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SunLine Transit Agency Fuel Cell Transit Bus: Fourth Evaluation Report

Technical Report
NREL/TP-560-44646-1
January 2009

Kevin Chandler, Battelle
Leslie Eudy, National Renewable Energy Laboratory

Link to Appendices

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Prepared under Task No. FC08.7820

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National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
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Acronyms and Abbreviations

ASME	American Society of Mechanical Engineers
CARB	California Air Resources Board
CNG	compressed natural gas
DGE	diesel gallon equivalent
DOE	U.S. Department of Energy
FCB	fuel cell bus
ft	feet
FTA	Federal Transit Administration
GGE	gasoline gallon equivalent
HHICE	hydrogen hybrid internal combustion engine
hp	horsepower
HVAC	heating, ventilation, and air conditioning
in.	inches
kg	kilogram
kW	kilowatts
lb	pounds
MBRC	miles between roadcalls
mph	miles per hour
NFCBP	National Fuel Cell Bus Program
NREL	National Renewable Energy Laboratory
PMI	preventive maintenance inspection
psi	pounds per square inch
RC	roadcall

Executive Summary

This report describes operations at SunLine Transit Agency for a prototype fuel cell bus and five new compressed natural gas (CNG) buses. This is the fourth evaluation report for this site, and it describes results and experiences from April 2008 through October 2008. These results are an addition to those provided in the previous three evaluation reports.

In mid-April 2008, UTC Power installed its newest version fuel cell power system into SunLine's fuel cell bus. This new version of the fuel cell power system is expected to perform much better in respect to the number of operating hours than the previous versions. So far at SunLine, this has been true. The fuel cell bus operated 11,461 miles and 885 hours (average operating speed of 13.0 mph) since the new fuel cell power system was installed, and UTC Power reports that there are no indications of the early power degradation that earlier versions experienced by this point.

During the evaluation period, the hydrogen fueling station provided 4,411 kg of hydrogen at an average cost of $16.00 including parts and labor, amortization of the equipment, and natural gas and utilities. SunLine indicates that the best steady-state operating point for the reformer system would be around $8 per kg or possibly less. The on-site CNG station provided fuel at an average of $1.74 per GGE.

The fuel cell bus was available more often during this evaluation period compared with previous reporting periods. This availability was a result of a significant reduction in issues with the traction batteries. The fuel cell bus was available at or near the 85% availability target six out of seven months including two months at 100% availability. The fuel economy continues to be significantly higher for the fuel cell bus compared with the CNG buses (2.6 times higher). Miles between roadcalls (MBRC) for the fuel cell bus has continued to be much lower than the conventional buses. The maintenance costs for the fuel cell and CNG buses are now similar with the fuel cell bus being 17% higher; however, all of the fuel cell propulsion-system parts have been covered under warranty.

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

Table ES-1. Summary of Evaluation Results

Data Item	Fuel Cell	CNG
Number of Buses	1	5
Data Period	4/08–10/08	4/08–10/08
Number of Months	7	7
Total Mileage in Period	11,461	159,150
Average Monthly Mileage per Bus	1,694	4,547
Availability (85% is target)	76%	86%
Fuel Economy (Miles/kg or GGE)	7.25	2.83
Miles between Roadcalls (MBRC) – All	1,433	8,842
MBRC – Propulsion Only	2,292	14,468
Total Maintenance, $/mile	0.49	0.42
Maintenance – Propulsion Only, $/mile	0.21	0.11

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Overview

SunLine Transit Agency provides public transit and community services to California's Coachella Valley. Headquartered in Thousand Palms, SunLine's service area of over 1,100 square miles includes nine member cities and a portion of Riverside County. SunLine has proactively adopted clean fuel technologies in their fleet, beginning with compressed natural gas (CNG) buses in 1994. Since then, the agency has tested many advanced technologies including buses that run on a blend of hydrogen and CNG, battery electric power, and fuel cells. Appendix A provides more information on SunLine.

In January 2006, SunLine began demonstrating one prototype fuel cell bus manufactured by Van Hool and ISE Corp. The prototype fuel cell bus features an electric hybrid drive system with a UTC Power PureMotion[1] 120 Fuel Cell Power System and ZEBRA batteries for energy storage. The bus is shown in Figure 1.

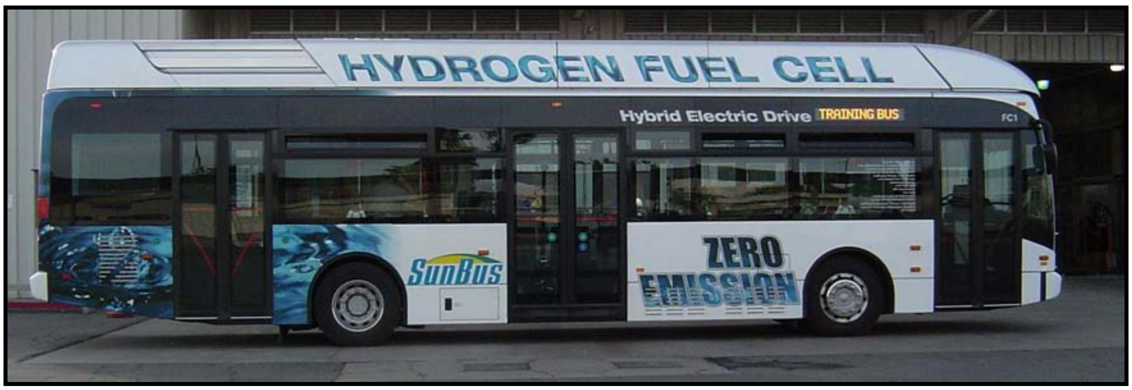

Figure 1. Fuel cell transit bus at SunLine

This report includes operations at SunLine for the fuel cell transit bus in revenue service. Five compressed natural gas (CNG) buses operating from the same SunLine location are being used as a baseline comparison. The CNG buses from Orion Bus Industries use Cummins Westport C Gas Plus natural gas engines (see Figure 2). Appendix B provides more detail about the bus technologies included in this evaluation. The next section discusses hydrogen and CNG fueling infrastructure, and Appendix C provides more detail about SunLine's facilities including modifications.

The Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) evaluates these buses to help determine the status of hydrogen and fuel cell systems and corresponding hydrogen infrastructure in transit applications. Appendix D describes NREL's transit bus evaluation activities for DOE and the Federal Transit Administration (FTA). NREL has published three previous evaluation reports for this ongoing study at SunLine.[2,3,4] These reports

[1] PureMotion is a trademark of UTC Power
[2] SunLine Transit Agency, Hydrogen-Powered Transit Buses: Preliminary Evaluation Results, February 2007, NREL/TP-560-41001, www.nrel.gov//hydrogen/pdfs/41001.pdf
[3] SunLine Transit Agency, Hydrogen-Powered Transit Buses: Evaluation Results Update, September 2007, NREL/TP-560-42080, www.nrel.gov/hydrogen/pdfs/42080.pdf

included data on the fuel cell bus, a hybrid hydrogen internal combustion engine (HHICE) bus, and CNG buses in operation at SunLine.

Figure 2. Orion V CNG bus at SunLine

This fourth evaluation report describes results and experiences with the fuel cell and CNG buses from April 2008 through October 2008. In April 2008, the newest version fuel cell power system from UTC Power was installed in the fuel cell bus. DOE and NREL are continuing to collect data on the bus to validate performance improvements resulting from the fuel cell system update. The evaluation for the HHICE bus has concluded; however, this report includes the fueling data on that bus to evaluate performance of the hydrogen station.

Hydrogen and CNG Fueling

Hydrogen fuel is supplied at SunLine by a HyRadix natural gas reformer. The fuel is compressed to 5,000 psi and dispensed into the buses. CNG is brought into the SunLine property via a high-pressure natural gas line and then compressed to 3,600 psi for delivery into the vehicles. Appendix C provides general descriptions of SunLine's hydrogen and CNG fueling infrastructure along with maintenance facilities.

SunLine provides both hydrogen and CNG for purchase at its public dispensing island. Because of this, SunLine is required to track all of its fueling events in gasoline gallon equivalent (GGE) units to comply with state fuel-sale regulations. In the case of hydrogen, the unit used is typically kilograms (kg)—one kg contains essentially the same energy as a GGE for fuel economy calculations. This report presents both GGE (or kg for hydrogen) and diesel gallon equivalent (DGE) for hydrogen and CNG fuel consumption. The end of Appendix E shows energy-conversion calculations for GGE and DGE.

[4] SunLine Transit Agency, Hydrogen-Powered Transit Buses: Third Evaluation Report and Appendices, June 2008, NREL/TP-560-43741-1, www.nrel.gov/hydrogen/pdfs/43741-1.pdf, and Appendix NREL/TP/560-43741-2, www.nrel.gov/hydrogen/pdfs/43741-2.pdf

Fueling Data Analysis – Figure 3 shows the average hydrogen dispensed per day into both of the hydrogen-fueled buses from April 2008 through October 2008. The calculation for this rate includes only the days in which the station dispensed hydrogen. The station was used at least once per day to fill at least one of the two hydrogen buses for 75% of the calendar days during the period. The overall average daily use was 27.4 kg per day. During this period, SunLine dispensed a total of 4,411 kg of hydrogen. The HHICE bus was not used much early in this evaluation period; however, by the end of the period, this bus was being used more than 2,500 miles per month, which caused the much-higher daily usage rates in September and October 2008.

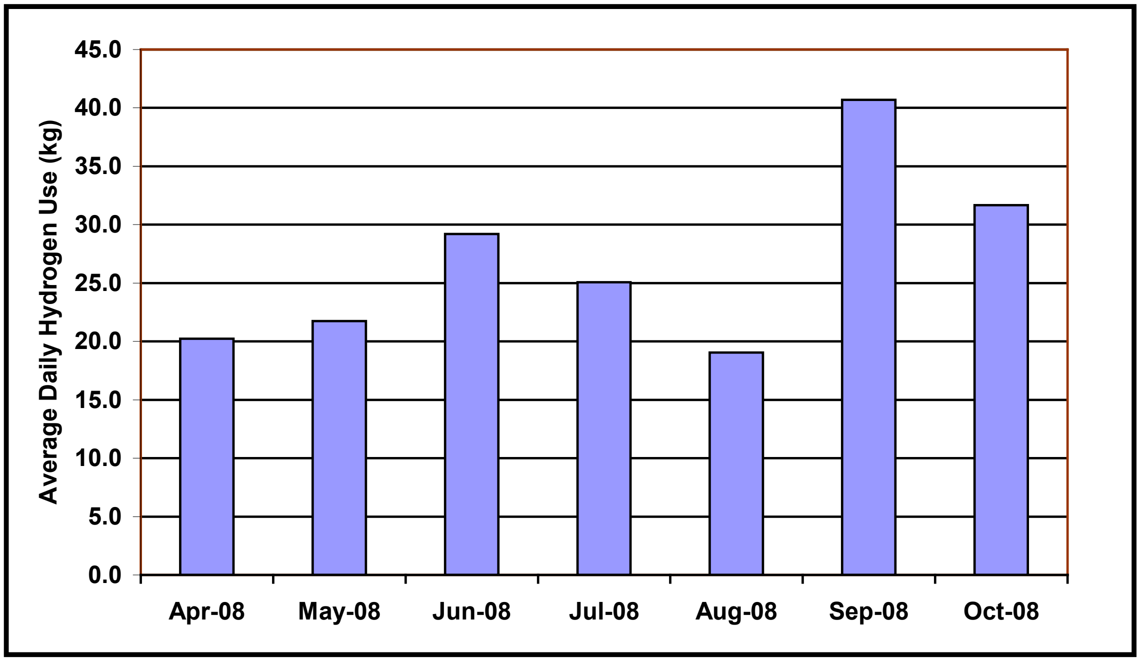

Figure 3. Average hydrogen dispensed per day (excluding 0 kg days)

