SunLine Transit Agency Advanced Technology Fuel Cell Bus Evaluation: Second Results Report

Leslie Eudy

National Renewable Energy Laboratory

Kevin Chandler

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[Link to appendices](#)

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-5600-52349-1
October 2011

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NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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Prepared under Task No. H270.8150

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Acronyms and Abbreviations

AQMD	Air Quality Management District
AT	advanced technology
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	kilograms
kW	kilowatts
lb	pounds
MBRC	miles between roadcalls
mpDGE	miles per diesel gallon equivalent
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

SunLine Transit Agency provides public transit services to the Coachella Valley area of California. SunLine has demonstrated hydrogen and fuel cell bus technologies for more than 10 years. This report describes operations at SunLine for their newest prototype fuel cell bus and five compressed natural gas (CNG) buses (with model year 2010-level emissions).

In May 2010, SunLine began demonstrating the Advanced Technology (AT) bus—a new-generation fuel cell bus developed by Bluways, Ballard Power Systems, and New Flyer. The AT fuel cell bus has a hybrid electric propulsion system based on the Siemens ELFA system, integrated by Bluways with Ballard's newest version fuel cell power system, and lithium-based hybrid batteries. The design incorporates the latest improvements to reduce weight and increase reliability and performance. Since it first went into service in May 2010, the fuel cell bus has operated almost 21,000 miles and has accumulated 1,776 fuel cell system hours (for an average operating speed of 11.7 mph). The operation of this new fuel cell bus at SunLine has been limited by air conditioning issues during the hot desert summer, some fuel cell power system issues, and some bus body work.

The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is working with SunLine to evaluate the bus in real-world service to document the results and help determine the progress toward technology readiness. NREL uses a standard data-collection and analysis protocol originally developed for DOE heavy-duty vehicle evaluations. NREL has previously published a report documenting the first seven months of operation. This report provides a summary of the results with a focus on the operation from December 2010 through June 2011.

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	12/10 – 6/11	12/10 – 6/11
Number of months	7	7
Total mileage in period	11,164	161,833
Average monthly mileage per bus	1,595	4,624
Availability (85% is target)	64	88
Fuel economy (miles/kg or GGE)	6.18	3.04
Miles between roadcalls (MBRC) – All	5,582	9,520
MBRC – propulsion only	5,582	16,183
MBRC – fuel cell system only	11,164	N/A
Total maintenance, $/mile	$1.16	$0.44
Maintenance – propulsion only, $/mile	$0.35	$0.15

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Introduction

In May 2010, SunLine Transit Agency began operating its newest fuel cell bus in service. This advanced technology (AT) fuel cell bus, built by New Flyer with a Bluways hybrid system and Ballard fuel cell power system, incorporates the latest design improvements to reduce weight and increase reliability and performance. SunLine is collaborating with the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) to evaluate the bus in revenue service. The first results report, which was published in March 2011,[1] covered data through November 2010. This report provides an update to that report and is focused on data from December 2010 through June 2011.

NREL Evaluations

NREL has been evaluating alternative fuel and advanced propulsion transit buses for DOE and the U.S. Department of Transportation's Federal Transit Administration (FTA) since the early 1990s. NREL's first evaluation of hydrogen fuel cell transit buses for DOE was in 2000 and continued with a series of evaluations at five transit agencies. These evaluations focus on determining the status of hydrogen and fuel cell systems and the corresponding infrastructure in transit applications to help DOE and FTA assess the progress toward technology readiness. NREL uses a standard data-collection and analysis protocol originally developed for DOE heavy-duty vehicle evaluations. This protocol was documented in a joint evaluation plan for transit bus evaluations.[2] Appendix A describes NREL's transit bus evaluation activities for DOE and FTA.

Host Site Profile: SunLine

SunLine Transit Agency provides public transit services to Southern California's Coachella Valley (including Palm Springs). Headquartered in Thousand Palms, California, SunLine's service area covers more than 1,100 square miles including nine member cities and a portion of Riverside County. SunLine has proactively adopted clean fuel technologies in its fleet, beginning with complete fleet implementation of 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 B provides more information on SunLine.

Fuel Cell Bus Evaluation at SunLine

SunLine continues to invest in advanced hydrogen and fuel cell bus technologies. The AT fuel cell bus represents a sixth generation of hydrogen-fueled buses operated by the agency. The bus is shown in Figure 1. This report describes SunLine's operation of the AT fuel cell transit bus in revenue service. The AT bus is a low floor, 40-foot New Flyer model with the latest advances designed to improve performance, reliability, and durability. The bus was designed in collaboration between Bluways,[3] Ballard, and New Flyer. Five compressed natural gas (CNG) buses operating from the same SunLine location are being used as a baseline comparison. These buses are 2008 model year New Flyer CNG buses with Cummins Westport ISL G natural gas

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[1] SunLine Transit Agency Advanced Technology Fuel Cell Bus Evaluation: First Results Report, NREL/TP-5600-50500, March 2011, www.nrel.gov/hydrogen/pdfs/50500.pdf.
[2] Fuel Cell Transit Bus Evaluations: Joint Evaluation Plan for the U.S. Department of Energy and the Federal Transit Administration, NREL/TP-560-49342-1, November 2010, www.nrel.gov/hydrogen/pdfs/49342-1.pdf.
[3] In February, 2011, Bluways acquired substantial assets and technology from ISE Corporation.

engines that are designed to meet 2010 emission regulations (see Figure 2). Appendix C provides more detail about the bus technologies included in this evaluation.

