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National Fuel Cell Bus Program: Accelerated Testing Evaluation Report

Alameda-Contra Costa Transit District
(AC Transit)

National
Fuel Cell Bus
Program

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13. ABSTRACT (Maximum 200 words) **This is an evaluation of hydrogen fuel cell transit buses operating at AC Transit in revenue service since March 20, 2006 compared to similar diesel buses operating from the same depot. This evaluation report includes results from November 2007 through October 2008. Evaluation results include implementation experience, fueling station operation, fuel cell bus operations at Golden Gate Transit, and evaluation results at AC Transit (bus usage, availability, fuel economy, maintenance costs, and roadcalls).**				
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Executive Summary

The Alameda-Contra Costa Transit District (AC Transit) has been operating three fuel cell buses in revenue service since March 20, 2006. This operation has been documented in previous evaluation reports from the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL). This report continues the evaluation at AC Transit; however, the funding for NREL's data collection and analysis has been transitioned from DOE to the Federal Transit Administration (FTA). Specifically, this report provides results of AC Transit's accelerated testing of its existing three fuel cell buses as part of FTA's National Fuel Cell Bus Program (NFCBP).

The accelerated testing results in this report include operation from November 2007 through October 2008 for the fuel cell buses with a focus on fuel cell bus operations from the last installation of new fuel cell power systems through October 2008. The diesel bus evaluation results are from January 2007 through December 2007.

Previous Demonstration Experience at AC Transit

The fuel cell buses at AC Transit are prototype and demonstration vehicles. The primary objective of these prototype demonstrations is to learn from problems that arise by identifying, resolving, and incorporating the lessons learned into future designs. A demonstration of this type is designed to push the technology to its limit (and beyond) to identify and address design issues. With this said, the general conclusion from the early operating data of these prototype fuel cell buses is that the implementation went extremely well, the buses were used with no safety incidents, and the public was very interested in the program; however, the level of bus usage and availability was low (58% as opposed to the target of 85%), and the miles between roadcalls (MBRC) was lower than desired (a factor of four to seven times lower than the baseline).

One positive result from this demonstration was that the fuel economy was at least 67% higher, but more in many cases, during the entire early operating period. There were two specific issues that caused the lower-than-desired availability and MBRC rate—issues with the fuel cell power systems and with the traction batteries. These two issues represent 33 of the 40 total propulsion-related roadcalls and 73% of the reasons for the buses being unavailable for service. The continued demonstration and accelerated testing are intended to resolve and move beyond these issues into nearly full transit bus operation before transitioning to new fuel cell buses in late 2009 or early 2010.

Accelerated Testing at AC Transit

The accelerated testing project at AC Transit was envisioned to include preparation and support to maximize operation of the three fuel cell buses and then support the transition to the next phase of the fuel cell bus program. The maximized operation includes operating the fuel cell buses in revenue service 16 to 19 hours per day, up to seven days per week, and is intended to accelerate planning for resources and training at AC Transit in preparation to support nearly full transit operation of the fuel cell buses. Secondly, the maximized operation is intended to help the manufacturers further validate the propulsion system, identifying the weakest areas, analyzing the root causes of failure, and making modifications and upgrades to increase durability and reliability. The resulting design changes will be incorporated into the next generation systems.

Public Outreach

AC Transit's hydrogen fuel cell vehicle program (HyRoad) has always had a significant focus on public awareness. Recently, AC Transit has completed a passenger survey to gauge the interest and thoughts of the riding public. The results from the survey were extremely positive. An estimate of the number of riders for the fuel cell buses was made using AC Transit's route ridership estimates and on-board automated passenger counters (APCs). The total estimate from March 20, 2006, through October 31, 2008, was nearly 278,000 passengers with more than half of those passengers riding during the accelerated testing period. These data indicate that the bus operation during the accelerated testing is meeting the objective of significantly increased bus usage.

Hydrogen Fueling

Hydrogen fuel is supplied at AC Transit by two steam methane reformers. The fuel is compressed and dispensed into vehicles at a final pressure of up to 5,000 psi. During the accelerated testing evaluation period, the AC Transit hydrogen station dispensed a total of 8,824 kg of hydrogen for the buses (total of 19,257 kg for the entire revenue service demonstration) with an overall average daily usage of 33.9 kg/day. The three buses were filled a total of 422 times during the accelerated testing evaluation period with an average fill amount of 20.9 kg/fill and an average fueling rate of 1.34 kg/min.

Evaluation Results

Table ES-1 provides a summary of results for several of the categories of data presented in this report.

Table ES-1. Summary of Evaluation Results

Data Item	Fuel Cell	Diesel
Number of Buses	3	6
Data Period	Through 10/08	1/07 – 12/07
Number of Months	~9	12
Total Mileage in Period	49,921	266,514
Average Monthly Mileage per Bus	1,837	3,702
Total Fuel Cell Operating Hours	4,957	N/A
Average Bus Operating Speed (mph)	10.1	N/A
Availability (85% is target)	61%	N/A
Fuel Economy (Miles/kg)	6.49	N/A
Fuel Economy (Miles/DGE[a])	7.33	4.20
Miles between Roadcalls (MBRC) – All	1,019	4,299
MBRC – Propulsion Only	1,189[b]	10,661
Total Maintenance, $/mile[c]	0.65	0.49
Maintenance – Propulsion Only, $/mile	0.15	0.10

a. Diesel gallon equivalent
b. For fuel cell propulsion only, MBRC was 6,240
c. Work order maintenance cost

Golden Gate Transit's Fuel Cell Bus Operating Experience

Golden Gate Transit (GGT) has participated in the fuel cell bus demonstration as a partner with AC Transit since 2003. AC Transit provides access to training on the fuel cell buses and infrastructure, shares information and lessons learned on the project, and has provided one of the three fuel cell buses for operation at GGT. This effort was accomplished between February 19 and March 21, 2008, for 24 weekdays. GGT worked diligently to carefully plan for and execute this fuel cell bus operation. Because of the high average operating speed at GGT, the fuel economy during this operation was significantly higher than for AC Transit at 8.8 miles per kilogram or 10.0 miles per diesel equivalent gallon.

What's Next for AC Transit?

AC Transit continues to operate the three existing fuel cell buses in their accelerated testing project for FTA's NFCBP. This continued operation has required AC Transit to invest significant resources into personnel, training, and equipment as discussed in this report. At the same time, CARB has required several California transit agencies (including AC Transit) to purchase new and advanced fuel cell buses as part of their zero-emission bus regulations. The Bay Area is now required to have 12 new and advanced fuel cell buses in operation in 2009. AC Transit is the managing partner for a Zero Emission Bay Area (ZEBA) working group (five transit agencies) to respond to CARB's advanced fuel cell bus demonstration.

The new Van Hool fuel cell buses (purchase price around $2.3 million each) with power systems from UTC Power have an improved design from the current fuel cell buses—they are lighter weight, three inches shorter in height, and have a different battery/energy storage design (lithium ion batteries are being considered). The first bus is now expected at AC Transit in fourth quarter 2009.

AC Transit continues to work on hydrogen fueling infrastructure for the existing and new fuel cell buses as well as light-duty fuel cell vehicles at the current operating location (Division 4) and now with a new station at Division 2 (Emeryville). This new station is more conveniently located for future bus operations with ZEBA partner transit agencies like GGT.

The next evaluation report as part of the AC Transit accelerated testing project is planned for mid 2009 but may change depending on updates in the delivery schedule of the new fuel cell buses.

Table of Contents

Introduction and Background

The Alameda-Contra Costa Transit District (AC Transit) has been operating three fuel cell buses in revenue service since March 20, 2006. This operation has been documented in three previous evaluation reports from the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL).[1,2,3] This report continues the evaluation at AC Transit; however, the funding for NREL's data collection and analysis has been transitioned from DOE to the Federal Transit Administration (FTA). Specifically, this report provides results of AC Transit's accelerated testing of its existing three fuel cell buses as part of FTA's National Fuel Cell Bus Program (NFCBP). The accelerated testing evaluation results in this report include operation from November 2007 through October 2008.

National Fuel Cell Bus Program (NFCBP)

In 2006, FTA initiated the NFCBP[4], which provided $49 million in competitive 50-50 government-industry cost share grants to facilitate the development of commercially viable fuel cell bus technologies. This FTA program was funded as part of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: a Legacy for Users (SAFETEA-LU). The objectives of the program include:

- Developing improved components and technologies for fuel cell buses, including fuel cell, energy storage, and power electronics technologies
- Demonstrating fuel cell buses equipped with these improved components and technologies
- Understanding the requirements of market introduction, including fuel supply, fueling infrastructure, supplier networks, maintenance, education, safety, and insurance
- Collaborating in the development of design standards for fuel cell bus technologies.

Announced on October 12, 2006, at SunLine Transit Agency, FTA awarded grants to three non-profit consortia—CALSTART (Pasadena, CA), Center for Transportation and the Environment (CTE, Atlanta, GA), and the Northeast Advanced Vehicle Consortium (NAVC, Boston, MA). Over a four-year period, these consortia will lead teams to develop and test components, conduct outreach, and demonstrate fuel cell buses in a variety of geographic locations and climates across the United States.

A portfolio of fourteen projects (managed by the three consortia) was competitively selected by FTA to best advance fuel cell bus commercialization, including eight planned demonstration projects. Bus demonstration projects include both evolutionary and "clean sheet" approaches

[1] Alameda-Contra Costa Transit District (AC Transit), Fuel Cell Transit Buses: Preliminary Evaluation Results, February 2007, NREL/TP-560-41041, http://www.nrel.gov/hydrogen/pdfs/41041.pdf
[2] Alameda-Contra Costa Transit District (AC Transit), Fuel Cell Transit Buses: Evaluation Results Update, October 2007, NREL/TP-560-42249, http://www.nrel.gov/hydrogen/pdfs/42249.pdf
[3] Alameda-Contra Costa Transit District (AC Transit), Fuel Cell Transit Buses: Third Evaluation Report, July 2008, NREL/TP-560-43545-1, http://www.nrel.gov/hydrogen/pdfs/43545-1.pdf
[4] FTA Bus Research and Testing Web site: http://www.fta.dot.gov/assistance/technology/research_4578.html

and incorporate multiple drive technologies and configurations, fuel cell stacks in various sizes, and various energy storage technologies. The buses being demonstrated incorporate components from four fuel cell power system manufacturers and various implementations of hybrid electric propulsion systems and energy storage—batteries and ultracapacitors.

Data collection, analysis, and reporting the results of the demonstrations are all high priorities for FTA. As such, FTA is collaborating with DOE and NREL to ensure that data are collected on all fuel cell bus demonstrations in a complete and consistent manner. FTA has tasked NREL as a third-party evaluator for the fuel cell buses developed and demonstrated under the NFCBP.

Under funding from DOE, NREL has been evaluating fuel cell buses to help determine the status of hydrogen and fuel cell systems in transit applications. NREL uses a standard data collection and analysis protocol that was established for DOE heavy-duty vehicle evaluations more then ten years ago. In May 2008, NREL published *Hydrogen and Fuel Cell Transit Bus Evaluations: Joint Evaluation Plan for the U.S. Department of Energy and the Federal Transit Administration*, which outlines the methodology and plans for both the DOE and FTA fuel cell bus evaluations[5] to be performed by NREL. Appendix A provides an overview of NREL's transit bus evaluation activities for DOE and FTA.

AC Transit Fuel Cell Bus Operation and Evaluation

AC Transit provides public transit service in the East Bay of the San Francisco, California, area including Oakland, California. The AC Transit service area of 360 square miles includes 13 cities and adjacent unincorporated areas in Alameda and Contra Costa counties. Since 2000, AC Transit has developed and operated a fuel cell demonstration program called the HyRoad. With a goal of demonstrating the viability of an emission-free transit system, this program includes operating fuel cell buses and passenger cars, on-site hydrogen production, fueling, vehicle maintenance, public outreach and education, and safety training.

Golden Gate Transit (GGT), headquartered in San Rafael, California, is participating in the AC Transit fuel cell bus demonstration and has operated one of the fuel cell buses for nearly a month as discussed later in this report. GGT is a part of the Golden Gate Bridge, Highway, and Transportation District, which is headquartered in San Francisco, California, and serves the North Bay area. Appendix B provides more information about AC Transit and GGT.

The development of the fuel cell buses is the result of collaboration between Van Hool, ISE Corporation, and UTC Power. The buses use the PureMotion[6] 120 Fuel Cell Power System manufactured by UTC Power in a hybrid electric drive system designed by ISE. The energy storage in this hybrid system consists of three ZEBRA (sodium/nickel chloride, high temperature) traction batteries.