Figure 4 shows the distribution of hydrogen amounts dispensed per fill by bus type. The two buses were filled a total of 201 times during the evaluation period for a total of 4,348 kg[5]. The fuel cell bus averaged 18.8 kg per fill, while the HHICE bus fuelings averaged 24.1 kg per fill. Figure 5 shows a cumulative fueling rate histogram for the SunLine hydrogen station from April through October 2008. The overall average fueling rate was 1.0 kg/min.

[5] This total is slightly lower than that shown for Figure 3. If the time for the fueling was not captured in data collection, Figures 4 and 5 exclude that fueling data.

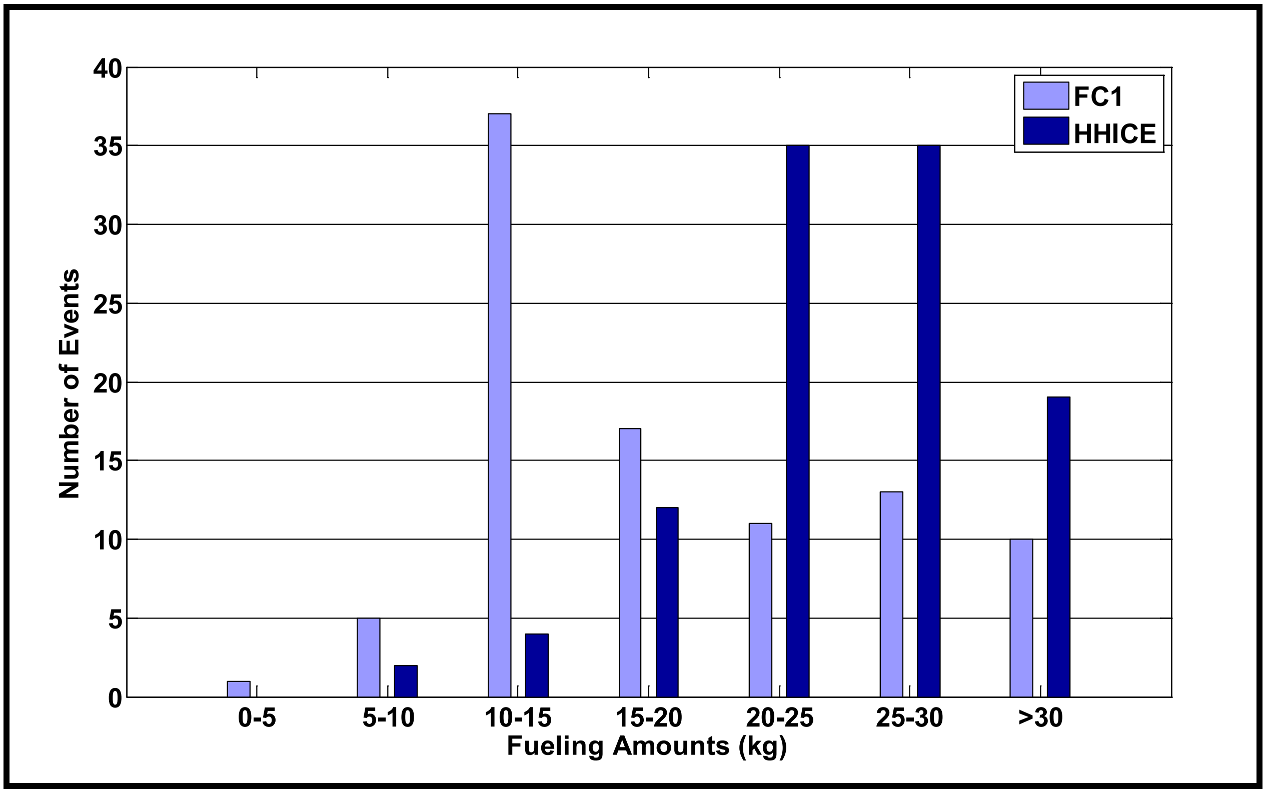

Figure 4. Distribution of fueling amounts

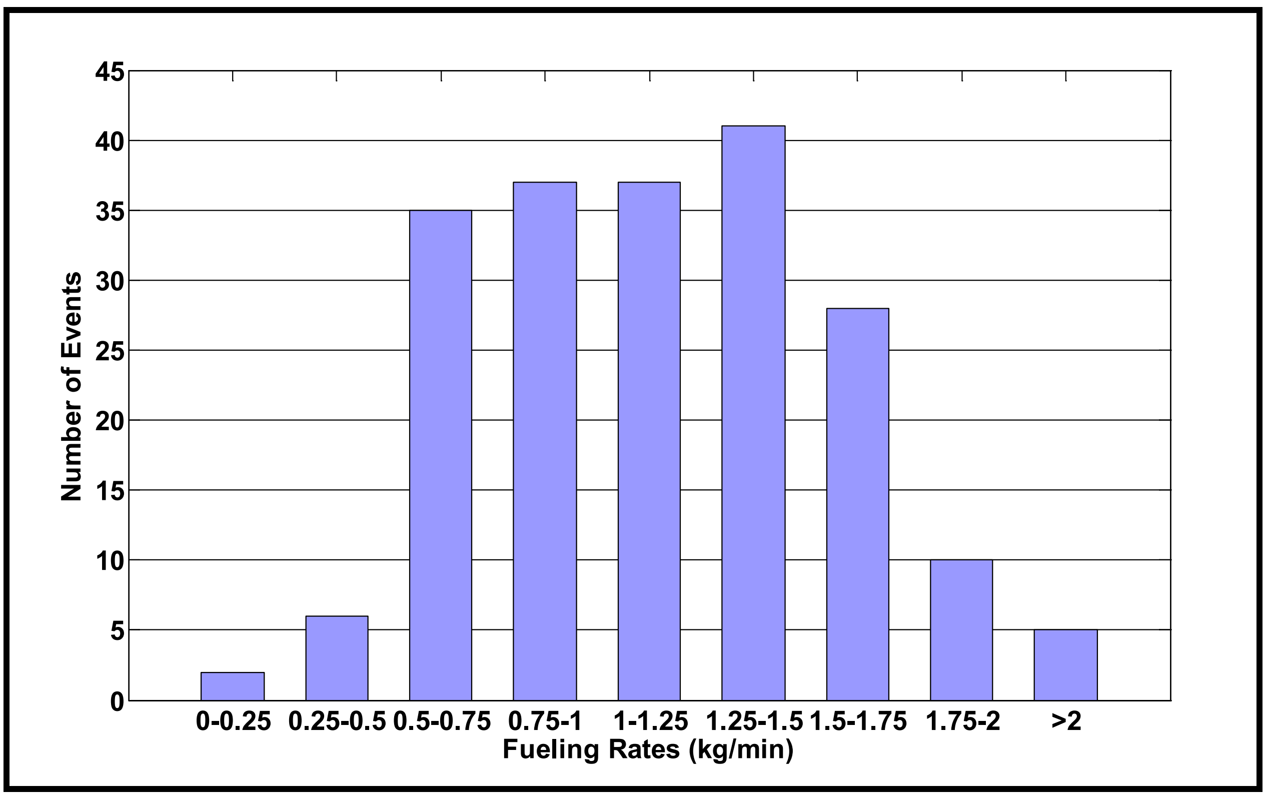

Figure 5. Cumulative fueling rate histogram

Hydrogen fuel costs at SunLine consist of the cost of natural gas for the reformer, maintenance of the station equipment, and capital costs amortization. SunLine performs the maintenance of the station including parts and labor. The average cost for hydrogen during the evaluation period was $16.00 per kg. SunLine indicates that the best steady-state operating point for the reformer system would bring the average cost of hydrogen to around $8 per kg.

SunLine supplies CNG fuel to users in its area, and the fueling station is accessible to the public. The high volume of natural gas use has allowed SunLine to command a low cost as a commodity user. During the evaluation period, the CNG price at the dispenser for SunLine (not the public price) was $1.74 per GGE. This price includes all costs—natural gas, maintenance, and station amortization.

Evaluation Results

The fuel cell bus has been in revenue service at SunLine since January 2006, and this report presents data through October 2008. The focus of this evaluation report is on the most-recent operating data for the fuel cell bus and CNG buses—April 2008 through October 2008. The fuel cell bus had the fuel cell power system replaced April 15–16, 2008, and went back into service on April 18, 2008. The evaluation period in this report includes only service of the new fuel cell power system starting on that date through October 2008. The CNG bus evaluation results include all of April 2008 through October 2008 operation.

