SUNLINE CLEAN FUELS MALL

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1. PROJECT GOALS

Hydrogen technology will one day help solve pollution and resource consumption problems. It offers a clean, safe, reliable, and domestically produced source of fuel. Hydrogen fuel cell vehicles (which emit only water) can replace those powered by hydrocarbon-based internal combustion engines (which emit greenhouse and smog-producing gases). Further environmental benefits can be realized when the hydrogen is generated using renewable resources, such as solar and wind. The result is a clean fuel for public and private transportation vehicles.

To establish hydrogen as a commercial transportation fuel, refueling infrastructure and hydrogen vehicles must be designed, built, operated, and maintained. Training and support services must be established and, above all, safety must be considered throughout. Successful projects build confidence in hydrogen systems and facilitate the transition of hydrogen technologies into the marketplace.

SunLine Transit Agency, Thousand Palms, CA, which services the Coachella Valley area, is operating one of the world's most diverse integrated hydrogen demonstration projects. At its Clean Fuels Mall and Beta Test Center for Advanced Energy Technologies, both renewable- and fossil-based hydrogen production technologies are being evaluated, along with compressed gas storage and dispensing equipment. Hydrogen produced on-site powers buildings and fuels a variety of transportation vehicles. The ongoing tests will pave the way for the future transition of the Coachella Valley's public transit system to hydrogen fuel cell vehicles and help advance the commercialization of clean energy technologies – one of SunLine's core missions. As its tagline indicates, SunLine is truly "Today's Model for Tomorrow's World".

2. GENERAL DESCRIPTION OF PROJECT

In 1994, SunLine became the first public transit agency in the nation to park all of its diesel buses and replace them, overnight, with buses powered by compressed natural gas (CNG). In conjunction with its conversion to natural gas, SunLine began helping manufacturers such as Cummins Engine Company, Detroit Diesel, Engelhard Corporation, and John Deere, to test and refine their clean fuels technologies. Since then, the agency has worked with dozens of automakers, engine manufacturers, technology firms, educators, and others to help move clean energy technologies from the lab to the street.

SunLine's first steps towards realizing a fleet of hydrogen-powered vehicles were taken in 1999. Because of its experience with alternative fuel technology, SunLine was tapped by the U.S. Department of Energy to relocate and reassemble completed projects by Clean Air Now and the Schatz Energy Research Center at Humboldt State University/City of Palm Desert. Vehicles and infrastructure technologies were moved to SunLine's Thousand Palms headquarters where they demonstrate a sustainable energy cycle: renewable energy is used to generate hydrogen, which is used to fuel zero emission vehicles. This massive task began with SunLine being assured that no one in the region had the expertise to do what was needed. Like many other myths surrounding hydrogen, this proved to be untrue. With help from the Schatz Energy Research Center, a good set of plans, and close supervision, local contractors were able to complete the job. The world's first hydrogen generation/storage/fueling and demonstration facility built by a public transit agency was officially christened in April 2000.

Since November 2000, SunLine has utilized hydrogen generated on-site to fuel vehicles including:

- two Hythane® buses (which use 80% CNG/20% hydrogen),
- the Ballard/XCELLSIS ZEbus (zero-emission fuel cell bus),
- the ThunderPower hybrid electric fuel cell bus,
- the nation's first street-legal hydrogen fuel cell mini-car (SunBug),
- three hydrogen fuel cell powered golf carts, and a
- a pickup powered by a hydrogen–fueled internal combustion engine.

Some of these vehicles are shown in Figure 1.

Figure 1: Top left to right: Hydrogen ICE pickup truck, Hythane® Bus, SunBug NEV and ZEbus

SunLine is operating this "lab on wheels" to determine the supportability, reliability, maintainability, and operability of hydrogen-powered vehicles and infrastructure technologies.

Hydrogen is produced on-site in two electrolyzers; a Hydrogen Burner Technology (HbT) natural gas reformer was also demonstrated in 2001.

To fund educational efforts associated with this project, technology and government partners were invited to participate as sponsors. Over $300,000 was raised from Ballard, Dynetek, ENRG, FIBA Technologies, Gaz de France, HbT, QuestAir, Shell Hydrogen, South Coast Air Quality Management District, Stuart Energy, Teledyne Energy Systems, TotalFinaElf, and the Webb Foundation.

Background

SunLine is the umbrella organization for three joint power authorities, SunLine Transit Agency, SunLine Services Group, and Community Partnership of the Desert, Inc., a non-profit 501 (c)(3) organization. All three entities serve the nine desert resort cities and unincorporated areas of Riverside County that make up California's Coachella Valley. All entities share a common board of directors, which is comprised of an elected official from each member jurisdiction.

To preserve one of the desert's primary tourist attractions – its clear blue skies, in 1992, SunLine's board members took a bold step and unanimously voted to replace the agency's fleet with one powered exclusively by an alternative fuel. At the same time, they passed a resolution mandating that alternative fuels would also power all vehicles purchased in the future.

SunLine staff researched alternative fuel technology and decided that compressed natural gas would be the best short-term fuel choice, as it offered immediate air quality benefits and serves as a bridge to the longer-term target - hydrogen. Working with College of the Desert and other partners to devise training curriculum, Southern California Gas Company and later ENRG to build the infrastructure, government agencies to address policy and permitting issues, and manufacturers to procure the necessary equipment – in 1994 SunLine made the swift, successful transition to a CNG fleet.