The evaluation also includes results from the operation of six Van Hool diesel buses in revenue service at the same location as the fuel cell buses. The diesel buses, which are used in the evaluation as a baseline, are equipped with Cummins ISL engines. Appendix C provides more detail about the buses and propulsion technologies included in this evaluation. Appendix D

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[5] Hydrogen and Fuel Cell Transit Bus Evaluations: Joint Evaluation Plan for the U.S. Department of Energy and the Federal Transit Administration, NREL/MP-560-42781, May 2008, http://www.nrel.gov/hydrogen/pdfs/42781-1.pdf
[6] PureMotion is a registered trademark of UTC Power.

provides information about the hydrogen fueling station and facilities modified for use with hydrogen. Updated information regarding hydrogen dispensing into the fuel cell buses is discussed later in this report.

Accelerated Testing at AC Transit

The accelerated testing project at AC Transit continues the existing partnership with UTC Power and Van Hool for continued demonstration of the three fuel cell buses. ISE continues to monitor the project but is no longer a major participant. As mentioned above, the NFCBP has introduced non-profit consortia leads for this FTA program. The project at AC Transit is managed through CALSTART in Pasadena, California. CALSTART works with public and private partners to accelerate the growth of advanced transportation technologies including fuel cells. CALSTART has been tasked with managing five of the fourteen projects in the NFCBP including fuel cell bus demonstrations (such as the AC Transit demonstration) as well as development of advanced components related to fuel cell propulsion system[7].

The accelerated testing project at AC Transit was envisioned to include preparation and support for maximizing operation of the three fuel cell buses and then supporting the transition to the next phase of the fuel cell bus program. The maximized operation includes operating the fuel cell buses in revenue service 16 to 19 hours per day, up to seven days per week, and is intended to accelerate planning for resources and training at AC Transit to prepare to support nearly full transit operation of the fuel cell buses. Secondly, the maximized operation is intended to help the manufacturers further validate the propulsion system, identifying the weakest areas, analyzing the root causes of failure, and making modifications and upgrades to increase durability and reliability. The resulting design changes will be incorporated into the next generation systems, which will be used in AC Transit's next phase of operation with 12 new fuel cell buses to be delivered in late 2009 and early 2010.

The 12 new fuel cell buses are a part of a multi-operator bus demonstration in the Bay Area for regulations promulgated by the California Air Resources Board (CARB). This new demonstration, currently designated the Zero Emission Bay Area (ZEBA) demonstration group, will be managed from AC Transit and will include participation by Golden Gate Transit (GGT), Santa Clara Valley Transportation Authority (VTA), San Mateo County Transit District (SamTrans), and San Francisco Municipal Transportation Agency (SF MTA). The next steps for fuel cell bus operation and demonstration at AC Transit will be discussed further at the end of this report (What's Next for AC Transit?).

What's in this Evaluation Report?

This evaluation report is focused on the AC Transit accelerated testing project as part of the FTA NFCBP. However, this report begins with a summary of the previous fuel cell bus experience at AC Transit to provide context for the objectives of the accelerated testing. Next, the accelerated testing has required AC Transit to do extensive preparation with additional resources and training to enable its staff to support nearly full transit operation of the fuel cell buses. AC Transit has continued to support public outreach with their fuel cell bus program, and results from a passenger survey and some ridership summaries are provided. A summary of the

[7] CALSTART Web site: www.calstart.org

hydrogen fueling during the accelerated testing is provided along with some statistics for life-to-date operation of the fueling station.

The bulk of the report provides summary results from the operation of the fuel cell buses from November 2007 through October 2008. The accelerated testing period was defined contractually to start with November 2007; however, the focus of the evaluation results is presented from the point at which the fuel cell power system (CSAs—cell stack assemblies) was last replaced for each of the three buses as follows:

- **Fuel Cell Bus 1 (FC1)**—CSAs replaced on March 7, 2008, re-started service on March 18, 2008
- **Fuel Cell Bus 2 (FC2)**—CSAs replaced on January 31, 2008, re-started service on February 5, 2008
- **Fuel Cell Bus 3 (FC3)**—CSAs replaced on December 11, 2007, re-started service on December 13, 2007

UTC Power has reported that this last change of the CSAs has incorporated many of the lessons learned from the previous operation of these fuel cell buses (and from the other operating locations), and previous early power-loss issues are believed to be resolved. The "clean point" for the accelerated testing evaluation includes the point that these fuel cell buses re-started service (FC—March 2008, FC2—February 2008, FC3—December 2007) through the current endpoint of October 31, 2008. This clean point evaluation period will be provided throughout the Evaluation Results section. The diesel bus baseline evaluation period has been completed and includes data from January 2007 through December 2007.

This report concludes with a description of the next steps for the accelerated testing and the next phase of AC Transit's program including the delivery of 12 new fuel cell buses.

Previous Demonstration Experience at AC Transit

As mentioned earlier, AC Transit's fuel cell buses began revenue service on March 20, 2006. This section focuses on the experience from the start of revenue service through the start of the accelerated testing project (October 31, 2007), and a summary of the results from that period is shown in Table 1. These data are provided as context for what came before the accelerated testing period and what issues were discovered during this nearly two-year operating period.

The fuel cell buses at AC Transit are prototype and demonstration vehicles. The primary objective of these prototype demonstrations is to learn from problems that arise by identifying, resolving, and incorporating the lessons learned into future designs. The objective of this demonstration of these buses has been to explore real-world service for validating the technologies and determining what modifications are needed to increase durability and reliability for future commercial product introduction. A demonstration of this type is designed to push the technology to its limit (and beyond) to identify and address design issues. With that said, the general conclusion from the early operating data of these prototype fuel cell buses is that the implementation went extremely well, the buses were used with no safety incidents, and the public was very interested in the program; however, the level of bus usage and availability was low (58% as opposed to the target of 85%), and the miles between roadcalls (MBRC) was lower than desired (a factor of four to seven times lower than the baseline).

Table 1. Summary of Previous Revenue Service Results

Data Item	Fuel Cell
Number of Buses	3
Data Period	3/20/06 – 10/31/07
Number of Months	19
Total Mileage in Period	60,198
Average Monthly Mileage per Bus	1,023
Total Fuel Cell Operating Hours	5,499
Average Bus Operating Speed (mph)	10.9
Availability (85% is target)	58%
Fuel Economy (Miles/kg)	6.22
Fuel Economy (Miles/DGE[a])	7.03
Miles between Roadcalls (MBRC) – All	1,281
MBRC – Propulsion Only	1,505[b]
Total Maintenance, $/mile[c]	0.57
Maintenance – Propulsion Only, $/mile	0.09

a. Diesel gallon equivalent
b. For fuel cell propulsion only, MBRC was 5,017
c. Work order maintenance cost

One positive result from this demonstration was that the fuel economy was at least 67% higher, but more in many cases, during the entire early operating period. There were two specific issues that caused the lower-than-desired availability and MBRC rate—issues with the fuel cell power systems and with the traction batteries. These two issues represent 33 of the 40 total propulsion-related roadcalls and 73% of the reasons for the buses being unavailable for service. The status of these two issues is currently as follows:

- **Fuel Cell Power System Issues**—UTC Power monitors the performance of the fuel cell power system to analyze actual performance versus predicted performance. The cell stack assemblies (CSAs) showed power degradation early in the operation of the bus. When the power degradation of the CSAs falls below 90 kW to 95 kW of the original 120 kW, the system is considered to be at the end of its life and should be replaced. This early power degradation was reported with the other fuel cell buses as well, and UTC Power reports the problem as an issue of contamination within the CSAs causing the premature degradation beyond end of life (considerably less number of hours of operation instead of the expected 4,000 hours or more). Generally, each of the three fuel cell buses has had the CSAs replaced multiple times so far with newer/upgraded units, including the newest ones as described above in the discussion of the clean points for this current evaluation report (What's in this Evaluation Report?).

- **Traction Battery Issues**—The ZEBRA batteries have experienced significant issues in this specific application. Three traction batteries on the bus are operated in parallel. A cell in a ZEBRA battery will typically fail in short circuit. A battery with failed cells has reduced voltage even though it still can be operated. Because the batteries are operated with a direct parallel connection, when the number of failed cells within each of the batteries is too different among the three batteries, it causes an unbalancing of the state of charge (SOC). This imbalance makes it difficult to keep the batteries in the recommended operating range. The present SOC balancing algorithm will disconnect a battery temporarily to keep the SOC balanced.

  This situation may mislead over-volt errors in the propulsion system, causing a shutdown of the bus. The battery manufacturer (MES-DEA), UTC Power, and ISE have been working on the issue for some time. Because failed cells are related to a stress condition due to the battery usage, some progress has been made with controller software changes to improve battery operation by refining some operational limits. Options for a balancing strategy are under discussion. More replacement batteries are kept in stock to increase the number of available better-matched batteries and to reduce the amount of downtime of the fuel cell bus both at AC Transit and the rest of the Van Hool fuel cell buses in California and Connecticut.

The accelerated testing project is intended to investigate the operation of the buses at or near full transit operation to maximize operating hours and miles used as quickly as possible. This investigation has been possible only with the newer fuel cell power systems, the investigation of the traction battery operation, and preparation by AC Transit to be able to support the operations and maintenance of the fuel cell buses. The next section explores all of AC Transit's efforts to support this attempt at operating the fuel cell buses in full transit operations.

Preparing for Full Transit Operation

An important aspect of the project at AC Transit is to begin working toward full transit operation with the fuel cell buses. In past projects, the fuel cell buses were limited to weekdays only, primarily during daytime hours. This schedule was to ensure the buses were covered by the few trained transit staff (or on-site OEM staff) in case of issues on the road. As the agency anticipates larger deployments, this service needs to transition to be more in line with the conventional diesel buses by operating the buses on multiple shifts and during weekends. To accomplish this schedule, the agency must train a larger number of staff to operate the buses as well as begin to perform more of the required maintenance and have enough trained staff to complete that maintenance.

Operator Training—When the fuel cell buses first went into service, AC Transit trained a selection of drivers to operate the fuel cell buses. The drivers were chosen based on the planned routes for the fuel cell buses. Each time the agency reconfigures its service; operators "sign up" to drive buses on specific routes. Once AC Transit determined which routes to run the fuel cell buses on, they were able to train the operators that were signed up for those routes. These drivers were given a general overview on hydrogen and safety, instructions on start-up and shut-down procedures, as well as information on error codes and what to do in case of an emergency. Operators were also trained from a list of replacement staff referred to as the "extra board." These operators are called in to replace regular operators when needed, such as vacation or sick days for the originally planned operator. Training staff from this pool ensured the buses did not get held from service because of a lack of trained operators. For operation prior to the accelerated testing period (prior to November 2007), the buses were considered available but were held from service 12% of the time for lack of a trained operator. During the accelerated testing period in this report, this situation has dropped to only 3% of available operating days, so the training strategy appears to be working.

Once the agency began increasing the use of the buses, it became necessary to train an increasing number of operators. Over the past year, AC Transit has trained all Division 4 (East Oakland) drivers to operate the fuel cell buses. As AC Transit hires new staff, or as operators transfer from other divisions, the agency is implementing additional training to cover all potential drivers of the fuel cell buses. Training for other divisions will begin once the agency determines where the fuel cell buses will be operated in the next phase of the demonstration.

Bus Fueling—Chevron employees were responsible for fueling the buses when the project began. This situation was not an issue when the buses were in limited service. The buses typically completed scheduled service early in the day when the hydrogen fueling station was staffed. Increased use of the fuel cell buses means the fueling has to be accomplished much later in the day, evening, or early morning. Because of this change, there was a need for more staff to be trained to fuel the buses. Chevron developed procedures to train and certify AC Transit personnel to fuel the buses, which began with selected individuals on the first shift but has increased to include second-shift staff. As of December 2008, a total of eight AC Transit staff members were certified fully to fuel the buses with hydrogen.