In this fourth evaluation report, the fuel cell bus is considered prototype technology in the commercialization process. The analysis and comparison discussions with standard CNG buses help create a baseline to measure the progress of this hydrogen propulsion technology. There is no intent to consider this implementation of a fuel cell bus as commercial (or full revenue transit service). The evaluation focuses on documenting progress and opportunities to improve the vehicle, infrastructure, and procedures.

Route Assignments

In general, buses at the two SunLine operating locations are dispatched randomly. The overall system average operating speed at SunLine is 13.2 mph. The fuel cell bus has been used almost exclusively on Line 50 (average speed of 14.1 mph). In-service data for the fuel cell bus during the evaluation period indicate an average operating speed of 13.0 mph based on mileage and fuel cell system operating hours. The CNG buses have been randomly dispatched with heavy use on Line 111 (average speed of 14.3 mph) and Line 14 (average speed of 14.7 mph), which are SunLine's top two routes.

Bus Use and Availability

Bus use and availability indicates reliability. Lower bus use may indicate downtime for maintenance or purposeful reduction of planned work for the buses. This section provides a summary of bus use and availability for the two study bus groups.

The fuel cell bus has planned service of one eight-hour shift per day for seven days per week. For the fuel cell bus, total mileage accumulation for the evaluation period was 11,461 miles, and the fuel cell system accumulated 885 hours, which indicates an average speed of 13.0 mph. Since the start of revenue operation of the fuel cell bus, the total mileage is 63,797 with 4,912 total hours for an overall average speed of 13.0 mph. This average is only slightly slower than the overall 13.2-mph average speed for all SunLine routes.

Table 1 summarizes the average monthly mileage accumulation by bus and study group for the evaluation period. This table omits the mileage accumulation for the fuel cell bus during April 2008 because the new fuel cell system was installed in the middle of the month. Using the CNG buses as the baseline, the fuel cell bus had an average monthly mileage 37% that of the CNG buses. This percentage is consistent in that the fuel cell bus has planned service at about half of the CNG buses, and the fuel cell bus had significant downtime for one month of the evaluation period, which the next section discusses.

