Final Report to

Department of Energy

February 2003

Hydrogen Commercialization: Transportation Fuel for the 21st Century

CONTRACT NUMBER: DE FC36-96GO10139

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EXECUTIVE SUMMARY

"Tonight I am proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles. Join me in this important innovation to make our air significantly cleaner, and our country much less dependent on foreign sources of energy."

-President George W. Bush, State of the Union Address, January 28, 2003

The President's call to reverse America's growing dependence on foreign oil harkens to the decision SunLine Transit Agency's board of directors made in 1994. That was the year SunLine accomplished the unthinkable by becoming the first transit agency in the world to park all of its diesel buses and switch overnight to a fleet powered 100% by clean-burning compressed natural gas (CNG). That was only the beginning.

Since 1999, SunLine Transit Agency has worked with the U.S. Department of Energy (DOE), U.S. Department of Defense (DOD), and the U.S. Department of Transportation (DOT) to develop and test hydrogen infrastructure, fuel cell buses, a heavy-duty fuel cell truck, a fuel cell neighborhood electric vehicle, fuel cell golf carts and internal combustion engine buses operating on a mixture of hydrogen and compressed natural gas (CNG).

SunLine has cultivated a rich history of testing and demonstrating equipment for leading industry manufacturers in a pre-commercial environment. Visitors to SunLine's "Clean Fuels Mall" from around the world have included government delegations and agencies, international journalists and media, industry leaders and experts and environmental and educational groups.

This is the final report of a three-year success story, which began with the DOE's decision to establish a hydrogen infrastructure in Southern California at SunLine Transit Agency in Thousand Palms, California. SunLine was tasked with taking two then-current DOE projects and moving them to SunLine to create an infrastructure that produced, compressed, stored and dispensed hydrogen to fuel cell vehicles using grid, solar and wind power.

The investment made by the DOE has yielded significant benefits. Not only was the project constructed as scheduled, but it has surpassed the original goals under SunLine's Best Test Center for Alternate Energy Technologies to become part of SunLine's daily operations and maintenance activities. In other words - our "rolling laboratory" has taken the technology out of the science lab and into the real world.

One of the project's significant objectives was to educate the public on the safety and reliability of fuel cell vehicles. By demonstrating fuel cell bus service using compressed hydrogen in a normal transit operation, officials and riders alike got to experience for themselves the pollution-free transportation technology of the future. Another objective was to show the potential to other transit operators for using a liquid fuel reformed to hydrogen in fuel cell buses.

To further enhance the public education component of the project, SunLine developed several additional strategies. Thirteen two-minute "Energy Matters" videos were distributed to PBS stations in major California media markets. The videos covered such topics as alternative fuels, electricity and the grid, fuel cells, micro-turbines, and new car technologies. The videos were also made available to teachers and administrators for classroom use.

SunLine worked with College of the Desert and other partners to develop the first training manual for hydrogen fuel cells and related technologies. The curriculum, funded in part by the Federal Transit Administration and the Department of Defense, is set to be delivered to students at College of the Desert and other community colleges throughout the state through the California Community Colleges' EdNet initiative.

The Hydrogen Fuel Cell Engines and Related Technologies training manual has also been posted on the NREL web site. Within the first two months of its appearance, the manual received 132,000 hits. According to NREL, this is the largest number of hits they have ever recorded in that short of a time span.

Other than cost, SunLine's track record of experience has identified several challenges to hydrogen commercialization:

- The need to improve fuel cell reliability
- The need to engage the insurance industry in over-coming liability issues
- The establishment of reasonable codes and standards
- The implementation of comprehensive hydrogen education and outreach programs to elevate public awareness to mainstream levels

SunLine has effectively demonstrated the need for a path of continuous improvement. Investments in fuel cell technology should be made on a measured basis of how they contribute to the global body of knowledge. While it is important to test and demonstrate the technology, it is also important to invest wisely. Finite resources should be devoted to those organizations and programs that have demonstrated a passion to make things work, the policies and political will to further hydrogen and fuel cell development and the capability to perform technology transfer to future organizations.

Selective investment is a must.

HYDROGEN COMMERCIALIZATION: TRANSPORTATION FUEL FOR THE 21ST CENTURY SUNLINE SERVICES GROUP

CONTRACT NUMBER: DE-FC36-96GO10139

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 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 that can be used to supply public and private transportation vehicles that emit only water.

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 toward realizing a fleet of hydrogen-powered vehicles were taken in 1999. Because of its experience with alternative fuel technology, SunLine was tapped by the 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. Partners during this activity are listed below:

EDUCATIONAL COLLABORATION

Advanced Transportation Technologies Initiative (ATTI)

College of the Desert - Energy Technology Training Center

Department of Environment / Urban Consortium Energy Task Force

Georgetown University

Humboldt State University - Schatz Energy Research Center

National Science Foundation

University of California - Riverside, CE-CERT

GOVERNMENT COOPERATION

California Air Resources Board

Coachella Valley Association of Governments

Federal Transit Administration

Palm Springs International Airport

South Coast Air Quality Management District

California Energy Commission

City of Palm Desert

Imperial Irrigation District

U.S. Department of Defense

U.S. Department of Energy

INDUSTRY COLLABORATION

Air Products

Allison Transmission

American Public Transportation Assoc.

Ballard (formerly XCELLSIS)

California Fuel Cell Partnership

California Hydrogen Business Council

California Natural Gas Vehicle Coalition

California Transit Association

Clean Air Now

Cummins Engine Company

DCH Technology

Detroit Diesel

Dynetek

Engelhard Corp.

ENRG (formerly Pickens Fuel Corp.)

Federal Mogul

FIBA Technologies

Fueling Technologies

Gaz de France
HbT
Hydrogen Components, Inc.
ISE Research
John Deere
National Hydrogen Association
Natural Gas Vehicle Coalition
Orion Industries, Ltd.
Quantum Technologies
QuestAir
Shell Hydrogen
Southern California Gas Co.
Southwest Research Institute
Stuart Energy
Teledyne Energy Systems
Thunderpower LLC
TotalFinaElf
UOP
UTC Fuel Cells
Wintec

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
- Pickup powered by a hydrogen powered internal combustion engine
- Over five passenger vehicles brought by automobile manufacturers for testing in the Coachella Valley
- Hydrogen Internal Combustion Engine Shelby Cobra.

Some of these vehicles are shown in Figures 1 and 2.

Figure 1: (left to right) SunBug NEV, Hythane® Bus, Hydrogen ICE pickup truck, and ZEbus, ThunderPower and Georgetown buses.

Figure 2: (left to right) ZEbus, ThunderPower and Georgetown buses

SunLine is operating this "lab on wheels" to determine the supportability, reliability, maintainability and operability of hydrogen-powered vehicles and infrastructure technologies. On-site hydrogen production is performed with two electrolyzers; a Hydrogen Burner Technology (HbT) natural gas reformer was also demonstrated in 2001.

Total funding and sources of funds is as follows:

Department of Energy	$ 650,408
South Coast Air Quality Management District	$ 223,100
City of Palm Desert	$ 192,967
Clean Air Now	$ 169,322
COLMAC	$ 140,704
Imperial Irrigation District	$ 60,000
Total	**$1,436,501**

While the DOE 3 year project provided the "seed" funding which attracted other hydrogen funds and related projects (see Appendix A for Projects/Contracts List), SunLine Transit Agency elected to create a hydrogen education and awareness program which went beyond the normal transit agency outreach efforts.

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

BACKGROUND

SunLine is the umbrella organization for three joint power authorities, SunLine Transit Agency, SunLine Services Group, and a non-profit 501(c)(3), Community Partnerships of the Desert, Inc. 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.

3. DESCRIPTION OF COMPONENTS

3.1 Photovoltaic Field

480 feet of raised photovoltaic concentrating and tracking panels (144 150-kW modules) and 218 Siemens solar panels have the combined capacity to produce 37 kW of electricity, which powers the Teledyne Energy Systems electrolyzer described below. 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.

Figure 3: Photovoltaic panels

The on-site distributed system also includes a D/C to A/C 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.

Figure 4: Teledyne Electrolyzer

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 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 (12000 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 with 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 Appendix B.

Figure 5: Stuart Electorlzer

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

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 3000 Sm^3 (104000 SCF) of hydrogen at 21.6 MPa (3130 psi).

The ASME tube tanks can store an additional 350 Sm^3 (12500 SCF) at 28 MPa (4000 psi). These tanks are attached to a cascade control panel 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 6: FIBA trailer with ground tanks

As 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. Examples of this are: (1) Michelen Bibemdum in Ontario, CA and Las Vegas, NV; (2) Vehicle testing in Reno, NV at an automobile manufacturing test facility and track. SunLine's DOT-approved trailer provides a ready distribution system, and the agency will soon increase its storage capacity and dispensing pressure to 5000 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 hydrogen and natural gas, which are stored separately, to be mixed as they are being pumped. Appendix C provides information on refueling procedures.

Figure 7: Ballard ZEbus refueled at SunLine.

3.4 Hydrogen Reformer

In addition to the two electrolyzers, for approximately one year, SunLine field-tested a stationary HbT reformer which generated hydrogen from natural gas. 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.

Figure 8: HbT Reformer

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 HbT Reformer was not part of the DOE infrastructure program but was demonstrated at SunLine Transit Agency by technology partners because of the DOE's investment at SunLine and SunLine's desire to be prepared for its own conversion to a hydrogen fuel cell fleet.

See Figures 9 and 10 for a detailed layout of the hydrogen infrastructure.

Figure 9: Facility Expansion Project

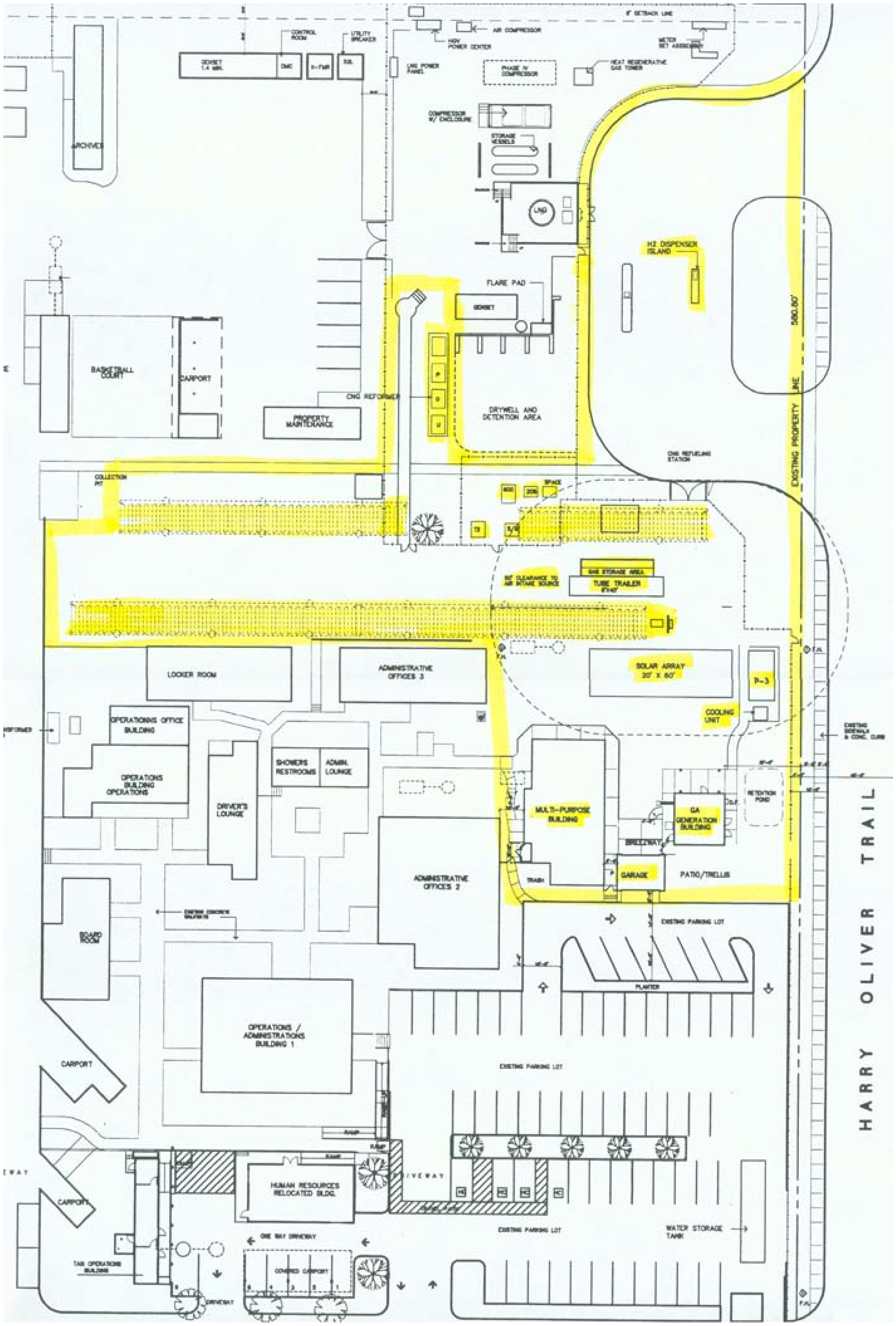
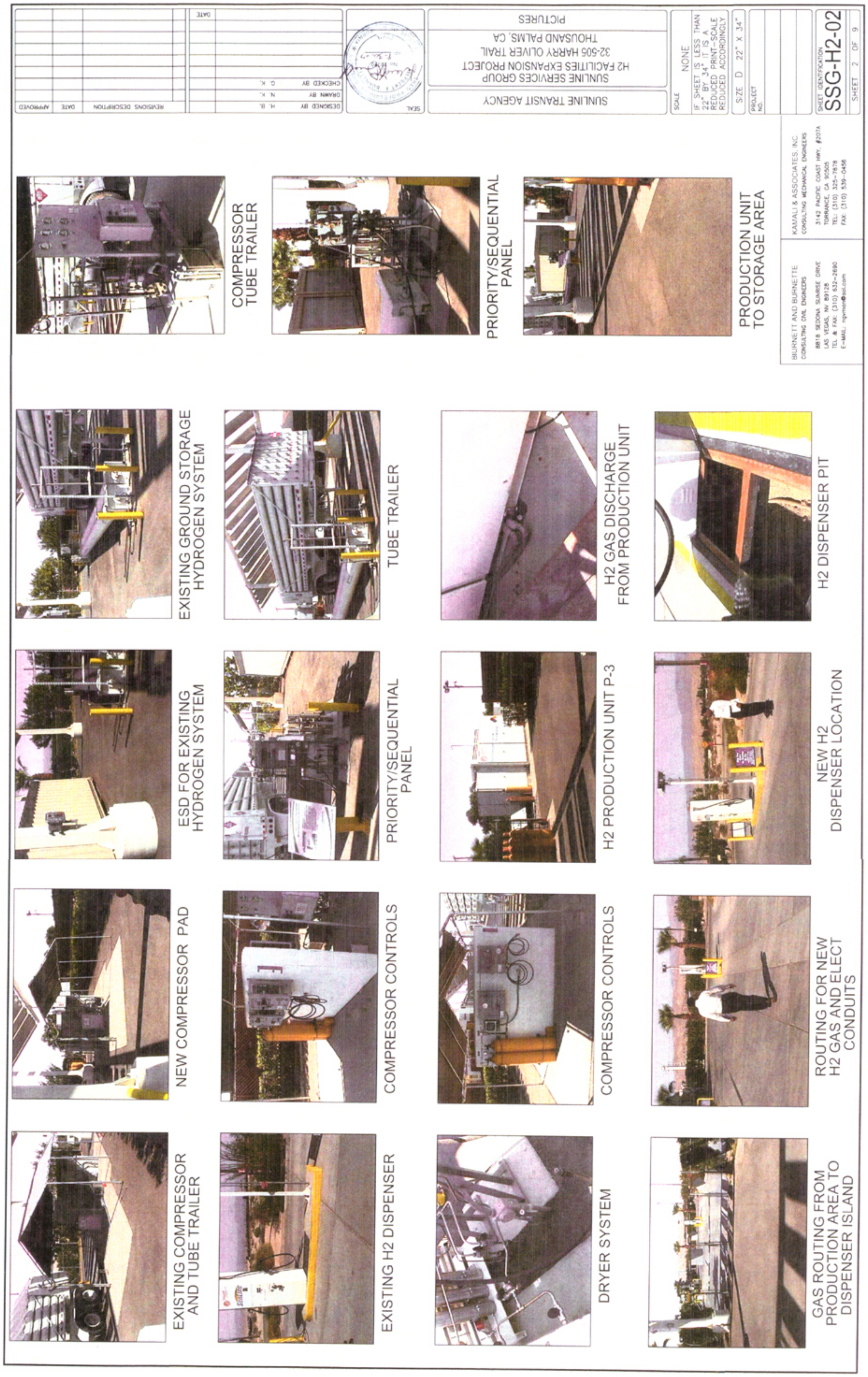


Figure 10: Facilities Expansion Project



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.

Figure 11: Shelby Cobra

The two Hythane® buses have been operating in regular scheduled transit service since November 2000 and operate on a November through April schedule. The six month schedule is due to the vehicles lack of air conditioning for the summer months. See Appendix D.

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 of these vehicles is shown in Appendix E. Further information is available in reports (1) "Renewable Hydrogen Transportation System for the City of Palm Desert, California", No. DE-FC36-96GO10139, October 7, 1999, Department of Energy and (2) "Renewable Hydrogen Transportation system for the City of Palm Desert" Contract No. 96055 February 2001, South Coast Air Quality Management District.

Figure 12: SunBug (center), 2 of 3 golf

3.5.2 Prototype Fuel Cell Buses

<u>ZEBus (XCELLSiS)</u>

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 (formerly XCELLSiS Fuel Cell Engines) Phase 3 (P3) Test Program included a two-year demonstration of P3 fuel cell buses at Chicago, Illinois, and Vancouver, British Columbia.

Figure 13: ZEbus

The 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. 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 3400 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).

Appendix F provides an overview of the P4 bus and its 205 kW fuel cell engine.

ThunderPower Fuel Cell Bus (ThunderPower, LLC)

The 30 foot Hybrid Fuel Cell Transit Bus ThunderPower is a joint venture between Thor Industries and ISE Research. It is one of the most advanced buses ever produced by a major Original Equipment Manufacturer with zero emissions and achieves 7 to 11 miles per gallon. El Dorado National developed the Bus Chassis.

The fuel cell was produced by UTC Fuel Cells which has over 40 years of experience including such applications as the US Space Shuttle. The 60 kW stack used on the ThunderPower bus is over 50% efficient, very quiet, and weighs the same as a typical car engine.

Figure 14: ThunderPower Bus

The fuel cell radiator is provided by Sumitomo Precision Products. The high performance cooling system is designed for 60 kW operation up to 50 degrees C.

Hydrogen storage is provided by QUANTUM Technologies. QUANTUM provides the ThunderPower bus with special tanks to hold 25 kg of hydrogen at 3600 psi, which equals 25 gallons of diesel fuel.

The battery pack is provided by Panasonic. The 600v battery pack includes 48 12-V high performance batteries that store and provide energy for all systems in the bus. The batteries are charged by the fuel cell and regenerative braking.

The drive system is provided by ISE / Siemens. The drive system includes two electric motors, inverters, and a combining gearbox. The two electric motors provide the bus with 170 kW and can match the performance of conventional engine driven buses.

The vehicle controls were provided by VANSCO. The vehicle control system is a multiplexing system that controls all accessory operations (driver controls, air and hydraulic, cooling system, energy management).

The funding partners for this project are the U.S. Department of Transportation, Sacramento Municipal Utility District (SMUD), CALSTART, and South Coast Air Quality Management District.

SunLine is a key technology partner for this project in demonstrating clean transportation solutions at its Beta Test Center for Alternative Energy Technologies. SunLine is using the bus in normal in-route service on its regularly schedule Line 50.

The bus went into transit service in November 2002 and continues in service. The current test period was delayed to November because of insurance concerns expressed to Thor Industries. These concerns point out the necessity of educating the insurance industry in the safety of fuel cell vehicles. The delay was specifically related to hydrogen and the traveling public. The insurance company placed a restriction that the bus could only operate "shadowing" another transit bus and was not allowed to carry passengers for three months. The ThunderPower bus performed these operations with a SunLine Transit Agency Motor Coach Operator.

Upon conclusion of the three month "operational practice phase", the bus was placed into service. On November 6, 2002 the ThunderPower bus departed SunLine's facilities at 6 a.m. for the first regularly scheduled Line 50 route with the first woman Motor Coach Operator to drive a fuel cell bus completely manufactured in the United States. To date the bus has performed flawlessly. The ThunderPower bus supported demonstration rides at the 2002 Fuel Cell Seminar held in Palm Springs in November 2002.

<u>Georgetown University Fuel Cell Bus</u>

Georgetown University introduced the first and only urban transit bus powered by a liquid-fueled Proton Exchange Membrane Fuel Cell. The primary energy source on this electric bus is a 100 kW fuel cell manufactured by the former XCELLSiS Gmbh, which is now a Business Unit Transportation within Ballad Power systems, Inc. This is the world's largest liquid fuel cell capable of operating on liquid fuel. Traction batteries provide surge power and a means to recover braking energy by regeneration.

Figure 15: Georgetown Bus

The fuel cell produces electricity by combining hydrogen and oxygen into water through an electrochemical process. Oxygen is taken from ambient air while hydrogen is extracted from liquid methanol using an on-board reformer.

The bus platform is a Nova BUS RTS wide front door model, seats 40 passengers, uses an electric drive train developed by BAE Systems Controls and has a range of 350 miles.

Booz Allen & Hamilton, Inc. completed system engineering tasks and developed the vehicle system controller.

Funding partners are the Federal Transit Administration and the U.S. Army's National Automotive Center (NAC). The objective of the funding partners is to commercialize the Fuel Cell technology for transit applications.

Georgetown University selected SunLine Transit Agency as a technology partner to assist in carrying out the above objective by demonstrating to other transit agencies throughout California the capabilities of the bus. The Georgetown University bus supported demonstration rides at the 2002 Fuel Cell Seminar held in Palm Springs in November 2002.

3.5.3 Prototype Fuel Cell Vehicle

National Automotive Center Diesel Reformer Fuel Cell Vehicle

In 1998, the U.S. Army's Tank-armaments and Automotive Command's National Automotive Center (NAC) awarded SunLine a contract to develop, test, and demonstrate a first generation diesel fuel cell reformer. This project is intended to aid the military in meeting Army After Next goals for fuel economy, performance improvement, and emissions reductions in medium and heavy trucks, while providing the same benefits to industry.

Figure 16: Phase 1 tractor

Phase 1 was to (1) utilize an existing SunLine class 8 line haul diesel tractor and modify it with a hybrid electric drive system with an on-board diesel generator and batteries for testing and characterization; (2) develop an on-board diesel reformer laboratory unit for testing with several blends of diesel fuel which would interface with a proton exchange membrane fuel cell; and (3) evaluate the world wide training programs for technicians of the 21st century and determine the types of training necessary for the future. Further information can be found in "Phase 1 Final Report Diesel Fuel Reformer for Fuel Cell Truck, U.S. Army Tank Automotive and Armaments Command, National Automotive Center" Agreement N0. DAAE07-98-3-0025, May 31, 2001.

Figure 17: Phase 2 tractor

Partners for Phase 1 were NAC, SunLine, University of California Riverside, College of the Desert, Hydrogen Burner Technology, ISE Research, and Zeopower.

Phase 2 (initiated in year 2000) is the incremental electrification of a new class 8 tractor, culminating with the demonstration of a diesel reformer / fuel cell hybrid electric drive train. The NAC, SunLine, and Southwest Research Institute (SwRI) are the partners.

The current configuration provides a light weight truck design from Peterbilt Motors Inc., Hydrogen Storage System from Dynetek Industries, Inc., a 5 kW solid oxide fuel cell from General Dynamics C4 Systems / Acumentrics as an auxiliary power unit (APU) for a first generation operation, efficient Cummins ISL engine from Cummins Inc., and low rolling resistance tires from Michelin North America.

During the course of the project and as electrical loads are transferred from the engine to the fuel cell, the fuel cell will be scaled up to 100-kW, the diesel engine removed, and an on-board diesel reformer installed. The vehicle is scheduled for hot weather testing in June 2003 and the DOE infrastructure will be the source of hydrogen for the planned testing.