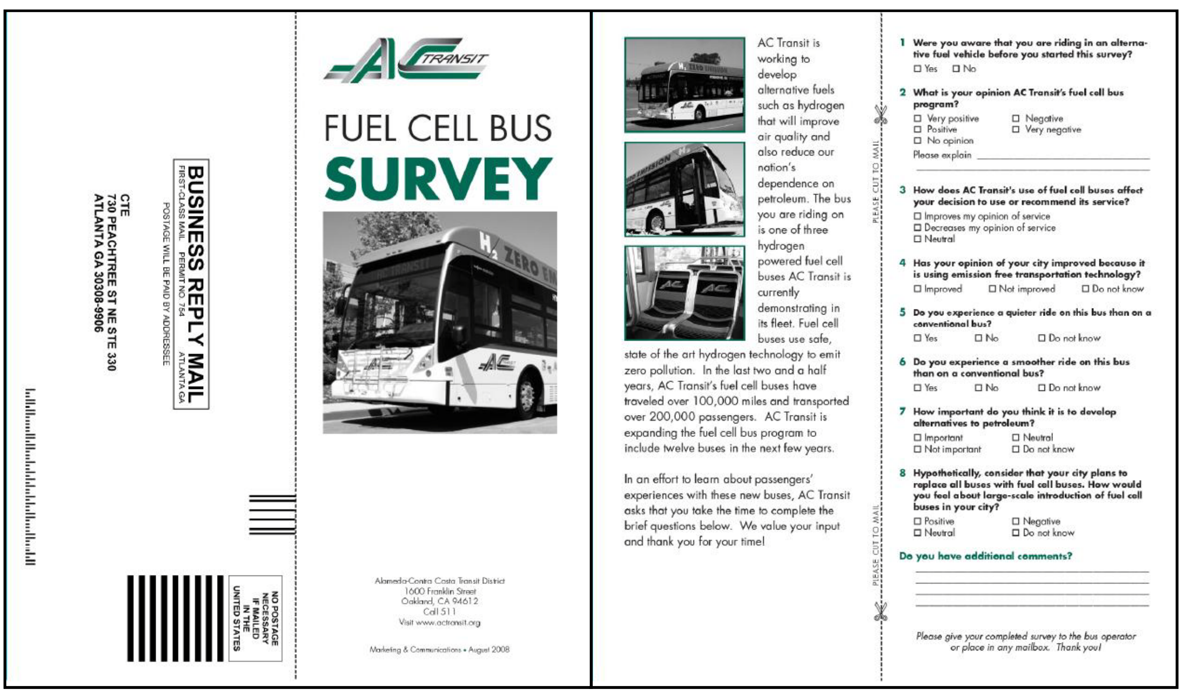
Maintenance—At the beginning of the demonstration, AC Transit had engineers from UTC Power and ISE on site at the division. These engineers were responsible for all maintenance on the fuel cell and hybrid systems as well as training for various agency staff. This situation is changing as the agency prepares for full-service operation of the buses. Under a continuing agreement with the fuel cell manufacturer, the UTC Power engineer is still stationed at the agency. AC Transit is now taking over more of the maintenance on the bus and hybrid systems. To accomplish this transition, AC Transit has assigned two Maintenance Trainers to the depot where the fuel cell buses are located. One was a new hire for the agency, and the other transferred from the training department. These Maintenance Trainers are responsible for a variety of duties on the fuel cell buses, including general upkeep and maintenance of the overall bus systems, assisting the UTC Power engineer on fuel cell system repairs as needed, and training other maintenance staff on the buses. They also are responsible for maintenance and training on a gasoline hybrid bus at the depot as well as training for the standard diesel buses.

Public Outreach

AC Transit's hydrogen fuel cell vehicle program (HyRoad) has always had a significant focus on public awareness. One of the major objectives of the program has been to provide opportunities to educate students, the general public in the Bay Area, and other interested parties such as federal and state government officials. Also, the operation of the fuel cell buses in revenue service provides an opportunity for the public to experience hydrogen fuel cell bus technology. Recently, AC Transit has completed a passenger survey to gauge the interest and thoughts of the riding public. Results from that survey are provided next. Also provided in this section is a summarized estimate of the number of passengers on the fuel cell buses.

Passenger Survey Results

AC Transit participated in a project to survey hydrogen fuel cell bus demonstrations around the world. This project, jointly conducted by the Center for Transportation and the Environment (CTE) and Breakthrough Technologies Institute (BTI), was funded through the FTA's NFCBP. The team interviewed a selection of representatives from various fuel cell bus demonstration projects with a goal of collecting lessons learned that could aid further development of the technology. The results of the study are expected to be published in early 2009. As part of the effort, the team developed a survey to understand how AC Transit's passengers are responding to the new technology buses. The survey was designed so riders could place the completed form in a box on the bus or return it by mail (see Figure 1). Over several months, AC Transit collected nearly 500 responses from passengers on the fuel cell buses.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AC Transit is working to develop alternative fuels such as hydrogen that will improve air quality and also reduce our nation's dependence on petroleum. The bus you are riding on is one of three hydrogen powered fuel cell buses AC Transit is currently demonstrating in its fleet. Fuel cell buses use safe, state of the art hydrogen technology to emit zero pollution. In the last two and a half years, AC Transit's fuel cell buses have traveled over 100,000 miles and transported over 200,000 passengers. AC Transit is expanding the fuel cell bus program to include twelve buses in the next few years.

In an effort to learn about passengers' experiences with these new buses, AC Transit asks that you take the time to complete the brief questions below. We value your input and thank you for your time!

PLEASE CUT TO MAIL

1 Were you aware that you are riding in an alternative fuel vehicle before you started this survey?
☐ Yes ☐ No

2 What is your opinion AC Transit's fuel cell bus program?
☐ Very positive ☐ Negative
☐ Positive ☐ Very negative
☐ No opinion
Please explain ____

3 How does AC Transit's use of fuel cell buses affect your decision to use or recommend its service?
☐ Improves my opinion of service
☐ Decreases my opinion of service
☐ Neutral

4 Has your opinion of your city improved because it is using emission free transportation technology?
☐ Improved ☐ Not improved ☐ Do not know

5 Do you experience a quieter ride on this bus than on a conventional bus?
☐ Yes ☐ No ☐ Do not know

6 Do you experience a smoother ride on this bus than on a conventional bus?
☐ Yes ☐ No ☐ Do not know

7 How important do you think it is to develop alternatives to petroleum?
☐ Important ☐ Neutral
☐ Not important ☐ Do not know

8 Hypothetically, consider that your city plans to replace all buses with fuel cell buses. How would you feel about large-scale introduction of fuel cell buses in your city?
☐ Positive ☐ Negative
☐ Neutral ☐ Do not know

Do you have additional comments?

Please give your completed survey to the bus operator or place in any mailbox. Thank you!

Figure 1. AC Transit fuel cell bus passenger survey

The results from the survey were extremely positive. The majority of passengers, over 74%, were already aware of the fact they were riding on an alternative fuel vehicle. When asked their opinion of AC Transit's fuel cell bus program, the responses were overwhelmingly positive.

Figure 2 provides the breakdown of responses to this question. More than 85% responded "very positive" or "positive." Only 6% had "negative" or "very negative" opinions of the program. More than half of the passengers surveyed also responded that their opinion of AC Transit's service improved as a result of the agency using fuel cell buses. More than 66% stated that their opinion had improved, 30% reported no change in their opinion, and only 3% reported their opinion had decreased. Over 70% of respondents also reported an improved opinion of the city because of the use of emission-free transportation technology.

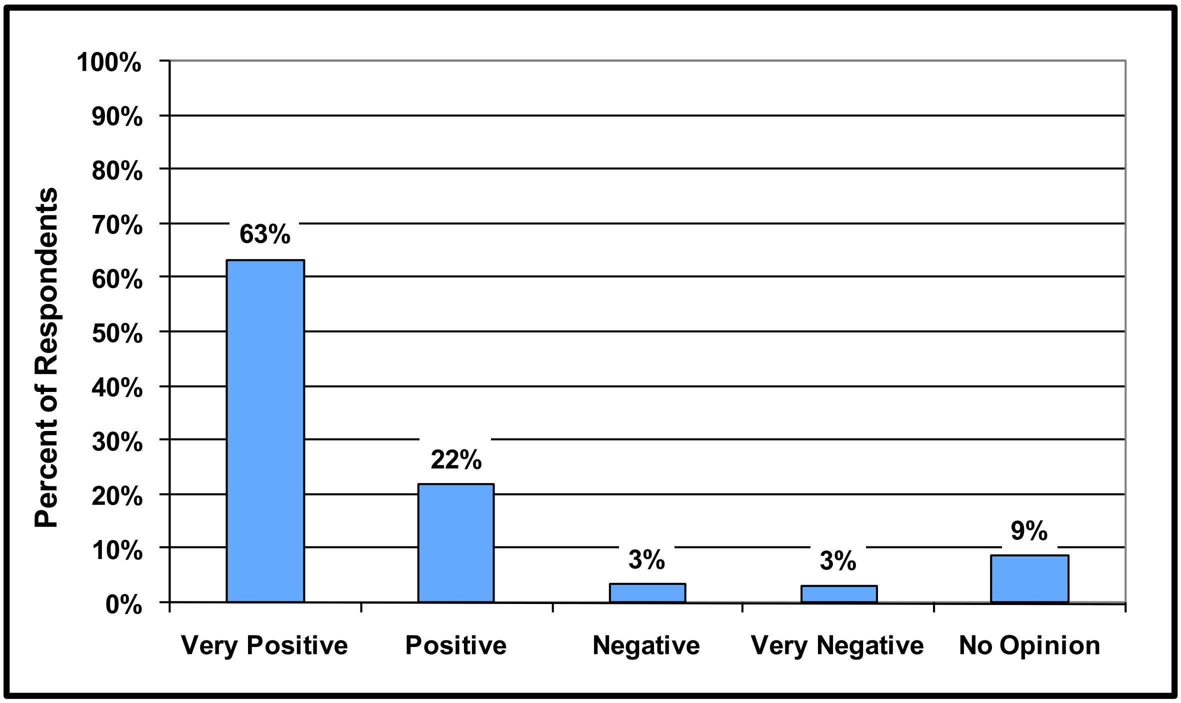

Figure 2. Passengers' opinions of AC Transit fuel cell bus program

Two survey questions focused on the passengers' opinions of the fuel cell bus performance in comparison with conventional technology buses. Figure 3 shows riders' opinions on the bus ride and noise level. More than 75% of respondents felt the fuel cell buses were quieter than a standard bus, and more than 63% felt the ride was smoother.

When questioned about developing alternatives to petroleum, over 90% of passengers responded that it was important. Figure 4 shows the breakdown of responses to this question. This overwhelming response is likely influenced by the high awareness in air pollution and energy issues in the state of California. The final survey question asked passengers their opinion on large-scale deployments of fuel cell buses in the area. The responses were again very positive toward the technology as shown in Figure 5. More than 81% stated they had positive feelings toward large-scale adoption of fuel cell buses in their city.

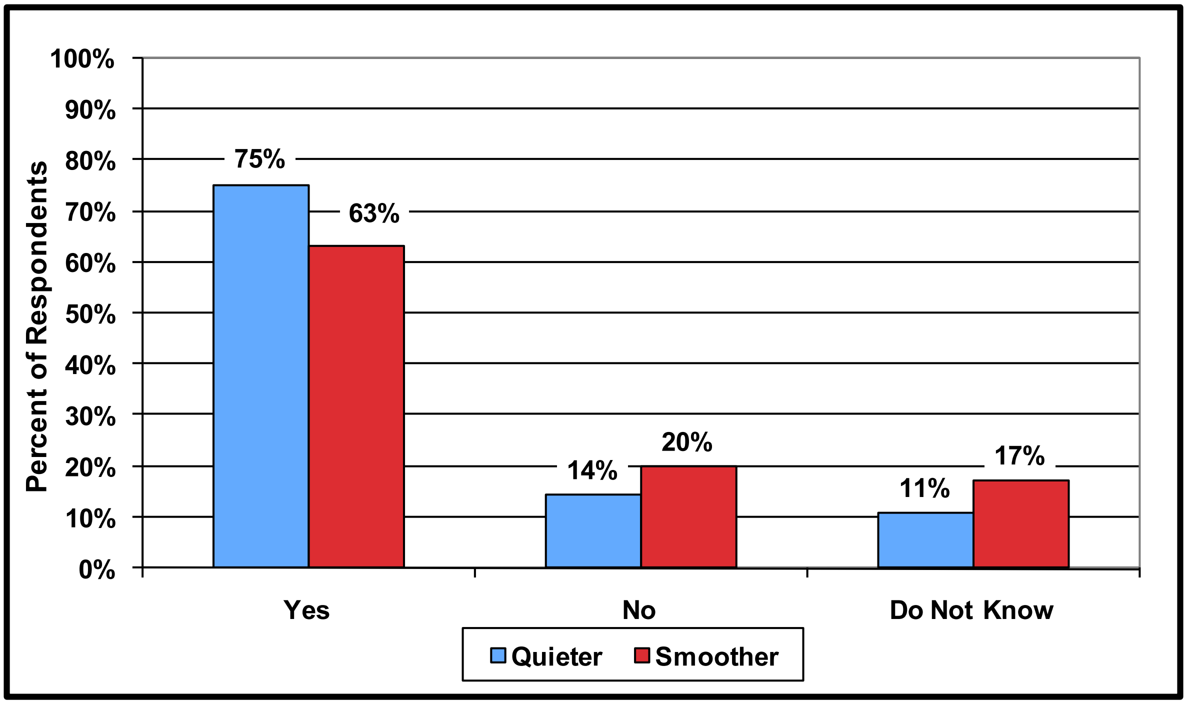

Figure 3. Passengers' opinions of fuel cell bus performance compared to conventional buses