Figure 1. SunLine's Advanced Technology fuel cell bus

Figure 2. New Flyer CNG bus at SunLine

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 D provides general descriptions of SunLine's hydrogen and CNG fueling infrastructure and of its 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 of hydrogen contains essentially the same energy as a GGE for fuel-economy calculations. This report presents both GGE (kg for hydrogen) and diesel gallon equivalent (DGE) for hydrogen and CNG fuel consumption. The end of Appendix E shows the energy-conversion calculations for GGE and DGE.

Fueling Station Data Analysis – SunLine currently operates two fuel cell buses in its service area: the AT fuel cell bus and a Van Hool fuel cell bus. To show overall performance of the station, the fueling analysis figures include hydrogen data for both buses. Figure 3 shows the average hydrogen dispensed per day into SunLine's fuel cell buses from May 2010 through June 2011. 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 81% of the calendar days during the period. In September, the buses were held out of service for several days because the station was low on fuel. The overall average daily use was 21.1 kg per day. During this period, SunLine dispensed a total of 7,293 kg of hydrogen. Less fuel was dispensed during December because the AT bus was unavailable for service during that month. The low point in April occurred because the other fuel cell bus was down for maintenance.

Figure 4 shows the distribution of hydrogen amounts dispensed per fill by bus. The buses were filled a total of 208 times during the evaluation period for a total of 3,249 kg hydrogen.[4] The average amount of hydrogen per fill was 15.6 kg per fill. Figure 5 shows a cumulative fueling rate histogram for the SunLine hydrogen station from December 2010 through June 2011. The overall average fueling rate was 0.96 kg per minute, and the average time for a fill was 16.3 minutes.

[4] This total is slightly lower than discussed above. If the time for the fueling was not captured in data collection, that fueling data was excluded for this calculation.

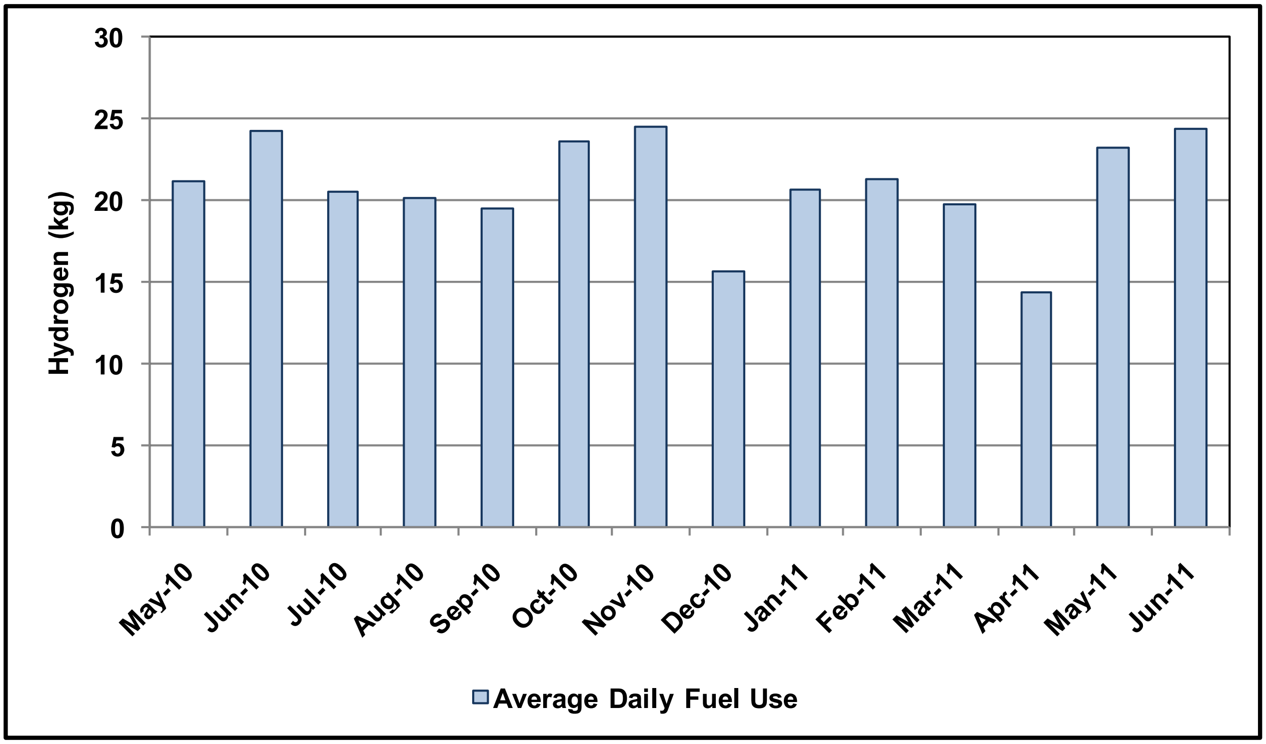

Figure 3. Average hydrogen dispensed per day (excluding 0 kg days)