Figure 2: The photovoltaic field

3. DESCRIPTION OF COMPONENTS

3.1 Photovoltaic field

Photovoltaic International (PVI; now Eco-Energies) has provided a total of 45 m^2 (480 sq. ft) of raised photovoltaic concentrating and tracking panels (144 modules with 150 W each). In addition, 218 Siemens solar flat plate panels (75 W/panel) have been installed. The combined capacity of the whole photovoltaic field is 38 kW_{peak} of electricity. It is primarily used to power the Teledyne Energy Systems electrolyzer described below. The photovoltaic field is shown in Figure 2. When available, excess electricity is used to support the Stuart Energy Systems electrolyzer, also described below, the adjacent Schatz Hydrogen Generation Building (which houses the Teledyne electrolyzer), and the Zweig Education Center.

The on-site distributed system also includes a DC to AC inverter to match power from the solar panels to the electric grid and a metered, step-down transformer that drops the voltage from the inverter to match system requirements. The meter records the photovoltaic energy received into the on-site distribution system.

3.2 Electrolyzers

The smaller of SunLine's two electrolyzers, a Teledyne Energy Systems unit, which, as mentioned, operates off solar power produced on site, requires 7.5 kW of electricity and produces 40 SCFH (standard cubic feet per hour) of hydrogen.

The system includes the following components:

- Teledyne Energy Systems Altus 20 electrolyzer
- PLC controlled chiller
- Teledyne Energy Systems dryer
- Pressure Dynamics 2-stage hydrogen compressor
- low-pressure storage cylinders

The hydrogen is separated from water, piped, and then compressed into mobile low-pressure storage tanks used to fill the golf carts and SunBug. These vehicles, built by the Schatz Energy Research Center, and jointly owned by SunLine and the City of Palm Desert, require a total of 10 Sm^3 (360 SCF) of hydrogen per day.

The second electrolyzer is a self-contained Phase 3 (P3) Stuart Energy unit that produces and compresses 42.2 Sm^3/h (1490 SCFH) of hydrogen at full current (12,000 A). The unit P3-1A demonstrates Stuart's MW-CST or multi-stack electrolyzer cell technology and is intended for use with bus fleets and large retail outlets. The system includes a self-contained hydrogen-processing module that includes a Comp-Air Reavell Model 5000 4-stage compressor with an outlet pressure of 35 MPa (5000 psi). The general operating characteristics of the electrolyzer cell are summarized in Table 1.

SunLine is currently working with other electrolyzer manufacturers to design demonstration projects that will allow additional technologies to be evaluated in field service.

Table 1: General operating characteristics of the Stuart electrolyzer cell

Maximum output	Sm^3/h (SCFH)	42.2 (1490)
Maximum pressure	MPa (psig)	27.6 (4000)
Cell voltage efficiency at 70°C and 95% max. output	% (HHV)	83
Gas purity (ex. Moisture)	%	99.65

3.3 Hydrogen storage system and fueling station

The FIBA Technologies storage system is comprised of a 16-tube Department of Transportation (DOT) storage trailer and two high-pressure ASME tube tanks. The DOT trailer can store up to 3,000 Sm^3 (104,000 SCF) of hydrogen at 21.6 MPa (3,130 psi). The ASME tube tanks can store an additional 350 Sm^3 (12,500 SCF) at 28 MPa (4,000 psi). These tanks are attached to a cascade control panel and are used to fill hydrogen buses and California Fuel Cell Partnership (CaFCP) vehicles at the public fueling island, located across from SunLine's on-site compressed natural gas and liquefied natural gas dispensers in Thousand Palms.

Figure 3: Ballard ZEbus fuel cell bus being refueled at SunLine.

Because SunLine's demand for hydrogen fluctuates with the number of vehicles being demonstrated, at times, its hydrogen generation exceeds the storage capacity. So the station is ready to market hydrogen to area customers, and/or provide fuel for remote events showcasing CaFCP vehicles. SunLine's DOT-approved trailer provides a ready distribution system, and the agency will soon increase its storage capacity and dispensing pressure to 35 MPa (5,000 psi) to better accommodate the automotive industry.

The public access fueling island was co-designed by Stuart Energy Systems and utilizes a Fueling Technologies dispenser. It features separate hoses/nozzles for pure hydrogen and Hythane®. The Hythane® system was specially designed to allow the hydrogen and natural gas, which are stored separately, to be mixed as they are being pumped.

3.4 Hydrogen reformer

In addition to the two electrolyzers, SunLine also field-tested a stationary HbT reformer, which generated hydrogen from natural gas, for approximately one year. The HbT unit utilized under-oxidized burner (UOB™) technology and a QuestAir purification system to produce 120 Sm^3 (4,200 SCFH) of hydrogen, enough to fill five buses a day. Hydrogen produced by the unit was targeted to be 99.999% pure.

The system included the following components:

- model 4200 NG-A UOB™ reformer/CO shift reactor skid
- Kaesser air-compressor
- pressure swing adsorption (PSA) purification unit
- water purification system
- Marley cooling tower
- integrated automatic programmable logic controller (PLC) controls
- pressure vessels for hydrogen storage.

The main results of the field test are as follows:

- The UOB™ (Under Oxidation Burner) accumulated over 2,500 hours of operation.
- The longest continuous operation of the UOB was 16 days, or 31 days, when adjusted for non-system faults.
- The UOB operated at 85m^3/h (3,000 scfh) and 99.95% hydrogen purity. This was significant as the system was rated for 120m^3/h (4,200 scfh) and 99.95% purity. 99.999% purity was obtained, but not for long periods of operation due to the PSA (Pressure Swing Adsorption) system, which was determined to be undersized for this unit.
- For the production of 3,000 scfh of hydrogen, 2,100 scfh (60 m^3/h) of natural gas was needed.
- Electrical consumption for pumps, air compressor, cooling tower, and system controls was 60 kWh.
- The CO shift catalyst showed no signs of degradation during >60 hours of operation. The unit ran 60 days without a shutdown due to maintenance.

