the storage compound to turn off the manual valve. There were no injuries, or threats of injuries, and no damage occurred, except for minor singeing on a corrugated canopy roof on one side of the station. Emeryville operations were suspended, and the fire chief ordered an evacuation of a nearby business and a high school. This incident is currently under investigation. Results will be reported once the investigation is complete.

Ridership

The ZEBA demonstration partners are interested in increasing public awareness for hydrogen and fuel cell technologies. One of the major objectives of the program has been to create opportunities to educate students, the general public in the Bay Area, and other interested parties, such as federal and state government officials. The ZEBA FCEBs have been used for a number of events and educational demonstrations since the program began.

In addition to participating in outside events, operating the FCEBs in revenue service is an opportunity for the public to experience hydrogen fuel cell bus technology. The ZEBA buses have all been equipped with automatic passenger counters to track ridership of the buses. Figure 12 shows the passenger counts by month and as a cumulative total. The monthly trend increases over time as the buses are delivered and placed in service. All 12 buses were in service by November 2011. The more recent jump in passenger numbers in the early months of 2012 indicates an increase in service hours and availability. By the end of April 2012, the FCEB fleet had carried more than one million passengers.

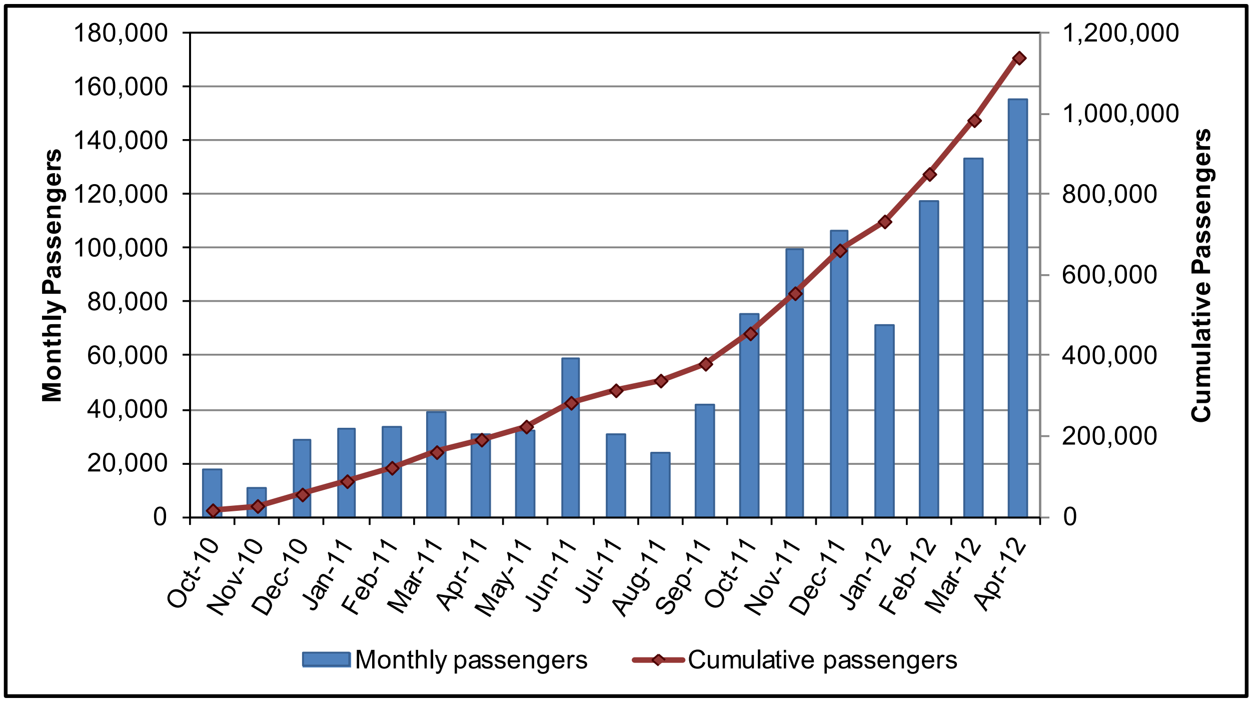

Figure 12. Number of FCEB passengers through April 2012

Evaluation Results

The results presented in this section are from September 2011 through April 2012. The start of the evaluation period was chosen based on the availability of fueling at the Emeryville Division, which went into operation in August 2011. All 12 FCEBs were operating from that location. Through April 2012, the FCEBs have operated 272,968 miles with fuel cell operations of 29,039 hours. This indicates an overall operation of 9.4 mph, which is similar to the planned operating speed of 9.3 mph as discussed next. In addition, these FCEBs have carried 1.14 million passengers so far.

Three diesel buses were selected as a comparison to the FCEBs. Similar route blocks have been selected for operation of the 12 FCEBs and three diesel buses operating from the Emeryville Division.

Fuel cell bus FC4 was out of service for nearly the entire evaluation period, as the data indicates. One of the original diesel buses (1211) had a significant accident prior to the evaluation period and has been replaced with another diesel bus (1208) operating from Emeryville.

Route Assignments

The FCEBs have been operating from AC Transit's Emeryville Division for the entire evaluation period presented here. The fuel cell and diesel study buses are operated on a set of route blocks on the 18 and 51B local routes, which include weekday and weekend service. Route 18 has an average operating speed for the buses of around 10 mph and the 51B operates at around 7 mph. The overall average speed is 9.3 mph for the route blocks assigned as part of this demonstration. Based on availability, the buses are randomly dispatched on these assigned route blocks.

Bus Use and Availability

Bus use and availability are indicators of reliability. Lower bus usage may indicate downtime for maintenance or purposeful reduction of planned work for the buses. This section summarizes bus usage and availability for the two study groups of buses.

Table 4 summarizes average monthly mileage for the study buses through April 2012. Several of the FCEBs are just going into service, and overall the FCEBs have achieved 44% of the usage of the diesel buses. The FCEBs' lower monthly mileage is a result of slowly putting these buses into full planned service. Once the FCEBs are ready for full service, this usage is expected to increase up to the level of the diesel buses.