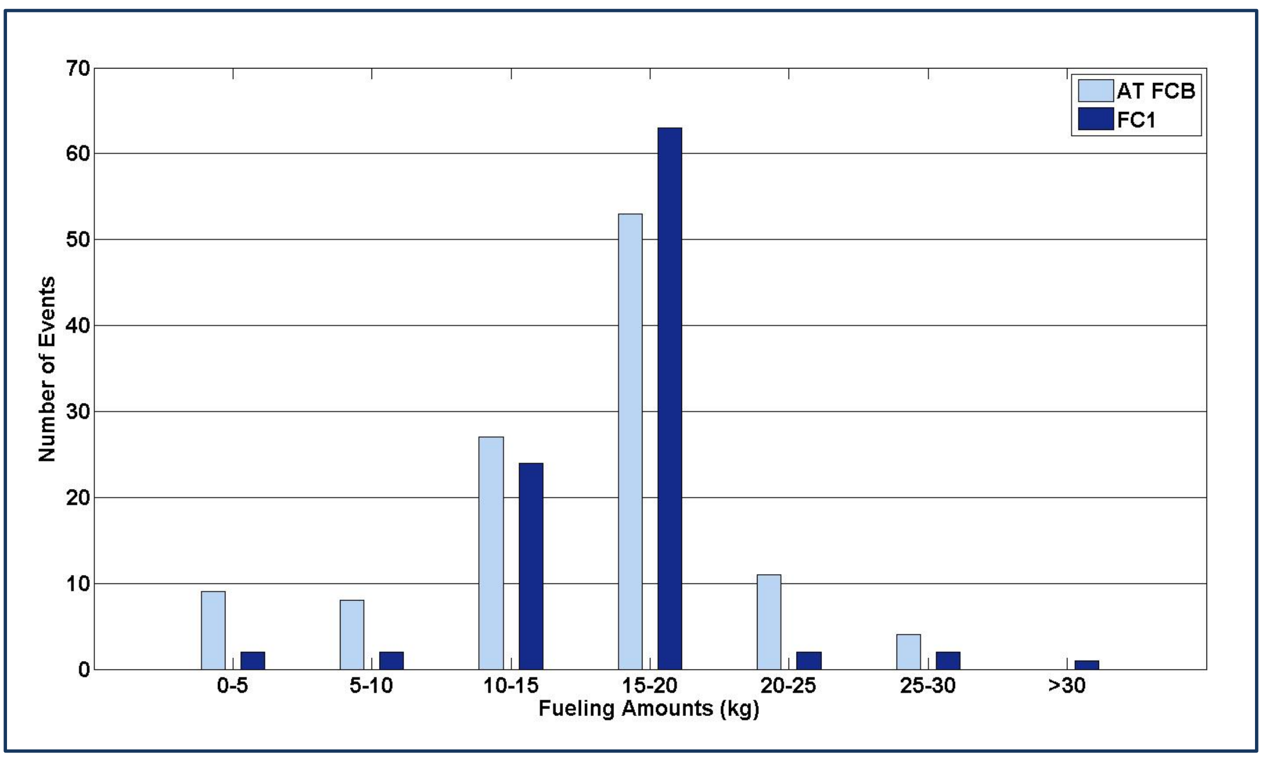

Figure 4. Histogram of fueling amounts by bus

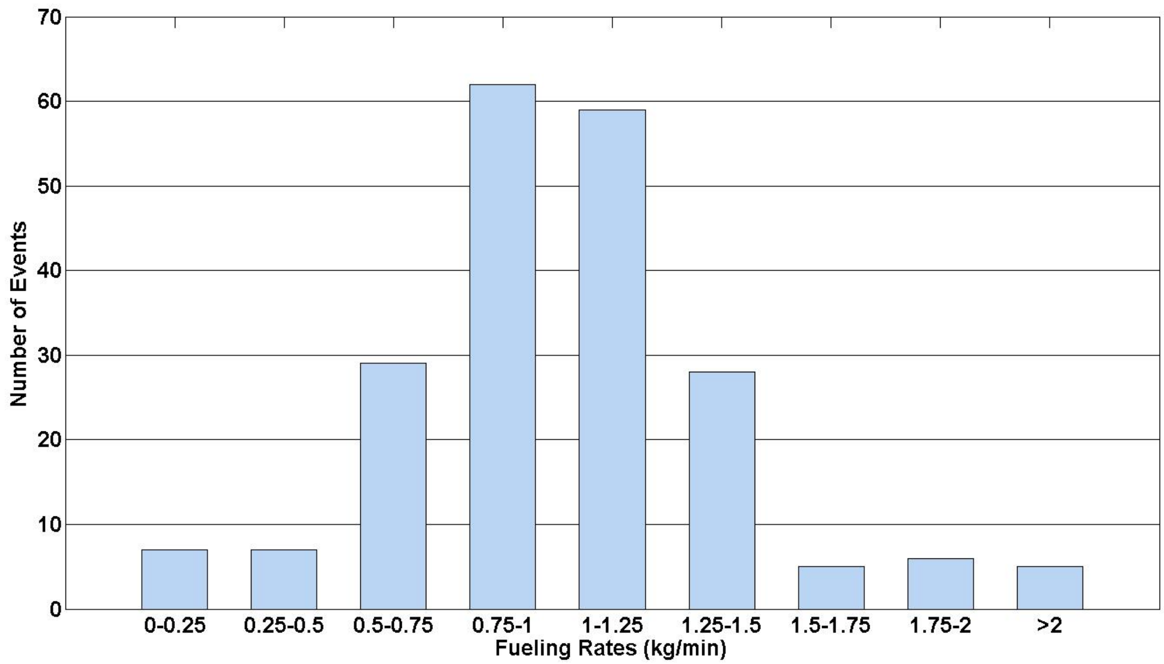

Figure 5. Histogram of fueling rates

Hydrogen fuel costs at SunLine consist of the cost of natural gas for the reformer, the cost for maintenance of the station equipment, and capital cost amortization. SunLine performs the maintenance of the station equipment, including parts and labor. The average cost for hydrogen during the evaluation period was $26.19 per kg (monthly costs ranged from a low of $6.65/kg to a high of $59.40/kg). Lower use of the station (when the buses were out of service) and higher maintenance costs contribute to higher monthly fuel costs. Figure 6 shows the monthly station use and hydrogen cost per kg since January 2010. DOE's target for hydrogen cost is between $2 and $4 per kg and is included on the chart. The figure shows the relationship between cost and station use. In most cases, the highest costs per kg occurred in months with the lowest station use. In February 2011, the station compressor failed and the added costs of repair led to the highest monthly cost during the data period. 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. This cost estimate is used in the cost calculations for the data results in the next section.

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 $0.97 per GGE. This price includes all costs—natural gas, maintenance, and station amortization.

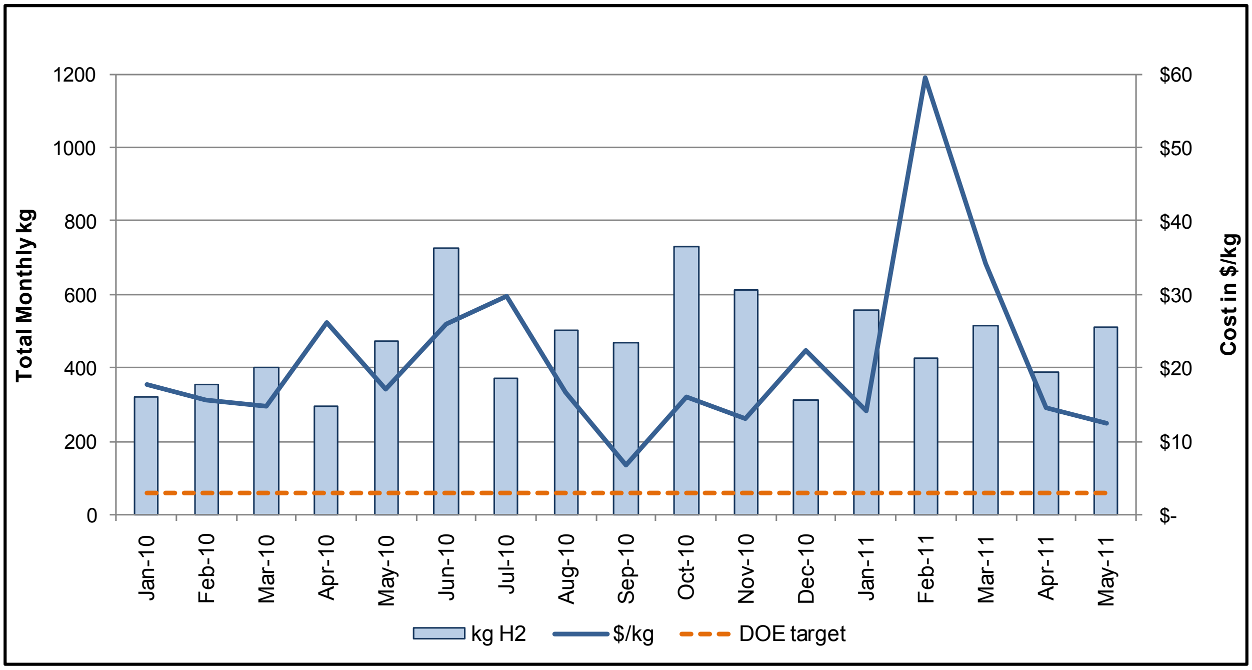