Figure 18: 5kW SOFC, SWRI

4. PERFORMANCE AND OPERATIONAL EXPERIENCE

4.1 Hydrogen Production by the Electrolyzers

Hydrogen production by the Teledyne electrolyzer, shown in Appendix G 1-4, is for a three-year period, beginning in July 2000. The solar panel power production for a two-year period is shown in Appendix H 1-2.

The hydrogen produced by the Stuart electrolyzer is shown in Appendix I 1-I4 is for a three-year period beginning in July 2000.

4.2 Hydrogen Reformer

The performance of the hydrogen reformer was satisfactory with a demonstrated capacity of 110 Nm^3/h (4200 SCFH) and a purity from 99.5% to 99.999%. It consumed approximately .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 million Btu; electricity at $0.085/kWh) the costs of hydrogen are $0.72 per 100 SCF. Using pipeline natural gas at $4.00/Mbtu would lead to hydrogen costs of $0.45 PER 100 SCF.

4.3 Vehicles

During SunLine's 13-month demonstration, which began 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. By comparison, a CNG bus at SunLine operates 6,900 hours per year. Powered by Ballard Mark 700 Series fuel cell stacks, the hydrogen-fueled ZEbus is and 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 data collected regarding the ZEbus during the period from July 2000 to August 2001. The full report regarding the ZEbus is available in the Federal Transit Administration Final Report, Cooperative Agreement Project Number CA-26-7022 September 2, 2001.

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

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

Short-term solutions to these problems could be:

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

In addition to these short term solutions more efforts 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.

4.4 Maintenance Facility for Hydrogen Buses

Currently, SunLine maintains its fleet of CNG buses in a large enclosed facility. By contrast, the Ballard/XCELLSiS, ThunderPower, and Georgetown University fuel cell buses were 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.

Figure 19: XCELLSIS maintenance facility

This $139,552 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.

SunLine's role in the ZEbus, ThunderPower, and Georgetown University programs 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, ThunderPower, and Georgetown University field engineers performed most other functions. When fuel cell buses are deployed in revenue service, it will soon be necessary to increase the hands-on involvement of transit personnel. A "master plan" for this transition is needed, perhaps through community colleges such as College of the Desert (leader in alternate fuels technology training) in Palm Desert, California.

- The existing facilities at SunLine Transit Agency to generate, store, and dispense hydrogen appear sufficient to meet SunLine's current fuel cell bus program, including 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 expanded fuel storage and a maintenance facility with increased capacity / capability. 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. A detailed Hydrogen Bus Evaluation Program has been formulated at NREL (not part of the three year infrastructure 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 ThunderPower fuel cell bus and the 4 fuel cell buses (1 for SunLine Transit Agency and 3 for AC Transit Agency – delivery expected July 2004) and document the results,
- Define and document infrastructure and facility modifications required to add hydrogen fueling and bus maintenance to the AC Transit site,

- Evaluate the performance, emissions, cost, and operating characteristics of the Hythane® buses. It is intended that the information collected will be made available on the World Wide Web.

5. TECHNOLOGY TRANSFER

5.1 Chula Vista Project

The investment of DOE funding at SunLine Transit Agency also leads to Technology Transfer. Currently SunLine is managing for the City of Chula Vista their mobile Stuart Energy hydrogen electrolysis unit to be used in conjunction with the City's fuel cell bus program. SunLine managed the development of specifications for the unit, proposal process, the project management of design, manufacture, and installation at the city of Chula Vista.

Following this model of "leader - follower" the Department of Energy will be able to stretch their funding and ensure that the risk inherent in these types of projects is reduced by having similar organizations under similar business conditions provide the education, training, operation and maintenance of infrastructure to support hydrogen transportation projects.

Project description:

SunLine Transit Agency and Chula Vista are demonstrating an advanced electrolyzer to produce hydrogen to support the operation of fuel cell buses at the respective sites.

This project consists of the demonstration of a Stuart Energy CFA 1350 Community Fueling Appliance with a hydrogen production capacity of 1350 scfh. The unit is an integrated production, compression, storage and dispensing system mounted on a single double deck trailer. Hydrogen generated will be stored in the 14 trailer mounted storage vessels at a MAWP of 6250psig. This complete assembly will be operated and demonstrated at the City of Chula Vista. In addition, SunLine is demonstrating a combination diaphragm compressor, 6000 psig storage system, a cascade control and 5000 psig dispenser. The latter is the new automobile standard.

The project addresses the following objectives:

- Produce high purity hydrogen at a pressure of 6,000 psig for fuel cell vehicle use
- Validate the technology through the reliable operation of the vehicles using the fuel produced
- Verify the ability of the vehicle operators to fill the vehicle with hydrogen
- Document, analyze and disseminate cost and performance data generated by the demonstration

Benefits:

The project will provide technology transfer benefits to Chula Vista and advance hydrogen fueling and fuel cell technology. In subsequent phases, the Chula Vista hydrogen production facility will incorporate technology refinements identified by SunLine and others. Other specific benefits will include:

- An opportunity to integrate alternative fuels in a multi-fleet operation
- An opportunity to train and educate Chula Vista employees and other interested potential agencies, to operate and maintain fueling technology
- Develop and provide a model-training curriculum with Community Colleges and Universities
- Expand hydrogen fueling and fuel cell technology to other markets, including heavy trucks
- Provide the opportunity to test fuel cell technology in a moderate climate with flat and hilly terrain

6. OUTREACH

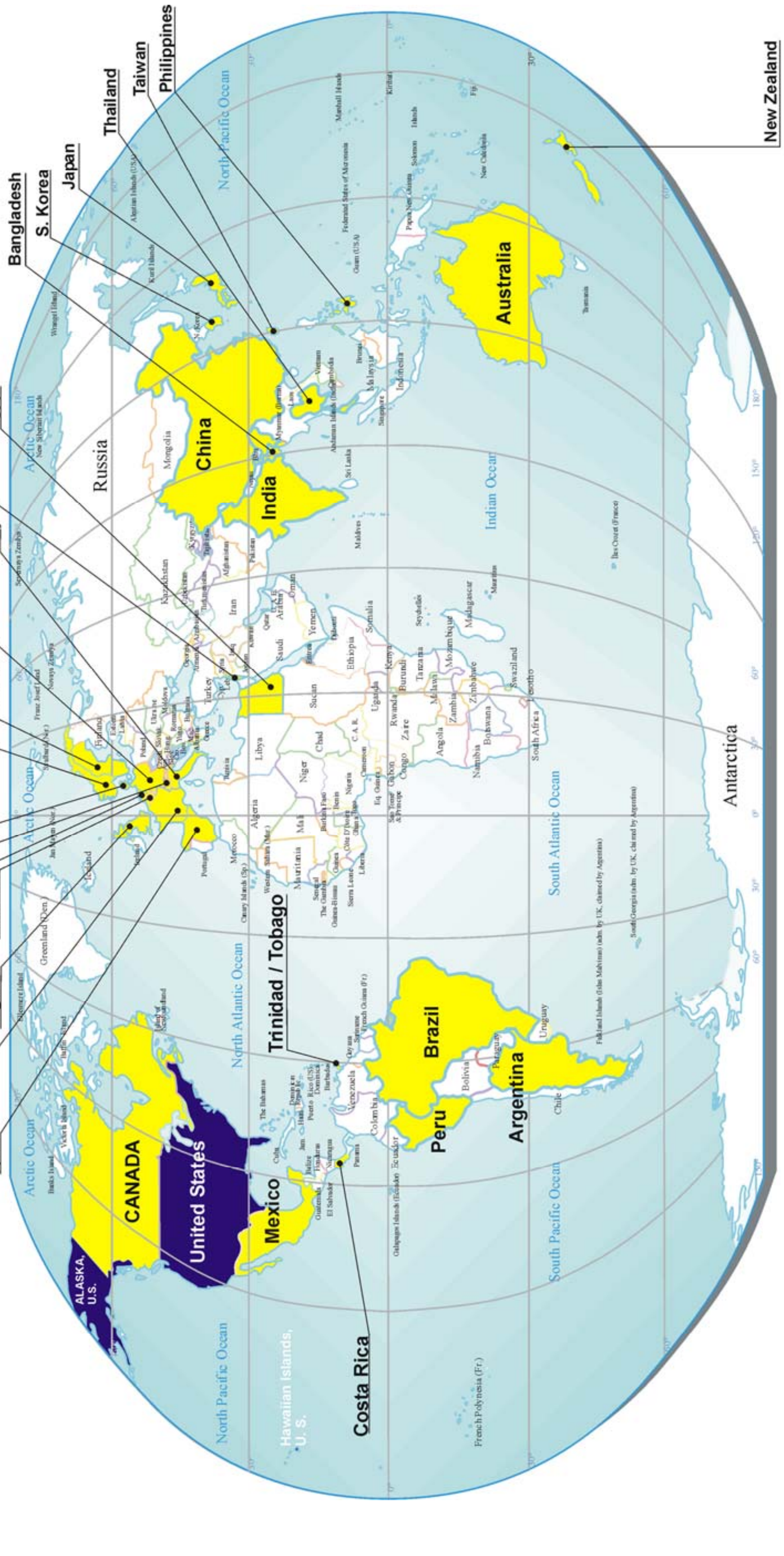
An important aspect of any hydrogen demonstration project is outreach. SunLine is committed to educating the public on the benefits of clean fuels technology and mass transportation. Since SunLine is currently the only site in the world where hydrogen generated on site from solar energy is used to power buildings, Hythane® 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, micro-turbines and new car technologies. The videos are also available to teachers and administrators for use in classrooms. SunLine is worked 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 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. The objective of the ThunderPower Program is to demonstrate fuel cell bus operations in normal transit operations. The significance of the Georgetown Bus Program is to demonstrate the capability of a liquid fuel cell bus to other potential transit agencies. Visitors from around the world (see Figure 24), 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, ThunderPower and Georgetown University buses and gain a better understanding of fuel cell technology at SunLine's Clean Fuels Mall.

Figure 24: SunLine – Impacting the World



Visitors from the following foreign countries have toured SunLine's facilities:

Argentina
Australia
Bangladesh
Belgium
Brazil
Canada
Costa Rica
Denmark
Egypt
England
France
Germany
India
Israel
Italy
Japan
Mexico
Netherlands
New Zealand
Norway
Peru
Philippines
South Korea
Spain
Sweden
Switzerland
Taiwan
Thailand
Tobago
Trinidad

TV/Film Crews from the US, Japan and Germany

VISITORS

Israli Minstry of the Environment driving a SunLine fuel cell vehicle

The late Congressman Sonny Bono ("early adapter" to hydrogen as a transporation fuel) drives a fuel cell vehicle at Clean Cites event, May 1996

Chairman William Keese from the California Energy Commsion visits SunLine's Clean Fuels Mall

Chinese Olympic delegation (one of many) visiting the DOE supported hydrogen infrastructure at SunLine

Tour group from Fuel Cell 2002 Seminar held in Palm Springs, November 2002

Pasadena Art School learning about hydrogen and its uses

DOE's Hydrogen Technical Advisory Panel visiting SunLine, November 2000

MICHELIN CHALLENGE BIBENDUM
OCTOBER, 2001

Hydrogen Fuel Cell Vehicles Supported by SunLine's Hydrogen Tube Trailer at Ontario, CA and Las Vega, NV

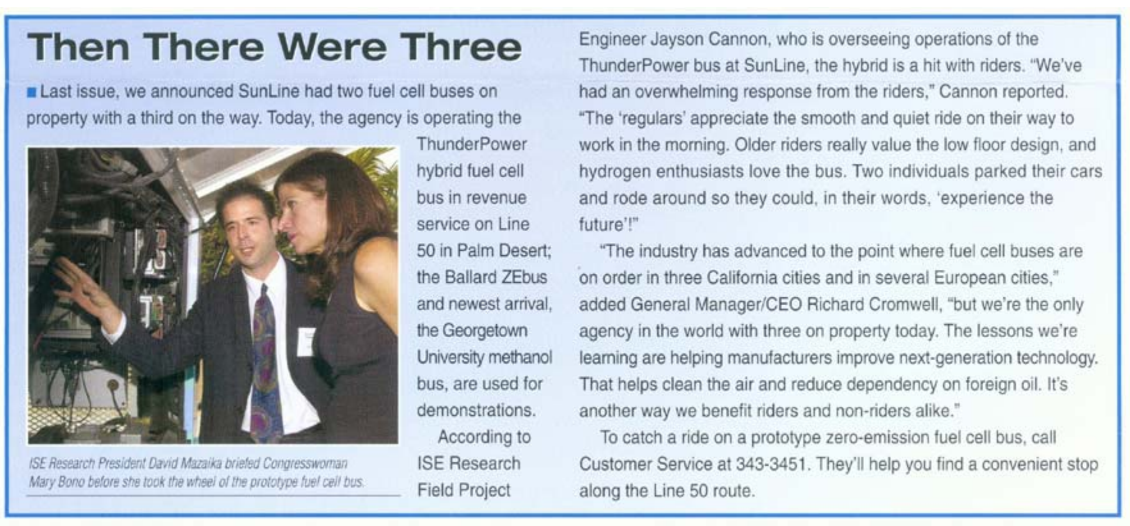
“A TIME TO LEARN AND A TIME TO DRIVE”

When SunLine converted its bus fleet to CNG, the agency partnered with College of the Dessert (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, SunLine/COD and partners took on a second alternate fuels education task: developing 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 and is currently posted on the web site of NREL. In the first two months of its posting it had received 132,000 "hits". According to NREL this is the largest number of hits for any document produced in the short space of time.

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

See Appendix K for SunLine Clean Fuels Mall – Visitor Log

Figure 20: SunBuzz, January 2003



Then There Were Three

■ Last issue, we announced SunLine had two fuel cell buses on property with a third on the way. Today, the agency is operating the ThunderPower hybrid fuel cell bus in revenue service on Line 50 in Palm Desert; the Ballard ZEbus and newest arrival, the Georgetown University methanol bus, are used for demonstrations.

ISE Research President David Mazaika briefed Congresswoman Mary Bono before she took the wheel of the prototype fuel cell bus.

According to ISE Research Field Project Engineer Jayson Cannon, who is overseeing operations of the ThunderPower bus at SunLine, the hybrid is a hit with riders. "We've had an overwhelming response from the riders," Cannon reported. "The 'regulars' appreciate the smooth and quiet ride on their way to work in the morning. Older riders really value the low floor design, and hydrogen enthusiasts love the bus. Two individuals parked their cars and rode around so they could, in their words, 'experience the future'!"

"The industry has advanced to the point where fuel cell buses are on order in three California cities and in several European cities," added General Manager/CEO Richard Cromwell, "but we're the only agency in the world with three on property today. The lessons we're learning are helping manufacturers improve next-generation technology. That helps clean the air and reduce dependency on foreign oil. It's another way we benefit riders and non-riders alike."

To catch a ride on a prototype zero-emission fuel cell bus, call Customer Service at 343-3451. They'll help you find a convenient stop along the Line 50 route.

Figure 21

Congresswoman Mary Bono driving ThunderPower accompanied by Richard Cromwell, III , General Manager of SunLine Transit Agency, October 2002

Figure 22

February 2002
Senator Barbara Boxer awards SunLine Transit Agency the "Conservation Champion Award"

Figure 23

February 24, 2002
Senator Barbara Boxer is shown here producing hydrogen from SunLine's Teledyne Energy Systems electrolyzer.

Figure 24

January 22, 2003
ThunderPower, Santa Barbara, CA,
Shown left to right:
Bill Clapper – SunLine Services Group
Jayson Cannon – ISE Research
Jaime Levin – AC Transit
Representative James Oberstar - MN
John Boesel - CalStart
Paul Scott – ISE Research

NEWS UPDATE

The Detroit News, February 4, 2003

http://www.detnews.com/2003/autosinsider/0302/04/b01-76664.htm

The Detroit News AUTOS insider detnews.com

Tuesday, February 4, 2003

National Automotive Center and SunLine Transit Agency developed fuel cell systems for electricity that can be used in trucks and military vehicles.

By Ed Garsten / *The Detroit News*

WARREN -- Eager to find more efficient ways of transporting troops and supplies -- the U.S. Army wants to absorb some of the costs and responsibility for developing fuel cell vehicles that could one day replace gas-powered cars and trucks.

The National Automotive Center at the Warren-based Army Tank-Automotive Armaments Command is working with the Department of Energy and domestic automakers to place fuel cell vehicles on military bases.

The Desert Sun, February 5, 2003

Sustainable fuel for a sustainable future

RICHARD CROMWELL III
VALLEY VOICE

In his recent address to the nation, President Bush cited the importance of reducing our dependence on foreign oil and developing a sustainable alternative. His solution (FreedomCAR — FreedomFUEL) is one we've long advocated in the Coachella Valley: developing hydrogen fuel-cell vehicle technology, hydrogen fueling infrastructure and deploying stationary hydrogen fuel cell power plants.

To get the country where it needs to go, it's clear we're going to need strong leadership by elected officials.

We'd like to take a minute to applaud a few who took bold action before it was mainstream. Back in 1992, SunLine Transit Agency's board of directors (comprised of an elected official from each valley city and the county of Riverside) voted unanimously to park our diesel buses and convert overnight to a fleet powered 100 percent by compressed natural gas.

In doing so, SunLine became the first transit fleet in the nation to make the wholesale switch to a clean alternate fuel. Subsequent boards endorsed our commitment to alternate fuels by unanimously supporting the creation of the Coachella Valley Clean Cities Coalition, and spurring our foray into testing hydrogen generation technologies, prototype fuel cell vehicles, and clean-burning stationary power technologies. They also unanimously supported the creation of the SunLine Clean Fuels Mall and beta test center for Advanced Energy Technologies, where for three years, SunLine has worked with government and technology partners to advance the commercialization of hydrogen technologies, and develop tools for public education and technology transfer.

But we've also had the good fortune to receive strong support at the national level. Sen. Barbara Boxer and Rep. Mary Bono have visited our facilities numerous times, and participated in events ranging from the opening of our hydrogen facilities to the launch of the first hydrogen fuel cell bus to go into revenue service. While at SunLine, Sen. Boxer drove SunBug, the first street-legal hydrogen fuel cell car in the United States. Rep. Bono took the wheel of the ThunderPower hybrid fuel cell bus.

Last year, we received a coveted Conservation Champion award from Boxer. The day she presented the award, SunLine board members had discussed with her the importance of sustainable energy in our national policy. She took our message back to Washington where the Energy Bill was being debated.

Bono, who has fought for our annual appropriations since taking office, recently agreed to take the lead on legislation that, if passed, will ensure multi-year funding for a national fuel-cell bus technology development program. The goal of the program is to move the technology from the lab into transit agencies across the country.

This week, the president made it clear the path our elected officials chose a decade ago was and is the path that is best for the nation. We want to recognize those who so boldly put the valley in the forefront of this great new frontier.

Richard Cromwell III is general manager/chief executive officer of SunLine Transit Agency and lives in Desert Hot Springs.

7. SUMMARY

Figure 25: SunBuzz, January 2003

Tour du Jour

Global visitors continue to tour SunLine's Clean Fuels Mall.

When the U.S. Department of Energy hosted a fuel cell conference in Palm Springs November 18-22, it was the largest and best attended to date. Nearly 2,500 registrants participated in seminars, rode the ThunderPower fuel cell bus (which SunLine and ISE Research brought to the Convention Center), and rode other prototype fuel cell cars, courtesy of the California Fuel Cell Partnership. Over 200 attendees also toured SunLine's Clean Fuels Mall to see firsthand how hydrogen generated from solar power is being used in zero-emission vehicles.

Other visitors of note included Congresswoman Mary Bono, at SunLine on October 31 to launch the ThunderPower bus into revenue service, a film crew shooting a PBS special on clean energy, a video crew shooting a documentary on energy sustainability for the state of California, members of the Japanese Electric Vehicle Association, France-based technology partner TotalFinaElf, the American Public Transportation Association Executive Committee and the International Energy Agency Executive Committee.

SunLine Transit Agency and SunLine Services Group constructed the first hydrogen generation, storage and dispensing station open to the public.

SunLine successfully operated the facility from April 28, 2000 through January 31, 2003.

The DOE investment in hydrogen infrastructure allowed SunLine to operate fuel cell vehicles and blended hydrogen / CNG vehicles.

The DOE investment in hydrogen infrastructure generated additional projects over a three year period.

Hydrogen was successfully produced from grid and solar power.

Hydrogen was dispensed at the public fueling island to heavy duty fuel cell buses, light duty fuel cell cars, fuel cell golf carts, and blended fuel (Hythane® buses).

Two different hydrogen production manufacturers electrolyzers (Stuart Energy Systems and Teledyne Energy Systems) were successfully tested and supported separate fleet operations. The electrolyzers were operated and maintained by SunLine personnel.

A Hydrogen Burner Technology natural gas reformer was successfully tested, operated and maintained by SunLine personnel.

The DOE infrastructure investment aided in the development of the training program "Hydrogen Fuel Cell Engine and Related Technologies" for 21st century hydrogen engine and infrastructure technicians.

The DOE infrastructure investment aided in identifying a new type of maintenance facility for use in moderate to extremely hot climates.

The SunLine hydrogen infrastructure was constructed by a transit agency.

SunLine Transit Agency and SunLine Services Group followed all applicable codes and standards and successfully achieved permits to construct and operate the world's first public hydrogen fueling station. Approval involved the County of Riverside as the host geographic site and the cities of Desert Hot Springs, Palm Springs, Cathedral City, Rancho Mirage, Palm Desert, Indian Wells, La Quinta, Indio, Coachella and County of Riverside as service operating sites. See Appendix L.

SunLine personnel collected data regarding the amount of electricity required to produce hydrogen from both grid and solar sources.

SunLine diagnosed and repaired hydrogen infrastructure problems based on normal wear and tear on equipment.

SunLine personnel using SunLine's 100,000 scf 16 tank tube trailer delivered hydrogen to an automobile manufacturer's field test facilities near Reno, Nevada.

SunLine personnel using the above tube trailer supplied hydrogen to the Michellen Bibendum Alternate Fuel rally in October 2001 at Ontario, California and Las Vegas, Nevada. Some of the support required in-route refueling.

SunLine efforts over the last three years have raised the awareness level of the need for consistent codes and standards for hydrogen station construction, production, compression, storage, and dispensing as well as vehicle maintenance facilities required and their construction and vehicle maintenance operations.

SunLine personnel drove the XCELLSiS ZEbus from Ontario, California to Las Vegas, Nevada without vehicle or refueling problems.

SunLine Transit Agency is successfully operating the ThunderPower fuel cell bus in daily route service in the Coachella Valley. The delay in initial operations imposed by the insurance industry for Thor Industries point to the immediate needs of including the insurance industry in fuel cell / hydrogen technology.

Figure 26: Document & Reports

SunLine Transit Agency is successfully demonstrating the Georgetown University fuel cell bus in demonstration rides.

SunLine successfully presented the Department of Energy, Federal Transit Administration, and Department of Defense programs throughout the United States, Germany, Canada, and Japan.

SunLine provided tours every week to local residents. SunLine provided tours to visitors from all over the world as well as conferences held in the Palm Springs area.

SunLine is currently the only site in the world where hydrogen generated on-site from solar energy is used to power buildings, Hythane® 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.

The following documents and reports were produced under the integrated funding approach:

Figure 27: Renewable Hydrogen Transportation System for the City of Palm Desert, California. No. DE-FC36-96G010139 Final Report (DOE).