3.5 Vehicles

A variety of vehicles are also being demonstrated. In addition to the buses described in more detail below, the station has provided fuel for two Hythane® buses, a hydrogen pickup, a hydrogen-powered Shelby Cobra race car, and a variety of prototype vehicles being developed by members of the California Fuel Cell Partnership.

3.5.1 Golf carts and SunBug

The three golf carts and SunBug previously described require a total of 10 Sm^3 (360 SCF) of hydrogen per day. A summary of some of the specifications is shown in Table 2.

Table 2: Passenger vehicle specifications

	Units	Golf Carts	SunBug
Fuel cell type		PEM	PEM
Fuel cell stack power at 600 mV/cell	kW (hp)	4.0 (5.4)	9 (12.2)
Number of cells		64	96
Fuel cell operating temperature	°C	50-60	50-60
Body and chassis		EZ-Go Golf Cart	Kewet El_Jet 3
Traction bus voltage (nominal)	V	36	48
Electric motor size	kW (hp)	1.5 (2.0)	7.5 (10)
Hybrid battery size	Ah	30	80
Cruising speed	km/h (mph)	21 (13)	56 (35)
Range	km (m)	24 (15)	48 (30)
Hydrogen tank volume	l	11.8	31.1
Hydrogen gas storage pressure	MPa (psig)	14 (2000)	21 (3000)
Refueling time	min	2	2

3.5.2 Prototype fuel cell bus

Jointly owned by Daimler Chrysler and Ford Motor Company, Ballard Power Systems is focused on developing, manufacturing, and commercializing fuel cell engines for transportation and stationary applications. The Ballard P4 fuel cell bus (ZEbus) is a standard low-floor transit bus purchased from New Flyer and converted by the XCELLSiS/Ballard team to fuel cell power. Table 3 provides an overview of the bus and its 205 kW fuel cell engine. The results from the P4 demonstration were positive and led to many design improvements, including the following:

- Engine volume reduction of 50%
- Weight reduction of 3,400 lb
- Eight fuel cell stacks (down from 20)
- Number of motors reduced to one (P3 had 12)
- Startup time reduced from 45 to 3 seconds
- Maintenance cost reductions (possibly as much as 90% compared to those of the P3 bus).

Table 3: Overview of the Ballard/XCELLSiS fuel cell engine and P4 fuel cell bus

Fuel cell engine	Technology	Direct-H_2 Proton Exchange Membrane
	Model	XCELLSiS XCS-HY-205
	Volume	5.32 m^3
	Weight	2,170 kg (4,774 lbs)
	Net shaft power	205 kW at 2,100 rpm
	Peak net torque	1,100 Nm at 800 rpm
	Net efficiency	44% to 37% (LHV)
	Operating temperature	70°C to 80°C
Hydrogen tank	Storage system	8 standard CNG cylinders
	Storage capacity	17,500 SCF of CH_2
	Compression	3,600 psig
Vehicle	Physical dimensions (L/W/H)	12.4/2.57/3.4 m (40.8/8.5/11.0 ft)
	Curb-weight	14,521 kg (32,019 lb)
	Gross vehicle weight rating	17,500 kg (38,588 lb)
	Carrying capacity (seated)	39 passengers + 1 driver
	Range	Approximately 360 km (225 miles)
	Air delivery system / max air flow	Two stage compressor / 600 SCFM
	Nominal operating pressure	200 kPa (30 psig)
	Cooling system	water / glycol
	System voltage range	600 to 900 V_{DC}
	Power conditioning	IGBT inverter, liquid cooled
	Electric traction drive	brushless DC, liquid cooled
	Power transmission	fixed ratio, direct drive
	Braking	dynamic (no regenerative)

4. PERFORMANCE AND OPERATIONAL EXPERIENCE

4.1 Photovoltaic field

The solar panel power production for four months in 2002 is shown in Figure 4, and a detailed day-by-day account is shown for the month of July in Table 4.

Table 4: Solar data supplied to SunLine's on-site distribution system

Day of Month	**Total kWh at Meter**	**kWh for Day**	**Peak kW**	**Comments**
1	29,604	80	11.03	
2	29,684	79	11.36	
3	29,763	77	11.36	
4	29,840	79	11.36	
5	29,919	75	11.09	
6	29,994	72	11.09	
7	30,066	79	11.09	
8	30,145	36	10.73	**inverter fault**
9	30,181	81	10.88	
10	30,262	54	9.29	**mostly cloudy**
11	30,316	6	8.4	**inverter fault**
12	30,322	48	10.78	
13	30,370	70	10.78	
14	30,440	75	10.78	
15	30,515	58	10.07	**hazy**
16	30,573	76	10.34	
17	30,649	76	10.43	
18	30,725	72	10.43	
19	30,797	86	10.95	
20	30,883	85	10.95	
21	30,968	89	10.95	
22	31,057	0		**inverter fault**
23	31,057	0		**inverter fault**
24	31,057	0		**inverter fault**
25	31,057	0		**inverter fault**
26	31,057	100	11.44	**cleared fault**
27	31,157	100	11.44	
28	31,257	100	11.44	
29	31,357	88	11.35	**sunny/ clear**
30	31,445	73	10.93	**hazy**
31	31,518	48	8.97	**hazy**