Figure 6. Comparison of monthly hydrogen use and cost per kg

Evaluation Results

SunLine placed the AT fuel cell bus in service on May 27, 2010. The focus of this report is the operating data collected on the fuel cell and CNG buses from December 2010 through June 2011. Appendix E provides a summary of all data. Appendix F provides a data summary in SI (metric) units.

Route Assignments

In general, SunLine's buses are randomly dispatched on its routes. The overall system average speed is 13.9 mph. The AT fuel cell bus was used exclusively on Line 53 (average speed of 12.9 mph). The five CNG buses were randomly dispatched with the majority of time (74%) split between Line 111 (35% at 13.9 mph), Line 14 (14% at 14.6 mph), and Line 30 (25% at 10.8 mph).

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 fuel cell and CNG buses.

The AT fuel cell bus has planned service of up to seven days per week. For this bus, total mileage accumulation for the evaluation period was 11,164 miles, and the fuel cell system accumulated 957 hours, which indicates an average speed of 11.7 mph. This average speed is lower than the overall 13.9-mph average speed for all SunLine routes and also lower than the average speed for the Line 53 operation to which the bus is assigned. This lower average speed has been caused by events and training where the bus was operated at a significantly lower speed. For in-service days during the evaluation period, the AT fuel cell bus averaged 7.5 hours per day with a maximum of 13.9 hours in one day.