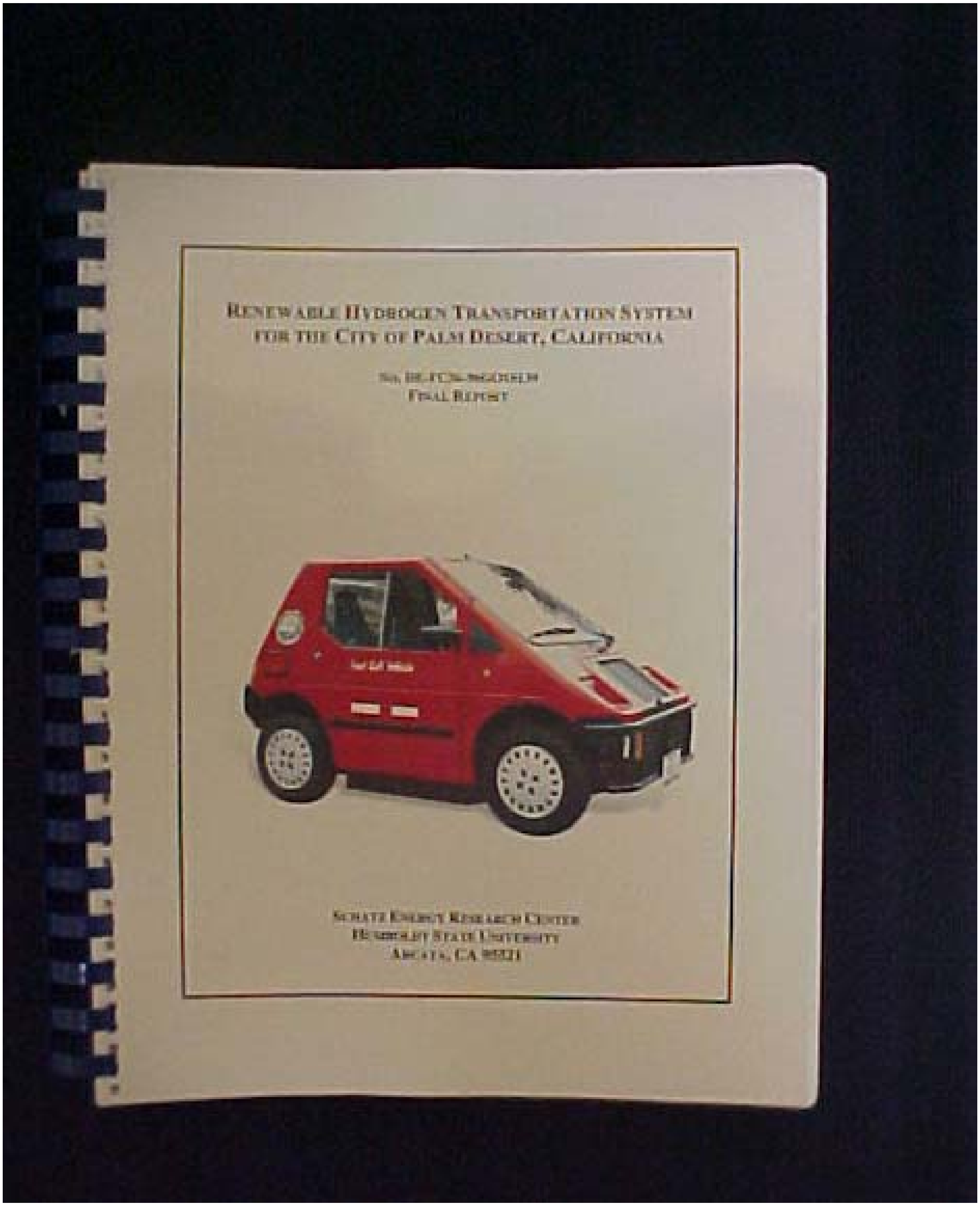


Figure 28: Operations and Maintenance Manual Schatz Hydrogen Generation Center, August 2002 (DOE).

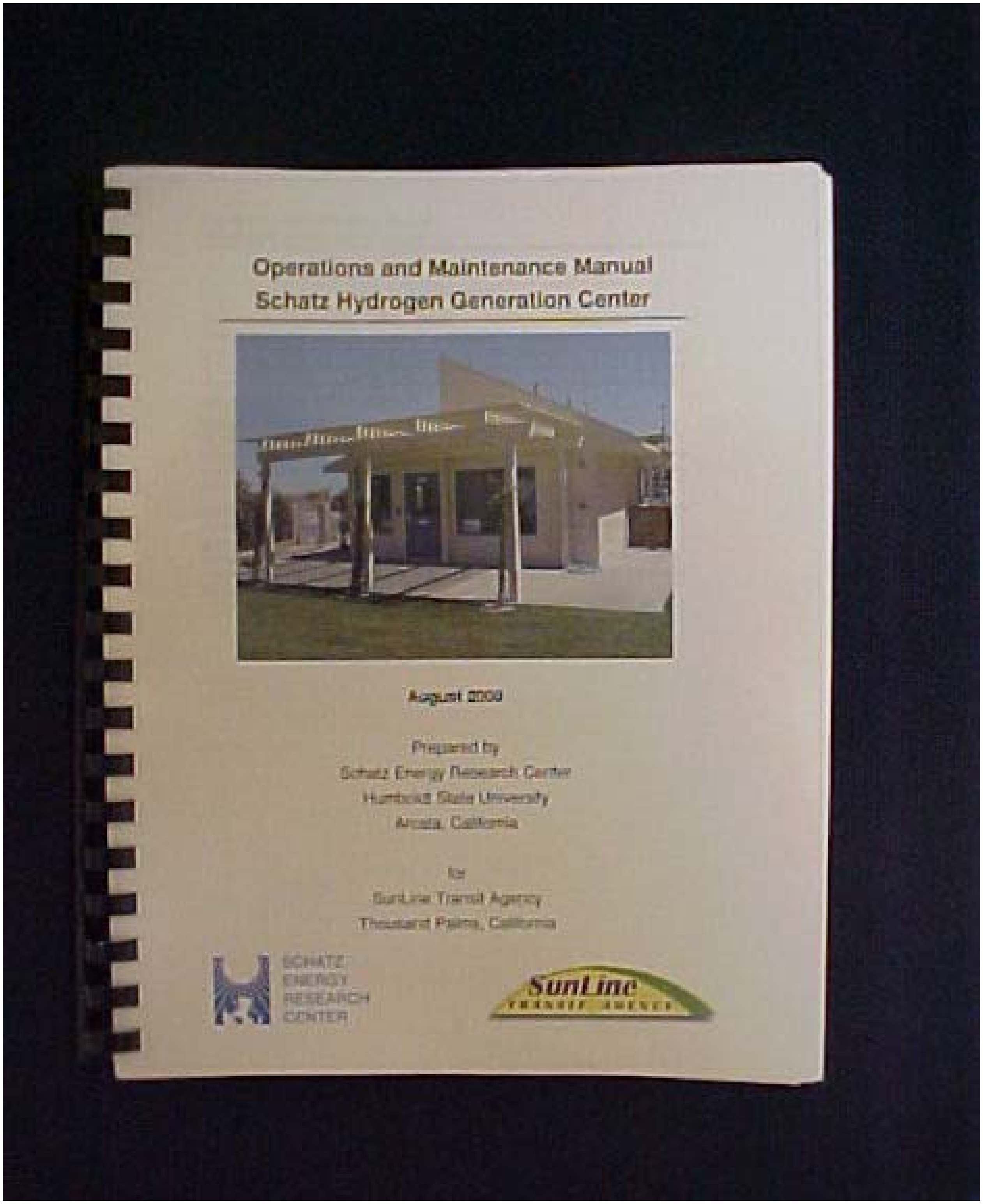


Figure 29: Solar Tracking Panel Operations and Maintenance Manual, SunLine Services Group (DOE).

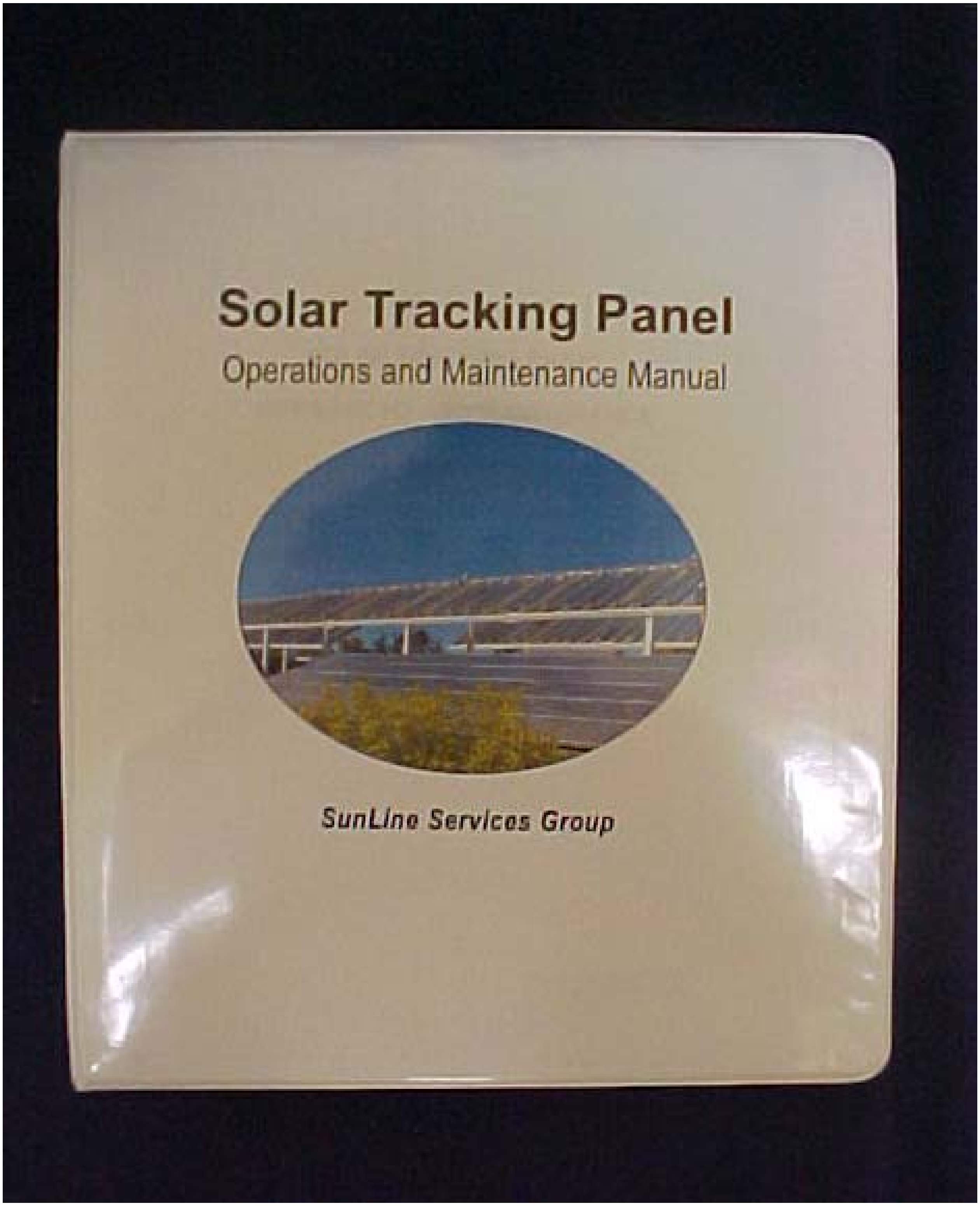


Figure 30: National Renewable Energy Laboratory and International Energy Agency, SunLine Clean Fuels Mall, August 2002.

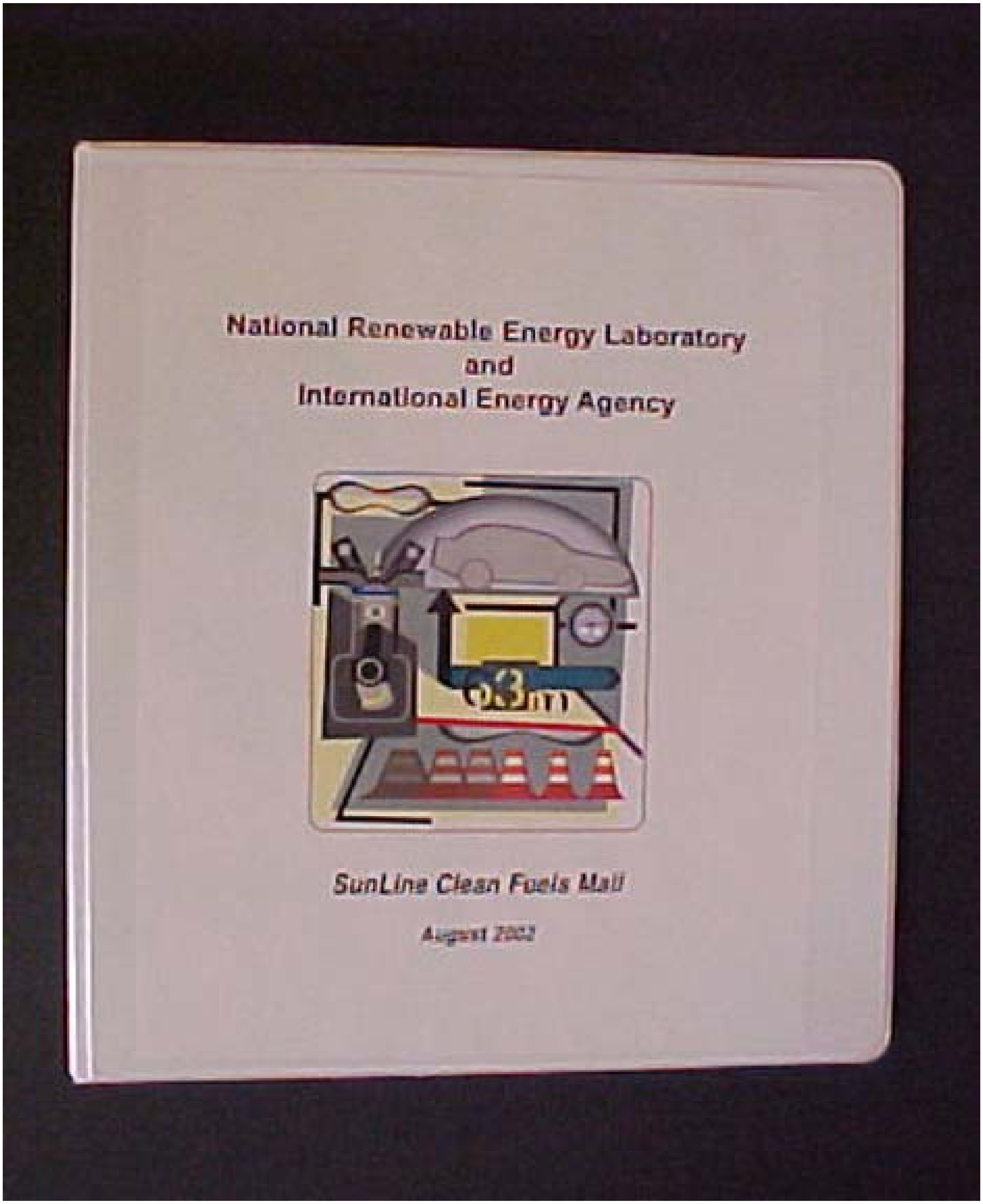


Figure 31: Codes and Standards Reference Guide by the Center for Hydrogen Safety, November 21, 2001 (DOE).

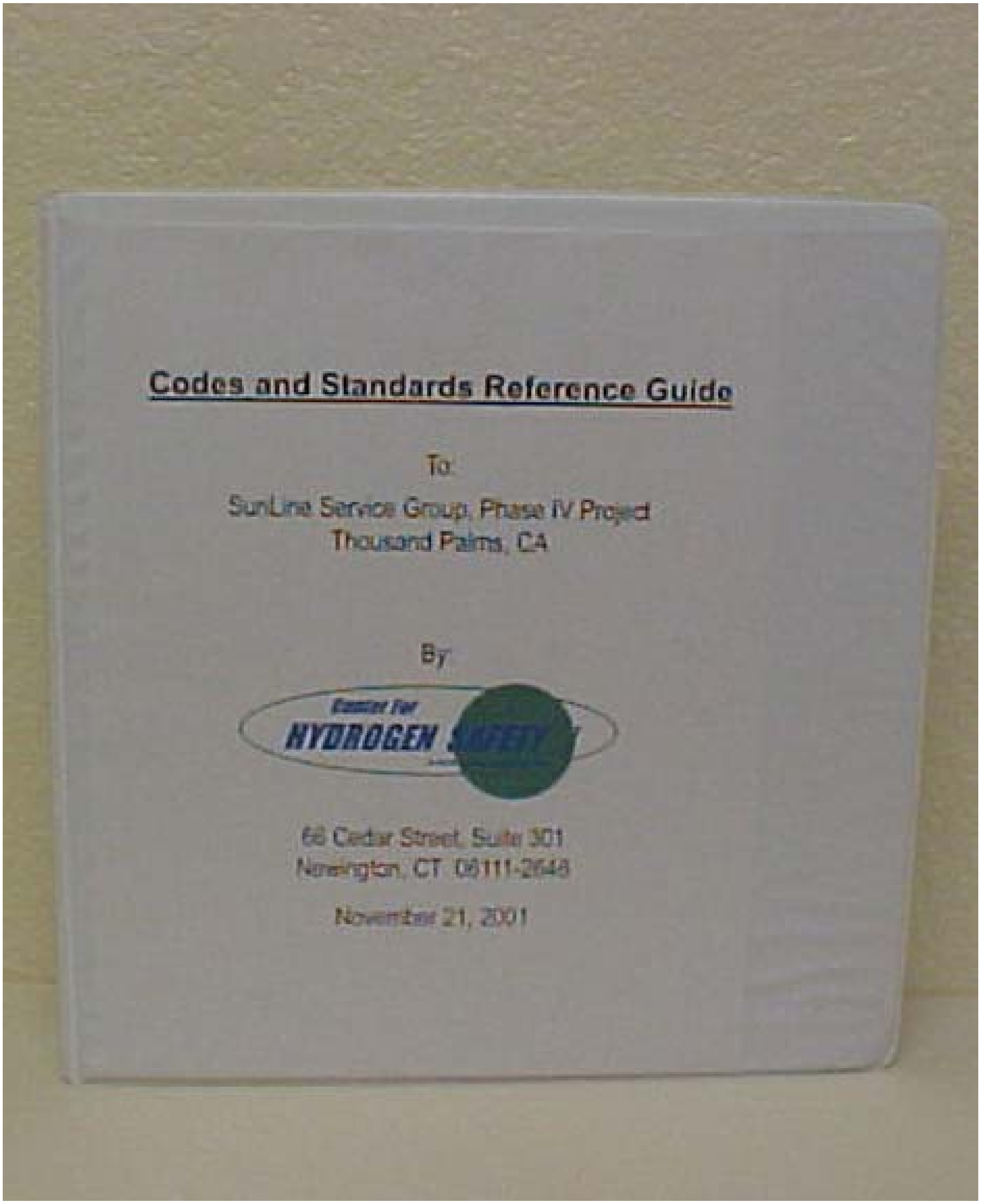


Figure 32: Operation and Maintenance Manual for Model PV-GTI Photovoltaic Inverter, Trace Technologies, December 2, 1999 (DOE).

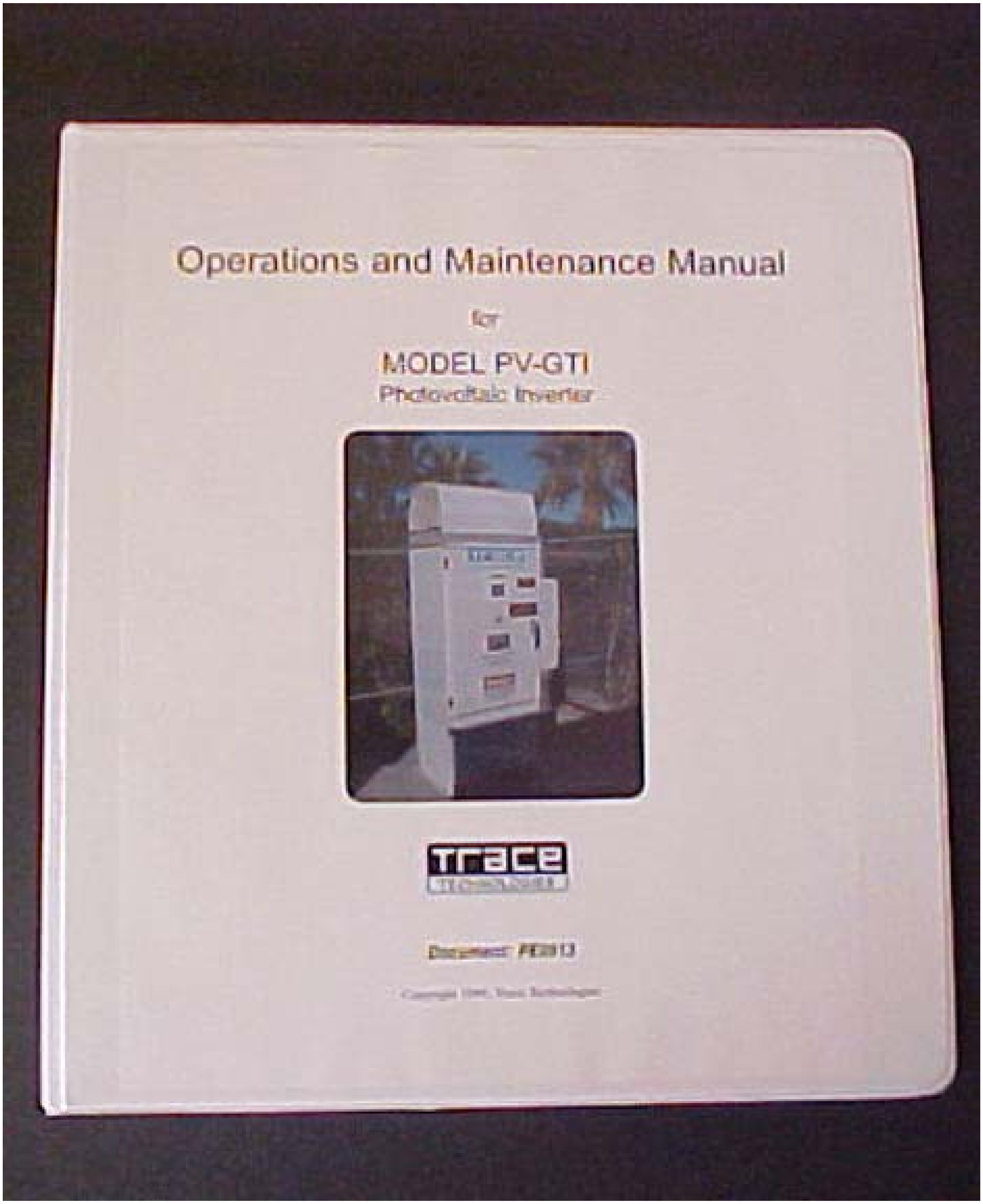


Figure 33: Final Report, SunLine Transit Agency, Cooperative Agreement Project Number CA-26-7022, September 2, 2001, testing of the XCELLSiS ZEbus (FTA), and "Hydrogen Fuel Cell Engines and Related Technologies" Training Manual, Cooperative Agreement, Project Number CA-26-7022 (FTA); Initiated by DOD.

Figure 34: Phase 1 Final Report, Diesel Fuel Reformer for Fuel Cell Truck, U.S. Army Tank Automotive and Armaments Command, National Automotive Center, Agreement No. DAAE07-98-3-0025, May 31, 2001 (DOD).