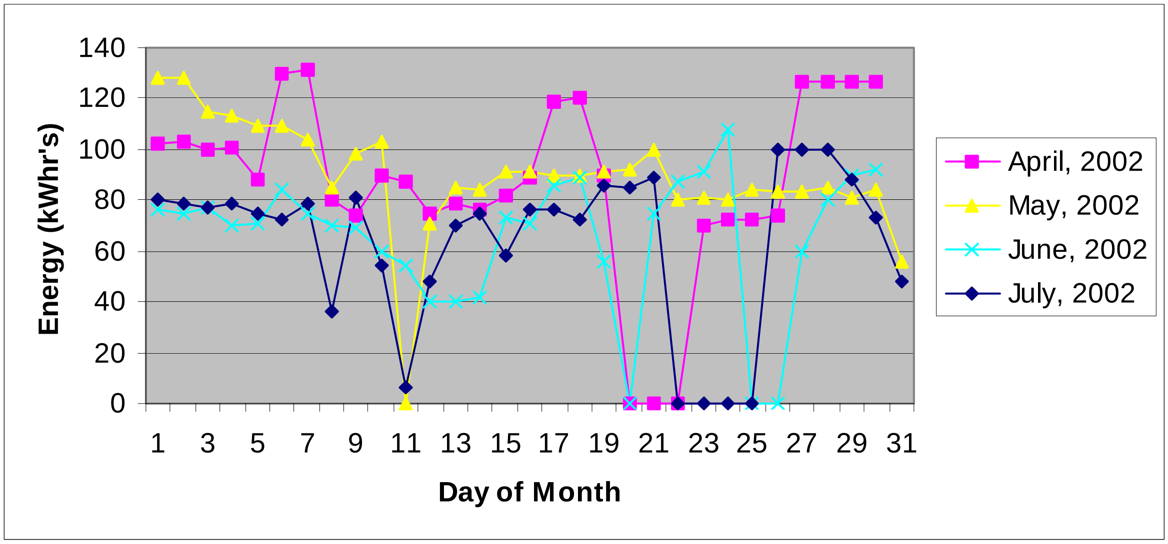
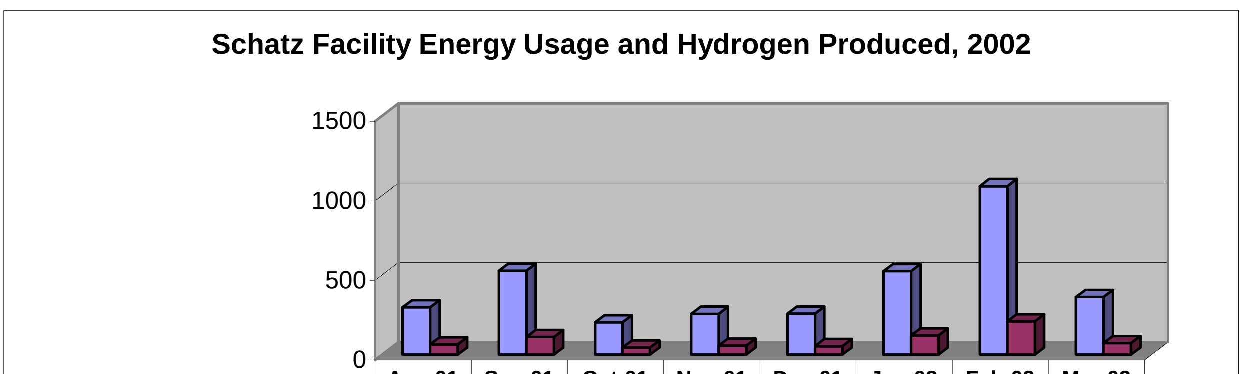


Figure 4: Solar power profile at SunLine

Since the installation in January 2001, the arrays have performed quite well. Of course there where changes made to the individual systems as we learned more about the environment and how its effects would change the arrays overall performance. The flat plate arrays seem to be the least effected by our environment, heat, sand, dust, etc. Because the concentrators require "clear" light, they are affected by the slightest change in "clearness," particularly when sand storms create dust in the air. Except for this, the concentrators by far, have an advantage over the flat plate arrays in terms of overall energy produced. Maintenance in terms of cleaning is key, especially with the concentrators.

4.2 Hydrogen production by the electrolyzers

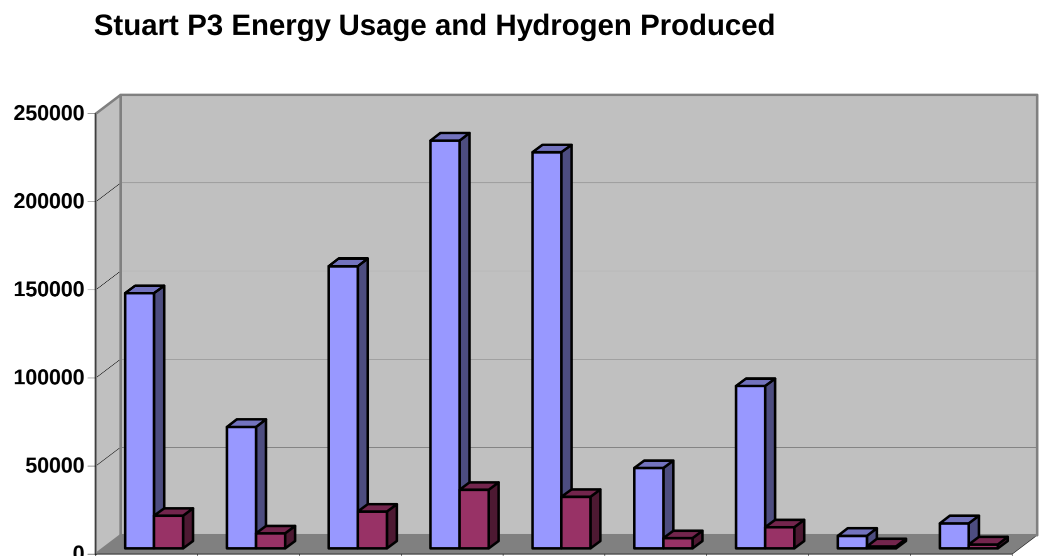
Hydrogen production by the Teledyne electrolyzer, shown in Figure 5, is for an 8-month period beginning in August 2001.