Table 1 summarizes the average monthly mileage accumulation by bus and study group for the evaluation period. Using the CNG buses as the baseline, the AT fuel cell bus had an average monthly mileage that was 34% that of the CNG buses. This low percentage is due to downtime of the fuel cell bus because of issues with the air conditioning, the fuel cell power system, and an accident that caused body damage.

Table 1. Average Monthly Mileage (Evaluation Period)

Bus	Starting Hubodometer	Ending Hubodometer	Total Mileage	Months	Monthly Average
AT FCB	**21,846**	**33,010**	**11,164**	**7**	**1,595**
603 CNG	127,214	161,166	33,952	7	4,850
604 CNG	114,908	141,107	26,199	7	3,743
605 CNG	123,453	155,704	32,251	7	4,607
606 CNG	115,209	149,283	34,074	7	4,868
608 CNG	119,160	154,547	35,357	7	5,051
Total CNG			**161,833**	**35**	**4,624**

Another measure of reliability is availability—the percentage of time that the buses are planned for operation compared with the time the buses are actually available for that planned operation.

Figure 7 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 the planned service days, which is typically every weekday. 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 AT fuel cell bus and the CNG buses.

Overall availability for the AT fuel cell bus was 64% of the time during the evaluation period. As mentioned earlier, this unavailability was caused by problems with the air conditioning, the fuel cell power system, and an accident causing body damage (December 2010). In April, the CNG buses experienced engine problems that caused significant downtime for repair.

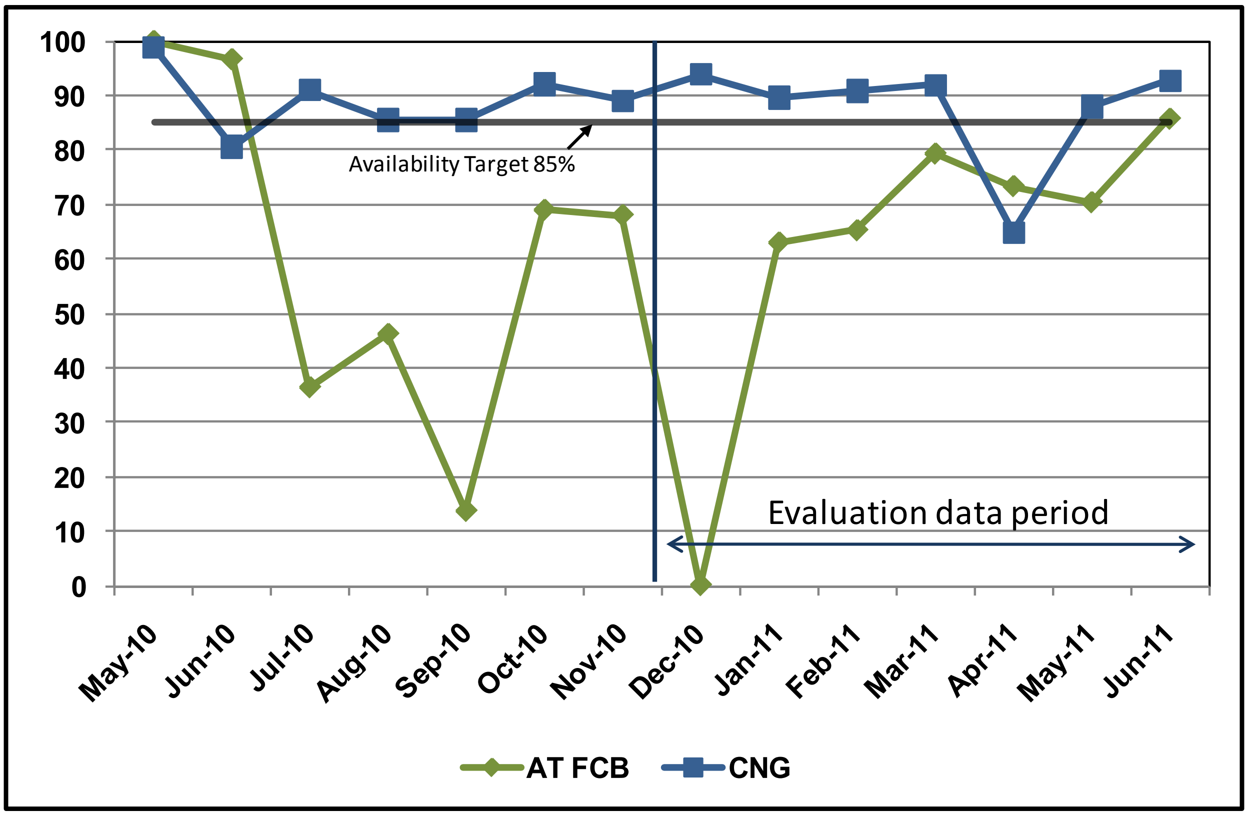

Figure 7. Availability for study bus groups

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 64%, and availability for the CNG buses was 88%. As discussed, the primary issues that kept the fuel cell bus out of service were downtime for transit agency maintenance—primarily for air conditioning and body work (31%), fuel cell propulsion (42%), and hybrid system issues (16%). Issues that kept the CNG buses out of service were general maintenance and engine problems.