Table 5. Average Monthly Mileage (Evaluation Period)

Bus	Starting Hubodometer	Ending Hubodometer	Total Mileage	Months	Monthly Average Mileage
FC4	28,334	28,631	297	8	37
FC5	16,588	29,514	12,926	8	1,616
FC6	31,611	46,909	15,298	8	1,912
FC7	27.407	43,145	15,738	8	1,967
FC8	7,400	27,243	19,843	8	2,480
FC9	6,140	15,161	9,021	8	1,128
FC10	5,710	24,199	18,489	8	2,311
FC11	3,373	16,766	13,393	8	1,674
FC12	5,715	14,621	8,906	8	1,113
FC14	783	14,242	13,459	7	1,923
FC15	317	11,530	11,213	7	1,602
FC16	245	8,669	8,424	6	1,404
Fuel Cell			**147,007**	**92**	**1,598**
1208	108,887	141,683	32,796	7	4,685
1209	121,866	146,532	24,666	8	3,083
1210	91,587	117,724	26,137	8	3,267
Diesel			**83,599**	**23**	**3,635**

Another measure of reliability is availability—the percentage of days that the buses are planned for operation compared with the days the buses are actually available. Figure 12 shows availability for each of the FCEBs during the reporting period (September 2011 through April 2012). This figure shows a significant increase in availability of the FCEBs from January through April 2012. In April 2012, six of the 12 buses were above 90% availability and were in operation for essentially all of the available days.

Table 5 summarizes the reasons for availability and unavailability for the fuel cell and diesel buses. During this reporting period, the average availability for the FCEBs was 56% and the diesel buses had 79% availability. Bus-related maintenance (separate from the fuel cell, hybrid, and traction battery systems) is the reason for the highest percentage of unavailability for both groups of buses.

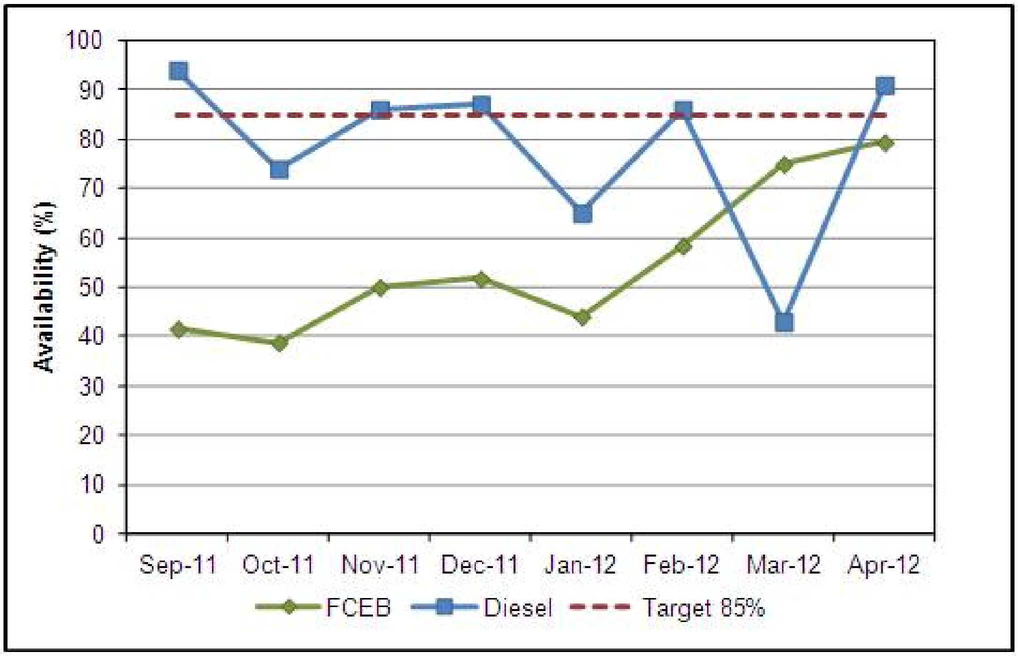

Figure 13. Availability for the two groups of buses

Table 6. Summary of Reasons for Availability and Unavailability of Buses for Service

Category	FCEB # Days	FCEB %	Diesel # Days	Diesel %
Planned work days	1,943		631	
Days available	1,087	56	**498**	79
Available	**1,087**	**100**	**498**	**100**
On route	1,023	94	498	100
Event/demonstration	23	2		
Training	10	1		
Not used	31	3		
Unavailable	**856**	**100**	**133**	**100**
Fuel cell propulsion	99	12		
Hybrid propulsion	30	3		
Traction battery issues	160	19		
Bus maintenance	557	65	133	100
Fueling unavailable	10	1		

Fuel Economy and Cost

As discussed above, hydrogen fuel is provided by a fueling station designed and constructed by Linde at AC Transit's Emeryville Division. The hydrogen is dispensed at up to 350 bar (5,000 psi). AC Transit employees performed nearly all fueling services for the hydrogen-fueled vehicles. Some of the fueling records from March and April 2012 were unavailable due to issues with the mass flow measurements. AC Transit and Linde were working to increase the hydrogen flow rate into the buses, which caused some issues with the ability to record the mass amounts. This problem was resolved by the middle of April 2012.

Table 6 shows hydrogen and diesel fuel consumption and fuel economy for the study buses during the reporting period. Overall, the FCEBs averaged 6.68 miles per kilogram of hydrogen, which equates to 7.55 miles per diesel gallon equivalent (DGE). The energy conversion from kilograms of hydrogen to DGE appears at the end of Appendix A. (Appendix B contains the summary statistics in SI units.) These results indicate that the FCEBs have an average fuel economy that is 89% higher than similar diesel buses. Figure 13 shows monthly average fuel economy for the FCEBs and diesel buses in miles per DGE. The average monthly high temperature is included in the graph to track any seasonal variations in the fuel economy due to heating or cooling of the bus, which might require significant additional energy use.

The cost of hydrogen production as dispensed is currently $9.34 per kg, not including the capital cost of the station. The hydrogen fuel cost per mile is $1.40. Diesel fuel cost during the reporting period was $3.18 per gallon and calculates to $0.79 per mile.

Table 7. Fuel Use and Economy (Evaluation Period)

Bus	Mileage (fuel base)	Hydrogen (kg)	Miles per kg	Diesel Equivalent Amount (gallon)	Miles per Gallon (mpg)
FC4	297	43.6	6.82	38.5	7.71
FC5	10,412	1,680.6	6.20	1,487.3	7.00
FC6	12,881	1,931.6	6.67	1,709.4	7.54
FC7	13,019	1,867.5	6.97	1,652.6	7.88
FC8	17,006	2,797.4	6.08	2,475.5	6.87
FC9	6,886	989.3	6.96	875.5	7.87
FC10	15,641	2,213.9	7.07	1,959.2	7.98
FC11	10,650	1,650.1	6.45	1,460.3	7.29
FC12	7,755	1,197.7	6.47	1,059.9	7.32
FC14	10,199	1,418.3	7.19	1,255.1	8.13
FC15	8,711	1,183.3	7.36	1,047.2	8.32
FC16	6,898	1,042.9	6.61	922.9	7.47
FCB Total	**120,355**	**18,016.0**	**6.68**	**15,943.4**	**7.55**
1208	32,410			7,641.1	4.24
1209	23,948			6,278.0	3.81
1210	25,740			6,590.2	3.91
Diesel Total	**82,098**			**20,509.3**	**4.00**