	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01	Jan-02	Feb-02	Mar-02
H2 Compressed (scf)	297	526	202	256	257	524	1059	362
Electrolyzer Energy (kWh)	64	110	44	56	53	120	209	72

Figure 5: Teledyne Energy Systems electrolyzer power usage and hydrogen production

The hydrogen produced by the Stuart electrolyzer, shown in Figure 6, is for a 9-month period beginning in April 2001. Over the period from Mid-July 2000 to December 31, 2001, the unit operated for 3,916 hours (cells and compressor), producing 73,291 Sm^3 (2,588,237 SCF) of hydrogen fuel. The demonstration is planned to continue until March 31, 2003.



	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01
H2 Compressed (scf)	144900	69000	160300	231600	224900	45600	92200	7131	14259
Total Cell Energy (kWh)	18500	8500	20900	33300	29300	5800	12000	1152	2272

Figure 6: Hydrogen produced using Stuart Energy Systems P3 Unit

Several objectives were identified for the demonstration and operation of Stuart's P3 electrolyzer at SunLine Transit Agency. Of course, the main purpose was to provide fuel for the XCELLSiS P4 bus, which was tested for ~13 months. A more important objective, from Stuart Energy's perspective, was to gain an understanding of their integrated package for remote generation at non-industrial consumer sites, where hydrogen generation for fueling applications is required. SunLine Transit Agency provided a good test site for this purpose. Up until a few years ago, Stuart Energy provided electrolyzers for industrial-type applications, in which a majority of the hydrogen processed was used for cooling purposes, and/or packaging. In its application at SunLine, the unit needed to be a "turn-key" operation. Initially, when the P3 fist arrived, no non-Stuart Employee could operate the electrolyzer without significant training and education. Today, four local operators are trained to run the unit at anytime, and the unit is nearly automatic in its operation. This is a significant improvement compared with the initial manual operation.

With any change, there are some drawbacks that are incurred and often times difficult to overcome. The availability of fuel seemed to be this drawback with the changes mentioned above. However, this was always the case; there were times when fuel was available but the P4 was not. Overall, fuel availability was near 80 to 90 percent.

4.3 Hydrogen reformer

The performance of the hydrogen reformer was satisfactory, with a demonstrated capacity of 110 Nm^3/h (4,200 SCFH) and a purity from 99.5% to 99.999%. It consumed approximately 0.68 scf of natural gas for every 1 scf of hydrogen generated. This performance was considered normal at that capacity. The combined energy consumption for air compressor, cooling water tower, quench water pumps, and system controls amounted to approximately 57 kWh. Using the SunLine utility costs (compressed natural gas at $ 7.90 per MBtu; electricity at $0.085/kWh) the costs of hydrogen are $ 25/Sm^3 ($0.72 per 100 scf). Using pipeline natural gas at $4.00/MBtu would result in hydrogen costs of $ 16/Sm^3 ($0.45 per 100 scf).

4.4 Vehicles

During SunLine's 13-month demonstration, which began in August 2000 and concluded in September 2001, the ZEbus traveled more than 24,000 km (14,900 miles) with a total run time of 865 hours. Powered by Ballard Mark 700 Series fuel cell stacks, the hydrogen-fueled ZEbus was the first bus demonstrated by the California Fuel Cell Partnership. The Partnership's goals are to advance the commercialization of fuel cell passenger cars and transit buses. SunLine Transit Agency, AC Transit, and Santa Clara Valley Transportation Authority are associate members of the Partnership and will serve as the initial test sites for the bus program. Buses currently on order are slated to arrive at the three transit properties in 2004; they will be used in daily revenue service.

During the test period, XCELLSiS field engineers handled the day-to-day operations of the P4 fuel cell bus and performed tests to verify and improve its commercial viability. Equipped with test instrumentation and water-filled tanks on the seats to simulate the curb weight of a loaded bus, the ZEbus was driven over a similar street route each day.

The California field trial program was designed to allow XCELLSIS to gather data for use in the design and development of commercial heavy-duty fuel cell engines. A summary of the accumulated miles and hours of ZEbus during the period from July 20, 2000 to February 1, 2001 is shown in Table 5.

Table 5: Summary of ZEbus runs from July 20, 2000 to February 1, 2001

	Distance		Time	Average speed	
	km	mi	h	km/h	mi/h
Transit track test (long endurance run)	4,146	2,577	106.8	38.8	24.1
All other runs (testing, demo, training)	1,006	625	93.6	10.7	6.7
Accumulated total running	5,152	3,202	200.4		

Specifically, the desert location provided ample opportunity to retrieve vital information on system function and performance in extreme temperature conditions. During the program, various upgrades were implemented, further enhancing the performance of the fuel cell engine.