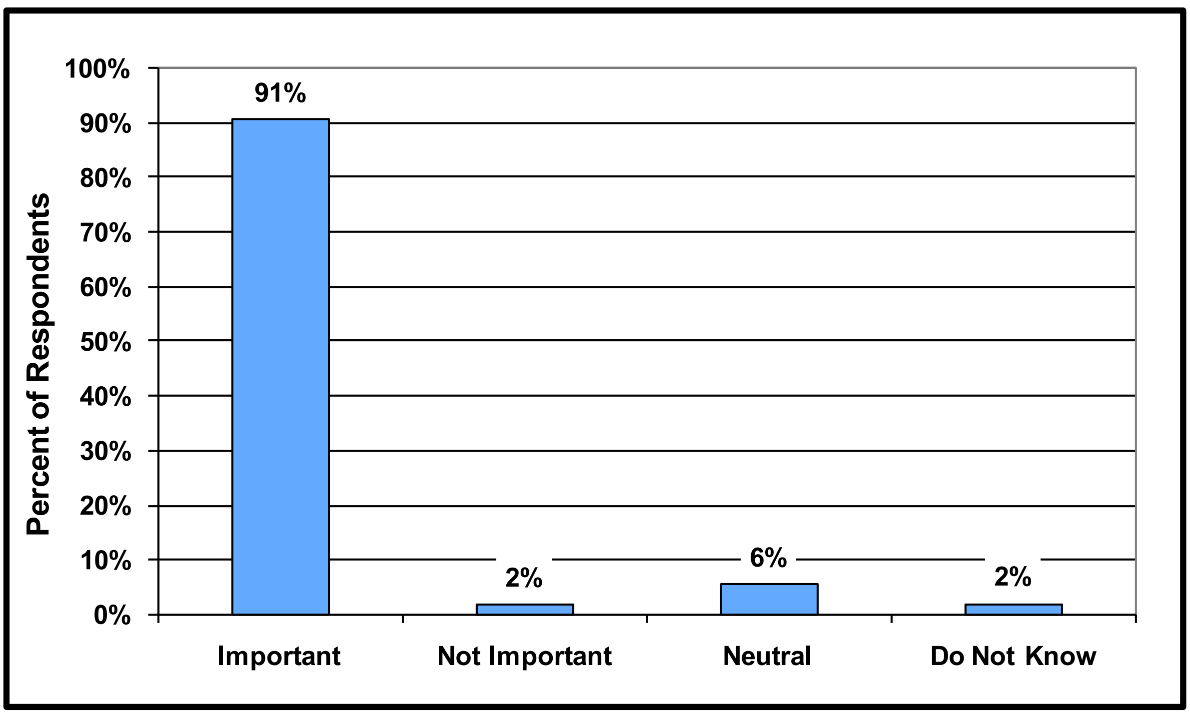

Figure 4. Passengers' opinions about developing petroleum alternatives

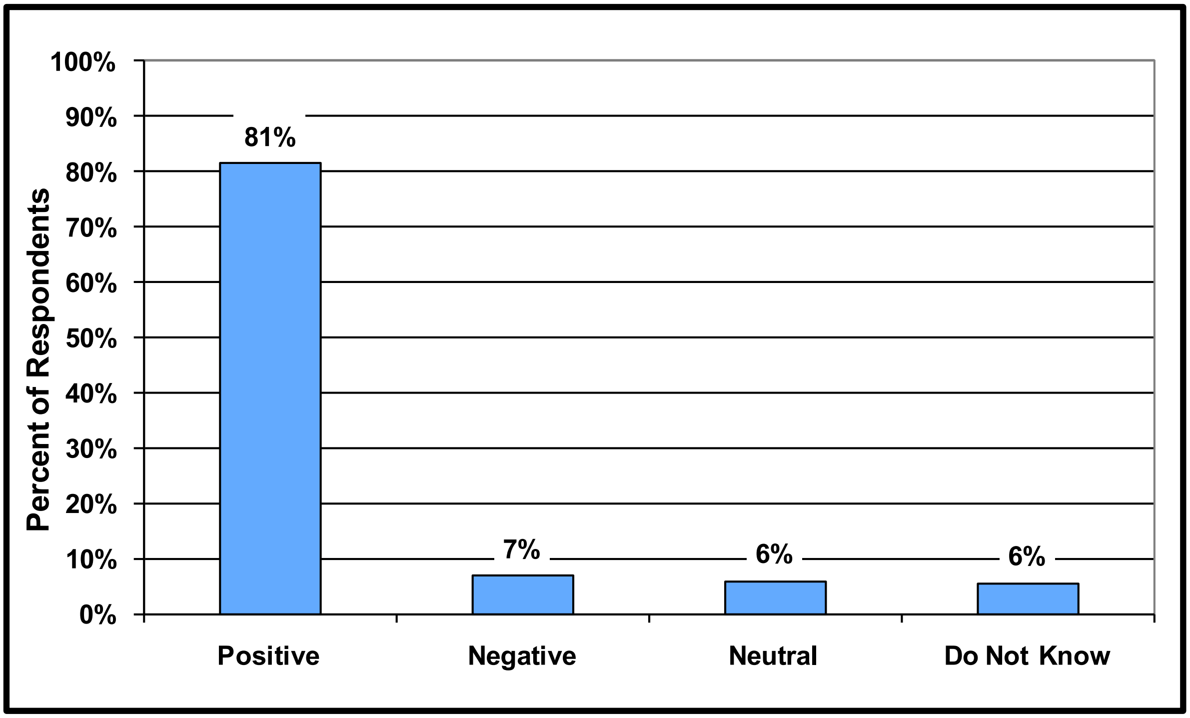

Figure 5. Passengers' opinions about large-scale deployments of fuel cell buses

Ridership

AC Transit, like most transit agencies, attempts to estimate ridership. This estimate is typically done by sampling ridership on the routes at different times of the day, days of the week, and times of the year. AC Transit's route ridership estimates were used to conservatively estimate the number of fuel cell bus revenue passengers since the buses went into service. From March 20, 2006, through the end of October 2008, each of the buses carried an average of 85,000 passengers with the total estimate being nearly 278,000 passengers. Figure 6 shows the ridership estimate by month and as a cumulative total.

The passenger estimates have also been supplemented by actual passenger counts from automated passenger counters (APC) installed on the buses. Actual counts on the buses started in 2008 for all three buses. These counts were also checked against the estimates provided by AC Transit to make sure they were consistent.

Note that the passenger count jumped significantly during the accelerated testing period (November 2007 through October 2008). More than half of the total passenger count occurred during the accelerated testing period—more than 145,000 passengers. These data indicate that the bus operation during the accelerated testing is meeting the objective of significantly increased bus usage.

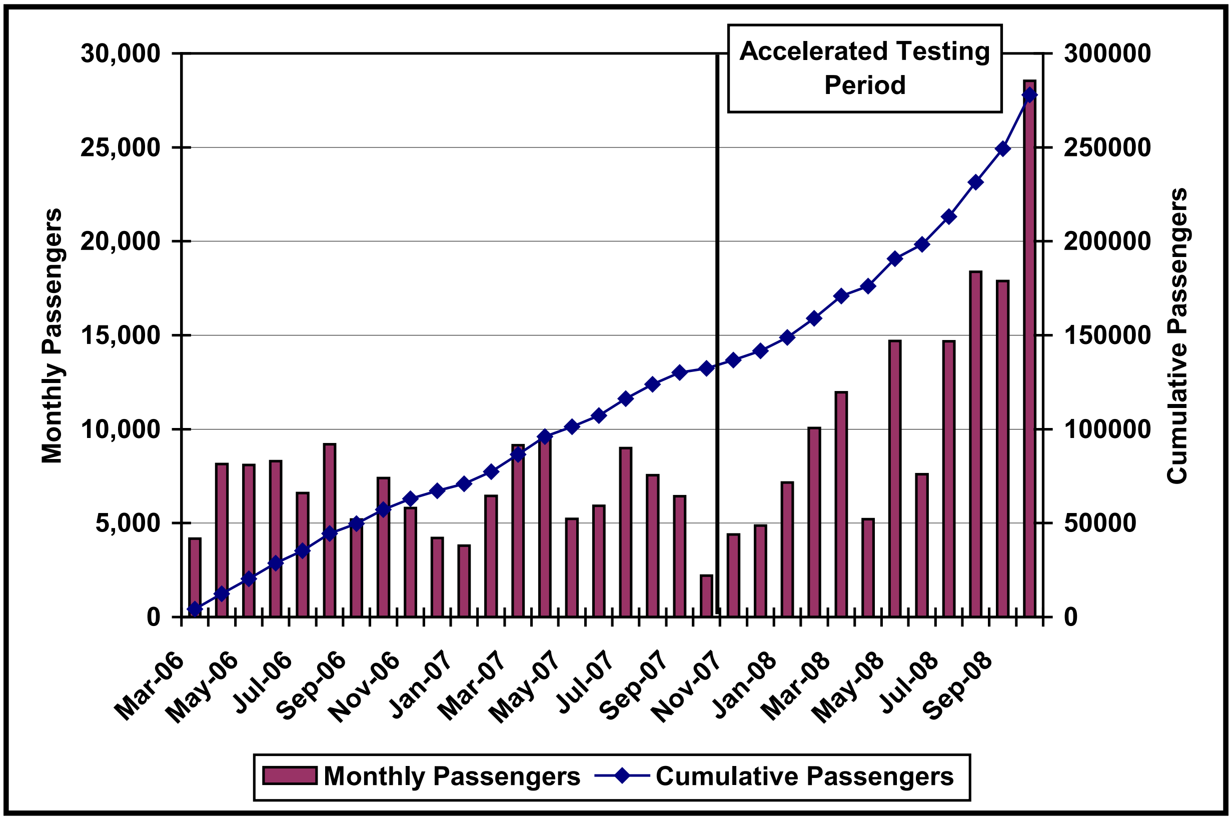

Figure 6. Ridership estimates for the fuel cell buses at AC Transit

Hydrogen Fueling

The hydrogen fueling station at AC Transit was designed by Chevron Technology Ventures and installed at the Division 4 (East Oakland) in 2005. The station includes two steam methane reformers that are capable of producing a total of 150 kg of hydrogen per day. Total storage capacity at the station is 366 kg of hydrogen at up to 6,250 psi. The station was inaugurated in March 2006 just prior to the start of revenue service for the fuel cell buses. Figure 7 shows one of the fuel cell buses at the hydrogen fueling island and the fueling connections. A more detailed description of the hydrogen fueling and maintenance facilities at AC Transit is provided in Appendix C.

Figure 7. Fueling at the Chevron Hydrogen Station

Figure 8 shows average daily hydrogen usage from the station during the accelerated testing evaluation period (November 2007 through October 2008) for buses only. AC Transit also has a fleet of seven light-duty hydrogen vehicles that uses the station as well, but that fuel consumption is not accounted for in this analysis and discussion. The overall average daily usage during this period was 33.9 kg/day for buses. The calculation for this rate includes only the days in which hydrogen was dispensed from the station for buses—64% of the calendar days during the period. A total of 8,824 kg of hydrogen was dispensed into buses during this period. Since the beginning of revenue service for the buses, the station has dispensed 19,257 kg of hydrogen into buses (again excluding the light-duty fuel cell fleet).

Figure 9 shows the distribution of hydrogen amounts per fill. The three buses were filled a total of 422 times during the accelerated testing evaluation period with an average fill amount of 20.9 kg/fill. Figure 10 shows the cumulative fueling rate histogram for the AC Transit station for the accelerated testing evaluation period. During this time, the overall average fueling rate was 1.34 kg/min. On average, it took approximately 15 minutes to fuel a bus.