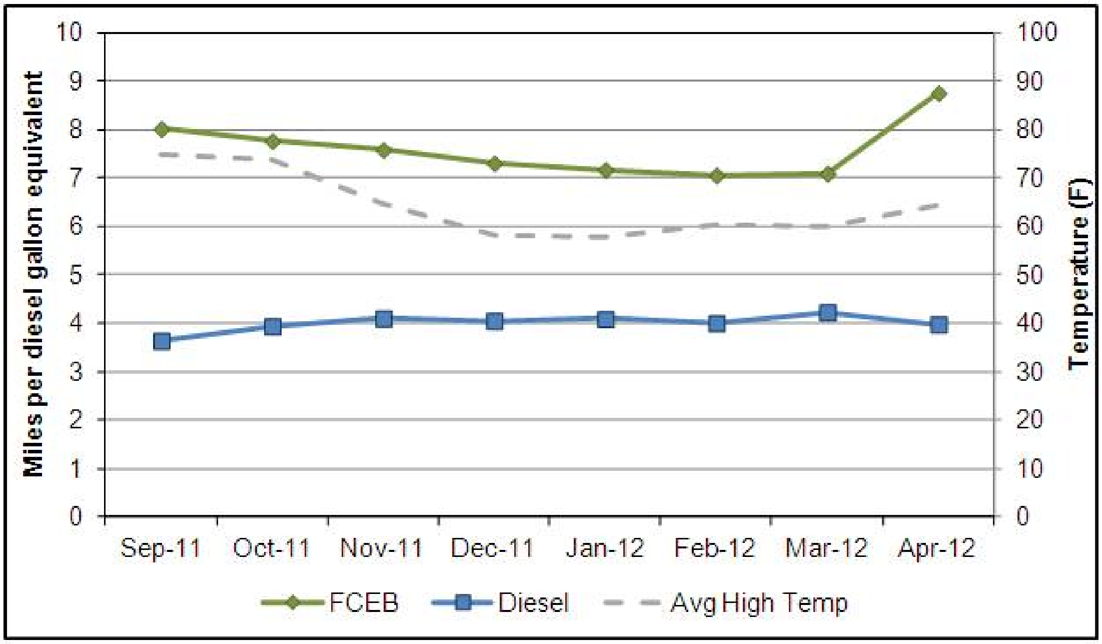

Figure 14. Average fuel economy for the fuel cell and diesel buses (evaluation period)

Maintenance Analysis

Warranty costs are not included in the cost-per-mile calculations. All work orders for the study buses were collected and analyzed for this evaluation. For consistency, the maintenance labor rate was kept at a constant $50 per hour; this does not reflect an average rate for AC Transit. This section first covers total maintenance costs and then maintenance costs by bus system.

Total maintenance costs – Total maintenance costs include the price of parts and labor rates at $50 per hour; they do not include warranty costs. Cost per mile is calculated as follows:

Cost per mile = [(labor hours * 50) + parts cost] / mileage

Table 7 shows total maintenance costs for the fuel cell and diesel buses. Scheduled and unscheduled maintenance cost per mile is provided for each bus and study group of buses. Note that the fuel cell bus maintenance is supported by one of UTC Power's engineers at AC Transit. AC Transit has two mechanics/trainers assigned to maintain the FCEBs and provide training; a supervisor for the program (from a maintenance perspective); and plans to add another mechanic/trainer. In addition, AC Transit has resources from this program for cleaning, fueling, and performing body work and painting for the FCEB fleet.

During the reporting period, the FCEBs had a 66% higher cost per mile for maintenance when compared to the three diesel buses.

Table 8. Total Maintenance Costs (Evaluation Period)

Bus	Mileage	Parts ($)	Labor Hours	Total Cost per Mile ($)	Scheduled Cost per Mile ($)	Unscheduled Cost per Mile ($)
FC4	297	983.91	179.1	33.47	0.00	33.47
FC5	12,926	918.06	198.0	0.84	0.22	0.62
FC6	15,298	7,294.68	364.4	1.67	0.14	1.52
FC7	15,738	7,618.40	290.9	1.41	0.29	1.12
FC8	19,843	2,295.17	297.1	0.86	0.26	0.61
FC9	9,021	2,469.25	330.8	2.11	0.28	1.82
FC10	18,489	2,413.55	328.8	1.02	0.30	0.72
FC11	13,393	2,258.66	226.0	1.01	0.21	0.80
FC12	8,906	1,216.49	391.0	2.33	0.44	1.89
FC14	13,459	1,973.25	218.6	0.96	0.28	0.68
FC15	11,213	1,542.02	222.8	1.13	0.29	0.84
FC16	8,424	744.44	172.2	1.11	0.21	0.90
Total Fuel Cell	**147,007**	**31,727.88**	**3,219.7**	**1.31**	**0.26**	**1.05**
1208	23,676	6,152.98	203.3	0.69	0.14	0.36
1209	24,666	8,443.84	363.1	1.08	0.12	0.96
1210	26,137	8,949.59	277.5	0.87	0.14	0.73
Total Diesel	**83,599**	**23,546.41**	**843.8**	**0.79**	**0.14**	**0.65**

Maintenance costs categorized by system – Table 8 shows maintenance costs by vehicle system and bus study group (without warranty costs). The vehicle systems shown in the table are as follows:

- **Cab, body, and accessories**: Includes body, glass, and paint repairs following accidents; cab and sheet metal repairs on seats and doors; and accessory repairs such as hubodometers and radios
- **Propulsion-related systems**: Repairs for exhaust, fuel, engine, electric motors, fuel cell modules, propulsion control, non-lighting electrical (charging, cranking, and ignition), air intake, cooling, and transmission
- **Preventive maintenance inspections (PMI)**: Labor for inspections during preventive maintenance
- **Brakes**
- **Frame, steering, and suspension**
- **Heating, ventilation, and air conditioning (HVAC)**
- **Lighting**
- **Air system, general**
- **Axles, wheels, and drive shaft**
- **Tires.**

Table 9. Maintenance Cost per Mile by System (Evaluation Period)

System	FCEB		Diesel	
	Cost per Mile ($)	Percent of Total (%)	Cost per Mile ($)	Percent of Total (%)
Cab, body, and accessories	0.56	42	0.26	33
Propulsion-related	0.39	30	0.22	28
PMI	0.23	17	0.09	11
Brakes	0.01	1	0.14	18
Frame, steering, and suspension	0.04	3	0.01	1
HVAC	0.01	1	0.03	4
Lighting	0.01	1	0.00	0
Air, general	0.05	4	0.03	4
Axles, wheels, and drive shaft	0.01	1	0.01	1
Tires	0.00	0	0.00	0
Total	**1.31**	**100**	**0.79**	**100**

The systems with the highest percentage of maintenance costs for the fuel cell and diesel buses were cab, body, and accessories; propulsion-related; and PMI. Brakes were also a high-cost maintenance category for the diesel buses. The FCEBs have had a few accidents causing significant body damage and repairs as indicated with the maintenance costs for cab, body, and accessories.