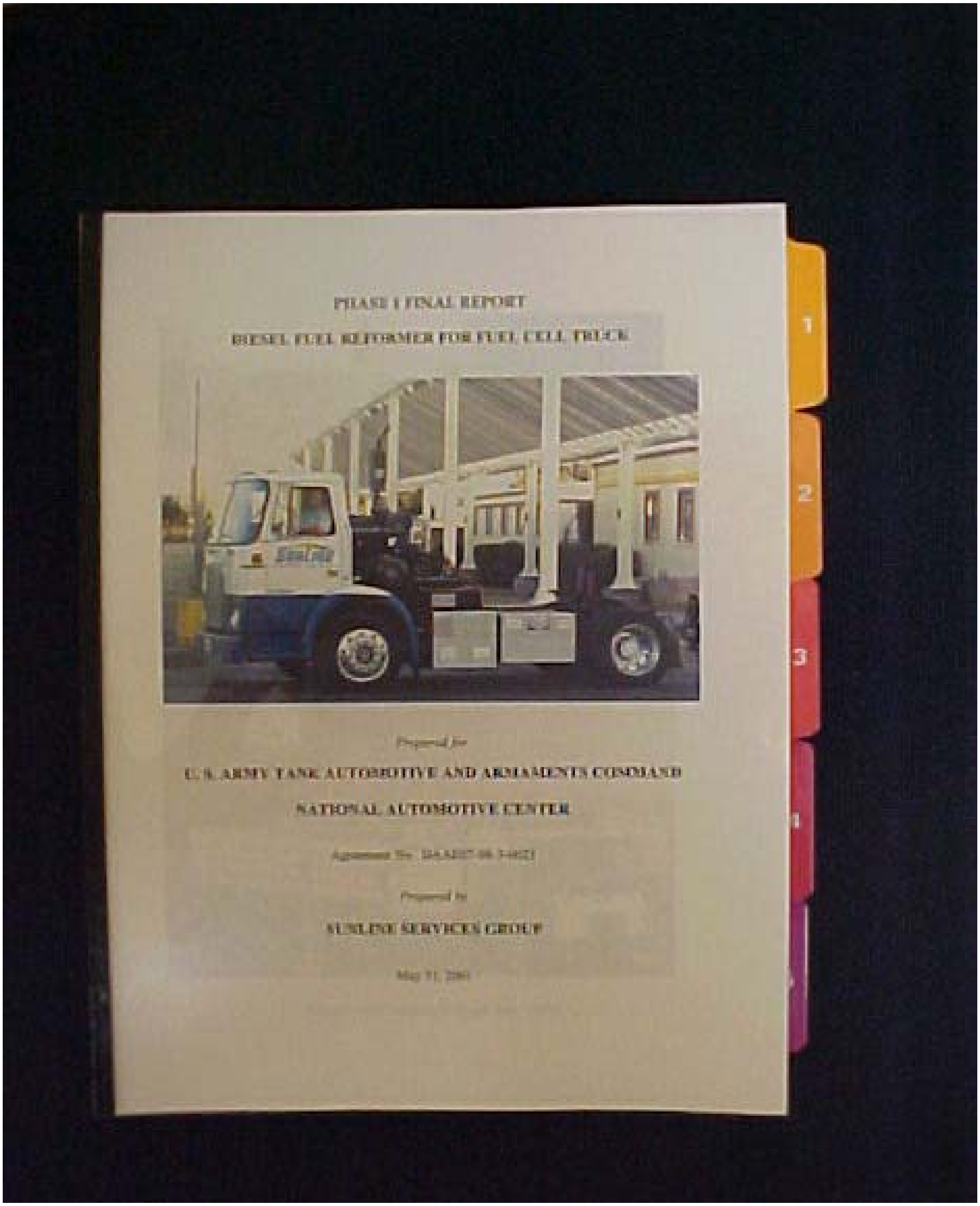


Figure 35: 1000 Palms HAZOPS Meeting Background Notes, July 9, 1999.

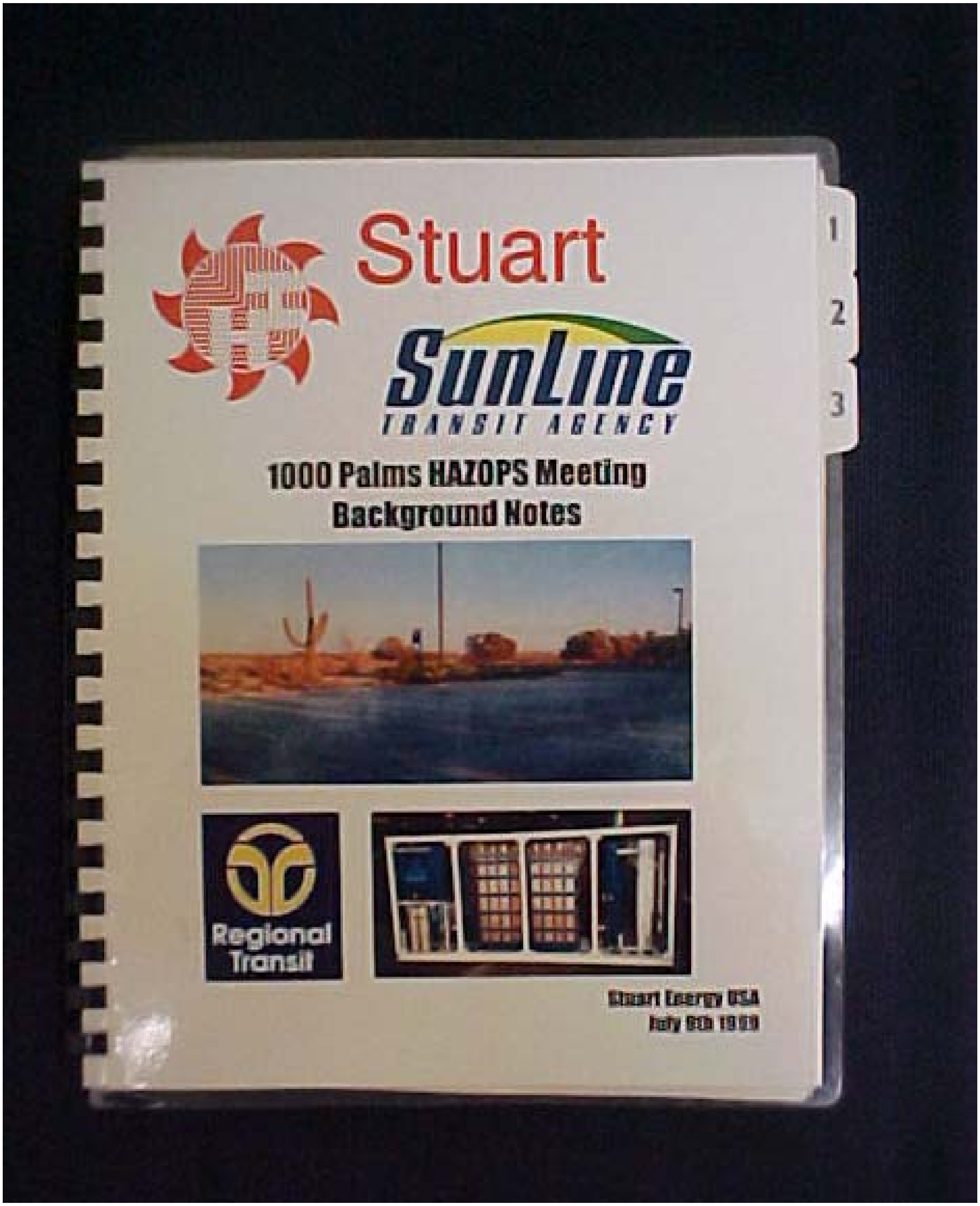
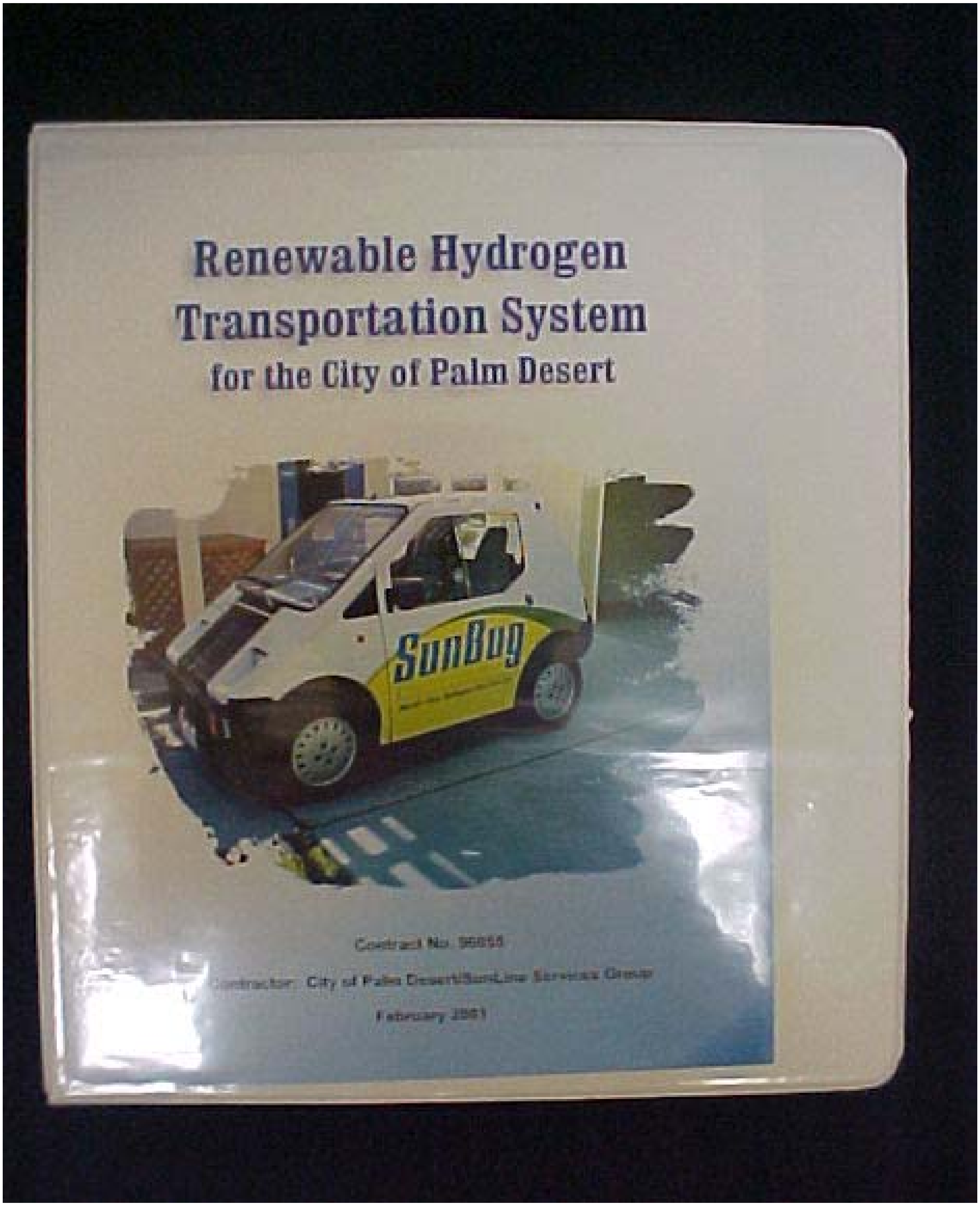


Figure 36: Renewable Hydrogen Transportation System for City of Palm Desert, February 2001.



8. CONCLUSIONS

The Coachella Valley Region serves as a model of a fully functioning hydrogen transportation system (generation, fueling, vehicles, and technician training) for replication across the country.

Construction of a public hydrogen refueling station does not take any additional skill sets beyond those for a CNG station. All codes and standards pertaining to hydrogen production, compression, storage, and dispensing, which are similar in nature to CNG stations, must be followed.

The biggest barrier to expanding 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.

A transit agency can successfully operate and maintain a hydrogen refueling facility with proper training.

SunLine Transit Agency personnel were successful in operating and maintaining fuel cell and blended fuel vehicles.

When fuel cell buses are deployed in revenue service, it will soon be necessary to increase the hands-on involvement of transit personnel.

The "seed" funding by the Department of Energy for infrastructure resulted directly in other hydrogen technologies being tested by other manufacturers of hydrogen related equipment.

In a transit operation, the production of hydrogen by grid and solar power is proven.

Individuals can perform hydrogen-refueling operations similar to CNG refueling operations with no noticeable differences.

Production of hydrogen from natural gas reformers at a transit facility is proven and can be incorporated in a hydrogen-fueled fleet with a smaller footprint and high capacity.

SunLine Transit Agency is a powerful force in developing the pathway for transit and other fleet operators to replicate the transition from a traditionally based fossil fuel fleet to an alternatively fueled fleet operating on hydrogen.

SunLine successfully demonstrated that it can utilize funding from the Department of Energy, Federal Transit Administration, and Department of Defense to create a single integrated program without duplication of effort while satisfying the requirements of each federal agency.

Figure 37: Training and Education

Following the same model for a training program developed by the College of the Desert for Compressed Natural Gas, SunLine developed a training program for technicians of the 21st Century. This training program covered not only Fuel Cells but also blended hydrogen fueled vehicles, pure hydrogen internal combustion engines and hydrogen production, compression, storage, and dispensing systems as well as all related hydrogen codes and standards.

A heavy-duty tent structure facility anchored by two 40-foot sea containers capable of supporting two fuel cell buses at one time was developed as a hydrogen maintenance facility. The structure is suitable between temperature extremes of 30 degrees to 130 degrees Fahrenheit.

The construction of a gaseous hydrogen infrastructure is similar in nature to construction projects related to compressed natural gas. Attention to codes and standards, as in all construction projects, is necessary and can be accomplished with normal skills found in local cities and counties.

The insurance industry is a significant barrier in commercialization of fuel cells and hydrogen for transportation purposes. The insurance industry requires education if it is expected to participate when these vehicles and its fuel are ready for the marketplace.

Data collected regarding the production of hydrogen identified the utility requirements and expected costs within the Coachella Valley Region.

During the course of testing 12,942 scf of hydrogen was produced using the Teledyne Energy Systems electrolyzer (40 scf/hr) and required 2,746 kW of power.

During the course of testing the Stuart Energy Systems electrolyzer (1400scf/hr) 3,420,773 scf of hydrogen was produced and required 425,557 kW of power.

The combined Solar Arrays from the Clean Air Now Project, Department of Energy and Imperial Irrigation District provided 38,943 kW of power to support SunLine's internal power grid.

Operation, maintenance, and support of a hydrogen infrastructure system at a fleet operation facility such as a transit agency is no different than a compressed natural gas facility with proper training related to hydrogen and its chemical properties and necessary safety procedures.

Because transit agencies have a normal education and outreach program for their customer base, they are the perfect forum for bringing hydrogen as a transportation fuel to the attention of the public. Transit programs are geared not only to transit riders but to the public in general in attempts to provide alternate sources of transportation. The vehicles are huge advertising machines.

Most of the equipment being tested at SunLine, either from a vehicle or an infrastructure viewpoint, is somewhere between prototype and pre-production. The equipment tested has not reached the stage of maturity in terms of reliability, or cost competitiveness that would allow a transit agency to invest its limited funding for fleet conversion at this time.

The Coachella Valley has the highest per capita recognition of hydrogen as a fuel source of any other region of the United States.

9. RECOMMENDATIONS

The demonstration programs at SunLine clearly display that more effort is required on the part of the federal government to support manufacturers of hydrogen producing equipment, hydrogen internal combustion engines, and fuel cells. Each of these areas requires a different degree of support depending on their maturity level.

The DOE investment at SunLine should be supported to continue testing of equipment at SunLine's Beta Test facilities where the equipment is put through rigorous field conditions for operations, maintenance, and support in extreme heat environment.

An education program for the insurance industry should be developed through the federal process to aid the industry in understanding the risks involved for fuel cells and hydrogen.

SunLine Transit Agency should be tasked and supported to be the Technology Transfer Agency to ensure the establishment of hydrogen infrastructure at public fleet locations occurs under a "leader – follower" concept. This approach would minimize the risk of duplicate expenditures, improve adherence to codes and standards, and provide training oversight to insure personnel are properly trained.

Funding should be provided to upgrade SunLine's prototype hardware to the next generation of equipment for further testing in order to further the path of continuous improvement for reliability of hardware.

Performance goals in terms of reliability targets (mean time between failure) should be established with manufacturers of hydrogen related equipment.

The DOE should encourage manufacturers of hydrogen prototype equipment to accomplish their testing at SunLine's Beta Test Center because of SunLine's proven abilities as a fleet operator and potential purchaser of equipment once it is ready for commercialization.

“Future Plans” of this final report has a list of recommended projects that should be undertaken to continue the focus on hydrogen as a transportation fuel.

INFRASTRUCTURE

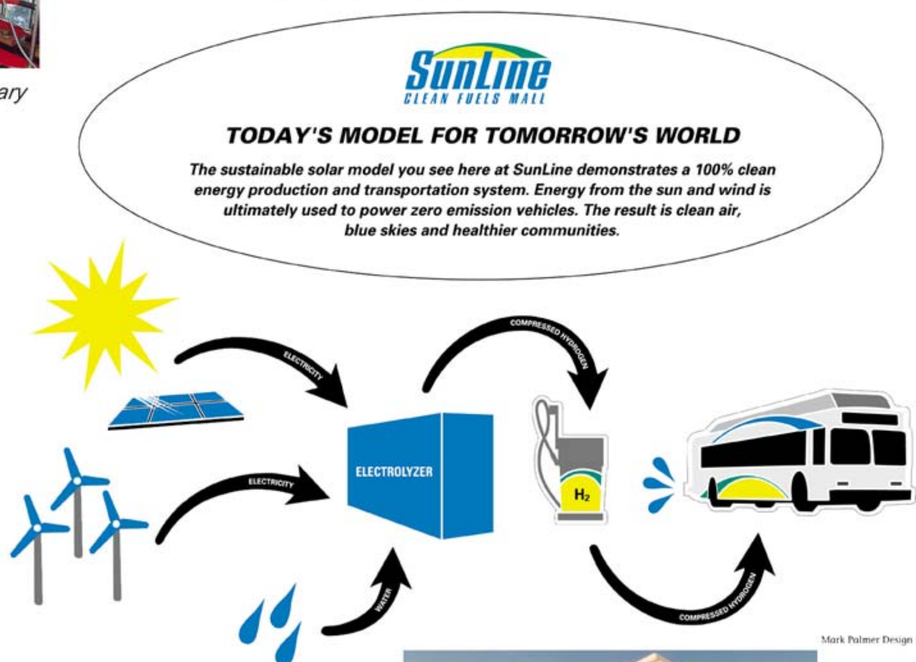
Solar panels provide energy to split water into the Stuart Energy Electrolyzer

Visitor entrance for tours at SunLine Transit Agency

Humboldt State University Schatz Energy Research Center Hydrogen Generation Building at SunLine

Fuel Cell for stationary power at SunLine

Hydrogen/Hythane® dispenser and leak protection system



Small hydrogen refueling station for fuel cell neighborhood electiric vehicles and fuel cell golf carts

SunLine's Dr. Bob Zweig Education and Outreach Facility - grand opening, April 2000

FUTURE PLANS

SunLine Transit Agency has entered into partnership with AC Transit to purchased 4 fuel cell buses. SunLine Transit Agency is purchasing a North American Bus Industries (NABI) 45 foot composite bus with a UTC fuel cell which will be integrated by ISE Research. AC Transit is purchasing a Van Hool 40-foot bus which also will be equipped with an UTC fuel cell and integrated by ISE Research.

SunLine Transit Agency is very impressed with Thor Industries fuel cell bus. However, Thor does not manufacture a 40-foot fuel cell bus, which are SunLine's requirements for its service territory. Information gained by Thor Industries and ISE Research from transit revenue service at SunLine will further the development of transit and fleet vehicle manufacturers.

In planning for its future, SunLine Transit Agency has purchased the 10 acres north of its current property, which will serve as additional space to operate and maintain bus fleet operations including refueling facilities associated with hydrogen.

The 'P3-1A' Bus Fueler prototype is part of Stuart Energy's Fleet Fuel Appliance development program, which is directed at 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 1-3 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 funded by DOE and Stuart energy, 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 roll-out 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 were incorporated into the design of the Phase 5 engine for installation in the 30 buses being delivered to European customers. The information gathered from SunLine will contribute to the 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 four years of experience 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 the test proves 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.

Figure 38: SunBuzz, January 2003

The Future of Mass Transit

The future offers faster service, fewer stops and an improved passenger experience.

The future of mass transit is spelled BRT. The acronym stands for Bus Rapid Transit – an innovative approach to using buses like high-speed light rail. Unlike light rail, which recent studies indicate costs an average of $13 million per mile, BRT uses rubber-tired vehicles at a cost of between $300,000 and $3 million per mile. It utilizes signal prioritization, better stations or shelters, fewer stops and faster service on more attractive vehicles. And in many cases, vehicles operate on dedicated lanes or guideways using optical guidance systems.

"Tracks aren't what make BRT fast," explains GM/CEO Richard Cromwell III. "It's the concept of giving priority to transit vehicles. Since transit vehicles carry more people than other vehicles, the goal is to maximize person throughput, not vehicle throughput."

Looking ahead is the only way to keep pace with future growth. SunLine's forward-thinking board recently approved continued study of the possibility of using BRT on a planned valley-wide express route in conjunction with CVAG. Watch for more details in the future.

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 technology 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.

PROPOSED PROJECTS: HYDROGEN PROGRAM 2003 - 2008

The following project outlines provides information for continuing technology improvements for hydrogen vehicles and equipment. Appendix M is a concise listing of project titles.

HYTHANE® SUNBUS AND HYDROGEN FUEL CELL VEHICLES

TRANSPORTATION

1. Performance and emissions of a blended hydrogen and compressed natural gas (HCNG) fueled light duty vehicles (platforms might include cutaway vans, a Ford Crown Victoria, F150 and F250 pick up trucks)

SunLine's successful demonstration of two Hythane® buses encouraged the agency to consider the blended fuel as a bridge from compressed natural gas (CNG) powered internal combustion engines to zero emission hydrogen powered fuel cells. Advances in CNG engine technology, combined with the support of an engine manufacturer, give this demonstration an even greater chance for success in achieving desired emission reductions with no significant loss in power or engine efficiency.

This project evaluates the performance and emissions of a state-of the-art Ford dedicated CNG engine fueled with Hythane® as CNG serves as a baseline. Performance and wear will be evaluated over a twelve-month period with a final inspection and emissions verification performed at the end of the test period. During the test period, boroscope and compression checks will be performed every 3,000 miles, corresponding with regular check-ups. After a twelve-month period or 24,000 miles of experience per vehicle, subject to positive results, SunLine will begin the phased conversion of all its light duty vehicles equipped with Ford engines.

Benefits:

CNG light duty engines are extremely reliable and exhibit limited wear in critical engine components while exhibiting ultra low emission vehicle (ULEV) characteristics. As a result, it is anticipated that current buses and engines may be in service for many more years. Blended fuels (Hythane® in particular) may well offer a low cost alternative to meeting 2007 regulations.

Partners:

Hydrogen components, NREL, SCAQMD, Ford Motor Company

2. Performance and emissions of hydrogen fueled Ford 460c.i. V8 in light duty vehicle application (possible platforms might include Crown Victoria, Vans, F150 and F250 pick up trucks)

Ford and Ballard Power Systems in cooperation with SouthWest Research Institute have demonstrated the operation of the above engine for a stationary power application. Advances in hydrogen fueled internal combustion engine technology, combined with the support of an engine manufacturer, give this demonstration an even greater chance for success in achieving desired emission reductions with no significant loss in power or engine efficiency in a transportation application.

This project evaluates the performance and emissions of a state-of the-art Ford dedicated CNG engines fueled with hydrogen as CNG serves as a baseline. Performance and wear will be evaluated over a twelve-month period with a final inspection and emissions verification performed at the end of the test period. During the test period, boroscope and compression checks will be performed every 3,000 miles, corresponding with regular check-ups. After a twelve-month period or 24,000 miles of experience per vehicle, subject to positive results, SunLine will begin the phased conversion of all its light duty vehicles equipped with Ford engines.

<u>Benefits:</u>

CNG light duty engines are extremely reliable and exhibit limited wear in critical engine components while exhibiting ULEV characteristics. As a result, it is anticipated that current vehicles and engines may be in service for many more years. Hydrogen fueled internal combustion engines (ICEs) may well offer a low cost alternative to meeting 2007 regulations in anticipation of wide spread availability of hydrogen fuel cell powered vehicles.

<u>Partners:</u>

Hydrogen components, NRGTech NREL, SCAQMD, Ford Motor Company

3. Performance and emissions of hybrid electric hydrogen fueled ICE bus (consider using Ford 460c.i. V8 developed by Ballard and Southwest Research Institute for power generation or Cummins B+ or C+ heavy-duty engine)

Hybrid electric bus technology is widely recognized as the path to hydrogen fueled-fuel cell bus technology. Hybrid electric diesels have been introduced in a number of transit agencies while a few hybrid CNG buses have been introduced in the L.A. area by L.A.M.T.A. The CNG hybrids were powered by Capstone Turbines and in one case by a dedicated CNG Ford 460 V-8 engine.

The recent work performed by Ballard Power Systems, Ford Motor Company, and SouthWest Research Institute with a hydrogen-fueled turbo-charged Ford 460 V-8 engine, provides an opportunity to use this engine in a hybrid electric bus configuration. The engine produces 140 kW at 3600 RPM and emissions data compared well to its CNG sibling.