Table 1. Average Monthly Mileage (Evaluation Period)

Bus	Starting Hubodometer	Ending Hubodometer	Total Mileage	Months	Monthly Average
FC1	**56,498**	**66,662**	**10,164**	**6**	**1,694**
563 CNG	89,320	126,342	37,022	7	5,289
565 CNG	110,370	139,248	28,878	7	4,125
566 CNG	91,523	120,696	29,173	7	4,168
567 CNG	90,552	119,066	28,514	7	4,073
568 CNG	107,510	143,073	35,563	7	5,080
Total CNG			**159,150**	**35**	**4,547**

Another measure of reliability is availability—the percent of time that the buses are planned for operation compared with the time the buses are actually available for that planned operation. Figure 6 shows the monthly average availability for each of the study bus groups. As shown in the chart, the availability goal is 85% for all buses. Availability for all of NREL's evaluations is calculated by including all weekdays. Weekends and holidays are included in the calculation only if the bus operated in service on those days. If a bus does not operate on the weekend or a holiday, it is not counted as unavailable. This strategy applies to both the fuel cell bus and the CNG buses.

The **fuel cell bus** was available at or near the 85% availability target six out of seven months of the evaluation period. For two months, the bus was available 100%. The availability was low during July 2008 due to an electrical problem in the hybrid system. The energy-storage (ZEBRA batteries) issues presented in previous reports has continued but has been much less of a problem with reducing availability.

- **Traction Battery Issues** – The ZEBRA batteries have experienced significant issues in this application. Three traction batteries on the bus operate in parallel. A cell in a ZEBRA battery typically will fail in short circuit. A battery with failed cells has reduced voltage even though it still can be operated. Because the batteries operate with a direct parallel connection, when the number of failed cells within each of the batteries is too different among the three batteries, the difference 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 bus shutdown. 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 use, 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 SunLine as well as the rest of the Van Hool fuel cell buses in California and Connecticut.

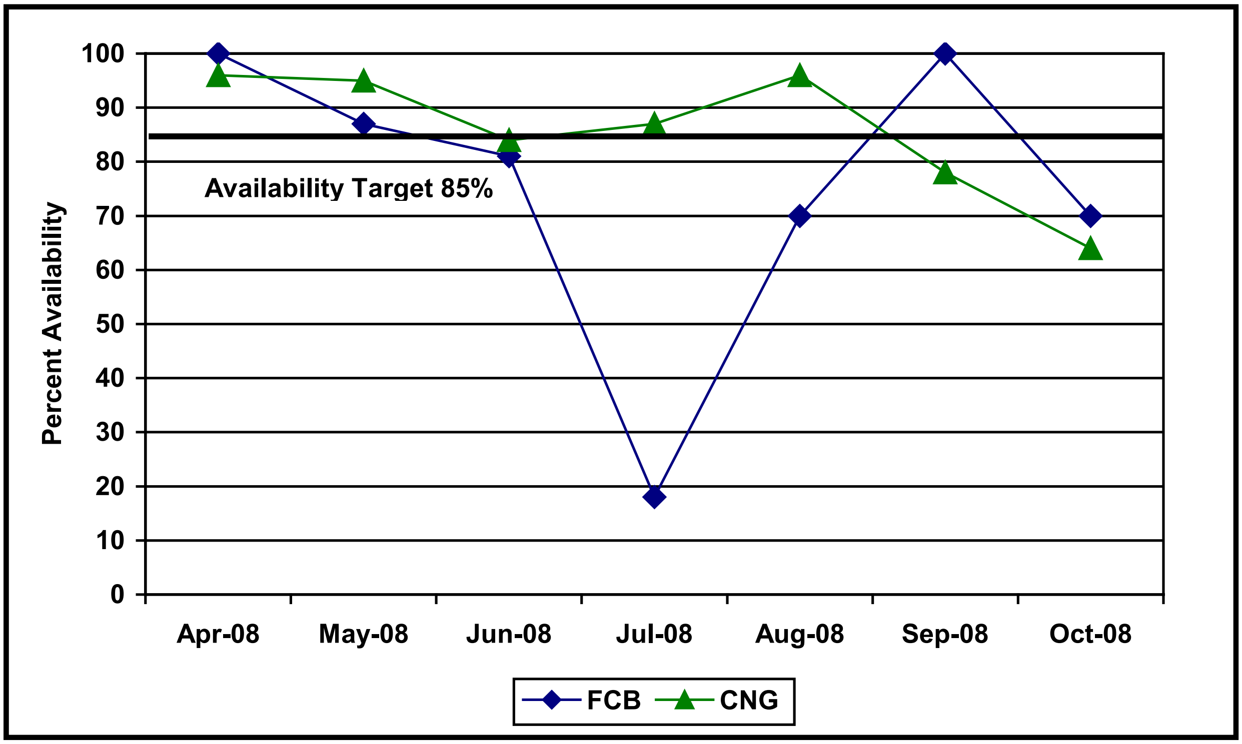

Figure 6. Availability for study bus groups

- **Fuel Cell 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 (at about 800 hours of operation instead of the expected 4,000 hours or more). A new version of CSAs replaced the CSAs on the SunLine fuel cell bus on April 15–16, 2008. UTC Power reported that this early power-degradation issue was resolved for these buses, and the results in this evaluation report support that assertion.

The chart shows that the CNG buses have been at or above the 85% availability target except during September and October 2008. This lower availability occurred because three of the five buses were out of service for a significant time to be repainted with SunLine's new paint scheme. Only one bus was out of service for a significant amount of time during those two months for a maintenance issue, which was a differential failure that required the drive axle to be replaced.

Table 2 provides a summary of the availability and unavailability reasons for each of the study bus groups. Overall, during the evaluation period, the average availability for the fuel cell bus was 76% and availability for the CNG buses was 86%. Issues that kept the fuel cell bus out of service included problems with the fuel cell system (51%), ISE propulsion (35%), SunLine maintenance (12%), and traction batteries (2%). Issues that kept the CNG buses out of service were general maintenance.