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

Category	AT FCB		CNG Buses	
	Number	Percent	Number	Percent
Planned work days	187		1,000	
Days available	120	64	877	88
Available	**120**	**100**	**877**	**100**
On-route	108	90	823	94
Event/demonstration	9	8	0	0
Training	3	3	4	0
Not used	0	0	50	6
Unavailable	**67**	**100**	**123**	**100**
Fuel cell propulsion	28	42		
Hybrid propulsion	7	10		
Traction batteries	4	6		
SunLine maintenance	21	31	123	100
Fueling unavailable	7	10		

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 a baseline, the AT fuel cell bus had a fuel economy two times higher than the CNG buses. Figure 8 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 $1.30 per mile for the fuel cell bus and $0.32 for the CNG buses. The fuel cost for CNG has been much lower than the cost for hydrogen production. And, the CNG fuel cost at $0.97 per GGE is much lower than the typical diesel fuel average cost per gallon.

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)
AT FCB	**11,164**	**1,806.7**	**6.18**	**1,598.8**	**6.98**
603 CNG	33,952	11,444.1	2.97	10,242.4	3.31
604 CNG	26,199	8,885.3	2.95	7,952.3	3.29
605 CNG	32,251	10,615.6	3.04	9,501.0	3.39
606 CNG	34,074	11,045.5	3.08	9,885.7	3.45
608 CNG	35,357	11,263.0	3.15	10.080.4	3.51
CNG Total	**161,833**	**53,253.5**	**3.04**	**47,661.9**	**3.40**

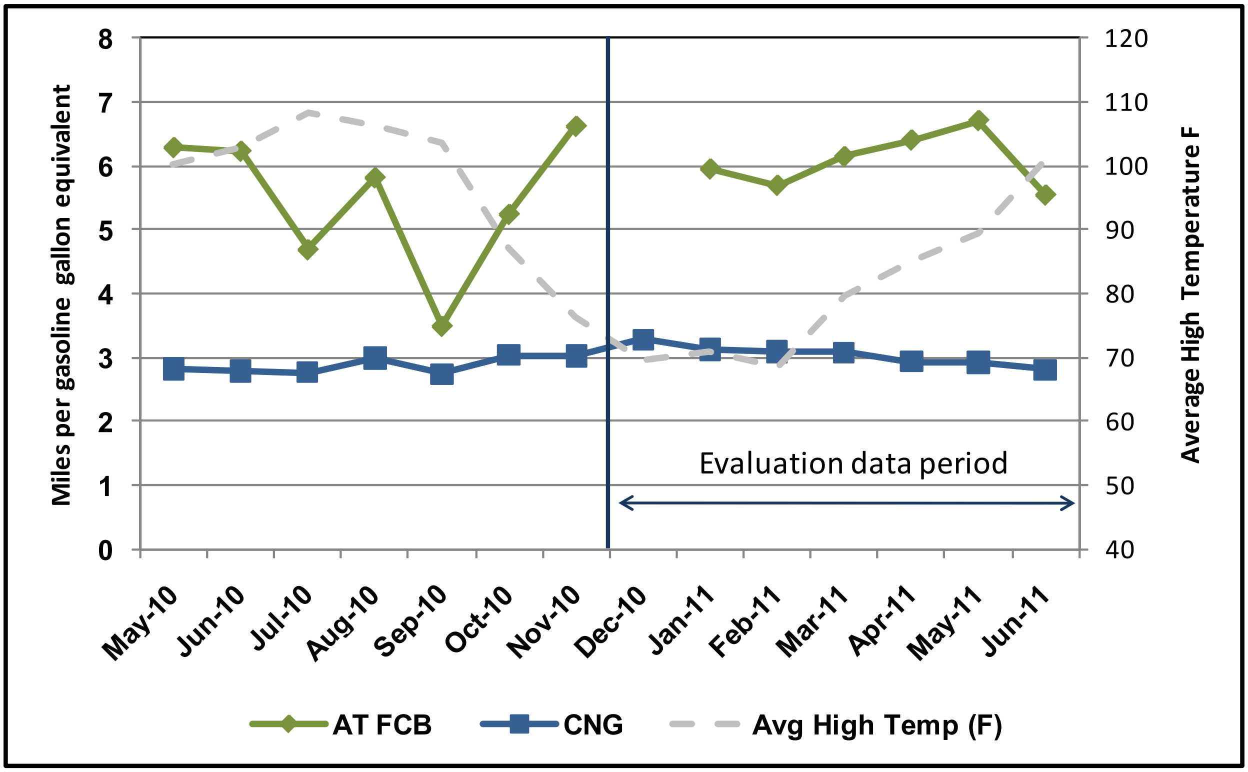

Figure 8. Average fuel economy (miles per kg or GGE)

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 separated 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 AT fuel cell bus and CNG buses. The CNG buses have total maintenance costs 62% lower than those of the AT fuel cell bus. The parts costs are low for the AT fuel cell bus because they typically are covered by the manufacturers for most of the propulsion system maintenance; however, SunLine's mechanics do nearly all of the work.