Benefits:

It is widely recognized that hybrid electric bus technology needs to be developed and tested further. Similarly, it is also recognized that hydrogen-fueled internal combustion engines may provide a bridge to fuel cells and support the early development of hydrogen fueling infrastructure. This project would enhance hybrid electric bus development, promote the development of fueling infrastructure and the development of hydrogen in internal combustion engines.

Partners:

Hydrogen components, NREL, SCAQMD, Ford Motor Company

4. Development, testing and performance assessment of hydrogen fueled fuel cell APU in class 8 tractor

Heavy-duty trucks are an essential part of the United States Army operations. Diesel fuel accounts for 70% of the total bulk tonnage shipped to support a typical military deployment. Similarly, heavy-duty trucks are used to move goods from coast to coast and from farms and factories to consumers.

The National Automotive Center (NAC), a division of the U.S. Army, has set a goal to reduce fuel consumption by exploring the use of fuel cells and electric drive systems. The '21st Century Truck' project was initiated to support this exploration. One of its key components is the development of an on-board diesel reformer that would enable hydrogen to be generated on-board from diesel, and address problems currently caused by diesel emissions. A unique aspect of this project is the dual potential use of the technology resulting in potential military and civilian applications and benefits.

Project participants are tasked to identify suitable existing near-term technologies, carry out design and integration for proof of concept, and validate the systems in real world testing. In addition, participants are contributing to the development of ancillary programs such as a model currriculum for mechanics and technicians training.

<u>Significance:</u>

New emerging fuel cell technologies have the potential to substantially increase fuel economy and reduce emissions of heavy-duty vehicles in both military and civilian applications.

<u>Partners :</u>

NAC, Cummins, Ballard, UTC, NREL

5. Testing and performance of sodium borohydride-fueled Chrysler minivan in a hot weather environment

Daimler Chrysler has successfully developed a sodium borohydride-fueled fuel cell powered minivan. The vehicle has been featured at a number of venues and continues to draw interest from the public at large.

Millenium Cell, the developers of hydrogen on demand (H.O.D.) systems featuring the production and utilization of sodium borohydride, are keen to further test and determine the advantages and limitations of H.O.D. systems in transportation applications. SunLine proposes to run the Daimler Chrysler minivan in the Coachella Valley for a period of one year and assess its performance, reliability and system efficiencies. The vehicle will be subjected to daily commuting in all weather conditions.

<u>Benefits:</u>

The Daimler Chrysler minivan will be subjected to daily commuting operations for a twelve-month period. Valuable information on the design, performance, benefits and shortfalls of H.O.D. systems will be reviewed and documented.

<u>Partners:</u>

Daimler Chrysler, NREL, SCAQMD, Millenium Cell

PRODUCTION AND INFRASTRUCTURE

1. Hydrogen production and fueling station reliability assessment (include electrolysis, natural gas reforming and possibly biomass-based process in evaluation)

SunLine has a unique position to compare the performance and operation of different hydrogen production technologies. SunLine currently operates two alkaline electrolyzers and will operate an auto-thermal natural gas reformer in the second quarter of 2003. Performance of the electrolyzers has been closely monitored over the last thirty months while the auto-thermal reformer will be the subject of 36 month CEC sponsored field verification study.

Positive reports have been published concerning the use of biomass feedstocks for hydrogen production and the potential for zero emissions. Gasification units have not yet been documented and there is an opportunity to test and assess the performance of such systems in a real world environment. The SunLine Clean Fuels Mall would provide an excellent location for the test and would allow a performance comparison with other hydrogen production systems.

Benefits:

It is recognized that the implementation of hydrogen production systems and the choice of feedstock will vary greatly from coast to coast and will be very much resource based. It is proposed to test, develop and assess the performance of different pre-commercialization systems and make the data available to DOE and potential developers of hydrogen fueling facilities.

Partners:

ChevronTexaco, Hyradix, NREL, SCAQMD, Stuart Energy Systems, Teledyne Energy Systems.

2. Development and testing of high pressure electrolyzer

SunLine's arrival into the hydrogen arena began with a request from the Department of Energy to disassemble two projects, relocate them to Thousand Palms, and integrate them into a system where hydrogen generated on-site would be used as a transportation fuel. The Stuart P3 prototype electrolyzer (the backbone of SunLine's generation capabilities and an upgrade from the original project) was installed and operational within 24 hours of arriving at the transit agency.

High-pressure electrolyzers offer significant advantages to low pressure electrolyzers. Gas clean-up is simplified, can be performed at relatively low pressures and the high pressure electrolyzers are well suited for use with diaphragm compressors. Finally, overall energy efficiency and capital costs may be lower than low-pressure systems.

Benefits:

SunLine created the first hydrogen fueling station in the U.S. built and operated by a public transit agency. High-pressure electrolyzers offer the opportunity to reduce capital and operating costs. Modular and user friendly, the electrolyzer could accommodate a number of vehicles and capacity can be expanded as required. Given the opportunity to use either electricity produced from renewable sources or off peak nuclear power, this technology would result in economical hydrogen production and zero emissions.

Partners:

Stuart Energy Systems, NREL, SCAQMD

3. Development of synthetic fuels production facilities and their impact on hydrogen availability and production costs

The future undoubtedly will include a variety of liquid and gaseous fuels. Hydrogen is an intermediate product in the production of Fischer-Tropsch Liquids (FTL). The latter may be produced from natural gas, subsea methane hydrates, biomass and coal, like hydrogen. Feedstock flexibility is critical to U.S. energy self-sufficiency and balance of payments. The biomass alternative means that FTL and hydrogen could be produced from waste and renewables. The use of natural gas as a feedstock could be particularly interesting from stranded gas fields where conversion to LNG is not feasible. Use of subsea methane hydrates as a feedstock offers the potential for very large domestic energy reserves for our country and an efficient production/finished fuel delivery system.

FT Diesel is a liquid at ambient temperature, has zero or near-zero sulfur and an energy density close to conventional diesel fuel. It may be used directly in diesel engines or as a blending stock. With the predictable demand for cleaner diesel fuel in the next ten years, FT diesel may transition from a product looking for a market to a product the market will seek out. FT diesel is currently being manufactured in small quantities.

Many manufacturers are viewing Fischer-Tropsch liquids as a viable way to use alternative fuels in diesel engines without compromising fuel efficiency, impacting infrastructure or fueling costs. The California Energy Commission states that the superior quality, cost and ease of distribution could lead to the production of 2 to 3 million barrels a day by 2005.

<u>Benefits:</u>

Combined hydrogen and FT diesel could be produced at the same facility. Investments in hydrogen production could be supported by the expansion of a zero sulfur FT diesel liquid. This would result in overall lower production costs for hydrogen and FT diesel. A feasibility study would be particularly useful to explore this opportunity.

<u>Partners:</u>

TotalFinaElf, UOP, Hyradix, NREL, SCAQMD

4. Solid Oxide Fuel Cell (SOFC) and PEM fuel cell reliability assessment and testing program in stationary application

As a member of the both the California Stationary Fuel Cell Collaborative and California Fuel Cell Partnership, SunLine is dedicated to advancing fuel cell and hydrogen generation technologies. From technology advancement and cost effectiveness perspectives, utilizing on-site infrastructure for distributed generation in addition to transportation applications is value-added. SunLine proposes to commission construction of a stationary demonstration of SOFC and PEM 5 kW fuel cells.

The production units would be an extension of the agency's education collaborative education/outreach program. Designed to educate while demonstrating stationary fuel cell technology, the fuel cells would provide power for light computer applications. The location of the fuel cells would be within the Clean Fuels Mall because it would be seen most frequently by industry partners and visitors.

<u>Benefits:</u>

By using hydrogen and natural gas in fuel cell applications, the project would demonstrate energy efficient distributed power generation for stationary power applications. In addition, SunLine staff will have the unique opportunity to participate in the construction, installation and operation of the agency's first stationary fuel cell. Advantages would be assessed and documented for the different technologies.

<u>Partners:</u>

Siemens, UTC, NREL, SCAQMD,

5. Hydrogen power park development, testing and economics

Since the invention of electricity and the internal combustion engine, the relative abundance and simplicity of fossil fuels made them the best available alternative for transportation fuel and for electricity generation. Fossil fuels have a number of shortcomings; including their contribution to global warming and location in inaccessible or foreign regions. This dependence has resulted in a society that is at risk in a number of areas.

We can mitigate these risks over the long term by developing and implementing a viable alternative to fossil fuels for both transportation and power generation. This alternative is the effective use of non-carbon, renewable energy sources, like wind and solar. These renewable energy resources have the potential to provide a 100% clean, green house gas (GHG), and indigenous energy solution. Historically, only limited use of these vast energy resources has been possible, as there has not been a complete and cost-effective technical solution. Wind turbines or solar panels on their own have not been effective, as they are inherently intermittent. In recent years renewable energy technologies have been developed to a point where, if the fundamental issue of energy storage could be addressed, a wide-scale commercial product could be developed.

A solution currently exists and has the potential to enable the mass commercialization of renewables for energy and transportation fuel. This solution is an electrolysis-based renewable energy station, and is the focus of this project.

Benefits:

This will be done by demonstrating the effectiveness and safety of the renewable energy station concept, and its near-term potential as a replacement alternative to fossil fuels. The proposed project will employ the best available water-electrolysis technology further developed from the technology demonstrated in “Filling Up With Hydrogen 2000”. This technology will be used in a modular and flexible renewable energy station that will be capable of meeting the DOE cost targets, demonstrated in real-world operating conditions.

Partners:

Stuart Energy Systems, Hyradix, Acumetrics, Plug Power, ChevronTexaco, NREL, SCAQMD

6. SunLine / Cummins In-Cylinder Hydrogen Experiment

Cummins and SunLine have a long history partnering on clean fuel projects. In 1998 SunLine selected Cummins as their partner for supplying natural gas engines to completely re-power their diesel bus fleet. We have continued to work together to pursue cleaner and more efficient technologies through the following programs:

- Electronic controlled gas engines
- Lower emissions full authority electronics
- Hydrogen/natural gas blends using the L10 engines
- Hydrogen/natural gas blends using 5.9BG+
- High efficiency/low emissions lean burn Power Generation project
- Hydrogen/natural gas blend in the HHP lean burn Power Generation program

Lean-Burn Power Generation Project Background

Cummins and SunLine have partnered to field test a Cummins high-efficiency lean-burn natural gas generator set. Other partners in this effort have included Southern California Gas Company, Imperial Irrigation District (IID) and Cummins Cal Pacific. The generator set went into full-time operation in mid-September of 2002.

Lean-burn technology provides an opportunity to improve emissions over conventional (stoichiometric) natural gas engines while maintaining high-level performance and power density. Cummins' line of high-range lean-burn products use closed loop control to optimize performance, efficiency and emissions. Lean burn technology reduces NO_X by decreasing the peak temperatures during the combustion process.

Cummins has delivered lean-burn power plants throughout the world. One of the driving factors for these type plants is the overall efficiency that can be obtained by recovering the waste heat in a combined heat and power plant, also known as a cogeneration plant. Cogeneration can achieve overall efficiency in the mid to high eighty percents. Combining this high level of overall efficiency with the low emissions of the lean burn engine and low operating costs results in a viable commercial product that is safe to the environment. Cummins intends to continue the development of lean-burn technology to reduce emissions to levels that do not require after-treatment.

Benefits:

In a separate research effort, Cummins and SunLine are testing and demonstrating the benefits of mixing hydrogen with compressed natural gas to further improve emissions for the transportation sector. This technology is a natural addition to the lean-burn natural gas distributed power field test currently underway at SunLine. While Cummins continues to improve the emissions using natural gas, further improvement can be achieved by introducing a mix of hydrogen (Proposed Hydrogen / Natural Gas Mixing (H_2CNG))

to the fuel. Testing a variable mix of hydrogen with natural gas at SunLine will provide an opportunity demonstrate the technology in a high horsepower, lean-burn natural gas generator and provide meaningful data to help determine the optimal mix rate.

Partners:

Cummins, Southern California Gas, SunLine Transit Agency

GENERAL

1. Development and testing of diagnostic fuel cell test equipment

Diagnostic products are still very much in the research and development stage. On-board diagnostics will be required for monitoring and providing information on failures, performance and safety. Off-board diagnostics will allow repair technicians to trouble shoot problems using data acquired by the on-board module.

Fuel Cell Component analyzers should have the following key features:

- Instantaneous and endurance testing of PEM fuel cell components
- Compact, integrated and self-contained
- Multi-channel – incorporating four independent test cells, load unit, humidifiers and controls
- User-friendly – automated, continuous and unattended operation
- User-programmable for specific multi-sequence testing
- Operating manual and training included
- Pic-control

SunLine will lead a team of experts in the development and demonstration of a diagnostic fuel cell tool for heavy-duty fuel cell applications.

<u>Benefits:</u>

Good research planning and diagnostic tools can eliminate years from the research and development cycle. SunLine hopes to be a major contributor in the development phase and be in a position to provide real time data to transportation and stationary fuel cell developers.

<u>Partners:</u>

S.E.R.C., Element One, Intelligent Energy, Ballard, NREL SCAQMD, United Technologies Corporation

PROJECT FUNDING – BREAKDOWN

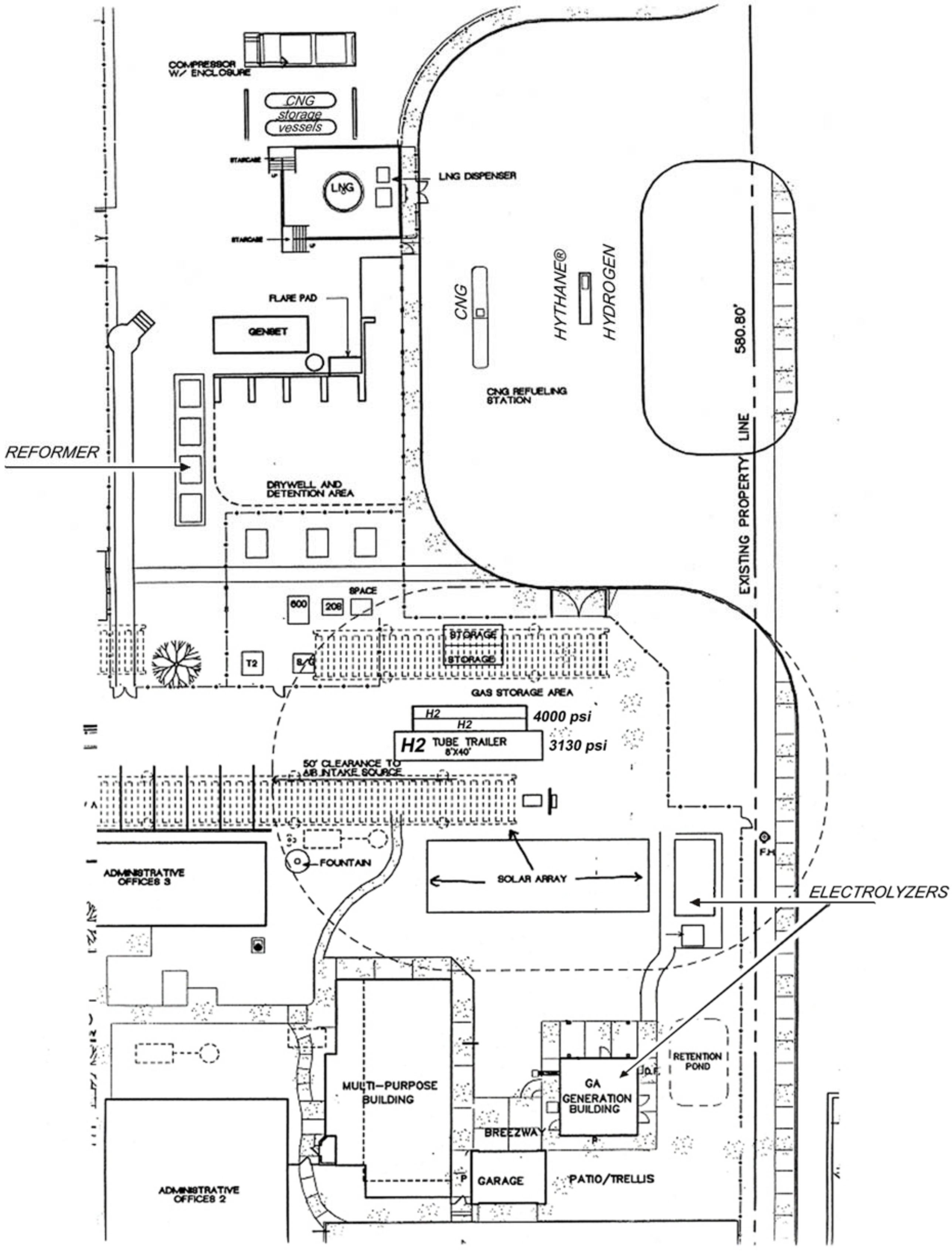
PROJECT TITLE: HYDROGEN COMMERCIALIZATION:
TRANSPORTATION FUEL FOR THE 21ST CENTURY

FUNDING

DC-FC36-96GO10139,A008,A009

	Total Funding ($)	Actual Cost ($)
Hydrogen Generation Building	90,766	90,766
Electrical Service	10,704	10,704
Solar Panel Installation	17,227	17,227
Transformer / Inverter	22,269	49,000
SERC Equipment / Software	326,718	326,718
Mobile rigs and Gas Storage	7,900	9,931
Safety Assessment	29,511	34,251
Dispenser Mixer	63,024	63,024
Other Clean Air Now Costs	43,030	47,761
Flame Detectors	9,415	9,415
Solar Tracking Panels	139,500	139,500
PVI Design	-0-	22,100
Support Structure	210,329	419,235
Storage Tanks	105,000	109,128
Garage	14,504	14,504
Multi-Purpose Building	5,000	157,120
Hydrogen Maintenance Pavilion	47,762	139,552
Security Cameras	18.457	18,457
DOE Miscellaneous	1,913	5,826
Start Up Costs	-0-	12,404
Other DOE Costs:		
Personnel	140,643	288,908
Ford Pick-up	1,182	2,364
Delivery Trailer	-0-	1,125
Trailer Modifications	-0-	1,250
Land Value	15,840	15,840
Power Consumption	3,438	3,438
Misc.	487	487
Aesthetics:		
Parking Lot, Fencing and Gates, Fire/Hydrant / Water Line relocation, Landscaping	110,882	142,018
TOTAL	**$1,435,501**	**$2,152,053**

Figure 39: Site Development



APPENDIX A

Projects/Contracts List

PAST PROJECTS

Project Name	***Dates***	***Funding***	***Partners***
Education, Outreach, Technology Transfer	Aug 2000 -	$500,000.00	Ballard, Dynetek, ENRG, FIBA Technologies, HbT/Gaz de France, QuestAir, SERC, Shell Hydrogen, SCAQMD, Stuart Energy, Teledyne Energy Systems, TotalFinaElf, Webb Foundation
Fuel Cell Training Manual	Sep 2001 - Mar 2002	$260,000.00	FTA, NAC
HbT Natural Gas Reformer	Jan 2001 - Dec 2001	$700,000.00	SCAQMD, CARB
Hythane Bus Demonstration Phase I	Nov 2000 - Apr 2001	$200,000.00	CEC
Solar Hydrogen Project	Apr 2000 -	$1,436,501.00	IID, SERC, DOE, SCAQMD, Colmac, CAN, City of Palm Desert
Stuart P3 Hydrogen Generation System	Jul 2000 - Aug 20002	Unknown	SCAQMD, Stuart Energy, DOE, CAN
ZeBus Demonstration (P4)	Aug 2000 - Sep 2001	$1,988,492.00	FTA

PRESENT PROJECTS

Project Name	***Dates***	***Funding***	***Partners***
Chula Vista Mobile Hydrogen System	Nov 2001 - Jul 2003	$1,000,000.00	CEC, DOE, Stuart Energy, Burnet & Burnette
CNG to Hydrogen Infrastructure Study	Jul 2002 - Sep 2003	$51,680.00	SCAQMD
Cummins 1.4 Megawatt Generator	Apr 2002 - Apr 2003	$800,000.00	Cummins, IID, So CA Gas Company
Educational Stationary Fuel Cell		$242,000.00	Colmac, IID, SERC
Georgetown Bus Demonstration	Aug 2002 - Jul 2003	$138,230.00	Georgetown University, Ballard Power Systems, FTA
Hydrogen Fuel Station Template Study		$68,554.00	ENRG, SCAQMD, Burnet & Burnette
Hydrogen Infrastructure Study	Nov 2002 - Mar 2003	$7,200.00	TIAX (formerly AD Little), CEC
Hythane Bus Demonstration Phase II	Oct 2002 - Oct 2003	$482,820.00	NREL, Cummins Westport, HCI Consulting, SCAQMD
Insulated Tank Project	Nov 2002 - Nov 2003	$484,500.00	SCI Composties, SCAQMD, LLNL
MicroTurbine	Jun 2002 - Jul 2003	$40,443.00 (Installation only)	SCAQMD, Capstone, C4, Inc. (plus Microturbine)

PRESENT PROJECTS continued

Project Name	***Dates***	***Funding***	***Partners***
Stack-in-the-Box Portable Fuel Cell		$35,000.00	Part of SunLine Education Program
Thunderpower FC Bus Demonstration	May 2002 - Mar 2003	$50,000.00	ISE Research, ThunderPower LLC
Wind to Hydrogen Project	Jul 2002 -	$1,200,000.00	ISE Reaserch, Quantum Technologies, SCAQMD, Stuart Energy, DOE, Wintec

FUTURE PROJECTS

Project Name	***Dates***	***Funding***	***Partners***
Fuel Cell Vehicles Upgrade		$445,000.00	DOE
Hawaiian Hydrogen Power Park	early 2003		State of HI, HI Natural Energy Institute, Stuart Energy, UTC
Millennium Cell	early 2003		TACOM, SwRI
NG Reformer Field Verification Study	Apr 2003 - Mar 2006	$470,000.00	DOE, CEC
Teledyne 4750 SCFH Electrolyzer	Oct 2002 - Dec 2004	$2,450,000.00	DOE, Teledyne
		$27,227,272.00	

<u>Vehicle Testing</u>	<u>Provided Hydrogen Fuel:</u>
Yamaha	CACFP 2002 Fuel Cell Conference
Toyota	Michelin Bibendum Challenge
Honda	Automotive Fuel Cell Testing, Reno, NV
Citaro (P5 Ballard)	Hyundai
Nissan	Daimler Chrysler

Source Information: SunLine Hydrogen Program, An Overview
Contract
Matrix

APPENDIX B

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

SunBus with Stuart Electrolyzer

APPENDIX C

Hydrogen Fueling Operations

SunLine Transit Agency conducts two types of hydrogen refueling depending upon which vehicle fuel cell or internal combustion Hythane® is employed. Currently, trained SunLine maintenance and utility personnel perform refueling. SunLine trains all authorized personal on proper refueling procedures. Refueling requires the use of a refueling card for the card reader and these are only issued to trained personnel.

- The bus fuel specification is > 99.9% hydrogen, 0 ppm CO, 0ppm sulphides, and < 1 ppm CO2
- Fuel cell bus and Hythane® bus refueling procedure
- Pre-fueling checks

Prior to fueling the bus, verify that:

- There is no electrical storm
- All emergency fire equipment is in place
- No open flames, sparks or smoking exist near the fueling site
- Sufficient supply fuel pressure exists to fill the bus
- The fueling supply hose is undamaged
- The fueling nozzle and internal O-ring (on hose) are clean and undamaged
- The fueling receptacle (on bus) is clean and undamaged

Fueling Procedure

1. Align the bus at the fueling facility in accordance with the location of the dispenser.
2. Set the master run switch to the STOP ENGINE position.
3. Apply the parking brake and chock the wheels.
4. Ensure that the driver's message center displays the OK TO START message. (After the bus has shut down, the engine voltage takes a few minutes to fall below a specified level. During this period, the driver's message center displays the BUS SHUTTING OFF message. The driver's message center will shut off 3 minutes after the bus has shut down, or when the battery knife switches are opened.)
5. Perform all pre-fueling checks.
6. Open the filling box and radiator grill.
7. Record the value indicated on the bus high pressure gauge or as displayed on a meter plugged into the communications connector.
8. Insert the fueling facility ground connector into the grounding receptacle.
9. Remove the cap from the bus fueling receptacle. Do not use any hand tools to remove the cap! If it does not loosen by hand, a fault may have occurred and the receptacle may be pressurized: abort fueling and refer to the proper procedure.
10. Couple the fueling facility supply hose nozzle to the bus fueling receptacle. Turn the nozzle lever to the locked position.