Table 2. Summary of Reasons for Availability and Unavailability of Buses for Service

Category	Fuel Cell Bus		CNG Buses	
	Number	Percent	Number	Percent
Planned Work Days	176		965	
Days Available	133	76	832	86
Available	**133**	**100**	**832**	**100**
On-Route	112	84	822	99
Event/Demonstration	21	16	1	0
Training	0	0	3	0
Not Used	0	0	6	1
Unavailable	**43**	**100**	**133**	**100**
Fuel Cell Propulsion	22	51		
ISE Propulsion	15	35		
Traction Batteries	1	2		
SunLine Maintenance	5	12	133	100
Fueling Unavailable	0	0		

Fuel Economy and Cost

Table 3 shows hydrogen and CNG fuel consumption and fuel economy for the study bus groups during the evaluation period. Using the GGE fuel economy and the CNG buses as the baseline, the fuel cell bus had a fuel economy 2.6 times higher than the CNG buses. Figure 7 shows average fuel economies for each of the study bus groups.

The fuel costs per mile for the study bus groups for the evaluation period were $1.10 per mile for the fuel cell bus and $0.61 for the CNG buses. The fuel cost for CNG has been much lower than the cost for hydrogen production.

Table 3. Fuel Use and Economy (Evaluation Period)

Bus	Mileage (Fuel Base)	Hydrogen (kg) or CNG (GGE)	Miles per kg or GGE	Diesel Equivalent Amount (Gallon)	Miles per Gallon (DGE)
FC1	**11,461**	**1,581.3**	**7.25**	**1,399.4**	**8.19**
563 CNG	37,022	13,145.6	2.82	11,765.3	3.15
565 CNG	28,878	10,087.1	2.86	9,028.0	3.20
566 CNG	29,173	10,732.3	2.72	9,605.4	3.04
567 CNG	27,883	9,628.9	2.90	8,617.8	3.24
568 CNG	35,563	12,381.7	2.87	11,081.6	3.21
CNG Total	**158,519**	**55,975.7**	**2.83**	**50,098.2**	**3.16**

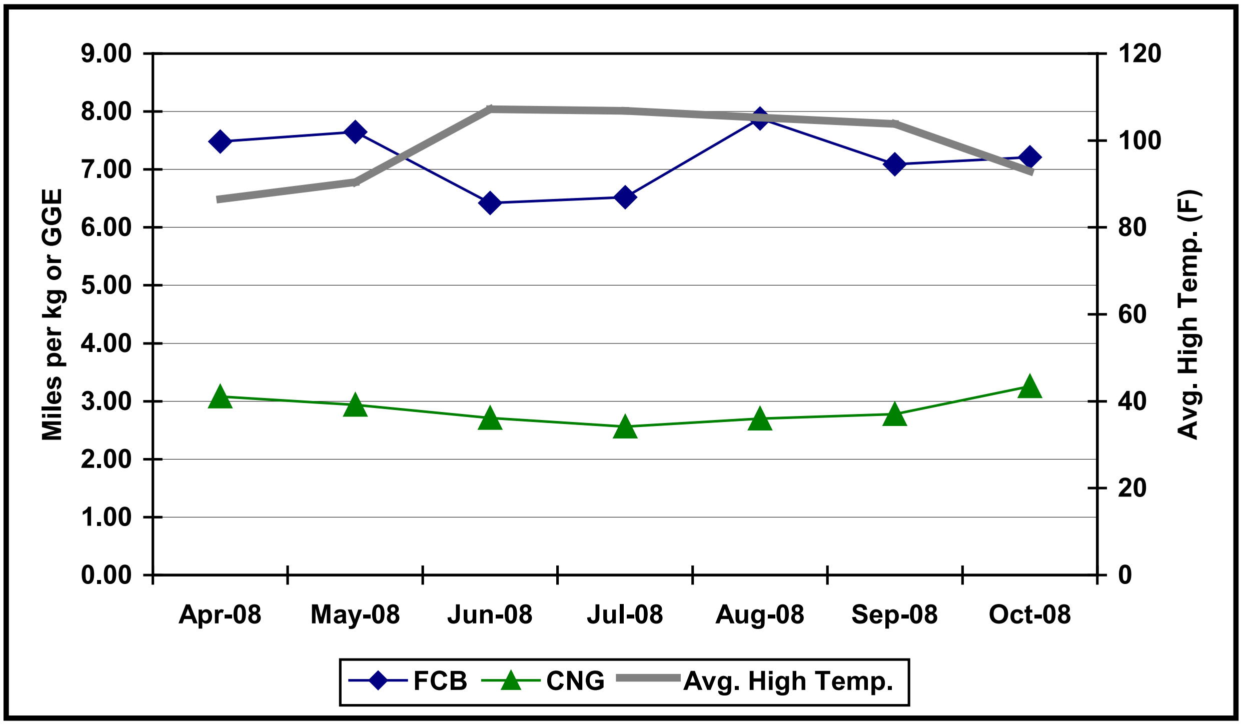

Figure 7. Average fuel economy (miles per kg or GGE)

Maintenance Analysis

The maintenance cost analysis in this section is only for the evaluation period. Warranty costs are generally not included in the cost-per-mile calculations. All work orders for the study buses were collected and analyzed for this evaluation. For consistency, we set the maintenance labor rate at $50 per hour, which does not reflect an average rate for SunLine. This section covers total maintenance costs first and then maintenance costs broken down by bus system.