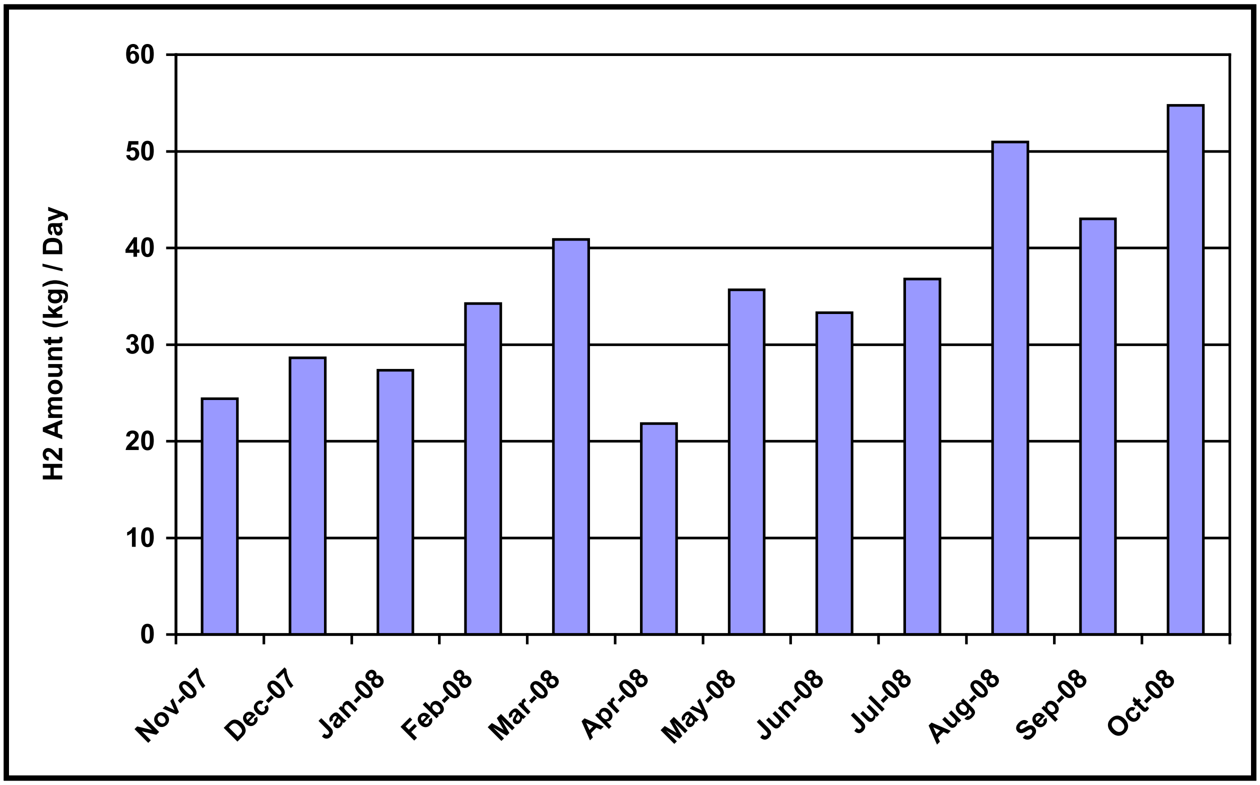

Figure 8. Average hydrogen use per day for AC Transit's fuel cell buses

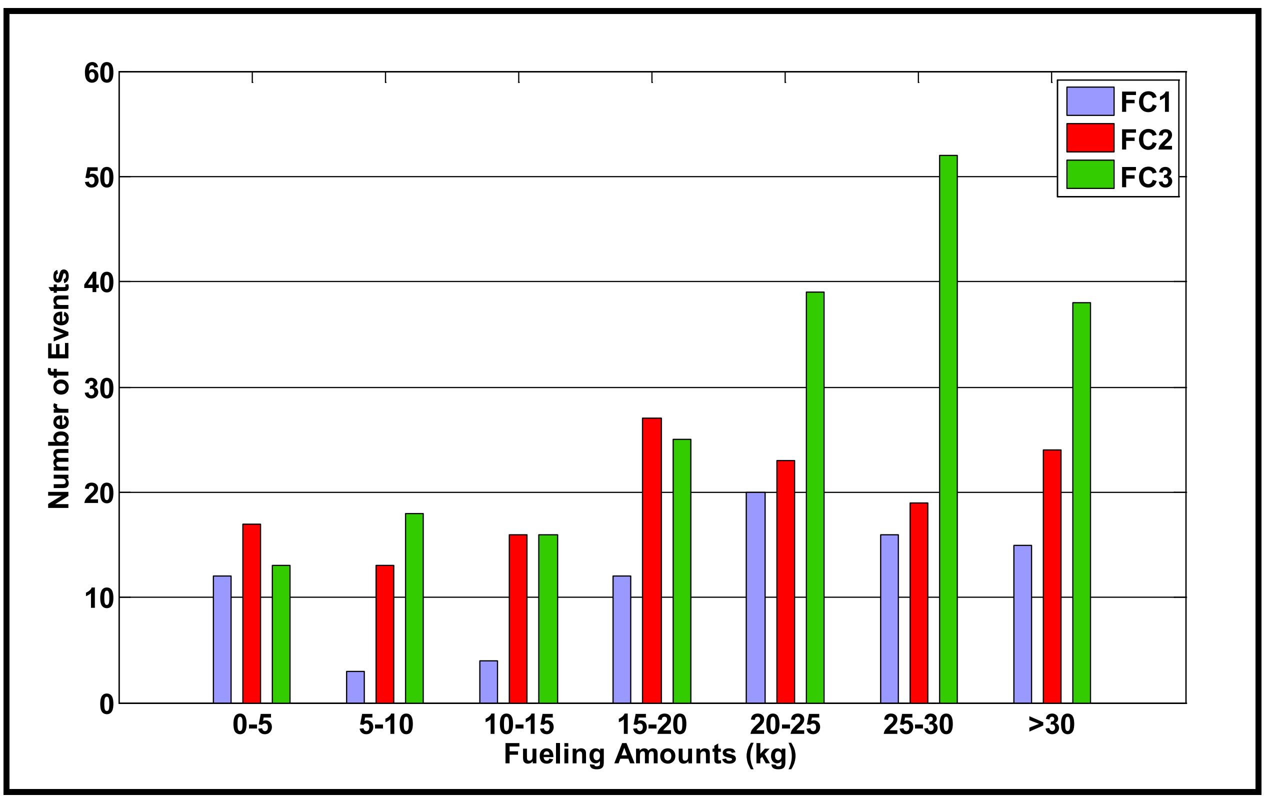

Figure 9. Distribution of average fill amounts for the fuel cell buses

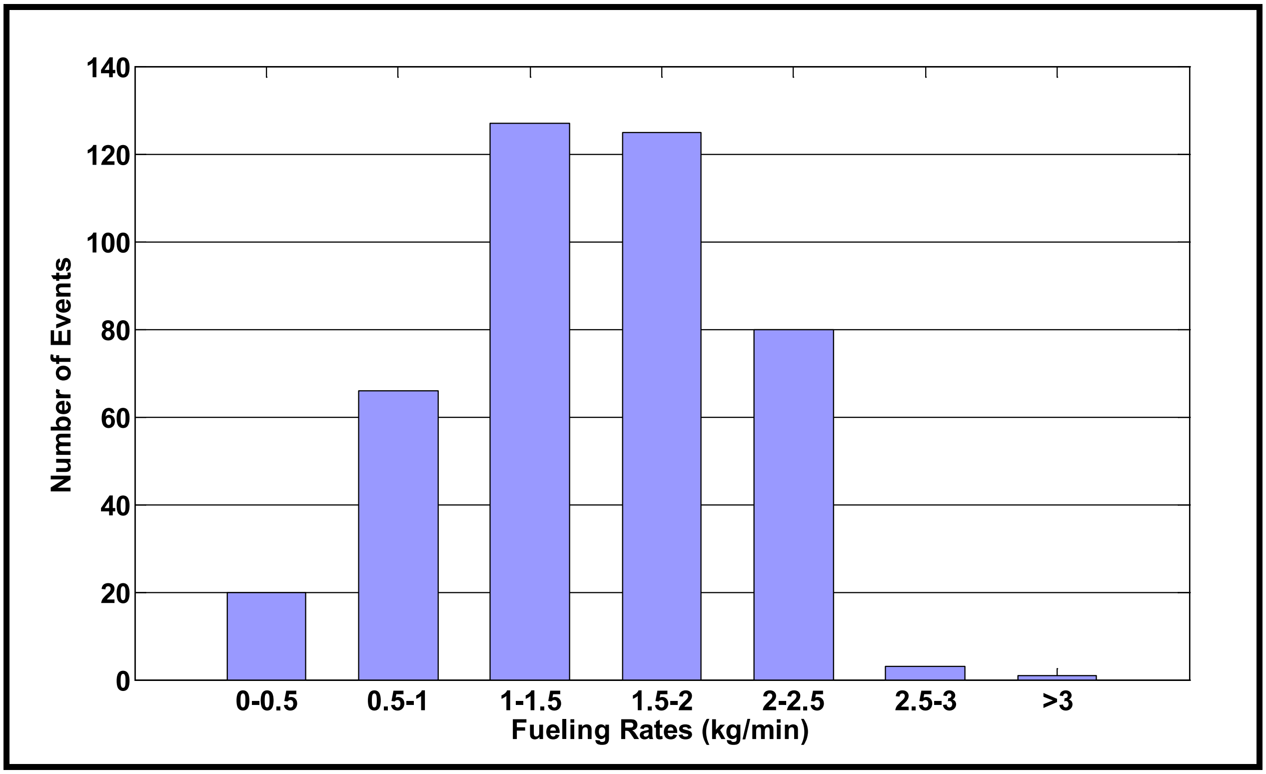

Figure 10. Fueling rate histogram for the AC Transit Hydrogen Energy Station (bus only)

Golden Gate Transit's Fuel Cell Bus Operating Experience

Golden Gate Transit (GGT) is one of three divisions operated by the Golden Gate Bridge, Highway & Transportation District (The District). The District's original mission was to maintain and operate the Golden Gate Bridge; however, increased traffic and congestion on the bridge in the late 1960s led to the formation of two additional divisions: GGT and Golden Gate Ferry. The current mission of the District is "to provide safe and reliable operation, maintenance and enhancement of the Golden Gate Bridge and to provide transportation services, as resources allow, for customers within the U.S. Highway 101 Golden Gate Corridor[8]." The transit system has grown to the extent that more than 11 million customers rode the transit system in fiscal year 2007; over 7 million of those customers were bus passengers. GGT operates 204 buses in various types of bus service, including inter-county, commuter express, and local. GGT operates primarily in Marin and Sonoma counties across the Bay northward from San Francisco. The service area covers 256 square miles. One of GGT's diesel buses is shown in Figure 11.

The District is unique among Bay Area transit operations because it receives no support from local sales tax measures or dedicated general funds. The District does not have the authority to levy taxes and relies upon surplus Bridge toll revenue as its only local support for the District's transbay transit services. Currently, GGT bus and ferry operations are funded approximately 42% by surplus Golden Gate Bridge tolls, 22% by transit fares, and 18% from government grants. The remaining 18% is covered by other sources including a contract with Marin County and revenues from advertising, concessions, and leases.

Figure 11. GGT diesel bus

GGT Ride for the Environment

In response to the CARB Transit Rule established in late 2000, GGT selected the clean diesel path to meet emission-reduction requirements. Those regulations called for an 85% reduction in particulate matter (PM) from a 2002 baseline by 2007. Since that time, GGT has taken

[8] Golden Gate Transit Web site at http://goldengate.org

aggressive steps not only to meet, but to exceed those regulations. GGT has employed a variety of improvements to its diesel fleet, including:

- Purchasing new buses with the cleanest available technology to replace older buses
- Switching to low-sulfur diesel fuel for the entire fleet
- Repowering older buses with low-emission engines
- Retrofitting buses with diesel-particulate filters
- Investigating new oil-filtration technologies to extend the oil change interval and reduce overall oil use.

GGT also has a rigorous inspection schedule to ensure the fleet operates at optimal levels with the lowest emissions. These steps enabled GGT to achieve a 97% reduction in PM levels from 1992 levels.

The agency is also looking toward the future of bus technologies by partnering with AC Transit to demonstrate fuel cell buses. This partnership was initiated in 2003 when the two agencies signed an agreement outlining the collaboration. Under the agreement, AC Transit would provide access to training on the fuel cell bus and infrastructure, share information and lessons learned on the project, and periodically make available one of the three fuel cell buses for temporary demonstration in GGT's service. In response, GGT would provide funds to AC Transit for general support of the project, pay all direct costs associated with the bus while operating in its service, and actively participate in the information sharing and any data-collection activities. Working with AC Transit was extremely important to GGT because it provided the opportunity for hands-on experience with the technology without making the early investment in hydrogen infrastructure.

Early on in the project, GGT's participation focused on learning what they could about the technology to prepare for eventual operation. AC Transit provided space for GGT personnel in training classes on general hydrogen awareness, specifics on operating and maintaining the buses, and hydrogen safety. GGT staff also participated in weekly conference calls on the project's progress and plans. All of this helped prepare the agency for finally operating a fuel cell bus.