11. Operate the fueling facility according to established procedures.
12. Uncouple the fueling facility supply hose from the bus and re-cap the fueling receptacle.
13. Remove the fueling facility ground connection from the bus.
14. Record the value indicated on the bus high pressure gauge (or as indicated on a pressure meter plugged into the communications connector).
15. Complete a fueling log.
16. Remove the wheel chocks.

Tube Trailer Preparation and Procedure (fuel cell buses only)

Attach the following fueling interfaces:

- A ground cable with a male Camlok ground stud termination, or suitable grounding clamp
- A fuel supply hose with a Sherex CH1000 nozzle (The fuel supply hose must be constructed of synthetic material, stainless steel braid, and pressure tested to 1.5 times the rated pressure.)
- A 3-way manual tube trailer bleed valve vented to atmosphere (to purge the supply hose)

Fueling Procedure

1. Locate the rear of the bus near the rear of the tube trailer.
2. Set the master run switch to the STOP ENGINE position.
3. Apply the parking brake and chock the wheels.
4. Ensure that the driver's message center displays the OK TO START message. (After the bus has shut down, the engine voltage takes a few minutes to fall below a specified level. During this period, the driver's message center displays the BUS SHUTTING OFF message. The driver's message center will shut off 3 minutes after the bus has shut down, or when the battery knife switches are opened.)
5. Ensure that the tube trailer brake is applied.
6. Perform all pre-fueling checks.
7. Open the filling box and radiator grill.
8. Record the value indicated on the bus high pressure gauge or as displayed on a meter plugged into the communications connector.
9. Ensure that the tube trailer pressure gauge indicates at least 500 psi more than the bus high pressure gauge.
10. Connect the tube trailer ground cable connector to Earth.
11. Connect another ground cable to the tube trailer grounding plate and to the bus grounding receptacle.
12. Remove the cap from the bus fueling receptacle. Do not use any hand tools to remove the cap! If it does not loosen by hand, a fault may have occurred and the receptacle may be pressurized: abort fueling and refer to the proper procedure.

13. Open the master tube trailer valve.

14. Check all supply line components for deformities, corrosion or other signs of damage.

15. Purge the supply line hose (if the tube trailer differs, follow appropriate purge procedure):

    a. Open any individual tube trailer valve - this pressurizes the fuel supply hose.

    b. Close the individual tank valve.

    c. Set the tube trailer bleed valve so that all the gauges in the fuel supply hose vents to atmosphere.

    d. Set the tube trailer bleed valve so that the gas will flow to the bus.

    e. Repeat a total of three (3) times.

16. Couple the fueling facility supply hose nozzle to the bus fueling receptacle. Turn the nozzle lever to the locked position.

17. Set the tube trailer valve so that the gas will flow to the bus.

18. Fuel from one tube trailer tank:

    a. Open any individual tube trailer valve - this pressurizes the fuel supply hose. Fuel the bus using only one tube trailer tank at a time.

    b. Continue to fuel the bus until the sound of rushing gas stops. The bus high pressure gauge should be within 200 psi of the supply pressure as indicated on the tube trailer pressure gauge.

    c. Close the individual tube trailer valve and open another tank's valve.

    d. Repeat until the bus fuel pressure matches that in any of the individual tube trailer tubes or the tube trailer is depleted.

17. Close the master tube trailer valve and ensure that all other individual tube trailer valves are closed.

20. Uncouple the fueling facility supply hose from the bus and re-cap the fueling receptacle.

21. Remove the fueling facility ground connection from the bus.

22. Record the value indicated on the bus high pressure gauge (or as indicated on a pressure meter plugged into the communications connector).

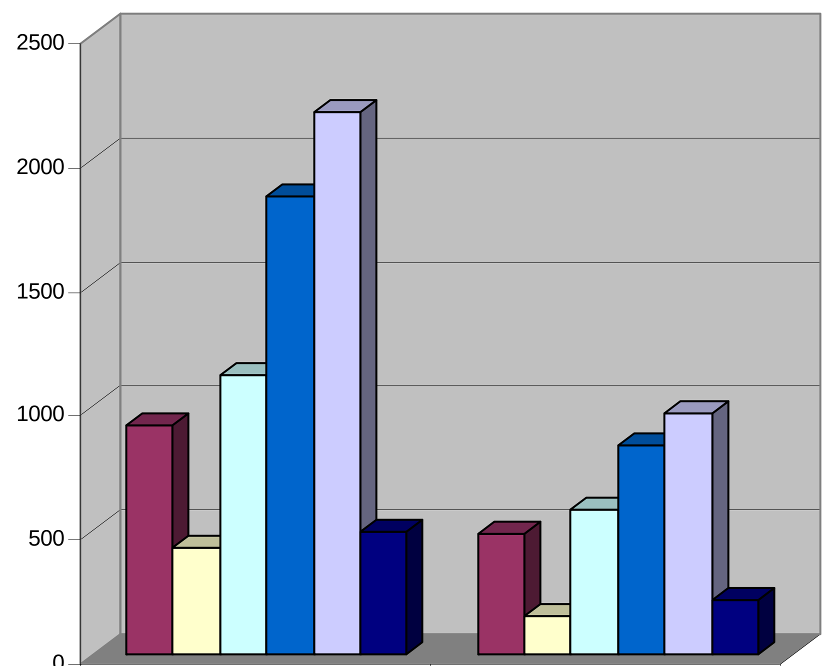
23. Complete a fueling log.

24. Remove the wheel chocks.

APPENDIX D

Hythane® Bus February 2001 – April 2002

Hythane® Bus Miles Driven, Hythane® Used, and Miles Per G.G.E.



	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

APPENDIX E

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

APPENDIX F

Overview of Ballard/XCELLSiS Fuel Cell Engine and P4 Fuel Cell Bus

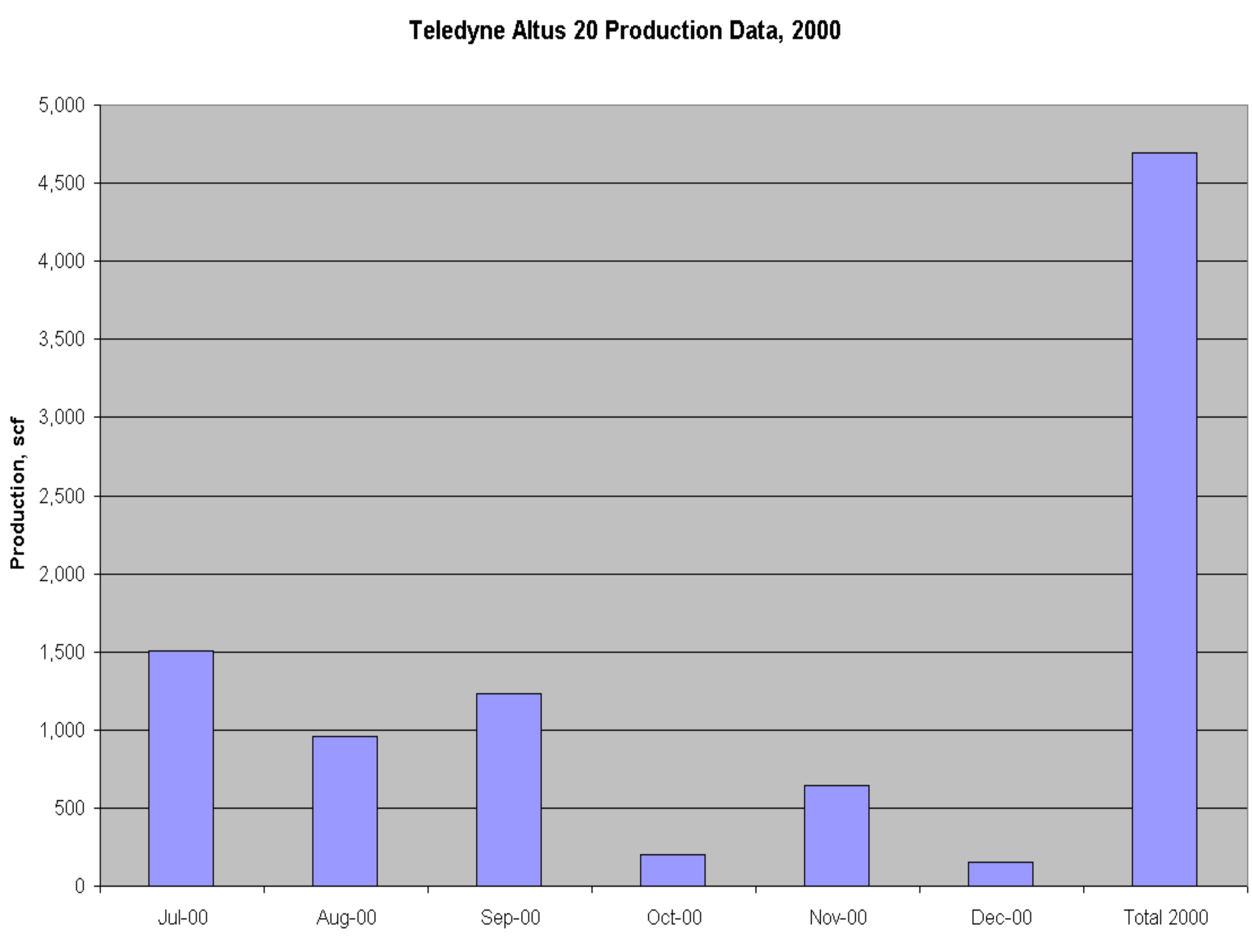
Fuel cell engine	Technology	Direct-H_2 Proton Exchange Membrane
	Model	XCELLSiS XCS-HY-205
	Volume	5.32 m^3
	Weight	2170 kg (4774 lbs)
	Net shaft power	205 kW at 2100 rpm
	Peak net torque	1100 Nm at 800 rpm
	Net efficiency	44% to 37% (LHV)
	Operating temperature	70°C to 80°C
Hydrogen tank	Storage system	8 standard CNG cylinders
	Storage capacity	17500 SCF of CH2
	Compression	3600 psig
Vehicle	Physical dimensions (L/W/H)	12.4/2.57/3.4 m (40.8/8.5/11.0 ft)
	Curb-weight	14521 kg (32019 lb)
	Gvwr	17500 kg (38588 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)

APPENDIX G - 1

Hydrogen Production Data for the Teledyne Electrolyzer

Teledyne Altus 20 Hydrogen Production Data, 2000

Month	Production, scf	Production, slm	Production, pounds	Production, kilograms	Power. kWh
Jul-00	1,509	42,719	8.10	3.68	264
Aug-00	955	27,037	5.12	2.33	166
Sep-00	1,231	34,863	6.61	3.00	212
Oct-00	203	5,762	1.09	0.50	40
Nov-00	643	18,197	3.45	1.57	118
Dec-00	157	4,435	0.84	0.38	34
Total 2000	4,697	133,013	25.21	11.46	834

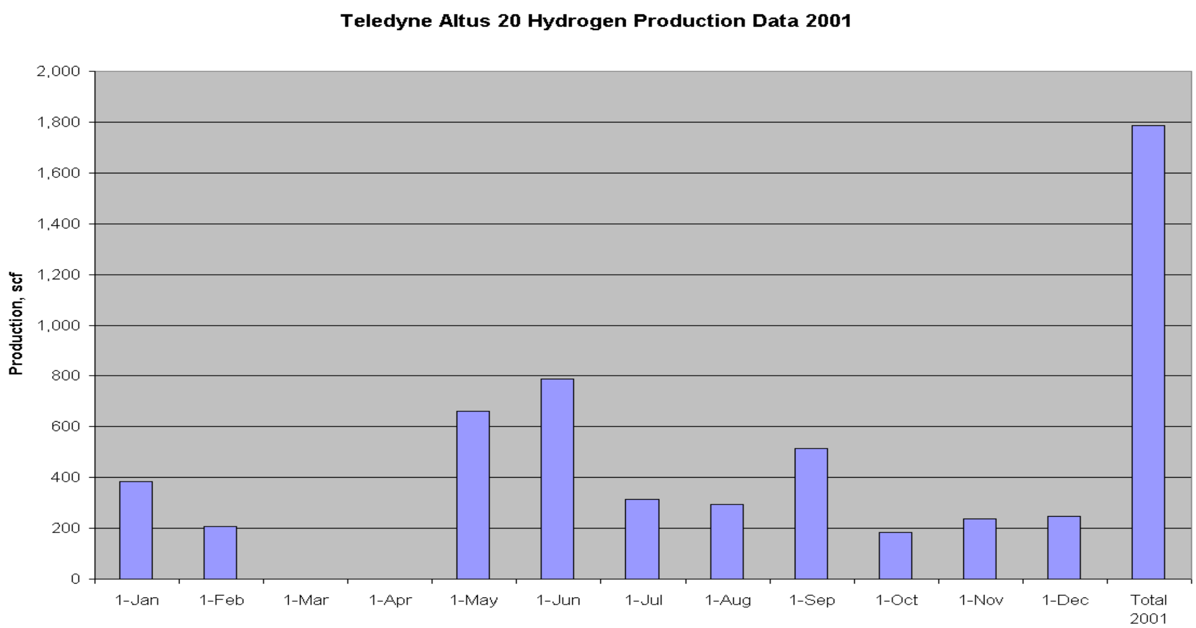


APPENDIX G - 2

Hydrogen Production Data for the Teledyne Electrolyzer

Teledyne Altus 20 Hydrogen Production Data, 2001

Month	Production, scf	Production, slm	Production, pounds	Production, kilograms	Power, kWh
Jan-01	382	10,829	2.05	0.93	75
Feb-01	208	5,902	1.12	0.51	75
Mar-01	0	0	0.00	0.00	152
Apr-01	0	0	0.00	0.00	51
May-01	662	18,746	3.55	1.61	153
Jun-01	789	22,339	4.23	1.92	158
Jul-01	313	8,873	1.68	0.76	69
Aug-01	293	8,304	1.57	0.72	62
Sep-01	513	14,513	2.75	1.25	107
Oct-01	184	5,209	0.99	0.45	41
Nov-01	239	6,758	1.28	0.58	54
Dec-01	246	6,959	1.32	0.60	51
Total 2001	3,829	108,432	9.59	4.36	384

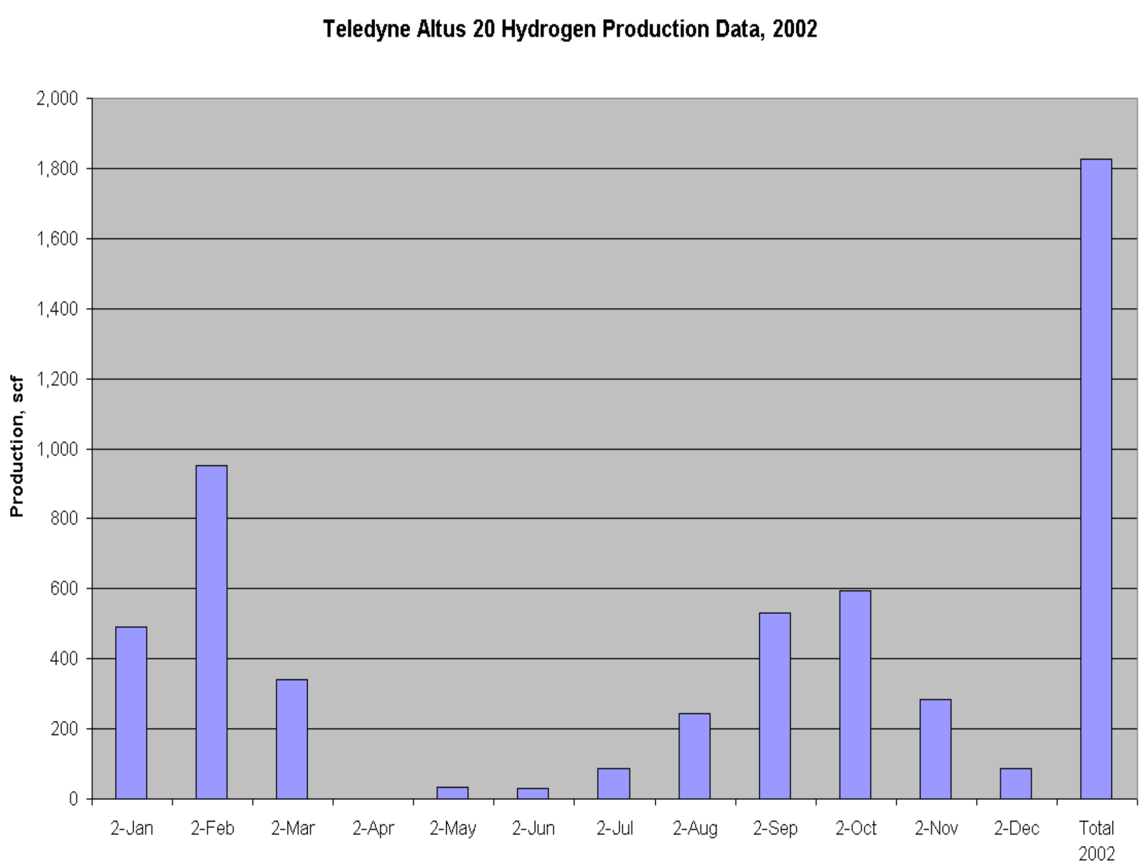


APPENDIX G - 3

Hydrogen Production Data for the Teledyne Electrolyzer

Teledyne Altus 20 Hydrogen Production Data, 2002

Month	Production, scf	Production, slm	Production, pounds	Production, kilograms	Power, kWh
Jan-02	490	13,865	2.63	1.19	117
02	951	26,917	5.10	2.32	199
02	342	9,680	1.83	0.83	70
02	0	0	0.00	0.00	0
May-02	35	978	0.19	0.08	82
Jun-02	31	887	0.17	0.08	6
Jul-02	87	2,460	0.47	0.21	14
Aug-02	245	6,949	1.32	0.60	49
Sep-02	532	15,055	2.85	1.30	102
Oct-02	595	16,853	3.19	1.45	125
Nov-02	283	8,007	1.52	0.69	65
Dec-02	85	2,414	0.46	0.21	18
Total 2002	1,827	51,738	9.80	4.46	373

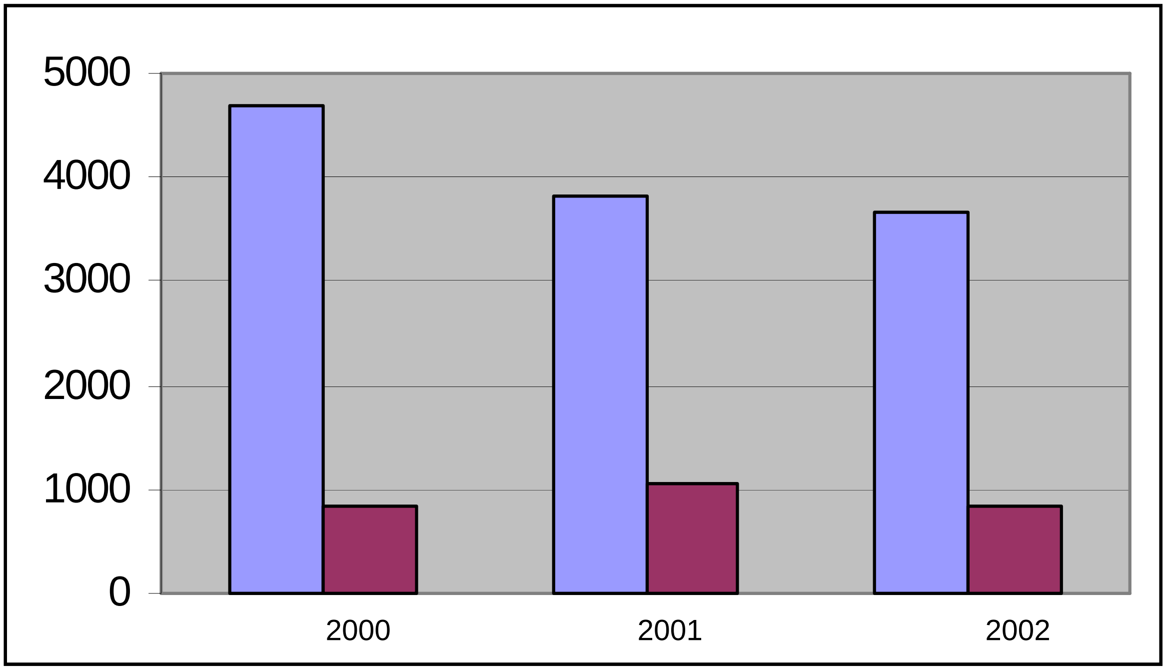


APPENDIX G - 4

Hydrogen Production Data for the Teledyne Electrolyzer

Annual Teledyne Altus 20 Production Data

Year	Production, scf	Production, slm	Production, pounds	Production, kilograms	Power, kWh
2000	4697	133013	25.21	11.46	834
2001	3829	108432	20.55	9.34	1048
2002	3675	104065	19.72	8.96	847
Total	12201	345510	65.48	29.76	2729

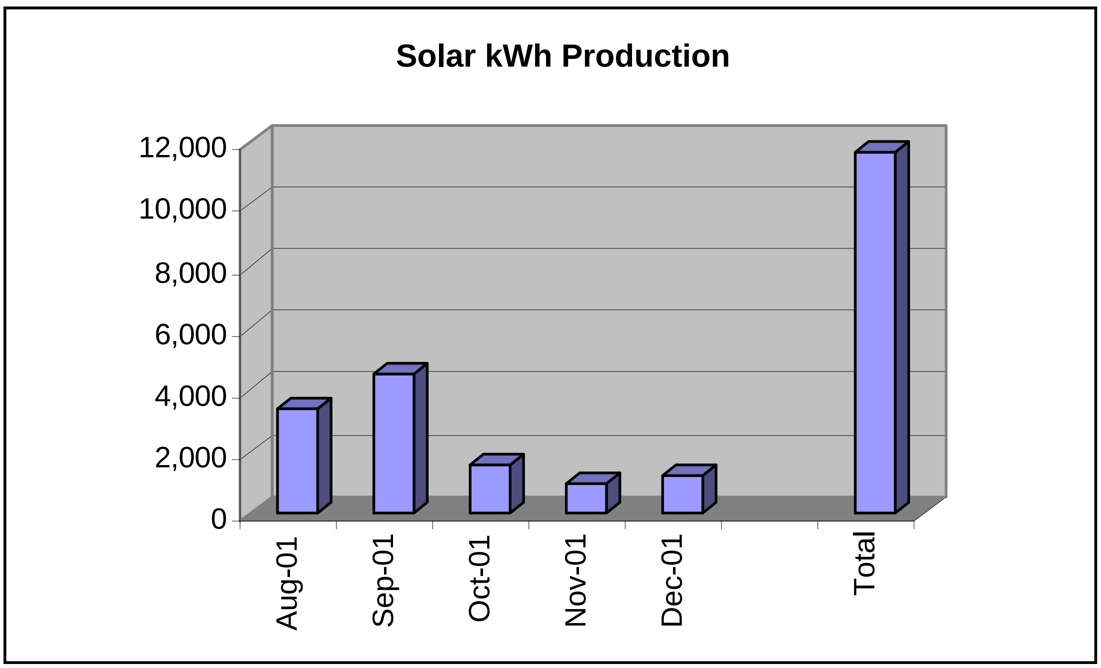


APPENDIX H - 1

Solar Production Data for the Solar Arrays

Solar Energy (kWh) Production

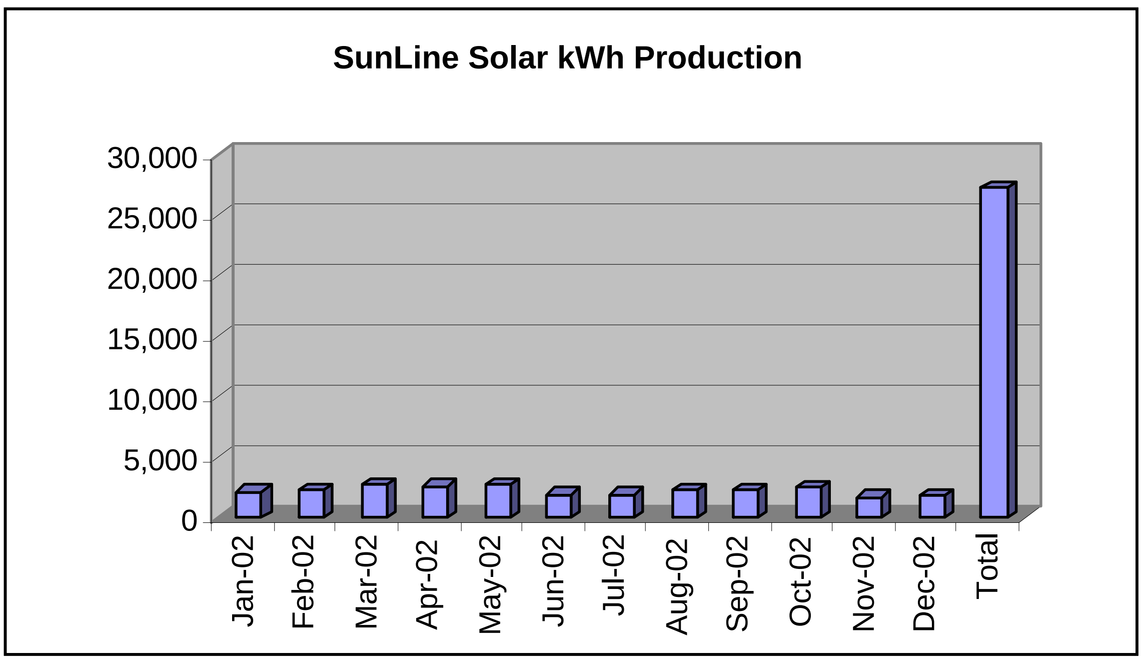
Period	Energy (kWh)
Aug-01	3,410
Sep-01	4,503
Oct-01	1,570
Nov-01	1,004
Dec-01	1,231
Total	**11,718**