Table 4. Total Maintenance Costs (Evaluation Period)

Bus	Mileage	Parts ($)	Labor Hours	Cost ($) per Mile
AT FCB	**11,164**	**$1,796.00**	**222.5**	**$1.16**
603 CNG	33,952	$3,907.59	158.25	$0.35
604 CNG	26,199	$6,512.39	178.25	$0.59
605 CNG	32,251	$6,086.75	204.5	$0.51
606 CNG	34,074	$5,735.39	198.5	$0.46
608 CNG	35,357	$3,616.83	169	$0.34
Total CNG	**161,833**	**$25,858.95**	**908.5**	**$0.44**

Maintenance Costs Separated 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**

For the AT fuel cell bus, the systems with the highest percentage of maintenance costs were cab, body, and accessories; propulsion-related; and PMI. The CNG buses had the same highest percentage of maintenance costs categories, but in a slightly different order – propulsion-related; cab, body, and accessories; and PMI.

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

System	AT FCB		CNG	
	Cost per Mile ($)	Percent of Total (%)	Cost per Mile ($)	Percent of Total (%)
Cab, body, and accessories	0.47	41	0.10	23
Propulsion-related	0.35	31	0.15	35
PMI	0.20	17	0.08	18
Brakes	0.00	0	0.06	12
Frame, steering, and suspension	0.03	2	0.01	2
HVAC	0.07	16	0.02	5
Lighting	0.02	2	0.01	3
Axles, wheels, and drive shaft	0.00	0	0.00	0
General air system repairs	0.02	1	0.00	0
Tires	0.01	1	0.01	2
Total	**1.16**	**100**	**0.38**	**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 (not including warranty). The fuel cell bus was under warranty during the entire evaluation period, and the CNG buses have continued to be under warranty for any engine issues. During the evaluation period of this report, the SunLine mechanics did nearly all of the maintenance on the AT 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 AT fuel cell bus had more than double the maintenance cost for propulsion-related maintenance compared with the CNG buses. The majority of this maintenance for the fuel cell bus has been labor.
- **Exhaust system –** Costs for this system for the study bus groups were low or zero.
- **Fuel system –** Costs for the fuel system were low for both bus groups.
- **Powerplant and electric propulsion –** The AT 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 (with none for electric propulsion – the CNG buses are not hybrids).
- **Non-lighting electrical (charging, cranking, and ignition) –** The AT fuel cell bus had some minor costs in this category relating to 24-volt batteries. The CNG buses mostly had preventive maintenance repairs in this category for spark plugs at the 24,000-mile preventive-maintenance cycle (and the 48,000-mile cycle) for each bus. The cost per mile in this category was the same.
- **Air intake –** Costs for this system for the study bus groups were low or zero.
- **Cooling –** The AT fuel cell bus had a few hours of maintenance on this system, and the CNG buses had low costs in this category.
- **Transmission –** Costs for this system for the study bus groups were low or zero.

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

Maintenance System Costs	AT FCB	CNG
Mileage	11,164	161,833
Total Propulsion-Related Systems (Roll-up)		
Parts cost ($)	46.64	13,744.81
Labor hours	78.00	217.75
Total cost ($)	3,946.64	24,632.31
Total cost ($) per mile	**0.35**	**0.15**
Exhaust System Repairs		
Parts cost ($)	0.00	168.95
Labor hours	0.0	2.0
Total cost ($)	0.00	268.95
Total cost ($) per mile	**0.00**	**0.00**
Fuel System Repairs		
Parts cost ($)	4.45	331.92
Labor hours	0.0	0.5
Total cost ($)	4.45	356.92
Total cost ($) per mile	**0.00**	**0.00**
Powerplant System Repairs		
Parts cost ($)	0.00	7,289.26
Labor hours	37.5	156.3
Total cost ($)	1,875.00	15,101.76
Total cost ($) per mile	**0.17**	**0.09**
Electric Propulsion System Repairs		
Parts cost ($)	0.00	0.00
Labor hours	9.5	0.0
Total cost ($)	475.00	0.00
Total cost ($) per mile	**0.04**	**0.00**
Non-Lighting Electrical System Repairs (General Electrical, Charging, Cranking, Ignition)		
Parts cost ($)	0.00	4,663.98
Labor hours	9.0	26.0
Total cost ($)	450.00	5,963.98
Total cost ($) per mile	**0.04**	**0.04**
Air Intake System Repairs		
Parts cost ($)	0.00	331.62
Labor hours	0.0	0.0
Total cost ($)	0.00	331.62
Total cost ($) per mile	**0.00**	**0.00**
Cooling System Repairs		
Parts cost ($)	42.19	583.32
Labor hours	22.0	33.0
Total cost ($)	1,142.19	2,233.32
Total cost ($) per mile	**0.10**	**0.04**
Transmission System Repairs		
Parts cost ($)	0.00	112.49
Labor hours	0.0	0.0
Total cost ($)	0.00	112.49
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[5]), 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 group in two categories: all RCs and propulsion-related-only RCs.