Propulsion-related maintenance costs – Propulsion-related vehicle systems include the exhaust, fuel, engine, electric propulsion, air intake, cooling, non-lighting electrical, and transmission systems. These systems have been separated to highlight maintenance costs most directly affected by the advanced propulsion system changes for the buses.

Table 9 shows the propulsion-related system repairs by category for the two study groups during the reporting period. The FCEBs had 77% higher maintenance costs, which indicate the amount of AC Transit mechanic labor that goes to support and maintain these buses. As mentioned above, UTC Power has an engineer on-site to supervise and complete maintenance of the fuel cell power system and related systems.

Table 10. Propulsion-Related Maintenance Costs by System (Evaluation Period)

Maintenance System Costs	Fuel Cell	Diesel
Number of buses	12	3
Mileage	147,007	83,599
Total Propulsion-Related Systems (Roll-up)		
Parts cost ($)	5,957.71	8,142.90
Labor hours	1,012.7	201.9
Total cost ($)	56,591.21	18,235.40
Total cost ($) per mile	**0.39**	**0.22**
Exhaust System Repairs		
Parts cost ($)	0.00	217.32
Labor hours	0.0	3.4
Total cost ($)	0.00	387.32
Total cost ($) per mile	**0.00**	**0.01**
Fuel System Repairs		
Parts cost ($)	15.47	692.04
Labor hours	166.7	9.6
Total cost ($)	8,350.47	1,172.04
Total cost ($) per mile	**0.06**	**0.01**
Power Plant System Repairs		
Parts cost ($)	260.89	3,767.42
Labor hours	204.0	100.0
Total cost ($)	10,461.39	8,767.42
Total cost ($) per mile	**0.07**	**0.10**
Electric Motor and Propulsion Repairs		
Parts cost ($)	1,251.77	0.00
Labor hours	458.5	0.0
Total cost ($)	24,175.77	0.00
Total cost ($) per mile	**0.16**	**0.00**
Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)		
Parts cost ($)	1,747.91	51.63
Labor hours	81.3	20.7
Total cost ($)	5,812.41	1,084.13
Total cost ($) per mile	**0.04**	**0.01**
Air Intake System Repairs		
Parts cost ($)	2,152.28	801.89
Labor hours	8.7	16.9
Total cost ($)	2,587.78	1,646.89
Total cost ($) per mile	**0.02**	**0.02**
Cooling System Repairs		
Parts cost ($)	529.39	1,484.11
Labor hours	93.5	48.0
Total cost ($)	5,203.39	3,884.11
Total cost ($) per mile	**0.04**	**0.05**
Transmission Repairs		
Parts cost ($)	0.00	1,128.49
Labor hours	0.0	3.3
Total cost ($)	0.00	1,293.49
Total cost ($) per mile	**0.00**	**0.02**

Roadcall Analysis

A roadcall or revenue vehicle system failure (as named in the National Transit Database[13]) is defined as a failure of an in-service bus that causes the bus to be replaced on route or causes a significant delay in schedule.[14] If the problem with the bus can be repaired during a layover and the schedule is kept, this is not considered a roadcall. The analysis described here includes only roadcalls that were caused by "chargeable" failures. Chargeable roadcalls include systems that can physically disable the bus from operating on route, such as interlocks (doors, air system), engine, or things that are deemed to be safety issues if operation of the bus continues. They do not include roadcalls for things such as problems with radios or destination signs.

Table 10 shows the MBRC for each study bus categorized by all roadcalls and propulsion-related-only roadcalls. The fuel-cell-related MBRC and roadcalls are included for the FCEBs. The diesel buses have better MBRC rates for both categories; however, the fuel cell power system has an MBRC of 8,167. Figure 15 presents this data graphically, charting the monthly MBRCs for the FCEBs and diesel buses.

Table 11. Roadcalls and MBRC (Evaluation Period)

	FCEB	Diesel
Mileage	147,007	50,803
All roadcalls	73	24
All MBRC	2,014	2,117
Propulsion roadcalls	49	14
Propulsion MBRC	3,000	3,629
Fuel-Cell related roadcalls	18	
FC System MBRC	8,167	

[13] National Transit Database website: www.ntdprogram.gov/ntdprogram/

[14] AC Transit defines a significant delay as 6 or more minutes.