The analysis of these data along with a corresponding analysis of road calls revealed that

- the high hours relative to low miles are the result of functional testing of the engine with the bus in static condition (i.e. non-road testing),
- the unexpectedly high bus failure rate (non-fuel cell related failures) directly affected availability for scheduled runs, and
- the fuel station performance resulted in limited fuel availability (see remarks above).

Short-term solutions to these problems could include:

- limiting the engineering P4T upgrades to essential requirements only,
- re-commissioning the test lab P4T engine in Vancouver, Canada for functional testing of components and sub-systems related to the bus engine, which could help to pre-empt failures, and
- reviewing and implementing alternate hydrogen sources at SunLine.

In addition to these short term solutions, more effort will be spent on completing functional tests, performing more long endurance runs, reducing the system sensitivity by adjusting warning and alarm settings, and reducing the downtime by focusing on improving system reliability.

Data on the fuel consumption of the ZEbus in the transit track tests and the corresponding driving range (based on a full tank), derived from these data are shown in Figures 7 and 8, respectively.

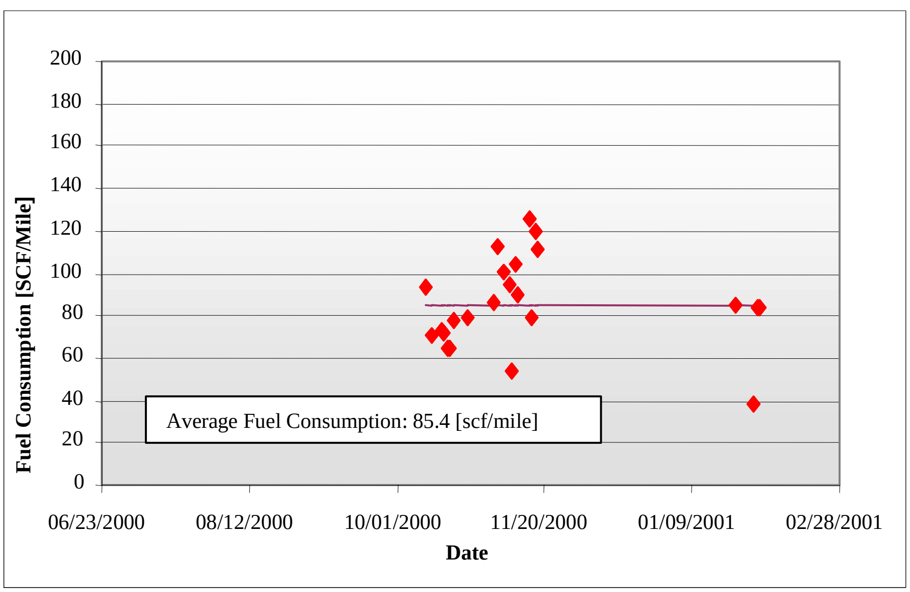


Figure 7: Fuel consumption of ZEBUS for transit track test

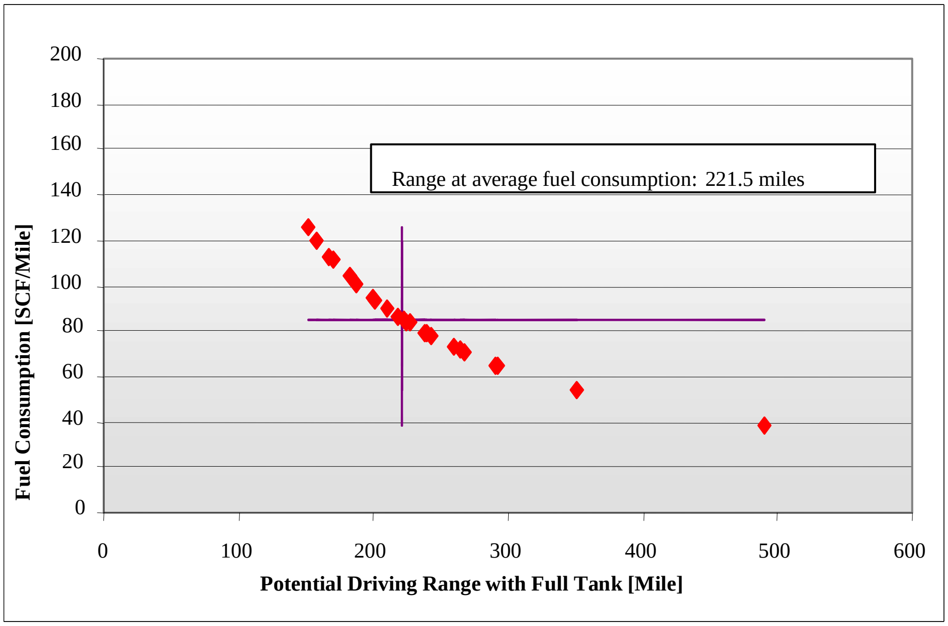
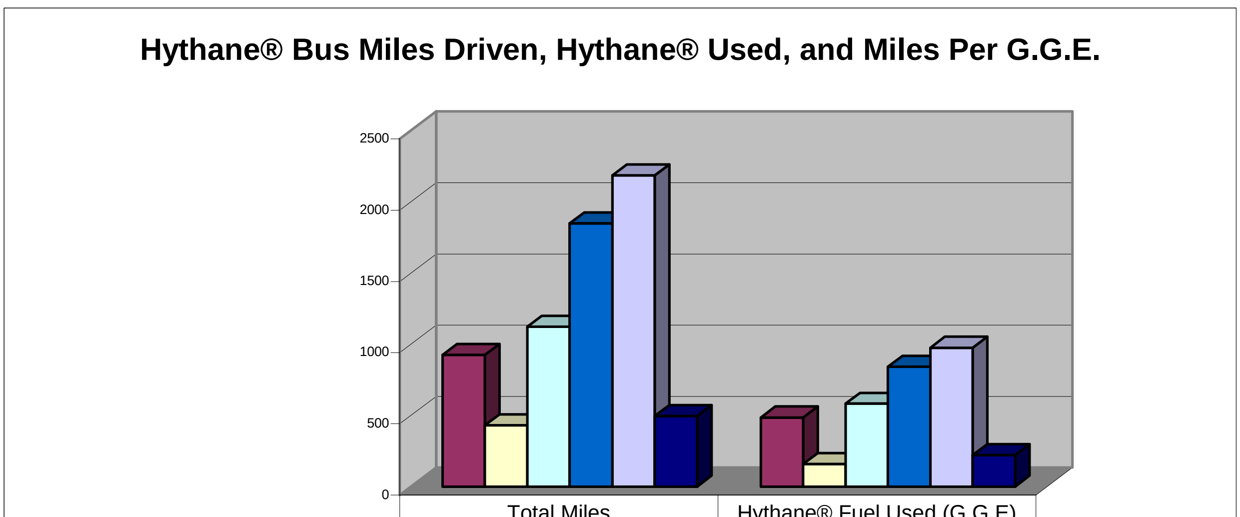