Total Maintenance Costs – Total maintenance costs include the price of parts and hourly labor rates of $50 per hour. Cost per mile is calculated as follows:

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

Table 4 shows total maintenance costs for the fuel cell bus and CNG buses. The CNG buses have total maintenance costs 17% lower than the fuel cell bus. The parts costs are low for the fuel cell bus because they are covered by the manufacturers for most of the propulsion system maintenance; however, SunLine's mechanics do most of the work. CNG bus number 565 had high maintenance costs because of a differential problem that ultimately required the drive axle to be replaced in October 2008.

Table 4. Total Maintenance Costs (Evaluation Period)

Bus	Mileage	Parts ($)	Labor Hours	Cost ($) per Mile
Fuel Cell	**11,461**	**583.54**	**101.3**	**0.49**
563 CNG	37,022	3,047.03	150.5	0.29
565 CNG	28,878	11,234.25	200.0	0.74
566 CNG	29,173	2,039.94	149.5	0.33
567 CNG	28,514	3,286.34	206.0	0.48
568 CNG	35,563	4,304.22	165.3	0.35
Total CNG	**159,150**	**23,911.78**	**871.3**	**0.42**

Maintenance Costs Broken Down by System – Table 5 shows maintenance costs by vehicle system and bus study group (without warranty costs included). 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**

The systems with the highest percentage of maintenance costs for the study groups were propulsion-related and PMI. For the fuel cell bus, the propulsion-related maintenance was significantly more than for the CNG buses; however, the PMI and cab, body, and accessories categories were essentially the same as for the CNG buses. The one category that was higher for the fuel cell bus was for frame, steering, and suspension, which was caused by three suspension repairs for replacing an air bag (each time). For the CNG buses, the only unusual cost category was the axles, wheels, and drive shaft, which was caused by the drive axle replacement for CNG bus number 565 mentioned above.

Table 5. Breakdown of Vehicle System Maintenance Cost per Mile (Evaluation Period)

System	Fuel Cell		CNG	
	Cost per Mile ($)	Percent of Total (%)	Cost per Mile ($)	Percent of Total (%)
Cab, Body, and Accessories	0.06	12	0.07	16
Propulsion-Related	0.21	43	0.11	26
PMI	0.11	22	0.10	24
Brakes	0.00	0	0.02	5
Frame, Steering, and Suspension	0.07	14	0.02	5
HVAC	0.03	6	0.02	5
Lighting	0.00	0	0.01	2
Axles, Wheels, and Drive Shaft	0.00	0	0.05	12
Tires	0.01	2	0.02	5
Total	**0.49**	**100**	**0.42**	**100**

Propulsion-Related Maintenance Costs – The propulsion-related vehicle systems include the exhaust, fuel, engine, electric propulsion, air intake, cooling, non-lighting electrical, and transmission systems. Table 6 categorizes the propulsion-related system repairs for the study bus groups during the evaluation period (no warranty). Each of the study bus groups was under warranty during the entire evaluation period. Also, the fuel cell bus was maintained by the UTC Power and ISE technicians when the fuel cell power system or drive system required significant repairs. During the evaluation period of this report, the SunLine mechanics did much of the maintenance on the fuel cell bus themselves supported by the manufacturers; however, as mentioned above, the manufacturers generally supplied the parts under warranty for the propulsion system, so the costs for these parts are not included.

- **Total propulsion-related** – The fuel cell bus had essentially double the maintenance cost for propulsion-related maintenance compared with the CNG buses. Most of this maintenance for the fuel cell bus has been labor.
- **Exhaust** – There were few or no costs for this system for the study bus groups.
- **Fuel** – Costs for the fuel system were low for both bus groups.
- **Powerplant and electric propulsion** – The fuel cell bus maintenance reported here involved almost exclusively SunLine mechanics supporting manufacturer work on the bus. The preventive maintenance for the CNG buses was almost exclusively in the powerplant category (and none for electric propulsion).
- **Non-lighting electrical (charging, cranking, and ignition)** – The fuel cell bus had some costs in this category relating to 12-volt batteries and no-start maintenance. The CNG buses mostly had preventive maintenance repairs in this category for spark plugs at the 18,000-preventive-maintenance cycle for each bus.

Table 6. Propulsion-Related Maintenance Costs by System (Evaluation Period)

Maintenance System Costs	Fuel Cell	CNG
Mileage	11,461	159,150
Total Propulsion-Related Systems (Roll-up)		
Parts cost ($)	190.49	8,914.10
Labor hours	44.0	170.5
Total cost ($)	2,390.49	17,439.10
Total cost ($) per mile	**0.21**	**0.11**
Exhaust System Repairs		
Parts cost ($)	0.00	23.82
Labor hours	0.0	2.0
Total cost ($)	0.00	123.82
Total cost ($) per mile	**0.00**	**0.00**
Fuel System Repairs		
Parts cost ($)	0.00	229.64
Labor hours	2.5	0.0
Total cost ($)	125.00	229.64
Total cost ($) per mile	**0.01**	**0.00**
Powerplant System Repairs		
Parts cost ($)	0.00	4,298.92
Labor hours	34.5	114.3
Total cost ($)	1,725.00	10,011.42
Total cost ($) per mile	**0.15**	**0.06**
Electric Propulsion System Repairs		
Parts cost ($)	132.57	0.00
Labor hours	7.0	0.0
Total cost ($)	482.57	0.00
Total cost ($) per mile	**0.04**	**0.00**
Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)		
Parts cost ($)	57.92	3,166.30
Labor hours	0.0	14.8
Total cost ($)	57.92	3,903.80
Total cost ($) per mile	**0.01**	**0.02**
Air Intake System Repairs		
Parts cost ($)	0.00	724.82
Labor hours	0.0	0.0
Total cost ($)	0.00	724.82
Total cost ($) per mile	**0.00**	**0.00**
Cooling System Repairs		
Parts cost ($)	0.00	250.28
Labor hours	0.0	31.0
Total cost ($)	0.00	1,800.28
Total cost ($) per mile	**0.00**	**0.01**
Transmission System Repairs		
Parts cost ($)	0.00	220.32
Labor hours	0.0	8.5
Total cost ($)	0.00	645.32
Total cost ($) per mile	**0.00**	**0.00**

- **Air intake** – The fuel cell bus had no costs in this category, and the CNG buses had only air filter changeouts.
- **Cooling** – The fuel cell bus had no costs in this category. The CNG buses had some repairs in this category; however, the cost was low.
- **Transmission** – Only the CNG buses had costs in this category for filters under preventive maintenance.