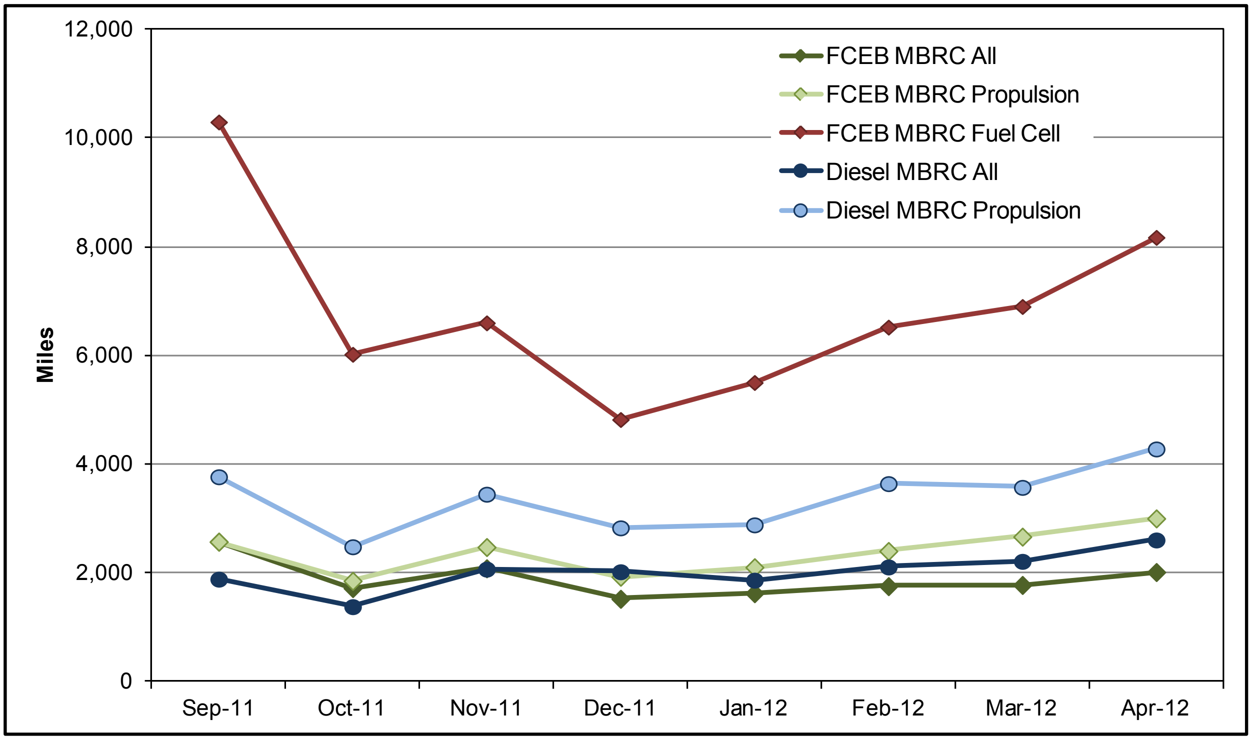

Figure 15. Monthly MBRC for the FCEBs and diesel buses

What's Next for ZEBA

The plans for the ZEBA demonstration are to continue operating out of Emeryville Division while the Oakland station is constructed. Once that station is operational, each division is to operate six buses. At the time of this report, the FCEBs were grounded awaiting the results of the investigation of the incident at the Emeryville station. AC Transit is working with the industry and hydrogen safety experts to determine the root cause of the issue and how to prevent another incident from occurring. Once the investigation is complete, the ZEBA demonstration team will determine the next steps to continue the project.

NREL will continue to evaluate the buses once they go back into service at AC Transit and will collect data and experience from the other operators once they put the buses in service. VTA and GGT also operate diesel hybrid-electric buses. NREL is planning to collect data on the hybrid buses to compare fuel efficiency with that of fuel cell buses in similar service. The next report is expected in late 2012.

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References and Related Reports

All NREL hydrogen and fuel cell-related evaluation reports can be downloaded from the following website: www.nrel.gov/hydrogen/proj_fc_bus_eval.html.

AC Transit

Chandler, K.; Eudy, L. (2011). *Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: First Results Report*. NREL/TP-5600-52015. Golden, CO: National Renewable Energy Laboratory.

Eudy, L. (2010). *Bay Area Transit Agencies Propel Fuel Cell Buses Toward Commercialization.* DOE/GO-102010-3067. Golden, CO: National Renewable Energy Laboratory.

Chandler, K.; Eudy, L. (2010). *National Fuel Cell Bus Program: Accelerated Testing Evaluation Report #2 and Appendices*. FTA-CO-26-7004-2010.1. Golden, CO: National Renewable Energy Laboratory.

Chandler, K.; Eudy, L. (2009). *National Fuel Cell Bus Program: Accelerated Testing Evaluation Report and Appendices*. FTA-CO-26-7004-2009.1. Golden, CO: National Renewable Energy Laboratory.

Chandler, K.; Eudy, L. (2007). *Alameda-Contra Costa Transit District (AC Transit), Fuel Cell Transit Buses: Third Evaluation Report and Appendices*. NREL/TP-560-43545-1, NREL/TP-560-43545-2. Golden, CO: National Renewable Energy Laboratory.

Chandler, K.; Eudy, L. (2007). *Alameda-Contra Costa Transit District (AC Transit), Fuel Cell Transit Buses: Evaluation Results Update*. NREL/TP-560-42249. Golden, CO: National Renewable Energy Laboratory.

Chandler, K.; Eudy, L. (2007). *AC Transit, Fuel Cell Transit Buses: Preliminary Evaluation Results.* NREL/TP-560-41041. Golden, CO: National Renewable Energy Laboratory.

Eudy, L. (2006). *AC Transit Demonstrates Three Prototype Fuel Cell Buses.* DOE/GO-102006-2286. Golden, CO: National Renewable Energy Laboratory.

General

Chandler, K.; Eudy, L. (2012). *FTA Fuel Cell Bus Program: Research Accomplishments through 2011*. FTA Report No. 0014, Washington, DC: Federal Transit Administration.

Eudy, L.; Chandler, K.; Gikakis, C. (2011). *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2011*. NREL/TP-5600-52927. Golden, CO: National Renewable Energy Laboratory.

Eudy, L. (2010). *Fuel Cell Transit Bus Evaluations, Joint Evaluation Plan for the U.S. Department of Energy and the Federal Transit Administration*. NREL/TP-560-49342. Golden, CO: National Renewable Energy Laboratory.

Eudy, L.; Chandler, K.; Gikakis, C. (2010). *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2010*. NREL/TP-560-49379. Golden, CO: National Renewable Energy Laboratory.

Eudy, L.; Chandler, K.; Gikakis, C. (2009). *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2009*. NREL/TP-560-46490. Golden, CO: National Renewable Energy Laboratory.

Eudy, L.; Chandler, K.; Gikakis, C. (2008). *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2008*. NREL/TP-560-44133. Golden, CO: National Renewable Energy Laboratory.

Eudy, L.; Chandler, K.; Gikakis, C. (2007). *Fuel Cell Buses in U.S. Transit Fleets: Summary of Experiences and Current Status.* NREL/TP-560-41967. Golden, CO: National Renewable Energy Laboratory.

BurbankBus

Eudy, L. (2010). *Fuel Cell Bus Takes a Starring Role in the BurbankBus Fleet.* DOE/GO-102010-3035. Golden, CO: National Renewable Energy Laboratory.

Connecticut Transit

Eudy, L. (2011). *Connecticut Nutmeg Fuel Cell Bus Project: Demonstrating Advanced-Design Hybrid Fuel Cell Buses in Connecticut.* DOT/FTA – NFCBP – FC3 – July 2011.

Chandler, K.; Eudy, L. (2010) *Connecticut Transit (**CT**TRANSIT) Fuel Cell Transit Bus: Third Evaluation Report and Appendices*. NREL/TP-560-47334-1, NREL/TP-560-47334-2. Golden, CO: National Renewable Energy Laboratory.

Chandler, K.; Eudy, L. (2009) *Connecticut Transit (**CT**TRANSIT) Fuel Cell Transit Bus: Second Evaluation Report and Appendices*. NREL/TP-560-45670-1, NREL/TP-560-45670-2. Golden, CO: National Renewable Energy Laboratory.