Figure 8: Potential driving range of ZEBUS with full tank

Data related to fuel usage and miles driven by the two Hythane® buses are shown in Figure 9.



	Total Miles	Hythane® Fuel Used (G.G.E)
Totals for Feb-2001	926	486
Totals for Mar-2001	431	159
Totals for Apr-2001	1125	583
Totals for Feb-2002	1849	843
Totals for Mar-2002	2187	977
Totals for Apr-2002	495	221

Figure 9: Hythane® Bus Miles Driven and Hythane® Usage

4.5 Maintenance Facility for Hydrogen Buses

Currently, SunLine maintains its fleet of CNG buses in a large enclosed facility. In contrast, the Ballard/XCELLSiS bus was maintained in a separate, smaller facility. This "outdoor-style" maintenance garage consists of an aluminum frame, fireproof canvas, and explosion-proof light fixtures. The "tent" structure is ventilated along the ridgeline to allow hydrogen gas to safely escape if it is inadvertently released from the vehicle. This $95,000 facility is sufficient to maintain two or more fuel cell buses. It is important to note that SunLine's maintenance facility, while perfect for the agency's warm climate, would not work for transit agencies in all climate zones. Despite an agency's location, however, all those incorporating hydrogen vehicles into their fleets will need to construct state-of-the-art maintenance facilities that meet all applicable safety codes and standards. The majority of these codes and standards refer to the NFPA for compressed gas storage, dispensing, and refueling. Also, the national electrical codes and standards were used. Currently, new codes and standards are being written for hydrogen to incorporate transportation other than bulk storage, i.e. hydrogen powered vehicles.

SunLine's role in the ZEbus program included testing, operating, maintaining, and fueling the bus. The agency provided motor coach operators, preventive maintenance, and some equipment replacement. To gain insights into advancing its direct-hydrogen PEM fuel cell technology, Ballard/XCELLSiS field engineers performed most other functions. When fuel cell buses are deployed in revenue service, it will be necessary to increase the hands-on involvement of transit personnel. A "master plan" for this transition is needed, perhaps through the California Fuel Cell Partnership.

- The existing facilities at SunLine Transit Agency for generating, storing, and dispensing hydrogen appear sufficient to meet SunLine's current fuel cell bus program, as well as their plans for modest expansion (~2 or 3 buses). Significantly expanding the fleet beyond a demonstration scale will likely require significant upgrades to key systems, such as expanding the fuel storage capacity and an improving the maintenance facility. SunLine Transit Agency is already addressing some of these concerns.
- According to SunLine personnel, the biggest barrier to expanding its hydrogen fuel cell bus operations is the current lack of hydrogen-specific regulations addressing safety. Without new codes and standards specifically designed for the unique characteristics of hydrogen, it's possible that fire-protection and code and safety officials will raise issues that could delay the commercial introduction of hydrogen fuel cell buses by many years.
- There are many logistical issues to be worked out before SunLine Transit Agency can optimize the emerging subsystems in its hydrogen infrastructure. For example, the HbT reformer system produced large volumes of wastewater each day during full operation. This effluent was not hazardous, but nonetheless had to be disposed of in an efficient, non-disruptive manner.

NREL has formulated a detailed Hydrogen Bus Evaluation Program to accompany the SunLine Transit project. The goal of this program is to evaluate the performance and operating characteristics of fuel cell buses in revenue service and characterize the maintenance and fueling infrastructure needed to fuel and maintain them. Because fuel cell buses are not commercially available, we will use the prototype fuel cell bus demonstration project at SunLine to understand the technology and plan for the future evaluation. Using the preliminary data collected, NREL plans to:

- develop and document the procedures necessary to evaluate fuel cell buses,
- perform baseline performance testing of the Ballard/XCELLSiS fuel cell bus and document the results,
- define and document infrastructure and facility modifications required to add hydrogen fueling and bus maintenance to the AC Transit site, and
- evaluate the performance, emissions, cost, and operating characteristics of the Hythane® buses. The information collected will be made available on the World Wide Web.