Table 7. Roadcalls and MBRC (Evaluation Period)

Bus	Mileage	All Roadcalls	All MBRC	Propulsion Roadcalls	Propulsion MBRC
AT FCB	**11,164**	**2**	**5,582**	**2**	**5,582**
603 CNG	33,952	2	16,976	2	16,976
604 CNG	26,199	2	13,100	1	26,199
605 CNG	32,251	8	4,031	5	6,450
606 CNG	34,074	3	11,358	2	17,037
608 CNG	35,357	2	17,679	0	
Total CNG	**161,833**	**17**	**9,520**	**10**	**16,183**

Summary of Experience to Date

The AT FCB has been in operation for more than a year and each of the partners feel positive about the project and the technology. SunLine is happy with how the project has progressed. Early issues have been resolved and the bus is operating well. Maintenance staff has come up to speed on the new bus systems and has learned to diagnose and repair most issues. The manufacturer partners–Ballard and Bluways–both feel the project is going well and that they have addressed the majority of the problems experienced in the early demonstration period. This section summarizes the challenges and achievements that the team has had so far in the demonstration.

Pilot Bus – The AT FCB was originally designed as the pilot bus to a much larger project in British Columbia, Canada. The bus was delivered in 2009 and the transit operator, BC Transit, ran the bus through a series of acceptance and operational tests over a period of about six months. This performance testing enabled the manufacturers to further refine and optimize the system and gave the transit agency firsthand experience with the bus and the technology. At the end of the test period, the design for the larger fleet had been finalized and the pilot bus was returned to Bluways. Prior to that, SunLine had received funding from the state of California for a new project to upgrade an older fuel cell bus with a new system. This project had stalled because of issues with the older bus and difficulties with retrofitting an old bus with a new design system. When the project team learned the pilot bus was available, SunLine was able negotiate with the state to reconfigure the original project. Bluways upgraded the pilot bus to

[5] Federal Transit Administration's National Transit Database website: www.ntdprogram.gov/ntdprogram/.

match the final design of the BC Transit buses and it was put in service at SunLine. This was a win-win for the parties involved; SunLine and the project team were able to purchase an advanced technology fuel cell bus that met the intent of the original project awarded by the state of California, and the manufacturers were able to further test this new fuel cell system in a hot dry climate.

Heat Exchanger Failure – A crack in the heat exchanger resulted in leaks. The component supplier updated and replaced the part, which appears to have solved the problem. This situation also occurred with the buses in Canada.

Fuel Cell Issues – Problems that caused downtime for the bus included a faulty motor controller cable and coolant flow sensor. The motor controller cable issue was intermittent, which made it more difficult and time-consuming to diagnose. Replacing the cable resolved the issue.

Temperature Issues – The extreme high summer temperatures have resulted in problems with the air conditioning. This was the primary reason for downtime in the early stage of the demonstration. The hybrid system is configured to cool the batteries with air from the bus's air conditioning unit. This unit is a prototype electrically-driven air conditioner model. The summer heat in SunLine's service area affects how well the air conditioning can keep up with demand for cooling passengers while keeping the batteries within proper operating temperature range. The air conditioner component manufacturer has upgraded the unit to more closely match the production unit configuration. SunLine continues to work with Bluways and the component manufacturer to address the issue.

What's Next for SunLine

This report covers SunLine's operation of the fuel cell and CNG buses from December 2010 through June 2011. The agency will continue working with DOE/NREL to collect data on the buses in service. The next report is expected to be published in early 2012.

SunLine is also leading a team to develop a purpose-built fuel cell bus that meets FTA "Buy America" requirements. Funded under the FTA's National Fuel Cell Bus Program, the **American Fuel Cell Bus Project** brings a new team of manufacturers to the fuel cell bus industry—ElDorado, BAE SYSTEMS, and Ballard. The design features a number of advancements that are expected to result in a highly efficient bus. Elements include advanced energy storage and new power electronics, high-efficiency accessories, and the newest-generation fuel cell on a U.S.-built chassis. This bus is in development and is expected to be ready for demonstration in late 2011 or early 2012.

Status of SunLine's Van Hool Fuel Cell Bus

SunLine has been operating a second fuel cell bus since December 2005. Operation and evaluation of this bus has been reported in five previous NREL evaluation reports. This Van Hool 40-foot bus was integrated by ISE Corp. (now Bluways) with a Siemens hybrid propulsion system, Zebra hybrid batteries, and UTC Power's fuel cell power system. This bus continues to operate in service with a total of 125,761 miles and 9,705 hours (an average operating speed of 13.0 mph) through June 2011. The current fuel cell power plant in the bus has been in service since August 2009. SunLine and UTC Power continue to support the operation of this bus.

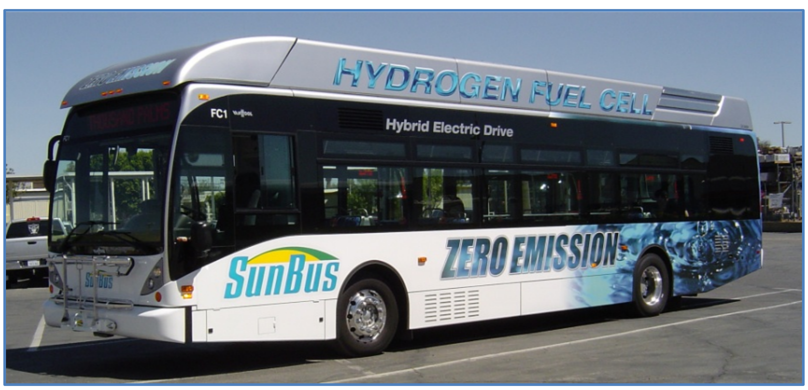

Figure 9. SunLine's Van Hool fuel cell bus

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