FCB Operating Experience

GGT staff knew that careful planning was essential to make its first actual fuel cell bus operating experience a success. The agency began by assembling a team of people to plan and conduct the demonstration. This team was made up of staff from maintenance, operations, safety, planning, and marketing. Not only did they need to ensure that agency staff was prepared, but the team also needed to inform local emergency-response officials, the community, and riders about the project.

Early Preparations

Route selection—GGT's service profile is very different from most transit agencies in the United States. Because GGT primarily serves commuters, the average speed is one of the highest in the country at 22 mph. Its diverse coverage area includes rural and city routes that travel through several micro climates, some of which are not conducive for buses in general. Prior to operation of one of the fuel cell buses, GGT analyzed its routes to determine the best match. The agency wanted to maximize the public exposure to the technology by selecting routes with high ridership; however, there was a concern with operating the fuel cell buses on certain routes primarily because the buses are taller than typical buses. The agency looked at the best routes that would provide the most public access without the need for tree trimming. To determine if the selected routes would pose any issues, GGT borrowed one of the fuel cell buses for mock runs to test clearance. GGT eventually decided to rotate operation of the fuel cell bus between four Marin Transit Local routes.

To operate the fuel cell bus, GGT selected two drivers who were well trained, experienced, and highly motivated to participate in this operation. The selections were made based on safety records, attendance, and the reputation of the drivers. GGT worked with the local union to ensure these drivers would be able to start their shifts at AC Transit's Division 4, where the buses are located. The bus would be driven from Oakland to GGT's operating area for the start of the shift and then returned at the end of the day to be fueled and charged for the next day's shift.

Coordination with AC Transit—GGT worked closely with AC Transit staff to coordinate the transfer of the bus and train operators on what to do in case of a problem. The two agencies set up communications for both sides for any emergency or safety issues. GGT contracted with the same towing company as AC Transit in case there was a need to tow the bus. AC Transit staff reprogrammed the headsign on the bus to include GGT route designations.

Because the two agencies use different equipment on their buses, the use of existing fareboxes and radios was an issue. GGT has a complicated fare structure that could not be easily programmed into the AC Transit fareboxes. One option considered was to temporarily install a GGT farebox onto the bus. AC Transit promised to provide a fuel cell bus each day for the project but could not guarantee the same bus would be available. Because of this situation, installation of another farebox was not practical. GGT elected to provide free service on the fuel cell bus during the demonstration, which was very popular with its riders. Radios installed on the buses were also different than the radios to which the GGT staff was accustomed. To solve this issue, GGT assigned a handheld unit or cell phone to the operators to communicate with dispatch.

Early on in the planning process, AC Transit and GGT developed a formal legal agreement to operate the fuel cell bus. This agreement outlined specific roles and responsibilities for each agency during the loan of a bus, including costs, agency obligations, and insurance needed. Because this arrangement was not something typically undertaken between the two agencies, getting the agreement signed and in place became one of the biggest challenges. Several legal roadblocks made the process take longer than anticipated.

Training of local fire and emergency responders—GGT contacted the local fire officials well in advance of the demonstration to inform them about the project and to arrange for training. After the first contact, GGT reported interest and acceptance from these officials. Approximately 20 firefighters and emergency responders attended the first training class, which included hands-on instruction on how to deal with a hydrogen fuel cell bus in an emergency situation. The excellent communication established early on between GGT and local officials went a long way to alleviate concerns.

Alerting riders and the community—GGT needed to inform its riders about the demonstration project to avoid confusion, especially with boarding a bus that looked very different from the rest of its fleet. The agency used a variety of methods to reach as much of the community as possible (shown in Figure 12). These included:

- Advertisements in local newspapers
- A handout to passengers (prior to demonstration) to alert them to the new look and free fare
- Alerts on the GGT Web site
- E-blast e-mails to passengers

Figure 12. GGT prepared handouts and Web pages to alert riders to the demonstration

A local newspaper, the *Marin Independent Journal*, ran an article on the GGT fuel cell bus demonstration. The article described the project and also provided information on the routes where the bus would be operated. GGT also placed a sign in the window of the bus for riders to see as they boarded. Because of these early communications, the agency reported very positive reactions from customers and the community.

Fuel Cell Bus Operations

The in-service demonstration of the fuel cell bus began on February 19, 2008. The agency operated a bus each weekday through March 21 for a total of 24 days. GGT reports a very successful first demonstration, accumulating 3,880 miles for a daily average of 162 miles. Because of the high average operating speed, the fuel economy for GGT operations was significantly higher than for AC Transit at 8.8 mi/kg or 10.0 mi/DGE. The logistics of getting a bus from Oakland to GGT's operating area and back each day went smoothly with no issues. Also, during the period, there were no roadcalls.

One of two assigned operator trainers rode the bus on-route during the demonstration. By selecting two trainers, GGT assured that one was on-board at all times. These trainers were able to answer passenger questions, leaving the driver free to drive the route. GGT reports that its customers are well educated and typically proactive on energy issues. As a result, the passenger and community response for the demonstration was very positive. Riders kept the GGT trainers busy answering a multitude of questions on the bus, hydrogen as a fuel, and fuel cell technology. According to GGT passenger counts, an estimated 2,630 passengers boarded the fuel cell bus during the demonstration.

Toward the end of the demonstration, AC Transit was instructed by the bus manufacturer to further govern the maximum speed of the fuel cell buses to 48 miles per hour. Because the buses are about 24 inches taller than standard buses, the manufacturer was concerned about stability at higher speeds. This concern caused an issue with operating on GGT routes: the lower speed meant the bus was not able to keep the schedule. Because of this inability to keep on schedule, GGT pulled the bus from service five days before the demonstration's scheduled end date.

Future Plans for Fuel Cell Buses at GGT

GGT's first experience operating a fuel cell bus was extremely positive. Early planning, anticipation of potential problems, up-front communication with the local community, and excellent coordination with AC Transit all contributed to the success. When asked what would have made the experience even better, GGT staff responded that they would have enjoyed more time to participate in public events to educate their customers about the technology. The agency also expressed a desire to have buses that look like the rest of the fleet and to have hydrogen fuel available at a closer location.

GGT is planning for its next fuel cell bus operation. The agency expects more operation time once the newest buses are delivered to AC Transit for the ZEBA demonstration project, which is described in more detail at the end of this report (What's Next for AC Transit?).

Fuel Cell Bus Operations—Evaluation Results

In this accelerated testing evaluation report, the fuel cell buses are considered to be prototype technology that is in the process of being commercialized. The analysis and comparison discussions with standard diesel buses help provide a baseline to show the progress of the fuel cell bus technology. The intent of this analysis is to determine the status of this implementation and to document the improvements that have been made over time at AC Transit. There is no intent to consider this implementation of fuel cell buses as commercial (or full revenue transit service). This evaluation focuses on documenting progress and opportunities to improve the vehicles, infrastructure, and procedures.

The evaluation period for the fuel cell and diesel baseline buses for this report includes 12 months of operation—November 2007 through October 2008 for the fuel cell buses and January 2007 through December 2007 for the diesel buses. The accelerated testing evaluation period for the fuel cell buses includes the 12-month period; however, as discussed above, the focus of this evaluation-results section will be on a clean point period that starts with the last replacement of the CSAs for the fuel cell buses through October 2008. The start of the clean point evaluation period is as follows:

- **Fuel Cell Bus 1 (FC1)**—CSAs replaced on March 7, 2008, re-started service on March 18, 2008
- **Fuel Cell Bus 2 (FC2)**—CSAs replaced on January 31, 2008, re-started service on February 5, 2008
- **Fuel Cell Bus 3 (FC3)**—CSAs replaced on December 11, 2007, re-started service on December 13, 2007

The diesel Van Hool buses started operation in 2003 – 2004 but did not start operating at Division 4 (East Oakland) until July 2005. Tracking these diesel buses has concluded, and a 12-month period of operation at AC Transit's Division 4 has been chosen for a baseline comparison with the fuel cell buses.

Route Descriptions

The fuel cell and diesel baseline buses are operated from AC Transit's Division 4, which operates 15 local, two all-nighter, 10 transbay, and 14 school routes with 179 buses total (138 buses for peak service). The average bus operating speed for weekday service from this division is 14.3 mph.

Early in revenue operation, the fuel cell buses were operated only during the week on two blocks of work that were created for testing the fuel cell and diesel baseline buses. This limited operation was done originally to help ensure that trained drivers and mechanics (and the manufacturer engineers) were available to work with the fuel cell buses. Also, AC Transit decided to place only two of the three fuel cell buses into service on any given weekday to allow for maintenance, training, and special events with the third fuel cell bus.

As AC Transit and the manufacturer partners gained experience, there was a desire to operate the fuel cell buses in a more aggressive manner. As discussed earlier, the accelerated testing project is focused on maximizing the operation of all three of the fuel cell buses. This effort has taken significant planning and work on the part of AC Transit staff and the manufacturers. To maximize the operation of the fuel cell buses, specific route blocks were defined so the fuel cell buses could attempt nearly full transit operation. During the accelerated testing evaluation period, the fuel cell buses have operated on all of the route assignments shown in Table 2.

Table 2. Route Blocks of Work Created for Fuel Cell Bus Operation

Route Block	Pull-Out Time	Pull-In Time	Total Time	Total Miles	Average Speed
Weekday Operation					
18	6:11 AM	11:47 PM	17.6	171	9.7
18	5:30 AM	7:09 PM	13.6	140	10.3
57	7:01 AM	12:44 AM	17.7	187	10.6
Weekend Operation					
57	6:36 AM	7:45 PM	12.2	127	10.5
57	8:06 AM	12:44 AM	16.7	180	10.8
57	5:08 AM	9:00 PM	15.9	175	11.0

As reported previously in evaluation reports on this demonstration at AC Transit, there are issues with meeting the long operation time of the route assignments because of the need to charge the batteries overnight before the next pullout. A full charge for the batteries requires between 4 and 4.5 hours. During bus operation on the route, the batteries are kept at 50% to 60% state of charge (SOC) to allow for significant energy regeneration from braking back into the batteries. The diesel buses were not restricted to these special blocks of work. These diesel buses were allowed to operate on other work blocks during the week and on weekends as well. This operation is reflected in the bus use, which is discussed next.

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 provides a summary of bus usage and availability for the two study groups of buses.

Usage for the fuel cell buses has increased nearly 80% during the accelerated testing period as compared with the previous revenue operations (March 2006 through October 2007). For the entire accelerated testing period (November 2007 through October 2008), the fuel cell buses averaged 1,516 miles per month. The average monthly mileage results in Table 3 focus on the clean point periods for the fuel cell buses; the first partial month of operation after the last fuel cell power system replacement has been removed from the calculation. The table shows that the average monthly mileage for the fuel cell buses was 1,837 miles per month. Compared with the diesel bus average mileage, the fuel cell buses have now achieved an average of 50% of full transit operation.

As part of the accelerated testing activity, the focus has been to maximize usage of the fuel cell buses. UTC Power requested that AC Transit prioritize the operation of one bus to attempt to reach 4,000 hours on the fuel cell system as quickly as possible. In this case, it was FC3 as the monthly average mileage shows. The average use of this bus was 64% of the diesel buses (significantly higher than the other two fuel cell buses). FC3 has also operated more than 2,300 hours since the last CSAs were installed. For the clean point evaluation period, the three fuel cell buses have operated a total of 4,957 hours, which implies operation at an average speed of 10.1 mph.

Table 3. Average Monthly Mileage (Evaluation Period)

Bus	Starting Hubodometer	Ending Hubodometer	Total Mileage	Months	Monthly Average Mileage
FC1	25,097	36,205	11,108	8	1,389
FC2	20,485	35,398	14,913	9	1,657
FC3	26,494	50,073	23,579	10	2,358
Fuel Cell			**49,600**	**27**	**1,837**
1043	111,443	155,982	44,539	12	3,712
1044	131,559	174,535	42,976	12	3,581
1045	142,518	186,774	44,256	12	3,688
1046	147,975	193,493	45,518	12	3,793
1047	128,064	173,870	45,806	12	3,817
1048	115,365	158,784	43,419	12	3,618
Diesel			**266,514**	**72**	**3,702**

Another measure of reliability is availability—the percent of days that the buses are planned for operation compared with the days the buses are actually available. Figure 13 shows monthly availability for each of the three fuel cell buses and an overall average availability for the group during the clean point evaluation period. The low availability months were generally caused by the need for traction battery replacements.