Chandler, K.; Eudy, L. (2008). *Connecticut Transit (**CT**TRANSIT) Fuel Cell Transit Buses: Preliminary Evaluation Results.* NREL/TP-560-43847. Golden, CO: National Renewable Energy Laboratory.

Eudy, L. (2008). ***CT**TRANSIT Operates New England's First Fuel Cell Hybrid Bus*. DOE/GO12008-2529. Golden, CO: National Renewable Energy Laboratory.

San Francisco Municipal Transportation Agency

Eudy, L. (2011). *Compound Fuel Cell Hybrid Bus Hits the Streets of San Francisco: San Francisco Hosts National Fuel Cell Bus Program Demonstration.* DOT/FTA – NFCBP – FC2 – July 2011.

SunLine

Eudy, L.; Chandler, K. (2011). *SunLine Transit Agency Advanced Technology Fuel Cell Bus Evaluation: Third Results Report*. NREL/TP-5600-54427, Golden, CO: National Renewable Energy Laboratory.

Eudy, L. (2012). *American Fuel Cell Bus Project: Developing and Demonstrating the Next-Generation Fuel Cell Electric Bus Made in America.* DOT/FTA – NFCBP – FC4 – March 2012.

Eudy, L.; Chandler, K. (2011). *SunLine Transit Agency Advanced Technology Fuel Cell Bus Evaluation: Second Results Report and Appendices*. NREL/TP-5600-52349-1, NREL/TP-5600-52349-2, Golden, CO: National Renewable Energy Laboratory.

Eudy, L.; Chandler, K. (2011). *SunLine Transit Agency, Advanced Technology Fuel Cell Bus Evaluation: First Results Report*. NREL/TP-5600-50500. Golden, CO: National Renewable Energy Laboratory.

Eudy, L.; Chandler, K. (2009). *SunLine Transit Agency, Fuel Cell Transit Bus: Fifth Evaluation Report and Appendices*. NREL/TP-560-46346-1, NREL/TP-560-46346-2. Golden, CO: National Renewable Energy Laboratory.

Chandler, K.; Eudy, L. (2009). *SunLine Transit Agency, Fuel Cell Transit Bus: Fourth Evaluation Report and Appendices*. NREL/TP-560-44646-1, NREL/TP-560-44646-2. Golden, CO: National Renewable Energy Laboratory.

Eudy, L. (2008). *SunLine Begins Extended Testing of Hybrid Fuel Cell Bus*. DOE/GO-102008-2610. Golden, CO: National Renewable Energy Laboratory.

Chandler, K.; Eudy, L. (2008). *SunLine Transit Agency, Hydrogen-Powered Transit Buses: Third Evaluation Report and Appendices.* NREL/TP-560-43741-1, NREL/TP-560-43741-2. Golden, CO: National Renewable Energy Laboratory.

Appendix A: Fleet Summary Statistics

Fleet Summary Statistics: ZEBA FCEB and Diesel Bus Groups and Evaluation Periods
Fleet Operations and Economics

	FCEBs 9/10-8/11	Diesel Buses 9/10-8/11	FCEBs 9/11-4/12	Diesel Buses 9/11-4/12
Number of vehicles	9	3	12	3
Period used for fuel and oil op analysis	N/A	3/11-8/11	9/11-4/12	9/11-4/12
Total number of months in period	N/A	6	8	8
Fuel and oil analysis base fleet mileage	N/A	57,338	120,355	82,098
Period used for maintenance op analysis	9/10-8/11	9/10-8/11	9/11-4/12	9/11-4/12
Total number of months in period	12	12	8	8
Maintenance analysis base fleet mileage	121,624	122,886	147,007	83,599
Average monthly mileage per vehicle	1,871	3,724	1,598	3,635
Availability	61%	N/A	56%	77%
Fleet fuel usage in H_2 kg/Diesel gal	N/A	15,364	18,016	20,509
Roadcalls	49	44	73	24
RCs MBRC	2,482	2,793	2,014	2,117
Propulsion roadcalls	32	18	49	14
Propulsion MBRC	3,801	6,827	3,000	3,629
Fleet miles/kg hydrogen	N/A		6.68	
(1.13 kg H_2/gal diesel fuel)				
Representative fleet MPG (energy equiv)	N/A	3.73	7.55	4.00
Hydrogen cost per kg	9.34		9.34	
Diesel gal cost		3.18		3.18
Fuel cost per mile	**N/A**	**0.852**	**1.398**	**0.794**
Total scheduled repair cost per mile	0.275	0.108	0.260	0.133
Total unscheduled repair cost per mile	1.228	0.543	1.051	0.653
Total maintenance cost per mile	**1.502**	**0.651**	**1.311**	**0.786**
Total operating cost per mile	**N/A**	**1.503**	**2.709**	**1.581**

Maintenance costs

	FCEBs 9/10-8/11	Diesel Buses 9/10-8/11	FCEBs 9/11-4/12	Diesel Buses 9/11-4/12
Fleet mileage	121,624	122,886	147,007	83,599
Total parts cost	20,334.27	23,141.22	31,727.88	23,546.41
Total labor hours	3247.6	1137.8	3219.7	843.8
Average labor cost (@ $50.00 per hour)	162,380.00	56,890.00	160,985.00	42,190.00
Total maintenance cost	182,714.27	80,031.22	192,712.88	65,736.41
Total maintenance cost per bus	20,301.59	26,677.07	16,059.41	21,912.14
Total maintenance cost per mile	**1.502**	**0.651**	**1.311**	**0.786**