APPENDIX H - 2

Solar Production Data for the Solar Arrays

Period	Energy (kWh)
Jan-02	2,166
Feb-02	2,349
Mar-02	2,757
Apr-02	2,612
May-02	2,774
Jun-02	1,961
Jul-02	1,962
Aug-02	2,330
Sep-02	2,275
Oct-02	2,502
Nov-02	1,746
Dec-02	1,791
Total	**27,225**

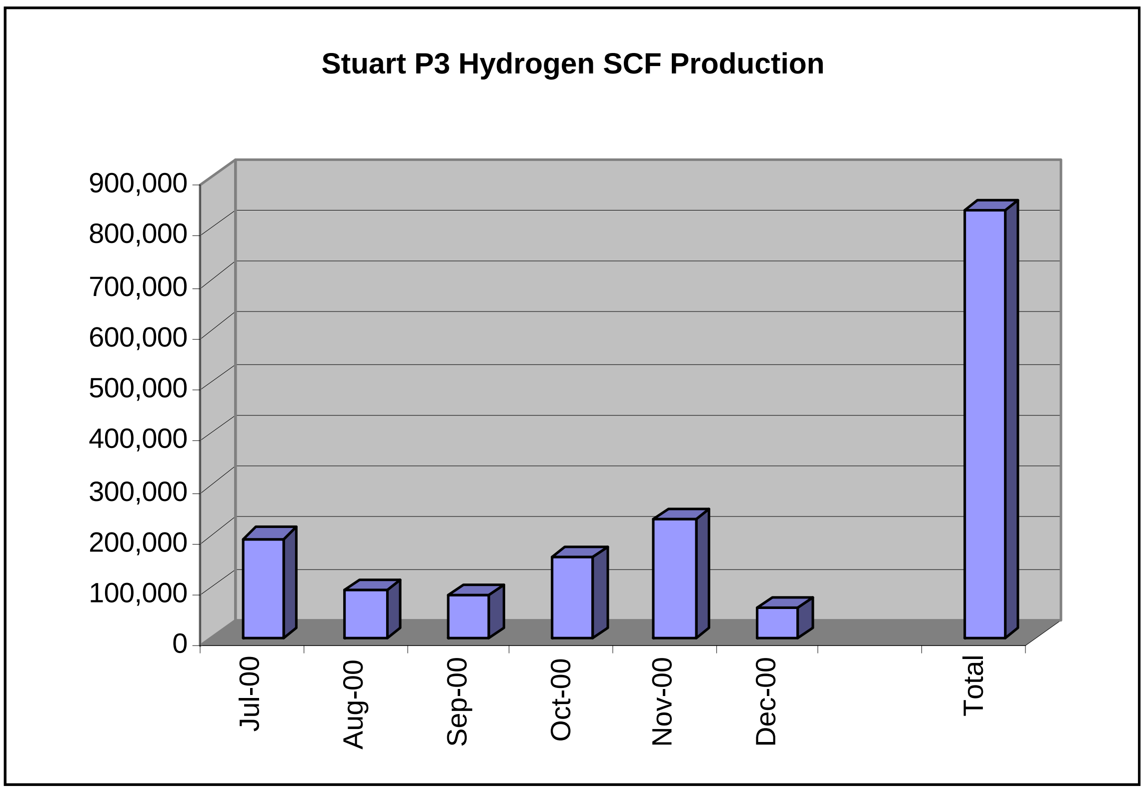


APPENDIX I -1

Hydrogen Production Data for the Stuart Energy Electrolyzer

Stuart P3 Hydrogen Production

H2 Produced	Standard Cubic Feet (SCF)	Standard Liters (SL)	Pounds (lbs)	Killiograms (kg)	Electrolyzer Energy Usage (kWh)
Jul-00	196,500	5,564,880	1,022	460	26,300
Aug-00	96,400	2,730,048	501	226	12,800
Sep-00	86,200	2,441,184	448	202	11,300
Oct-00	159,900	4,528,368	831	374	21,300
Nov-00	232,900	6,595,728	1,211	545	28,700
Dec-00	61,600	1,744,512	320	144	7,700
Total	**833,500**	**23,604,720**	**4,334**	**1,950**	**108,100**

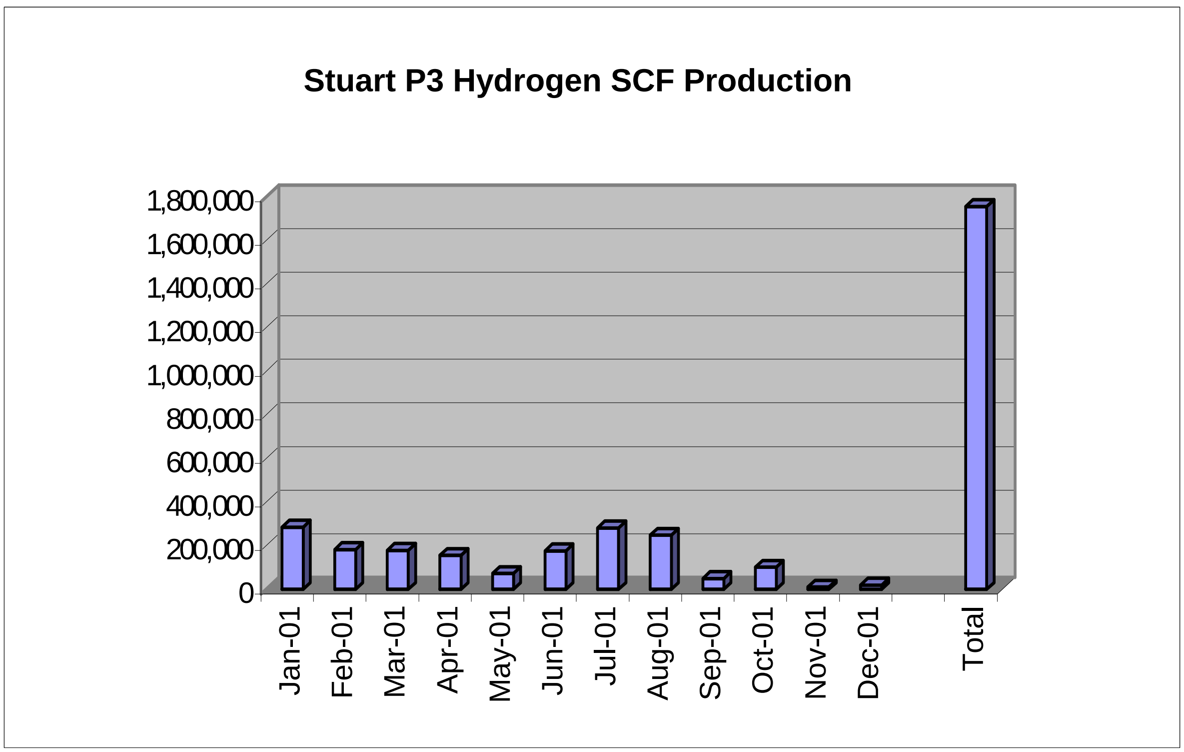


APPENDIX I - 2

Hydrogen Production Data for the Stuart Energy Electrolyzer

Stuart P3 Hydrogen Production

H2 Produced	Standard Cubic Feet (SCF)	Standard Liters (SL)	Pounds (lbs)	Killiograms (kg)	Electrolyzer Energy Usage (kWh)
Jan-01	284,800	8,065,536	1,481	666	34,100
Feb-01	181,800	5,148,576	945	425	21,600
Mar-01	177,800	5,035,296	925	416	22,100
Apr-01	155,500	4,403,760	809	364	18,500
May-01	72,700	2,058,864	378	170	8,500
Jun-01	176,400	4,995,648	917	413	20,900
Jul-01	280,700	7,949,424	1,460	657	33,300
Aug-01	247,100	6,997,872	1,285	578	29,300
Sep-01	49,000	1,387,680	255	115	5,800
Oct-01	100,600	2,848,992	523	235	12,000
Nov-01	9,285	262,951	48	22	1,152
Dec-01	19,052	539,553	99	45	2,272
Total	**1,754,737**	**49,694,152**	**9,125**	**4,106**	**209,524**

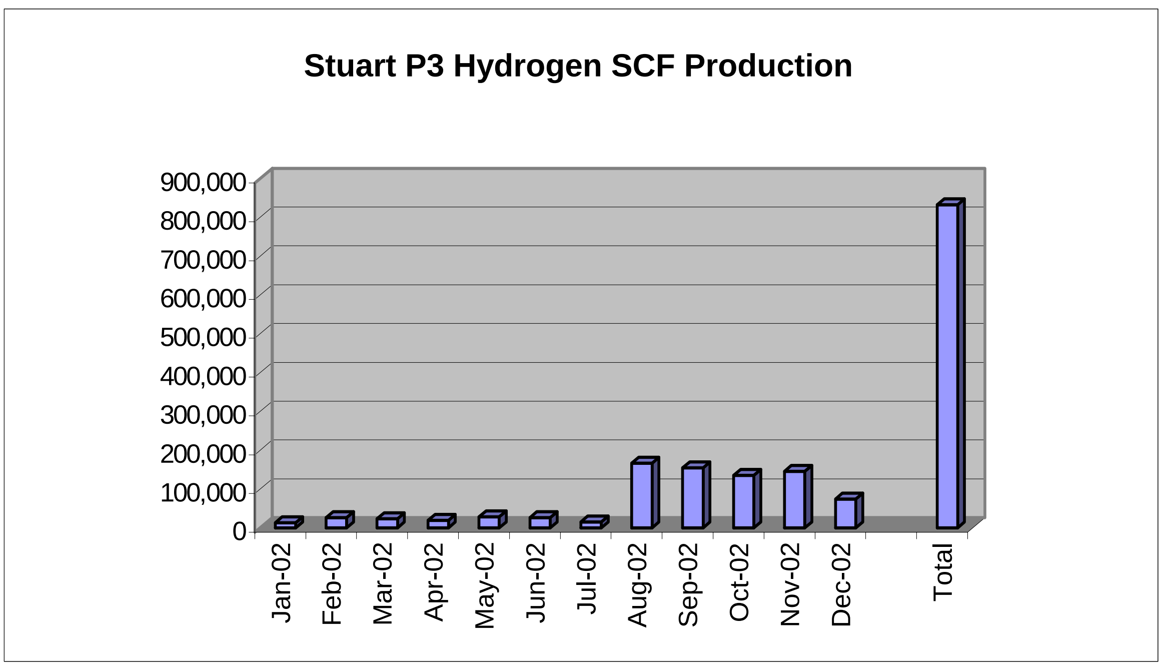


APPENDIX I - 3

Hydrogen Production Data for the Stuart Energy Electrolyzer

Stuart P3 Hydrogen Production

H2 Produced	Standard Cubic Feet (SCF)	Standard Liters (SL)	Pounds (lbs)	Killiograms (kg)	Electrolyzer Energy Usage (kWh)
Jan-02	13,324	377,336	69	31	1,524
Feb-02	26,600	753,312	138	62	3,408
Mar-02	23,333	660,791	121	55	3,000
Apr-02	19,833	561,671	103	46	2,499
May-02	29,167	826,009	152	68	3,700
Jun-02	26,833	759,911	140	63	3,473
Jul-02	15,400	436,128	80	36	1,788
Aug-02	166,950	4,728,024	868	391	22,044
Sep-02	155,041	4,390,761	806	363	20,538
Oct-02	135,289	3,831,384	704	317	17,316
Nov-02	145,775	4,128,348	758	341	18,683
Dec-02	74,991	2,123,745	390	175	9,960
Total	**832,536**	**23,577,420**	**4,329**	**1,948**	**107,933**

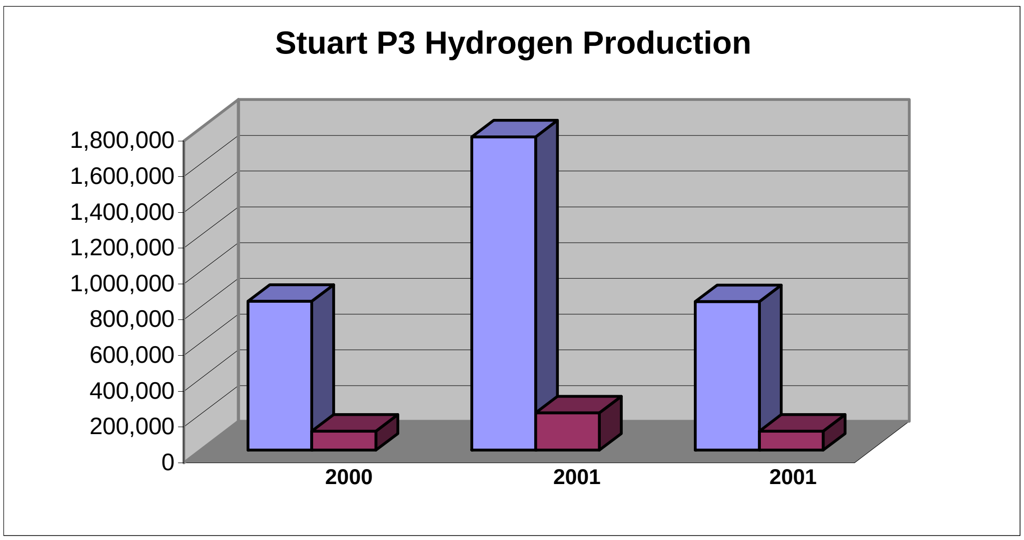


APPENDIX I - 4

Hydrogen Production Data for the Stuart Energy Electrolyzer

Stuart P3 Hydrogen Production

Year	H2	KWh
2000	833,500	108,100
2001	1,754,737	209,524
2002	832,536	107,933



3. APPENDIX

Glossary:

- **ATF:** Automatic transmission fluid.
- **Degradation:** Decreased performance over a period of time.
- **DI water:** De-Ionized water.
- **Driving Range:** The driving distance at a given fuel consumption and fuel amount.
- **Fuel Consumption:** The fuel consumed per mile.
- **Glycol:** Anti-Freeze coolant.
- **Lube Oil:** Lubrication oil.
- **MTBF:** Mean time between failures.
- **OEM:** Original equipment manufacturer.
- **Road call:** En-route interruption of revenue service and field service had to been called in.
- **SCF:** A cubic foot of gas at 14.7 psia and 60 °F.
- **Transit Track Test:** Test on designed standard bus route.

Unit Conversion:

1 kg = 2.20462 lb
1 m = 3.2808 ft
1 m^3 = 35.3147 ft^3
1 mile = 1.609334 km
1 gallon = 3.7854 liters

1 SCF contains 0.0053154 lb of hydrogen.

APPENDIX J

SunLine Clean Fuels Mall – Visitor Log

Some tour groups were too large to capture individual names.

YEAR/DATE	COUNTRY	ORGANIZATION
2000		
February 8	Japan	Undetermined
March 31	US	CA Hydrogen Bus Council
April 28	GRAND OPENING	Many visitors and dignitaries
May 2	US	LMTA/Collins Tour
May 9	US	General Tour
May 22	US	Fuel Cell Group
May 23	US	Fuel Cell Conference
May 24	US	2000 Fuel Cell Conference
May 25	US	2000 Fuel Cell Conference
June 10	US	Industry Trek
July 4	US	General Tour
July 7	Japan	Undetermined
July 19	US	SERC
July 20	US	ZF
July 27	Japan	Television Crew
August 3	US	Mass Institute of Tech
August 7	US	SoCal Gas Company
August 8	US	Foothill
August 16	US	College of the Desert / Automotive Technology Training Institute
August 21	Canada	Dynetek Industries Ltd
August 29	US/Canada	FIBA / Stuart Energy / HbT / SCAQMD
August 31	Canada	XCELLSiS/Dr. F. Panik
September 5	US	Kiwanis Club of Palm Springs Presentation
September 6	US	California Energy Comm
September 7	US	Desert Hot Springs Rotary
September 14	US	Univ CA/Riverside
September 21	India	UNDPGEF Delegation
September 22	Japan	Honda Motors
September 27	US	Dennis Acuri, Supervisor Roy Wilson’s Office
October 2	US	SAIC
October 2	US	City of Merced, CA
October 3	US	Police Academy

YEAR/DATE	COUNTRY	ORGANIZATION
2000/cont.		
October 3	US	Intelligent Working Group
October 9	US	Retired MD Forum Presentation
October 9	US	Air Products & Chemicals
October 10	US	Palm Springs City Mngr
October 11	US	Coachella Valley Rotary
October 11	US	ISE Research / Thor Industries
October 19	US	SunLine Planning Dept.
October 31	Brazil	EMTU
November 2	Japan	WE-NET
November 7	US	Indio, CA/Public Works Dir
November 7	Japan	E-Touch International
November 9	US	College of the Desert / Students
November 14	US	HTAP
November 15	Germany	BMW
November 15	US	Pandit Patel Impco
November 16	US	General Tour
November 16	US	California Energy Comm
November 17	US	Am Automobile Club
November 20	US	College of the Desert / Students
November 20	US/Japan	Yamaha / UCR CECert
November 27	US	City of Coachella
November 28	France	Gaz de France
November 29	Germany	Daimler/Chrysler
December 6	US	City of Rancho Cucamonga, CA
December 6	US	Amastad High School, Indio, CA
December 6	US	SCAQMD
December 8	US	General Tour
December 8	Canada	Fueling Technologies
December 12	US	Council, City of Palm Desert
December 14	US	Dr. Robert Zweig
December 15	Japan	Japan Public Television
December 18	US	Palm Springs Desert Resorts Convention & Visitors Bureau
December 19	US	Sweet Water
December 21	US	City Manager, Cathedral City, CA
December 22	US	General Tour
December 22	US	Palm Springs Life Magazine

YEAR/DATE	COUNTRY	ORGANIZATION
2001		
January 2	US	City of Indian Wells, CA
January 3	US	3RV
January 3	US	CalStart/WestStart
January 5	US	Montana Dakota Utility
January 8	US	General Electric
January 10	US	Los Angeles Dept of Transportation
January 10	Taiwan	Undetermined
January 10	US	Southern Ca Public Power Authority
January 11	US	SRT
January 15	France	Gaz de France
January 15	US/France	Michelin Challenge Bibendum
January 17	US	Dr. Robert Zweig
January 17	US	General Dynamics
January 23	US	General Tour
January 29	US	General Tour
January 30	US	Morongo Indian Reservation Planning Committee
February 1	US	Metrolink, Rock Island, IL
February 2	US	Office of Congresswoman Mary Bono
February 5	Japan	Tokyo Gas Company
February 5	Japan	Iwatani International
February 6	US	Dr. Robert Zweig & Retired MDs
February 6	US	SCAQMD
February 6	Japan	Nissan Motor Corp
February 9	US	California Energy Commission
February 14	US	The Desert Sun
February 14	US	Robert Webb Foundation
February 15	US	EPA
February 15	US	Imperial Irrigation District & Supervisor Roy Wilson
February 16	Japan	Tokyo Gas Company
February 21	US	General Tour
February 23	US	General Tour
February 27	US	Rancho Mirage City Council
February 28	Australia	Dept of Transportation
March 2	US	General Tour
March 2	US	SCAQMD
March 2	Germany	German Public Television
March 3	US	Green Party

YEAR/DATE	COUNTRY	ORGANIZATION
2001/cont.		
March 6	France	Total FinaElf
March 9	US	General Tour
March 12	Japan	WE-NET
March 16	Mexico	Mexican HFCBS Project
March 16	US	STATV, Inc.
March 22	US	Cathedral City City Council
March 23	US	EM Transit Agency
March 23	US	General Tour
March 27	US	General Tour
March 29	Canada	British Columbia Assoc
March 29	US	CNGVC
March 29	US	First Community Bank Advisory Committee
March 30	US	General Tour
April 5	US	NAC
April 5	US	College of the Desert Students
April 6	US	General Tour
April 10	US	MCI
April 11	The Netherlands	Shell Hydrogen
April 12	US	Authur D. Little Co
April 25	The Netherlands	Shell Hydrogen
April 27	US	SoCal Gas Co
May 3	US	Desert Hot Springs City Manager Orientation
May 3	US	Mid-Western Utility
May 8	US	Cal State Fullerton
May 10	US	National Ski Association
May 14	US/Japan	Honda Motor Co
May 15	US	Fuel Cell Workshop
May 15	US	QUANTUM
May 16	US/Japan	IQPC Conference - Palm Springs
May 18	US	Houston Metro & Reliant Energy
May 24	US	SCAQMD
May 24	US	Texaco Energy Systems
May 25	US	Garden Grove SD/SoCal Gas/City of Industry Disposal/San Juan Capistrano USD Ware Disposal
June 1	US	General Tour
June 1	US/Japan	Japan Metals & Chemicals USA Inc
June 6	US	Environmental Holdings

YEAR/DATE	COUNTRY	ORGANIZATION
2001/cont.		
June 11	US	Texaco Energy Systems
June 11	US	Capstone
June 12	US	Vestes, SunLaw, BP Capital LLC
June 19	US	QUANTUM
June 21	US	Desert Hot Springs City Manager
June 22	Japan	Toyota Motor Co
June 22	US	General Tour
June 22	US	SoCal Gas Co
June 25	US	Santa Clara Transit
June 29	US	General Tour
July 5	Germany	General Motors
July 6	US	General Tour
July 10	Germany	BMW Hydrogen Technicians
July 11	US	SWRI
July 13	France	Nuclear Regulatory Agency (w/SCAQMD, CEC, CARD, UCR
July 13	Germany, Denmark, Italy, Spain, England, The Netherlands, France, Belgium	European Journalists
July 13	US	City of LA & ENRG
July 18	US/Japan	Chicago Fuel Cell Seminar and visitors from Japan
July 20	US	WinTek
July 23	Canada	Canadian Ambassador
July 24	US	The Desert Sun
July 27	US	General Tour
July 31	Israel	Minister of Environment
August 2	US	Santa Clara Valley Transit
August 2	US	NAC
August 3	Japan	Agricultural Delegation
August 3	US	General Tour
August 3	US	Children's Discovery Museum
August 8	US	Allison Transmission
August 9	US	The Desert Sun Environmental Committee
August 10	US	General Tour
August 11	Japan	Honda Motor Co
August 15	US	Cathedral City Elementary School Students
YEAR/DATE	**COUNTRY**	**ORGANIZATION**
2001/cont.		