Roadcall Analysis

A roadcall (RC), or revenue vehicle system failure (as named in the National Transit Database[6]), 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. If the problem with the bus can be repaired during a layover and the bus remains on schedule, this is not considered a RC. The analysis provided here includes only RCs caused by "chargeable" failures. Chargeable RCs include systems that can physically disable the bus from operating on route, such as interlocks (doors and wheelchair lift) and engine problems. Chargeable RCs do not include RCs for things such as radios or destination signs.

Table 7 shows the RCs and miles between roadcalls (MBRC) for each study bus in two categories: all RCs and propulsion-related-only RCs. The fuel cell bus had several RCs and low vehicle use, which indicates the prototype nature of the technology. For the fuel cell bus, the five propulsion RCs were caused by the fuel cell system (4 RCs) and traction batteries (1 RC). The CNG buses had propulsion RCs for the engine (7 RCs), electrical gauges (3 RCs), and charging light (1 RC).

Table 7. Roadcalls and MBRC (Evaluation Period)

Bus	Mileage	All Roadcalls	All MBRC	Propulsion Roadcalls	Propulsion MBRC
Fuel Cell	**11,461**	**8**	**1,433**	**5**	**2,292**
563 CNG	37,022	0		0	
565 CNG	28,878	6	4,813	4	7,220
566 CNG	29,173	5	5,835	4	7,293
567 CNG	28,514	5	5,703	2	14,257
568 CNG	35,563	2	17,782	1	35,563
Total CNG	**159,150**	**18**	**8,842**	**11**	**14,468**

[6] Federal Transit Administration's National Transit Database Web site: www.ntdprogram.gov/ntdprogram/

What's Next for SunLine?

This report covers SunLine's operation of the fuel cell and CNG buses from April 2008 through October 2008. SunLine, FTA, and UTC Power have entered into a new agreement to operate a new fuel cell power system for another two-year period, and this evaluation report represents the first seven months of this period. The next evaluation report will include another seven to eight months of operation and should be released in the fall of 2009.

Advanced Fuel Cell Bus Project: In 2002, SunLine tested an early prototype hybrid fuel cell bus in service for six months. ISE designed the system on a 30-foot Thor bus chassis. SunLine plans to demonstrate this bus with a new hybrid FC powertrain under funding from CARB, AQMD, and FTA. The redesigned bus system will incorporate the newest design fuel cell from Ballard and advanced lithium batteries. The bus is expected to be ready for service in the fall of 2009 and will operate for at least two years.

American Fuel Cell Bus Project: Funded under the FTA's National Fuel Cell Bus Program, SunLine is leading a team to develop a purpose-built fuel cell bus that meets "Buy America" requirements. The design features a number of advancements that are expected to result in a highly efficient bus. Elements include:

- Lightweight, U.S.-built, bus body
- Advanced windows to reduce interior heat
- Advanced energy storage and new power electronics
- High-efficiency accessories
- Newest-generation fuel cell

Contacts

DOE
1000 Independence Ave., SW
Washington, DC 20585

John Garbak, Technology Validation Manager, Vehicle Technologies Program
Phone: 202-586-1723
E-mail: john.garbak@ee.doe.gov

NREL
1617 Cole Boulevard
Golden, CO 80401

Leslie Eudy, Senior Project Leader
Phone: 303-275-4412
E-mail: leslie_eudy@nrel.gov

Battelle
505 King Avenue
Columbus, OH 43201

Kevin Chandler, Program Manager
Phone: 614-424-5127
E-mail: chandlek@battelle.org

SunLine
32-505 Harry Oliver Trail
Thousand Palms, CA 92276

Tommy Edwards, Director of Maintenance
Phone: 760-343-3456
E-mail: tedwards@sunline.org

UTC Power
195 Governor's Highway
South Windsor, CT 06074

Michael Tosca, Senior Product Marketing and Sales
Phone: 860-727-7324
E-mail: michael.tosca@utcpower.com

Matthew Riley, Systems Engineer
Phone: 860-727-2864
E-mail: Matthew.Riley@utcpower.com

ISE Corporation
12302 Kerran Street
Poway, CA 92064

Paul Scott, Chief Scientific Officer
Phone: 858-413-1742
E-mail: pscott@isecorp.com

HyRadix
175 West Oakton Street
Des Plaines, IL 60018

Terry Schuster, Director of Sales
Phone: 630-416-7425
E-mail: terry.schuster@hyradix.com

New Flyer
Winnipeg, Manitoba
Canada R2J 4B9

Paul Zanetel, Chief Technical Advisor
Phone: 204-982-8180
E-mail: paul_zanetel@newflyer.com

Van Hool
Bernard Van Hoolstraat 58
B-2500 Lier Koningshooikt
Belgium

Paul Jenné, Automotive Relations
Phone: +32 (3) 420 22 10
E-mail: paul.jenne@vanhool.be

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This report describes operations at SunLine Transit Agency for a prototype fuel cell bus and five new compressed natural gas (CNG) buses. This is the fourth evaluation report for this site, and it describes results and experiences from April 2008 through October 2008. These results are an addition to those provided in the previous three evaluation reports.

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