Breakdown of Maintenance Costs by Vehicle System

	FCEBs 9/10-8/11	Diesel Buses 9/10-8/11	FCEBs 9/11-4/12	Diesel Buses 9/11-4/12
Fleet mileage	121,624	122,886	147,007	83,599
Total Engine/Fuel-Related Systems (ATA VMRS 27, 30, 31, 32, 33, 41, 42, 43, 44, 45, 46, 65)				
Parts cost	2,114.69	7,982.80	5,957.71	8,142.90
Labor hours	1,065.42	226.15	1,012.67	201.85
Average labor cost	53,271.00	11,307.50	50,633.50	10,092.50
Total cost (for system)	55,385.69	19,290.30	56,591.21	18,235.40
Total cost (for system) per bus	6,153.97	6,430.10	4,715.93	6,078.47
Total cost (for system) per mile	**0.4554**	**0.1570**	**0.3850**	**0.2181**
Exhaust System Repairs (ATA VMRS 43)				
Parts cost	0.00	0.00	0.00	217.32
Labor hours	0.0	4.5	0.0	3.4
Average labor cost	0.00	224.50	0.00	170.00
Total cost (for system)	0.00	224.50	0.00	387.32
Total cost (for system) per bus	0.00	74.83	0.00	129.11
Total cost (for system) per mile	**0.0000**	**0.0018**	**0.0000**	**0.0046**
Fuel System Repairs (ATA VMRS 44)				
Parts cost	0.00	293.57	15.47	692.04
Labor hours	378.7	3.5	166.7	9.6
Average labor cost	18,935.00	175.00	8,335.00	480.00
Total cost (for system)	18,935.00	468.57	8,350.47	1,172.04
Total cost (for system) per bus	2,103.89	156.19	695.87	390.68
Total cost (for system) per mile	**0.1557**	**0.0038**	**0.0568**	**0.0140**
Power Plant (Engine) Repairs (ATA VMRS 45)				
Parts cost	18.08	627.31	260.89	3,767.42
Labor hours	205.0	82.8	204.0	100.0
Average labor cost	10,251.50	4,137.50	10,200.50	5,000.00
Total cost (for system)	10,269.58	4,764.81	10,461.39	8,767.42
Total cost (for system) per bus	1,141.06	1,588.27	871.78	2,922.47
Total cost (for system) per mile	**0.0844**	**0.0388**	**0.0712**	**0.1049**
Electric Propulsion Repairs (ATA VMRS 46)				
Parts cost	893.78	0.00	1,251.77	0.00
Labor hours	227.3	0.0	458.5	0.0
Average labor cost	11,362.50	0.00	22,924.00	0.00
Total cost (for system)	12,256.28	0.00	24,175.77	0.00
Total cost (for system) per bus	1,361.81	0.00	2,014.65	0.00
Total cost (for system) per mile	**0.1008**	**0.0000**	**0.1645**	**0.0000**

Breakdown of Maintenance Costs by Vehicle System (continued)

	FCEBs 9/10-8/11	Diesel Buses 9/10-8/11	FCEBs 9/11-4/12	Diesel Buses 9/11-4/12
Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)				
Parts cost	691.75	1,133.69	1,747.91	51.63
Labor hours	229.6	14.8	81.3	20.7
Average labor cost	11,480.50	737.50	4,064.50	1,032.50
Total cost (for system)	12,172.25	1,871.19	5,812.41	1,084.13
Total cost (for system) per bus	1,352.47	623.73	484.37	361.38
Total cost (for system) per mile	**0.1001**	**0.0152**	**0.0395**	**0.0130**
Air Intake System Repairs (ATA VMRS 41)				
Parts cost	221.11	458.29	2,152.28	801.89
Labor hours	3.0	23.5	8.7	16.9
Average labor cost	150.00	1,175.00	435.50	845.00
Total cost (for system)	371.11	1,633.29	2,587.78	1,646.89
Total cost (for system) per bus	41.23	544.43	215.65	548.96
Total cost (for system) per mile	**0.0031**	**0.0133**	**0.0176**	**0.0197**
Cooling System Repairs (ATA VMRS 42)				
Parts cost	289.97	5,383.04	529.39	1,484.11
Labor hours	15.8	87.7	93.5	48.0
Average labor cost	791.50	4,383.00	4,674.00	2,400.00
Total cost (for system)	1,081.47	9,766.04	5,203.39	3,884.11
Total cost (for system) per bus	120.16	3,255.35	433.62	1,294.70
Total cost (for system) per mile	**0.0089**	**0.0795**	**0.0354**	**0.0465**
Hydraulic System Repairs (ATA VMRS 65)				
Parts cost	0.00	6.71	0.00	0.00
Labor hours	0.0	0.0	0.0	0.0
Average labor cost	0.00	0.00	0.00	0.00
Total cost (for system)	0.00	6.71	0.00	0.00
Total cost (for system) per bus	0.00	2.24	0.00	0.00
Total cost (for system) per mile	**0.0000**	**0.0001**	**0.0000**	**0.0000**
General Air System Repairs (ATA VMRS 10)				
Parts cost	2,387.24	1,801.06	3,875.75	723.46
Labor hours	114.2	80.0	66.4	35.7
Average labor cost	5,707.50	4,000.00	3,321.50	1,785.00
Total cost (for system)	8,094.74	5,801.06	7,197.25	2,508.46
Total cost (for system) per bus	899.42	1,933.69	599.77	836.15
Total cost (for system) per mile	**0.0666**	**0.0472**	**0.0490**	**0.0300**

Breakdown of Maintenance Costs by Vehicle System (continued)

	FCEBs 9/10-8/11	Diesel Buses 9/10-8/11	FCEBs 9/11-4/12	Diesel Buses 9/11-4/12
Brake System Repairs (ATA VMRS 13)				
Parts cost	12.70	2,363.46	321.45	7,301.74
Labor hours	13.0	55.0	24.0	83.5
Average labor cost	650.00	2,750.00	1,200.00	4,172.50
Total cost (for system)	662.70	5,113.46	1,521.45	11,474.24
Total cost (for system) per bus	73.63	1,704.49	126.79	3,824.75
Total cost (for system) per mile	**0.0054**	**0.0416**	**0.0103**	**0.1373**
Transmission Repairs (ATA VMRS 27)				
Parts cost	0.00	80.20	0.00	1,128.49
Labor hours	6.0	9.5	0.0	3.3
Average labor cost	300.00	475.00	0.00	165.00
Total cost (for system)	300.00	555.20	0.00	1,293.49
Total cost (for system) per bus	33.33	185.07	0.00	431.16
Total cost (for system) per mile	**0.0025**	**0.0045**	**0.0000**	**0.0155**
Inspections Only - no parts replacements (101)				
Parts cost	0.00	0.00	0.00	0.00
Labor hours	576.0	182.3	669.0	140.1
Average labor cost	28,801.00	9,112.50	33,449.50	7,005.00
Total cost (for system)	28,801.00	9,112.50	33,449.50	7,005.00
Total cost (for system) per bus	3,200.11	3,037.50	2,787.46	2,335.00
Total cost (for system) per mile	**0.2368**	**0.0742**	**0.2275**	**0.0838**
Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)				
Parts cost	8,503.72	4,611.10	18,550.84	4,695.10
Labor hours	1306.6	505.3	1281.2	344.1
Average labor cost	65,328.00	25,263.50	64,059.00	17,203.00
Total cost (for system)	73,831.72	29,874.60	82,609.84	21,898.10
Total cost (for system) per bus	8,203.52	9,958.20	6,884.15	7,299.37
Total cost (for system) per mile	**0.6070**	**0.2431**	**0.5619**	**0.2619**
HVAC System Repairs (ATA VMRS 01)				
Parts cost	4,102.75	3,763.91	897.40	1,914.87
Labor hours	57.0	31.3	14.7	8.4
Average labor cost	2,850.00	1,562.50	735.00	420.00
Total cost (for system)	6,952.75	5,326.41	1,632.40	2,334.87
Total cost (for system) per bus	772.53	1,775.47	136.03	778.29
Total cost (for system) per mile	**0.0572**	**0.0433**	**0.0111**	**0.0279**