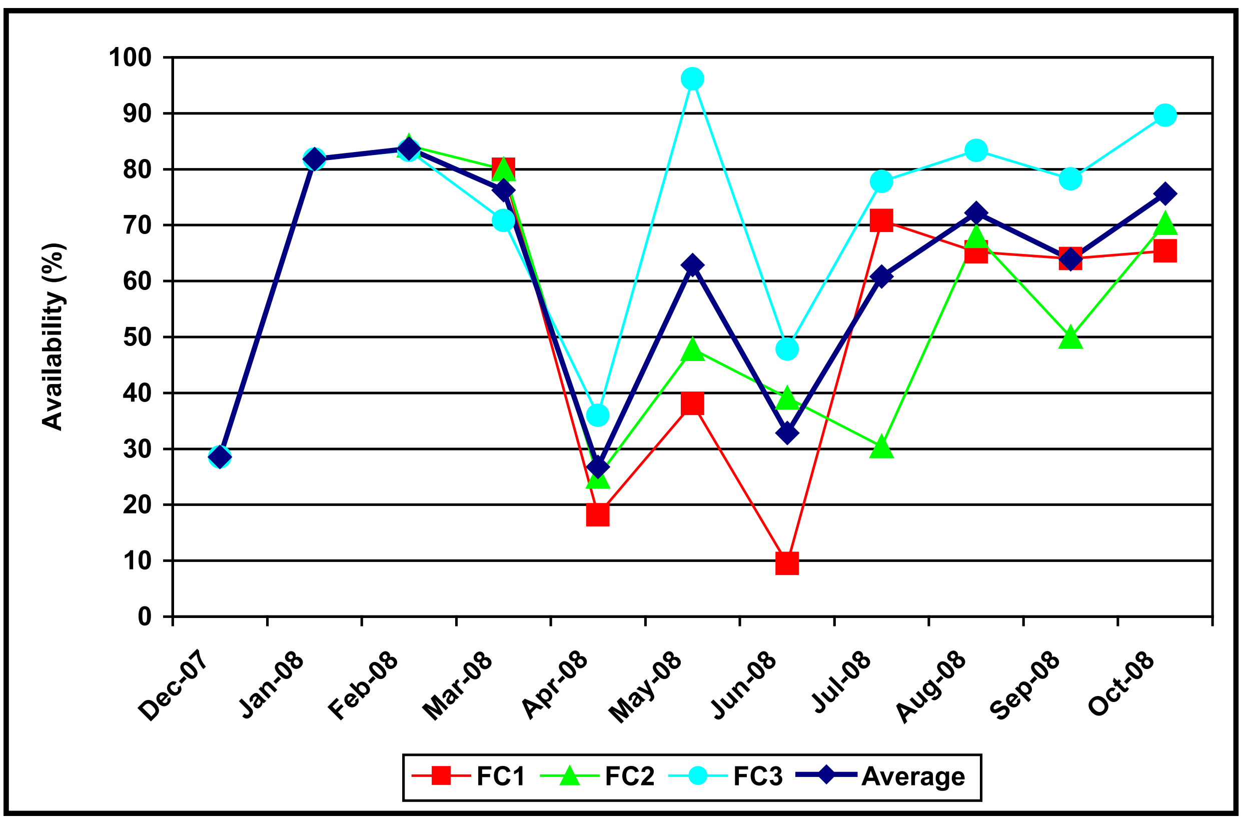

Figure 13. Availability for all three fuel cell buses and overall average

Table 4 summarizes the reasons for availability and unavailability for each of the three fuel cell buses. During the clean point evaluation period, the average availability for the fuel cell buses was 61%. The overall availability percentage by bus and overall average is highlighted in blue in the table. The unavailability category with the highest percentage was issues with the traction batteries (59% of all unavailable days). As discussed above (Previous Demonstration Experience at AC Transit), there continue to be traction battery issues. The issues include problems with matching SOC among the three traction batteries, the software to manage this SOC, and the interface between the propulsion system software and traction battery software. The manufacturers continue to work on these issues to support maximum operation of the fuel cell buses; however, it continues to be the major obstacle to the planned operation in the accelerated testing activity.

Table 4. Summary of Reasons for Availability and Unavailability of Buses for Service

Category	FC1		FC2		FC3		Group Total	
	Days	%	Days	%	Days	%	Days	%
Planned Work Days	172		213		254		639	
Days Available	87	51	117	55	187	74	391	61
Available	**87**	**100**	**117**	**100**	**187**	**100**	**391**	**100**
On Route	73	84	102	87	166	89	341	87
Event/Demonstration	6	6	7	6	10	5	23	6
Training	4	5	3	3	7	4	14	4
Not Used	4	5	5	4	4	2	13	3
Unavailable	**85**	**100**	**96**	**100**	**67**	**100**	**248**	**100**
Fuel Cell Propulsion	14	16	6	6	17	25	37	15
ISE Hybrid Propulsion	0	0	12	13	1	2	13	5
Traction Battery Issues	55	65	61	63	30	45	146	59
AC Transit Maintenance	10	12	12	13	12	18	34	14
Fueling Unavailable	6	7	5	5	7	10	18	7

Fuel Economy and Cost

Hydrogen fuel is supplied by the Chevron–AC Transit Hydrogen Energy Station at the East Oakland Division. The hydrogen is dispensed at up to 5,000 psi for the three fuel cell transit buses. During the accelerated testing evaluation period, AC Transit employees provided nearly all fueling services for the hydrogen-fueled vehicles, and Chevron electronically reported the fueling amounts.

Table 5 shows hydrogen and diesel fuel consumption and fuel economy for the study buses during the clean point evaluation period. Overall, the three fuel cell buses averaged 6.49 miles per kg of hydrogen, which equates to 7.33 miles per diesel gallon equivalent (DGE). The energy conversion from kg of hydrogen to DGE is provided at the end of Appendix E. It was also reported that the fuel cell buses had approximately 367 kg of hydrogen removed during the accelerated testing evaluation period so that the buses could be taken into the maintenance facility. This amount of hydrogen removed and vented equates to 4% of the hydrogen dispensed into the buses. AC Transit has been working to minimize the amount of hydrogen vented by managing the amount of bus operation and fueling before planned bus maintenance. The amount of hydrogen vented from the buses prior to maintenance has not been included in the fuel economy calculations.

As mentioned earlier, the buses are plugged in each night to recharge the batteries. This energy added to the fuel cell buses each night is not currently accounted for in the fuel economy calculation. AC Transit has been collecting monthly total charging energy for the fuel cell buses. In comparing this monthly energy with the total monthly hydrogen fuel energy used by the buses, this charging energy represents 3% to 5% of the total energy used by the buses. To be completely accurate, the fuel cell fuel economy should be reduced up to 5% or reduced to 6.96 miles per DGE. This fuel economy would then be 66% higher than the diesel buses.

Table 5. Fuel Use and Economy (Evaluation Period)

Bus	Mileage (Fuel Base)	Hydrogen (kg)	Miles per kg	Diesel Equivalent Amount (Gallon)	Miles per Gallon (mpg)
FC1	10,089	1,544.1	6.53	1,366.5	7.38
FC2	14,880	2,155.1	6.90	1,907.2	7.80
FC3	23,770	3,812.7	6.23	3,374.1	7.04
FCB Total	**48,739**	**7,511.9**	**6.49**	**6,647.7**	**7.33**
1043	43,835			10,765.1	4.07
1044	42,379			9.916.2	4.27
1045	44,256			10,381.1	4.26
1046	45,518			10,873.8	4.19
1047	45,673			10,744.5	4.25
1048	42,914			10,295.4	4.17
Diesel Total	**264,575**			**62,976.1**	**4.20**

Figure 14 shows monthly average fuel economy in both miles per kg and miles per DGE for the fuel cell buses as well as the baseline diesel bus average of 4.20 miles per gallon. Note that the peak fuel economy for the fuel cell buses occurred during February and March 2008, which coincides with the GGT operation of one of the fuel cell buses. The GGT fuel cell bus operation and fuel economy was significantly higher than the AC Transit operation and influenced the overall fuel economy during the accelerated testing evaluation period.

The operating cost for hydrogen production and dispensing for AC Transit is currently estimated at between \$6 and \$8 per kg. This amount, which excludes capital expenses, was generated using early data (not optimized operation) and conservative maintenance and operating estimates. Using the \$8 per kg cost estimate for hydrogen fuel indicates a cost per mile for the fuel cell buses of \$1.23. The average diesel fuel cost per gallon during the evaluation period is \$2.29 per gallon. This average indicates a \$0.55-per-mile cost. The diesel cost per mile is about 45% of the fuel cell bus fuel cost per mile.

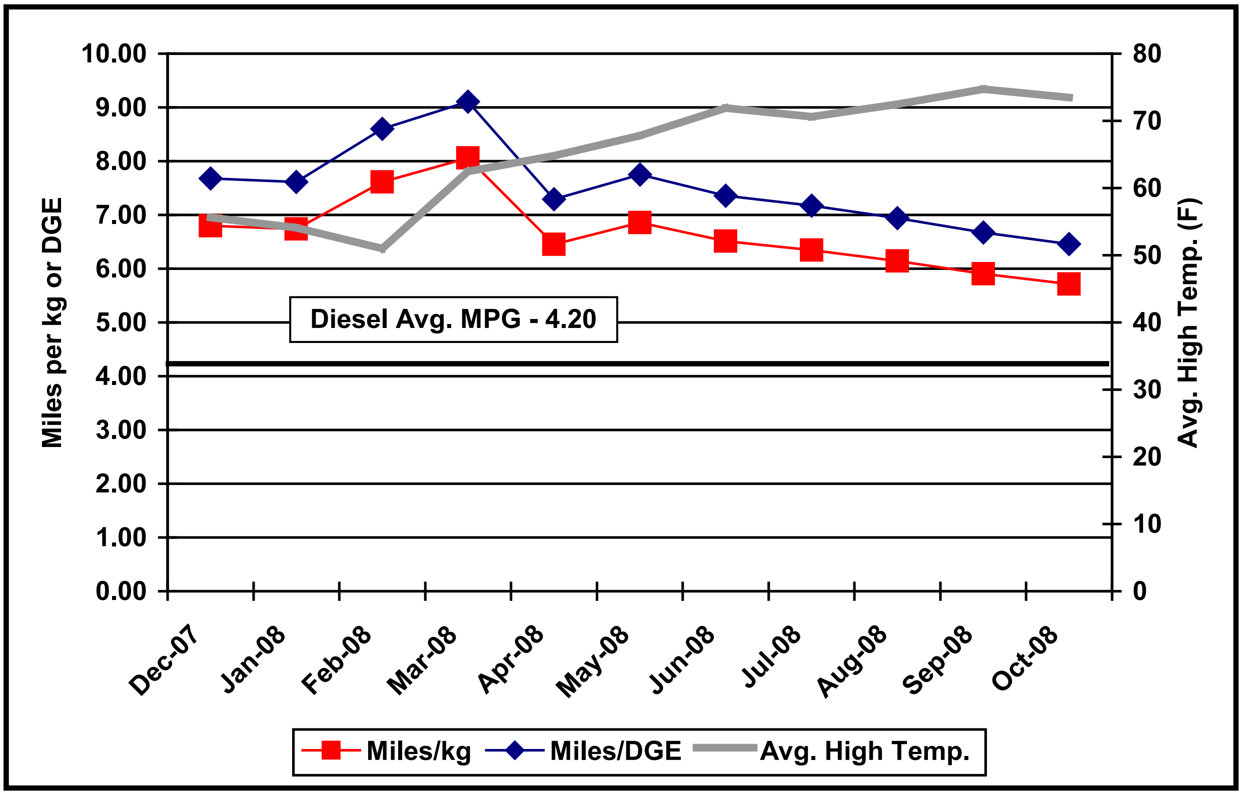

Figure 14. Average fuel economy (evaluation period)

Maintenance Analysis

The maintenance cost analysis in this section is only for the clean point evaluation period (last CSA/fuel cell power system replacement through October 2008). 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 broken down by bus system.

Total Maintenance Costs—Total maintenance costs include the price of parts and labor rates of $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 6 shows total maintenance costs for the fuel cell and diesel buses. Note that the fuel cell bus maintenance was still being supported by on-site warranty work done by the manufacturer engineers physically located at AC Transit. The AC Transit mechanics have supported the work done by the manufacturer engineers and have done cleaning and maintenance of the bus (inside and outside). Some support has been provided for responding to roadcalls, and that effort is reflected in the maintenance discussion that follows. During the accelerated testing evaluation, AC Transit personnel have essentially taken over all of the maintenance and support of the fuel cell buses except for maintenance by the UTC Power engineer.