5. OUTREACH

An important aspect of any hydrogen demonstration project is outreach. SunLine is committed to educating the public on the benefits of clean fuels technology and mass transportation. Because SunLine is currently the only site in the world where hydrogen, produced on-site from solar energy, is used to generate power for buildings, as a fuel in Hythane®-powered and zero-emission fuel cell vehicles, and will, in the near future, demonstrate hydrogen generation from wind power, it is ideally positioned to educate as it demonstrates.

SunLine built and operates the world's first Clean Fuels Mall where compressed natural gas, liquefied natural gas, hydrogen, and Hythane® are available to the public 24 hours a day. Additionally, global shoppers for electrolyzers, reformers, and other equipment that generates, stores, and dispenses alternative fuels can visit SunLine to see prototype and product-development units in operation. SunLine has worked with the equipment manufacturers to develop educational displays throughout its facilities.

SunLine has produced an educational video series entitled "Energy Matters." Thirteen, two-minute videos distributed to PBS stations in major California markets cover such topics as alternative fuels, electricity and the grid, fuel cells, microturbines, and new car technologies. The videos are also available to teachers and administrators for use in classrooms. SunLine is working with the South Coast Air Quality Management District to develop a workbook for middle school children that corresponds to the video series.

A significant objective of the Ballard/XCELLSiS Phase 4 Program was to educate the public on the safety and reliability of fuel cell vehicles. The ZEbus provided officials and riders alike with an opportunity to experience the pollution-free transportation technology of the future. Visitors from around the world, including numerous government delegations and agencies, international journalists, industry leaders and experts, environmental groups, and educational groups, traveled to Thousand Palms, California to ride the ZEbus and gain a better understanding of fuel cell technology at SunLine's "Clean Fuels Mall".

When SunLine converted its bus fleet to CNG, the agency partnered with the College of the Desert (COD), the local community college, to devise a training curriculum. Located in Palm Desert, California, COD now offers a unique Advanced Transportation Technologies program that teaches students about clean fuel vehicles, electronics, and systems that will run the vehicles of the future. Students who complete the two-year program earn an Automotive

Technologies Associate of Arts Degree and acquire in-demand job skills repairing and maintaining clean fuel vehicles. That program was so successful that SunLine/COD and partners took on a second alternate fuels education task— to develop the first training manual for hydrogen fuel cells and related technologies. The recently completed curriculum, funded in part by the Federal Transit Administration, will soon be taught to students at COD and other community colleges.

Finally, representatives of SunLine are traveling throughout the region and around the world to share their experiences and outline the opportunities presented by clean fuel vehicles. Audiences include the technical hydrogen community, policy makers, financial officers, community groups, and schools.

6. CONCLUSIONS AND FUTURE PLANS

The 'P3-1A' Bus Fueler prototype is part of Stuart Energy's Fleet Fuel Appliance development program, which is focused on meeting the fueling needs of hydrogen buses, trucks, and other centrally-fuelled vehicles. The P3-1A configuration installed at SunLine Transit can meet the fueling needs of between one and three hydrogen buses, and the flexible platform can be scaled up to service 10 or more buses. The Fleet Fuel Appliance program is a multi-phase program, which is in its final year. The next stage of development will build on the successes of the Fleet Fuel Appliance program, while focusing on aggressive cost and efficiency targets. The ultimate cost target for Stuart Energy's transportation fueling solutions are US$600/kW for 10,000 scfpd and US$300/kW for 100,000 scfpd, assuming production volumes of 10,000 units. Stuart Energy will continue to engage in key fueling demonstrations such as the one at SunLine Transit in preparation for the rollout of hydrogen vehicles. Demonstration projects provide both a proving ground for technology as well as an opportunity to capture early market share and build brand awareness. Initial markets are anticipated to develop in the latter half of this decade and will likely include regulated and government fleets.

During the ZEbus test program, various upgrades were implemented, further enhancing the performance of the Phase 4 205 kW XCELLSIS engine. These technological efficiencies will be incorporated into the design of the Phase 5 engine, which will be installed in 30 buses scheduled for delivery to European customers beginning in 2002. The information gathered from SunLine will contribute to the refinement of key operating parameters for the Phase 5 engine and will provide a foundation for field service operations in Europe and California.

With eight years of experience in CNG vehicle technology and the knowledge gained in hydrogen production, storage, and utilization, SunLine Transit Agency is poised to begin transitioning the Coachella Valley’s public transit fleet to zero-emission hydrogen fuel cell vehicles.

In the interim, until fuel cell buses are commercially available, the agency will test Hythane® in closed-loop CNG engines. If these tests prove successful, SunLine’s CNG fleet will be converted to Hythane® with the end goal of replacing its entire fleet (buses, trucks, and passenger vehicles) with zero emission fuel cell vehicles.

SunLine will continue to expand its on-site hydrogen production capacity. In an effort to test the viability of as many renewable sources of hydrogen as possible, the agency recently established the SunLine Beta Test Center for Advanced Energy Technologies, where multiple clean fuels/clean energy technologies are tested and demonstrated.

As early as 2003, phased conversion of the transit fleet to Hythane® and hydrogen fuel cell vehicles will begin. SunLine will work with its partners to incorporate the latest technological developments and to publicize the opportunities hydrogen technologies present. By continually demonstrating the safety and reliability of hydrogen technologies, SunLine will help lead the way to our hydrogen future. SunLine is truly today's model for tomorrow's world.

7. LIST OF CONTACTS

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