Breakdown of Maintenance Costs by Vehicle System (continued)

	FCEBs 9/10-8/11	Diesel Buses 9/10-8/11	FCEBs 9/11-4/12	Diesel Buses 9/11-4/12
Lighting System Repairs (ATA VMRS 34)				
Parts cost	1,209.62	741.13	290.00	71.59
Labor hours	29.3	25.0	24.4	1.3
Average labor cost	1,464.50	1,250.00	1,220.50	62.50
Total cost (for system)	2,674.12	1,991.13	1,510.50	134.09
Total cost (for system) per bus	297.12	663.71	125.88	44.70
Total cost (for system) per mile	**0.0220**	**0.0162**	**0.0103**	**0.0016**
Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)				
Parts cost	2,003.56	538.18	1,751.91	375.92
Labor hours	60.5	16.3	103.2	10.5
Average labor cost	3,023.50	816.50	5,161.00	525.00
Total cost (for system)	5,027.06	1,354.68	6,912.91	900.92
Total cost (for system) per bus	558.56	451.56	576.08	300.31
Total cost (for system) per mile	**0.0413**	**0.0110**	**0.0470**	**0.0108**
Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)				
Parts cost	0.00	1,339.60	5.48	294.86
Labor hours	3.8	16.5	22.6	12.5
Average labor cost	191.50	825.00	1,131.50	625.00
Total cost (for system)	191.50	2,164.60	1,136.98	919.86
Total cost (for system) per bus	21.28	721.53	94.75	306.62
Total cost (for system) per mile	**0.0016**	**0.0176**	**0.0077**	**0.0110**
Tire Repairs (ATA VMRS 17)				
Parts cost	0.00	0.00	0.00	0.00
Labor hours	6.8	0.0	0.0	0.0
Average labor cost	341.50	0.00	0.00	0.00
Total cost (for system)	341.50	0.00	0.00	0.00
Total cost (for system) per bus	37.94	0.00	0.00	0.00
Total cost (for system) per mile	**0.0028**	**0.0000**	**0.0000**	**0.0000**

Notes

1. To compare the hydrogen fuel dispensed and fuel economy to diesel, the hydrogen dispensed was also converted into diesel energy equivalent gallons. Actual energy content will vary by locations, but the general energy conversions are as follows:

> Lower heating value (LHV) for hydrogen = 51,532 Btu/lb
> LHV for diesel = 128,400 Btu/lb
> 1 kg = 2.205 * lb
> 51,532 Btu/lb * 2.205 lb/kg = 113,628 Btu/kg
> Diesel/hydrogen = 128,400 Btu/gal /113,628 Btu/kg = 1.13 kg/diesel gal

2. The propulsion-related systems were chosen to include only those systems of the vehicles that could be affected directly by the selection of a fuel/advanced technology.

3. ATA VMRS coding is based on parts that were replaced. If there was no part replaced in a given repair, then the code was chosen by the system being worked on.

4. In general, inspections (with no part replacements) were included only in the overall totals (not by system). Category 101 was created to track labor costs for PM inspections.

5. ATA VMRS 02-Cab and Sheet Metal represents seats, doors, etc.; ATA VMRS 50-Accessories represents things like fire extinguishers, test kits, etc.; ATA VMRS 71-Body represents mostly windows and windshields.

6. Average labor cost is assumed to be $50 per hour.

7. Warranty costs are not included.

Appendix B: Fleet Summary Statistics – SI Units

Fleet Summary Statistics: ZEBA FCEB and Diesel Bus Groups and Evaluation Periods

Fleet Operations and Economics

	FCEBs 9/10-8/11	Diesel Buses 9/10-8/11	FCEBs 9/11-4/12	Diesel Buses 9/11-4/12
Number of vehicles	12	3	12	3
Period used for fuel and oil op analysis	N/A	3/11-8/11	9/11-4/12	9/11-4/12
Total number of months in period	N/A	6	8	8
Fuel and oil analysis base fleet kilometers	N/A	92,274	193,687	132,120
Period used for maintenance op analysis	9/10-8/11	9/10-8/11	9/11-4/12	9/11-4/12
Total number of months in period	12	12	8	8
Maintenance analysis base fleet kilometers	195,730	197,760	236,578	134,536
Average monthly kilometers per vehicle	3,011	5,993	2,572	5,850
Availability	61%	N/A	56%	77%
Fleet fuel usage in H2 kg	N/A	15,364	18,016	20,509
Roadcalls	49	44	73	23
RCs KMBRC	3,994	4,495	3,241	3,856
Propulsion roadcalls	32	18	49	14
Propulsion KMBRC	6,117	10,987	4,828	6,336
Fleet kg hydrogen/100 km	N/A		9.30	
(1.13 kg H2/gal diesel fuel)				
Rep. fleet fuel consumption (L/100 km)	N/A	63.42	31.16	59.14
Hydrogen cost per kg	9.34		9.34	
Diesel cost/liter		0.84		0.84
Fuel cost per kilometer	**N/A**	**0.507**	**0.869**	**0.490**
Total scheduled repair cost per kilometer	0.171	0.067	0.162	0.083
Total unscheduled repair cost per kilometer	0.763	0.338	0.653	0.406
Total maintenance cost per kilometer	**0.933**	**0.405**	**0.815**	**0.489**
Total operating cost per kilometer	**N/A**	**0.911**	**1.683**	**0.979**

Maintenance costs

	FCEBs 9/10-8/11	Diesel Buses 9/10-8/11	FCEBs 9/11-4/12	Diesel Buses 9/11-4/12
Fleet mileage	195,730	197,760	236,578	134,536
Total parts cost	20,334.27	23,141.22	31,727.88	23,546.41
Total labor hours	3247.6	1137.8	3219.7	843.8
Average labor cost (@ $50.00 per hour)	162,380.00	56,890.00	160,985.00	42,190.00
Total maintenance cost	182,714.27	80,031.22	192,712.88	65,736.41
Total maintenance cost per bus	15,226.19	26,677.07	16,059.41	21,912.14
Total maintenance cost per kilometer	**0.934**	**0.405**	**0.815**	**0.489**