Table 6. Total Maintenance Costs (Evaluation Period)

Bus	Mileage	Parts ($)	Labor Hours	Cost per Mile ($)
FC1	11,108	947.24	107.5	0.57
FC2	14,913	6,601.66	109.8	0.81
FC3	23,900	8,040.65	122.7	0.59
Total Fuel Cell	**49,921**	**15,589.55**	**340.0**	**0.65**
Avg. per Bus	**20,730**	**3,674.86**	**160.6**	**--**
1043	44,539	10,791.13	109.0	0.37
1044	42,976	12,104.40	156.3	0.46
1045	44,256	16,832.13	154.8	0.56
1046	45,518	12,102.17	169.3	0.45
1047	45,806	15,192.03	120.1	0.46
1048	43,419	19,613.14	167.4	0.64
Total Diesel	**266,514**	**88,635.00**	**877.0**	**0.49**
Avg. per Bus	**44,419**	**14,772.50**	**146.2**	**--**

AC Transit has expressed a strong desire to have its mechanics get more involved in all maintenance activities for the fuel cell buses so they get the experience. AC Transit has assigned one project manager/supervisor and two mechanic trainers to work on the fuel cell buses. This addition of resources for fuel cell bus maintenance was necessary based on the desired increase in operation along with the future plans for more fuel cell buses.

Maintenance issues for the fuel cell buses centered on problems with the traction batteries and fuel cell system on each of the buses. One of the fuel cell buses (FC2) had the brakes relined. FC3 had issues with vandalism and window replacements several times during the evaluation period.

Maintenance issues for the diesel buses were mostly related to engine problems with the turbocharger (two buses), injectors and pump (two buses), and coolant surge tank (five buses). The diesel buses also had significant brake repair costs for standard relining (eight times). The other major maintenance-cost issues were for accident repair and replacing seats and windows (five buses).

The total maintenance costs, without warranty costs, are much lower for the diesel buses. The per-bus results for the fuel cell buses compared with the diesel buses are as follows:

- Usage/Mileage—The fuel cell buses are 47% lower than the diesel buses
- Parts Costs—The fuel cell buses are 75% lower than the diesel buses
- Labor Hours—The fuel cell buses are 10% higher than the diesel buses
- Cost per Mile (without warranty costs)—The fuel cell buses are 33% higher than the diesel buses

The maintenance costs for the fuel cell buses are generally higher than for past evaluation results, which is an indication of the added support directly from AC Transit maintenance personnel. This higher cost is especially the case with the number of mechanic labor hours.

Maintenance Costs Broken Down by System—Table 7 shows maintenance costs by vehicle system and bus study group (without warranty costs). The vehicle systems shown in the table include the following:

- **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 7. Maintenance Cost per Mile by System (Evaluation Period)

System	Fuel Cell*		Diesel	
	Cost per Mile ($)	Percent of Total (%)	Cost per Mile ($)	Percent of Total (%)
Cab, Body, and Accessories	0.20	31	0.16	32
Propulsion-Related	0.15	23	0.10	20
PMI	0.10	15	0.07	14
Brakes	0.13	20	0.11	22
Frame, Steering, and Suspension	0.04	6	0.02	4
HVAC	0.02	3	0.01	2
Lighting	0.00	0	0.01	2
Air, General	0.00	0	0.00	0
Axles, Wheels, and Drive Shaft	0.01	2	0.01	2
Tires	0.00	0	0.00	0
Total	**0.65**	**100**	**0.49**	**100**

* Excludes warranty work costs

The systems with the highest percentage of maintenance costs for the fuel cell buses were cab, body, and accessories; propulsion-related; brakes; and PMI. These systems were also the highest maintenance cost systems for the diesel buses.

Propulsion-Related Maintenance Costs—Propulsion-related vehicle systems include the exhaust, fuel, engine, electric propulsion, air intake, cooling, non-lighting electrical, and transmission systems.

Table 8 shows the propulsion-related system repairs by category for the two study groups during the evaluation period (no warranty costs). The fuel cell buses had higher maintenance costs (50% higher), which continue to indicate the amount of AC Transit mechanic activity in supporting and maintaining the fuel cell buses. UTC Power still has an engineer on site to supervise and complete maintenance of the fuel cell power system and related systems.

Table 8. Propulsion-Related Maintenance Costs by System (Evaluation Period)

Maintenance System Costs	Fuel Cell	Diesel
Mileage	49,921	266,514
Total Propulsion-Related Systems (Roll-up)		
Parts cost ($)	616.90	18,794.62
Labor hours	132.2	173.1
Total cost ($)	7,225.40	27,448.12
Total cost ($) per mile	**0.15**	**0.10**
Exhaust System Repairs		
Parts cost ($)	0.00	5,091.03
Labor hours	0.0	28.0
Total cost ($)	0.00	6,491.03
Total cost ($) per mile	**0.00**	**0.02**
Fuel System Repairs		
Parts cost ($)	0.00	2,561.24
Labor hours	1.0	17.8
Total cost ($)	50.00	3,451.24
Total cost ($) per mile	**0.00**	**0.01**
Powerplant System Repairs		
Parts cost ($)	289.98	3,549.02
Labor hours	57.2	56.4
Total cost ($)	3,148.48	6,368.52
Total cost ($) per mile	**0.06**	**0.02**
Electric Motor and Propulsion Repairs		
Parts cost ($)	0.00	0.00
Labor hours	70.0	0.0
Total cost ($)	3,500.00	0.00
Total cost ($) per mile	**0.07**	**0.00**
Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)		
Parts cost ($)	4.71	1,809.52
Labor hours	3.0	33.4
Total cost ($)	154.71	3,478.52
Total cost ($) per mile	**0.00**	**0.01**
Air Intake System Repairs		
Parts cost ($)	322.21	959.66
Labor hours	0.0	0.0
Total cost ($)	322.21	959.66
Total cost ($) per mile	**0.01**	**0.00**
Cooling System Repairs		
Parts cost ($)	0.00	4,237.93
Labor hours	1.0	29.0
Total cost ($)	50.00	5,687.93
Total cost ($) per mile	**0.00**	**0.02**
Transmission Repairs		
Parts cost ($)	0.00	451.46
Labor hours	0.0	2.5
Total cost ($)	0.00	576.46
Total cost ($) per mile	**0.00**	**0.00**

Roadcall Analysis

A roadcall (RC) or revenue vehicle system failure (as named in the National Transit Database) 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[9]. If the problem with the bus can be repaired during a layover and the schedule is kept, this is not considered a RC. The analysis provided here includes only RCs that were caused by "chargeable" failures. Chargeable RCs include systems that can physically disable the bus from operating on route, such as interlocks (doors, air system), engine, etc. or things that are deemed to be safety issues if operation of the bus continued. They do not include RCs for things such as problems with radios or destination signs.

Table 9 shows the RCs and miles between roadcalls (MBRC) for each study bus categorized by all RCs and propulsion-related-only RCs. The diesel buses have much better MBRC rates for both categories. This lower rate is indicative of the prototype status of the fuel cell buses.

Table 9. Roadcalls and MBRC (Evaluation Period)

Bus	Mileage	All Roadcalls	All MBRC	Propulsion Roadcalls	Propulsion MBRC	Fuel Cell only MBRC
FC1	11,108	11	1,010	8	1,389	5,554
FC2	14,913	21	710	19	785	7,457
FC3	23,900	17	1,406	15	1,593	5,975
Total FCB	**49,921**	**49**	**1,019**	**42**	**1,189**	**6,240**
1043 Diesel	44,539	6	7,423	2	22,270	
1044 Diesel	42,976	15	2,865	5	8,595	
1045 Diesel	44,256	16	2,766	6	7,376	
1046 Diesel	45,518	7	6,503	3	15,173	
1047 Diesel	45,806	9	5,090	4	11,452	
1048 Diesel	43,419	9	4,824	5	8,684	
Total Diesel	**266,514**	**62**	**4,299**	**25**	**10,661**	

[9] AC Transit defines a significant delay as six or more minutes.

What's Next for AC Transit?

AC Transit continues to operate the three existing fuel cell buses in their accelerated testing project for FTA's NFCBP. This continued operation has required AC Transit to invest significant resources into personnel, training, and equipment as discussed in this report. At the same time, CARB has required several California transit agencies (including AC Transit) to purchase new and advanced fuel cell buses as part of their zero-emission bus regulations. The Bay Area is now required to have 12 new and advanced fuel cell buses in operation in 2009. AC Transit and UTC Power announced (May 6, 2008) an order for a minimum of eight new fuel cell power systems. These new fuel cell power systems are planned for delivery in 2009 and 2010.

AC Transit is now the managing partner for a Zero Emission Bay Area (ZEBA) working group to respond to CARB's advanced fuel cell bus demonstration. The ZEBA group includes several Bay Area transit agencies:

- AC Transit
- Santa Clara Valley Transportation Authority (VTA)
- Golden Gate Transit (GGT)
- San Mateo County Transit District (SamTrans)
- San Francisco Municipal Transportation Agency (SF MTA)[10]

VTA and SamTrans have recently committed to transfer funds to AC Transit to purchase an additional four fuel cell buses for the CARB demonstration. AC Transit will own and maintain the 12 new fuel cell buses and will be responsible for managing the operation and demonstration; however, several of the ZEBA partners may operate these buses for a period of time during the demonstration. Each ZEBA transit agency is participating in the on-going operations with financial and planning support. Another four new fuel cell buses have been purchased from AC Transit's order by UTC Power for operation in Connecticut and other selected areas under the FTA's NFCBP.

The new Van Hool fuel cell buses (purchase price around $2.3 million each) with power systems from UTC Power have an improved design from the current fuel cell buses—they are lighter weight, three inches shorter, and have a different battery/energy storage design (lithium ion batteries are being considered). The first bus is now expected at AC Transit in fourth quarter 2009.

- **Accelerated Testing (FTA NFCBP)**—As the new fuel cell buses start to arrive at AC Transit, the plan is to remove the existing three fuel cell power systems and install them into the first three new fuel cell buses for operation at AC Transit. The existing/older fuel cell bus gliders are planned to be transferred to UTC Power. The other nine new fuel cell buses will arrive at AC Transit with new fuel cell power systems. The accelerated testing project with AC Transit and FTA is expected to continue through 2011.

[10] SF MTA is a voluntary participant. Its fleet of trolley buses already meets CARB zero-emission bus regulations.

- **NREL Evaluation of AC Transit Fuel Cell Buses**—The current evaluation of accelerated testing at AC Transit is being funded by FTA in conjunction with their NFCBP. Once the new buses for the ZEBA/CARB fuel cell bus demonstration start to arrive at AC Transit and the older fuel cell buses are taken out of service, the evaluation funding will be transitioned back to DOE. This transition is expected to happen in late 2009 or early 2010. The DOE evaluation plans include all 12 of the new fuel cell buses for the planned ZEBA/CARB demonstration.

AC Transit continues to work on hydrogen fueling infrastructure for the existing and new fuel cell buses as well as light-duty fuel cell vehicles. Chevron and AC Transit plan to transition the current hydrogen fueling facility to AC Transit once the current light-duty vehicle operation commitments at AC Transit's D4 are complete. The terms of this transfer have not yet been completed. At the same time, AC Transit is planning the construction of a new hydrogen fuel station at their Emeryville depot (Division 2). This new fueling station will be a combined facility for light-duty fuel cell vehicles and fuel cell buses. A solar-powered electrolyzer will generate up to 60 kg of hydrogen for the light-duty vehicles, while a methane steam reformer will produce as much as 200 kg of hydrogen for as many as six fuel cell buses. This new station will be a convenient fueling location for future bus operations by ZEBA partner transit agencies like GGT and SF MTA.

The next evaluation report as part of the AC Transit accelerated testing project is planned for mid 2009 but may change depending on updates in the delivery schedule of the new fuel cell buses.

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Acronyms and Abbreviations

AC Transit	Alameda-Contra Costa Transit District
APC	automated passenger counter
BTI	Breakthrough Technologies Institute
CARB	California Air Resources Board
CSA	cell stack assembly
CTE	Center for Transportation and the Environment
DGE	diesel gallon equivalent
DOE	U.S. Department of Energy
FTA	Federal Transit Administration
GGT	Golden Gate Transit
HVAC	heating, ventilation, and air conditioning
kg	kilogram
MBRC	miles between roadcalls
min	minutes
mpg	miles per gallon
mph	miles per hour
NAVC	Northeast Advanced Vehicle Consortium
NFCBP	National Fuel Cell Bus Program
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer
PM	particulate matter
PMI	preventive maintenance inspection
Psi	pounds per square inch
RC	roadcall
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: a Legacy for Users
SamTrans	San Mateo County Transit District
SF MTA	San Francisco Municipal Transportation Agency
SOC	state of charge
VTA	Santa Clara Valley Transportation Authority
ZEBA	Zero Emission Bay Area

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Reports from DOE/NREL evaluations can be downloaded via the following Web sites:

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