August 16	Japan	JRC
August 17	US	General Tour
August 24	US	OSK-60G (So Cal Gas, Imperial Irrigation District, Cummins, SCAQMD)
August 27	US	Shasta College
August 31	Japan	Sumitomo Corp
September 7	US	BIA Legislative Affairs Committee
September 14	US	Loma Linda Univ Occupational Medicine Students
September 14	US	NGVC
September 21	US	General Tour
September 26	US/France	Michelin Challenge Bibendum
September 28	US	Alt Fuels Advisory
September 28	US	Transportation Foundation
September 28	Japan	
October 10	US	College of the Desert
October 17	The Netherlands	Shell Hydrogen
October 17	Philippines	
October 19	US	Student Film Crew
October 22	US	College of the Desert Students
October 24	Switzerland	PSI
October 24	US	US Dept of Interior
October 26	US	Huntington Beach Elementary School Science Instructors
October 26	US	Indio Charter School Students
October 26	US	CA Science Teachers Association
November 1	US	UCR Chancellor
November 2	US	San Diego State Univ
November 5	US	Natural Energy Laboratory of Hawaii
November 8	US	College of the Desert Students
November 9	Israel	Ministry of the Environment
November 9	US	Jurupa School District
November 16	US	City of Santa Fe Springs
November 16	US	General Tour
December 3	US	National Fire Protection Association
December 12	Peru	Energy Delegation
December 14	US	Santa Clara Transit Authority
December 18	US	Dean, Cal State/SB Natural Sciences Dept
December 20	US	Governor Davis Office
YEAR/DATE	**COUNTRY**	**ORGANIZATION**
2002		
January 4	US	General Tour

January 7	US	ENRG
January 18	US	NY City Transit Authority
January 18	US	Elysa Markowitz (TV host)
January 18	France	UOP
January 18	US	Leadership Coachella Valley
January 21	Australia	University
January 24	US	SCAQMD
January 29	Denmark, Italy, Japan, Spain, Sweden, US, Germany, The Netherlands, France	International Gas Union
January 30	US	SoCal Gas Co
February 4	US	Bell South/DOE
February 5	US	Reel Impact/DOE Film Documentary
February 6	Japan	Aizawa Tour
February 6	US	Disney, EroEngineering & Houston Advanced Technology
February 7	Canada	Natural Resources Canada/Transportation Energy Technologies
February 7	US	Governor Davis' Office
February 8	US	CNGVC Board
February 12	US	Art Center Pasadena Auto Design Students
February 13	US	Cal State/San Bernardino TRAC Committee
February 19	US	Desert Amateur Radio Club
February 22	US	ENRG & Peco Energy
February 22	Japan	Tokyo TV
February 24	US	Senator Barbara Boxer
February 26	Bangladesh	CNG/Energy Delegation
February 27	US	ENRG Board of Directors
Feb 28/Mar 1	Japan	Tokyo TV
March 1	US	Blue Skies, Pacific LNG, Coastal Petroleum
March 8	US	Ecotek
March 8	US	Ztek Corp
March 13	US	Colliers International
March 13	US/Japan	Yamaha
March 15	Japan	WE-NET
YEAR/DATE	**COUNTRY**	**ORGANIZATION**
2002/cont.		
March 15	US	General Tour

March 19	England	British Consulate/Chicago
March 22	US	General Tour
March 25	Japan	Energy Delegation
April 9	US	US Department of Commerce
April 10	US	Future Car Congress/Video Shoot
April 12	US	Pepperdine Univ Environmental Resources Students
April 12	US	Energy 2002 Planning Committee
April 12	US	Phillips Petroleum
April 13	US	Am Chemical Society
April 14	US	College of the Desert Students
April 17	US	College of the Desert Students
April 19	US	Marywood Day School Students
April 26	US	LA MTA
May 2	Mexico	Mexicali, Mexico Delegation & ENRG
May 3	US	General Tour
May 13	Canada/ Germany	Daimler/Chrysler & XCELLSiS
May 15	US	AMCO
May 22	US	City of LA
May 24	Bangladesh	Energy Delegation
May 25	Mexico	Ixtapa-Zihuatanejo (Palm Desert sister city)
June 2	US	Energy 2002 Conference Delegation
June 7	US	City of Santa Clarita
June 8	US	Hydrogen Now
June 14	US	Leadership Coachella Valley
June 17	Japan	WE-NET
June 17	Japan	Nittan Sanyo Corp
June 18	US	Art Center Pasadena Auto Design Students
June 28/29	US	Hydrogen Business Council
June 28	Philippines	Office of Environmental Management
June 28	Costa Rica	Experto de Suplencia en Econmica Ambiental, Minsterio de Cooperacion Internacional Holanda
July 2	Japan	
July 16	US	Institute of Transportation Engineers
July 19	US	CVAG/SCAQMD
July 22	Australia	Oz Fuel Cells
July 30	Japan	Toyota/Mitsui
YEAR/DATE	**COUNTRY**	**ORGANIZATION**
2002/cont.		
August 7	Canada	British Petroleum
August 8	US	Dr. Robert Zweig Family

August 9	US	Council of Electronics Instructors
August 9	US	Bellflower Unified School District
August 9	US	General Tour
August 16	Japan	Nittan Sanyo Corp
August 21-28	Japan/US	Nissan
September 3	Italy	Department of Energy
September 6	Japan	Asahi University Students
September 13	US	DOE
September 13	US	Gavial Engineering & Manufacturing
October 4	US	Cal State/San Bernardino
October 14	Thailand/India	US-AEP Sponsored – four Thai & three Indian
October 14	Japan	Japan Natural Gas Forum
October 14	US	CV Mosquito Vector Control District
October 16	China	China/Cummins Delegation
October 23	US	Alternative Energy Special Interest Group
October 25	US	CA Council of Electronics Instructors Conference Delegates
October 30	US	Country of Riverside
October 31	Japan	Japan Electric Vehicle Association
November 1	US	Kinectrics
November 1	US	NY City Transit Delegation
November 4	US	College of the Desert Students
November 6	US	College of the Desert Students
November 8	US	
November 11	US	World Link Media
November 11	US	BC Gas
Nov 13-16	US	APTA Executive Committee
November 18	International	2002 Fuel Cell Seminar Delegates
November 19	US	Hawaiian Electric Co
November 19	US	INEEL-Rechtel BWXT Idaho LLC
November 22	US	International Energy Agency
November 22	International	2002 Fuel Cell Seminar Delegates
November 22	International	2002 Fuel Seminar Executive Committee
December 3	Japan	Cosmo Research Institute
December 3	Italy	Hydrogen System Laboratory
December 6	US	College of the Desert
December 13	US	General Tour
December 27	US	Gavial Engineering and Manufacturing

APPENDIX K

Experiences with Permitting, Codes and Standards Used in Design and Permitting of the Facility

SunLine appears to have had an advantage in the siting of its hydrogen generation, storage, and dispensing facilities and equipment. When SunLine embarked on the CNG pathway, it expended considerable time in educating the fire marshals and emergency management personnel in the 9 cities and County of Riverside. SunLine is located in the County of Riverside but its CNG buses are operated throughout the Valley.

SunLine hired a County employee (paid his salary) to assist in the permitting process and identify barriers as the CNG station proceeded during its design phase. At the end of the design phase only, one change was made to the system and that was the orientation of the CNG tanks from a north-south orientation to an east-west orientation based on location of inhabited buildings at SunLine.

When the time came to engage the local fire marshals and emergency managers to discuss how to proceed with the permitting, codes and standards, and installation of SunLine's hydrogen infrastructure, the whole meeting took 35 minutes. Because of the time spent in 1993 on education of safety and building officials, the only questions asked after the description of the proposed project were:

1. Is it correct that you are already dealing with flammable gases? The answer is yes.

2. Is it correct that you are dealing with compressed gases in high volumes? The answer is yes.

3. Is it correct that you have policies and procedures in place for dealing with flammable, compressed gases and their associated equipment? The answer is yes.

4. Is it correct that you have a formal and an on-going training program to deal with flammable, compressed gases and that all personnel are trained in accordance with the requirements for these gases? The answer is yes.

The conclusion was, "We do not need to spend any more time discussing this. You need to go ahead and get your project permitted."

Permitting

The permitting process for SunLine's hydrogen infrastructure began with the County of Riverside. The permits required from the County of Riverside were for Humboldt State University's Schatz Energy Research Center (SERC) Hydrogen Building which houses the Teledyne Energy Systems electrolyzer, the Hydrogen Vehicle Storage Facility, installation of hydrogen tanks and piping, the flat plate array, the Solar Structure for tracking panels, the Stuart Energy electrolyzer, and the 1,800 sq ft Multipurpose Room.

The County of Riverside requires "substantial conformance" first. During the course of construction, SunLine's legal counsel researched this issue and SunLine is no longer required to go through substantial conformance. The County did require SunLine to obtain "sign off" from the Coachella Valley Water District for SERC Hydrogen Building, vehicle storage, hydrogen tanks and solar flat plat arrays. The County also required SunLine to obtain a grading permit for the entire site before any construction on the hydrogen building started in 1999.

The County does not require permits or inspections on concrete pads (flatwork). Upon application for a building permit there are 5 departments that review plans and comment or require changes fire, health, engineering, planning, transportation and building. The County then issues one permit for a project.

All electrical is included in the permits for structure (whatever it may be). Any electrical work (transformer, etc) was inspected by Imperial Irrigation District (IID) and when IID authorizes hook up, that constitutes approval.

The County did not require permits for the HbT Reformer. Photos were taken for all installations as construction proceeded to provide a visual record of the installation.

Codes and Standards

The following codes and standards were used at SunLine and SunLine was evaluated against those standards and a report issued dated November 25, 2000 from the "The Center of Hydrogen Safety":

1. NFPA 70, "National electric Code – 1999 Edition", Chapter 5's Special Occupancies, pages 309 through 359 that cover electrical classifications;
2. NFPA 497, "Classification of Flammable Liquids, Gases, Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas – 1997 Edition", pages 1 through 62:
3. NFPA 496 – 1998, "Purged and pressurized Enclosures for Electrical Equipment – 1998 Edition", pages 1 through 20;
4. NFPA 50A, "Gaseous Hydrogen Systems at Consumer sites – 1999 Edition", pages 1 through 10;
5. NFPA 50B, "Liquefied Hydrogen systems at Consumer Sites – 1999 Edition", pages 1 through 12 plus one Formal Interpretation – 1 page;
6. NFPA 853, "Installation of Stationary Fuel Cell Power Plants – 2000 edition", pages, 1 through 13;
7. NFPA 10, "Standard for Portable Fire Extinguishers – 1998 Edition", pages 1 through 56 plus 3/31/98 Errata;
8. NFPA 52, Compressed Natural Gas (CNG) Vehicular Fuel Systems Code – 1998 Edition", pages 1 through 30;
9. NFPA 30A, "Motor Fuel dispensing and Repair Garages – 2000 Edition", pages 1 through 41;
10. ISO 13984 – Liquid hydrogen – Land vehicle fuelling system interface;
11. ISO 14687 – Hydrogen fuel – Product specification;
12. ISO – 197 – Transportation;
13. ANSI 221.83 / CGA 12.10;
14. ASME B31 – code for Pressure Piping, Piping for Gaseous Hydrogen Storage and Piping for Liquid Hydrogen Storage Vessels;

15. ASME Boiler and Pressure Vessel Code;

16. CGA G-5.4, Compressed Gas Association Standard for Hydrogen Piping at Consumer Locations

17. 29 CFR 1910.103;

18. 49 CFR Regulations for Transportation Equipment and the Transport of Hydrogen;

19. 49 CFR – Transportation, Scope of Subchapter C – Hazards Classification for Gaseous Hydrogen and Liquid Hydrogen.

Other documents were not reviewed because they either did not pertain to the gaseous hydrogen systems being used or still are under development by various working groups and were not available as November 2001.

The following page depicts a layout of the hydrogen, CNG, and LNG infrastructure at SunLine Transit Agency.

APPENDIX L

Proposed Project Titles – Hydrogen Program 2003-2008:

Transportation:

1. Performance and emissions of HCNG fueled light duty vehicles (platforms might include cutaway vans, Crown Victoria, F150 and F250 pick up trucks)
2. Performance and emissions of hydrogen fueled Ford 460c.i. V8 in light duty vehicle application (possible platforms might include Crown Victoria, Vans, F150 and F250 pick up trucks)
3. Performance and emissions of hybrid electric hydrogen fueled ICE bus (consider using Ford 460c.i. V8 developed by Ballard and Southwest Research Institute for power generation or Cummins B+ or C+ heavy-duty engine)
4. Development, testing and performance assessment of hydrogen fueled fuel cell APU in class 8 tractor
5. Testing and performance of sodium borohydride-fueled Chrysler minivan in hot weather environment

Production and infrastructure:

1. Hydrogen production and fueling station reliability assessment (include electrolysis, natural gas reforming and possibly biomass based process in evaluation)
2. Development and testing of high pressure electrolyzer
3. Development of synthetic fuels production facilities and their impact on hydrogen availability and production costs
4. SOFC and PEM fuel cell reliability assessment and testing program in stationary application
5. Hydrogen power park development, testing and economics

General:

1. Development and testing of diagnostic fuel cell test equipment

APPENDIX M

Hydrogen Commercialization: Transportation Fuel for the 21st Century

CONTRACT NUMBER: DE FC36-96GO10139

January 2004 – January 2006

EXECUTIVE SUMMARY

This report covers an amendment (15) to project DE-FC36-96G010139 "Hydrogen Commercialization: Transportation Fuel for the 21st Century", January 2004 to January 2006. SunLine's Thousand Palms facility has changed dramatically over the two years with the addition of equipment from various other projects. The new fueling capabilities have given SunLine the capability to fuel buses and vehicles with a station at or near commercial standards. The hydrogen station is scheduled for an upgrade in 2007 with funding from the South Coast Air Quality Management District (AQMD) and the Federal Transit Administration (FTA). It will consist of a commercial reformer, additional storage; a dedicated bus dispenser hose, a card lock system and a booster compressor upgrade. SunLine was able to successfully demonstrate with the U.S. Department of Energy (DOE) funding (Hyradix) and AQMD (SunLine) the utilization of a natural gas onsite prototype reformer and procure a commercial reformer as part of this process.


SunLine TRANSIT AGENCY SunLine SERVICES GROUP

Final Report to

Department of Energy

February 2003

Hydrogen Commercialization:
Transportation Fuel for the 21st Century

CONTRACT NUMBER: DE FC36-96GO10139

In June 2004, an on-road testing program, under a contract with the National Renewable Energy Laboratory (NREL) and AQMD (Report #NREL/TP 540-.8707), to test two newly modified hydrogen and compressed natural gas (HCNG) buses in fixed route service and operate them "head to head" with two CNG buses, was completed. The two HCNG buses operated on a blend of 80% CNG and 20% hydrogen.

SunLine Transit agency now has (2) hydrogen powered buses. SunLine Transit Agency has purchased a hydrogen internal combustion engine (HICE) hybrid electric heavy duty bus and a hydrogen fuel cell heavy duty hybrid bus (FCB). The buses remain in service and data is being collected on the performance, reliability and fuel consumption. A study with NREL on the data collection will be conducted over the next 2 years which ends in 2008.

Tours have been conducted and continue to provide valuable information to the general public as well as visitors from around the world on Hydrogen and Alternative fuels. Each semester our local community college provides tours of the facility for the several environmental classes conducted during the semester. SunLine recommends continued support from the DOE to programs like these for hydrogen infrastructure and commercialization of hydrogen technology to move the United States to its ultimate goal for a sustained, safe and economical energy source for a free and clean air America.

PROJECT SUMMARY

This report covers an amendment (15) to project DE-FC36-96G010139 Hydrogen Commercialization: Transportation Fuel for the 21st Century from January 2004 to January 2006.

This proposal is to continue the current project for one year to continue to demonstrate the Department of Energy's efforts to commercialize hydrogen as a transportation fuel. Operate and maintain the hydrogen infrastructure investment of the department of Energy at SunLine Transit Agency. This infrastructure produces hydrogen utilizing solar and grid energy for fuel cell and hydrogen internal combustion engine buses as demonstrating vehicles in revenue service.

SunLine's Thousand Palms facility has changed dramatically over these two years with the addition of equipment from various other projects. The new fueling capabilities have given SunLine the capability to fuel buses and vehicles with a station at or near commercial standards. The station has given SunLine the opportunity to host vehicle testing by original equipment manufacturers (OEMs) developing hydrogen fueled vehicles. To date the majority of all automobile manufactures endeavoring in hydrogen fuel technology, have fueled at this DOE sponsored facility.

The hydrogen station is scheduled for an upgrade in 2007 with funding from AQMD and FTA. It will consist of a commercial reformer, additional storage, a dedicated bus dispenser hose upgrade, a card lock system, and a booster compressor upgrade. This will allow 24/7 access to the H2 station without an attendant.

HYDROGEN ATR REFORMER

Installation of a HyRadix natural gas prototype reformer at SunLine was completed in September 2003. This project was funded by DOE (HyRadix) and AQMD (SunLine). The unit was brought completely on line in March 2004. The Hyradix Adéo Prototype system completed a one month demonstration period in April 2004. The goal of the demonstration run was to operate the Adéo HFG at 90% of its rated capacity (90 Nm^3 hr) for ten consecutive days within a 30 day period. A product hydrogen purity greater than 99.5 vol% and carbon monoxide concentration less than 1 ppm were to be maintained during the run. The ten day run started on 17 April 2004 and completed on 30 April 2004. This will increase the capacity of hydrogen production by 28,252 NCF/Day (Normal Cubic Feet): Day = 8rs of operation. A Fire Marshall final inspection was conducted in June 2004 and gave us the ability to run the unit unattended over night. SunLine personnel were trained in August 2004 and began full operation of the prototype unit in December 2004 for use as a primary fuel source for hydrogen fueling. A complete report was provided to DOE and accepted by AQMD in 3rd quarter 2005. (Attachment A)

Some problems with the operation of the reformer were experienced in August 2005. New heat exchangers were installed along with a new ATR catalyst to keep the unit operational. During this time, SunLine continued to benefit from the hydrogen being produced by the prototype. The prototype ATR Adéo produced nearly 30,000 kg of hydrogen during the life of this project. The natural gas hydrogen reformer was scheduled for decommissioning in the 3 qtr 2006. An RFP was conducted for a new commercial reformer coinciding with decommission of this successful prototype.

SunLine began the procurement process for a new commercial unit in early 2006. During this process, many other reformer manufactures technology was evaluated. Almost all the other reformer manufactures were still in a developmental phase of production. After the evaluation process a new Hyradix Adéo unit was chosen as a replacement due to the commercial status of the unit.

The new commercial HyRadix ATR Adéo unit was installed fall 2006. This was part of the AQMD/FTA funding project for 2006 and included a six year maintenance contract as well as other upgrades to individual components of the station.

HYDROGEN ELECTROLYZERS AND WINTEC WIND TURBINE

SunLine and Stuart Energy were unable to devise a mutual contract agreement in 2003-2004. Subsequently, the Mark IV that was scheduled for installation at SunLine was removed from SunLine in early 2004 and placed at another facility in Manitoba.

The Wintec project also concluded operation in 2005. The unit was decommissioned and shipped back to the manufacture. The trailer storage used for this project was not certified for road use by DOT. A limited amount of hydrogen was used for SunLine operation due to the trailer status. Transportation of the hydrogen from Wintec to SunLine was not legally possible with the trailer. Certification of the storage trailer system was attained after the project's completion.

SOLAR PANELS

To date over 50,000 kw has been produce to produce hydrogen. With the deterioration of the 480 feet of raised photovoltaic concentrating and tracking panels, we now only average @ >18 kW per hour during daylight hours. All the energy produced is now used for the reformer operation. Regular cleaning of the 218 Siemens solar panels is done on a quarterly basis to maximize the output of this system. Some problems with the data display screen could not be corrected due to the lack of support from Trace technologies. Some data is collected from an external meter (EMON meter). New panels are being looked at for future expansion to help with the reformer hydrogen production.

HCNG TESTING

In June 2004, an on-road testing program under a contract with NREL and AQMD to test two newly modified HCNG buses in fixed route service and operate them "head to head" with two CNG buses was completed. The two HCNG buses operated on a blend of 80% CNG and 20% hydrogen. The crux of the project was to run the buses on a blended fuel with little or no modification to the engine. This operation was successful with just one component change (mass flow sensor) and an engine calibration change preformed by Westport Innovations. Testing of emissions was through NREL's contract with West Virginia University. The HCNG buses continued to be used in regular service until the buses were retired in March 2006. The buses were part of an overall bus replacement program initiated in the first part of 2006. A comprehensive report was submitted to NREL for review and published by NREL in late September 2005 (document number NREL/TP-540-38707).

INSULATED TANK PROJECT

The Insulated tank project was scheduled for equipment installation in July 2004. A SunLine technician traveled to Lawrence Livermore National Laboratory (LLNL) in Livermore, CA to assist in the installation. The vehicle was completed and tested in late July 2004 and subsequently delivered to SunLine in mid August. In use testing began in September and was completed in 3rd quarter 2005. An in-use report was supplied to LLNL for analysis and the vehicle was pulled out of service due to the weight limit of the truck with the new equipment installed. No further development of this project was done by SunLine after the vehicle was put out of service. LLNL was seeking funding to move the project to the third phase of the project. No final report was received from LLNL by SunLine.

TWO 40-FOOT HYDROGEN BUSES

SunLine Transit Agency now has two hydrogen powered buses. SunLine Transit Agency has purchased a hydrogen internal combustion engine (HICE) hybrid electric heavy duty bus and a hydrogen fuel cell heavy duty bus (FCB). The buses remain in service and data is being collected on the performance, reliability, and fuel consumption. A study with NREL on the data collection will be conducted over the next two years.

HICE Bus

Delivery of the hydrogen internal combustion engine hybrid electric heavy duty bus was taken in November 2004. The bus began fixed route service on December 16, 2004. In January 2005 the SunLine Hydrogen Internal Combustion Engine Hybrid Bus was taken to Manitoba Transit to conduct cold weather testing. (Attachment B) The vehicle logged only 804 miles during the test due to problems that occurred with the station due to the cold weather. In the spring the bus was brought back to SunLine and put into regular service in the Coachella Valley.

The hydrogen hybrid internal combustion engine bus has required special maintenance to the engine. Some problems with premature failures of the harmonic balancers have caused several replacements. Other engine operating problems have occurred with the intake manifold gaskets and fuel injectors. These problems have not been completely understood yet, but are being continuously monitored by SunLine, ISE and Ford Power Products. The HICE bus was sent to Dallas for the American Public Transportation Association (APTA) conference in September 2005 and received rave revues. The hydrogen hybrid internal combustion engine continued to be in operation until November 2005 when the engine experienced some internal problems at 18,473 miles. The engine was replaced and rebuilt with a new block and new pistons and put back into regular service. To date since arrival in December 2005 the bus has logged over 54,300 revenue miles in service at SunLine.

Fuel Cell Bus

SunLine has purchased one of four fuel cell hydrogen hybrid electric heavy duty demonstration buses in conjunction with Alameda-Contra Costa Transit District (AC Transit). [*As per Section 9 "Future Plans" pg 47*] A technician was sent to AC Transit to assist in the chassis installation and interior installation in 1st quarter 2005. The bus was shipped to ISE (in San Diego, CA) for the drive train installation and the UTC Power fuel cell integration. The new fuel cell bus began road testing in October of 2005. A fuel specification was developed and agreed upon for fuel cell warranty purposes and a certified test center (Smart Chemistry) was located to conduct the analysis. A preliminary sample was tested in 3rd quarter 2005. (Attachment C) Quarterly samples are now taken to ensure purity levels are maintained to the agreed specification. A preliminary study with NREL was conducted in 2006. An additional study will be completed in 2008. A problem with the Fuel Cell was encountered in 2006 on the FCB. Some proactive measures were taken to address the problem. Current operation hours have been cut back until further analysis can be conducted. To date this vehicle has logged over 36,000 miles and 1,800 load hours.

SunLine also entered into a solicitation with the FTA's National Fuel Cell Bus Program for funding of an additional bus in 2008. SunLine was awarded funding in the North American Fuel Cell Bus program for a state of the art fuel cell bus with technology advancement attained from the Van Hool Bus project. The new bus and fuel cell will be built in North America. This bus is expected to be delivered by July 2009 and will also be tracked by NREL.

PUV OPERATION

The three personal utility vehicles have been decommissioned. They are housed in the Shatz Energy Garage at SunLine. One of the vehicles is still in operation and was modified into a miniature bus. This miniature bus continues to operate and is used for outreach programs and educational purposes. It has been used in several local parades in the Coachella Valley. The Kewet is still operational and is displayed during regular tours of SunLine hydrogen fueling station.

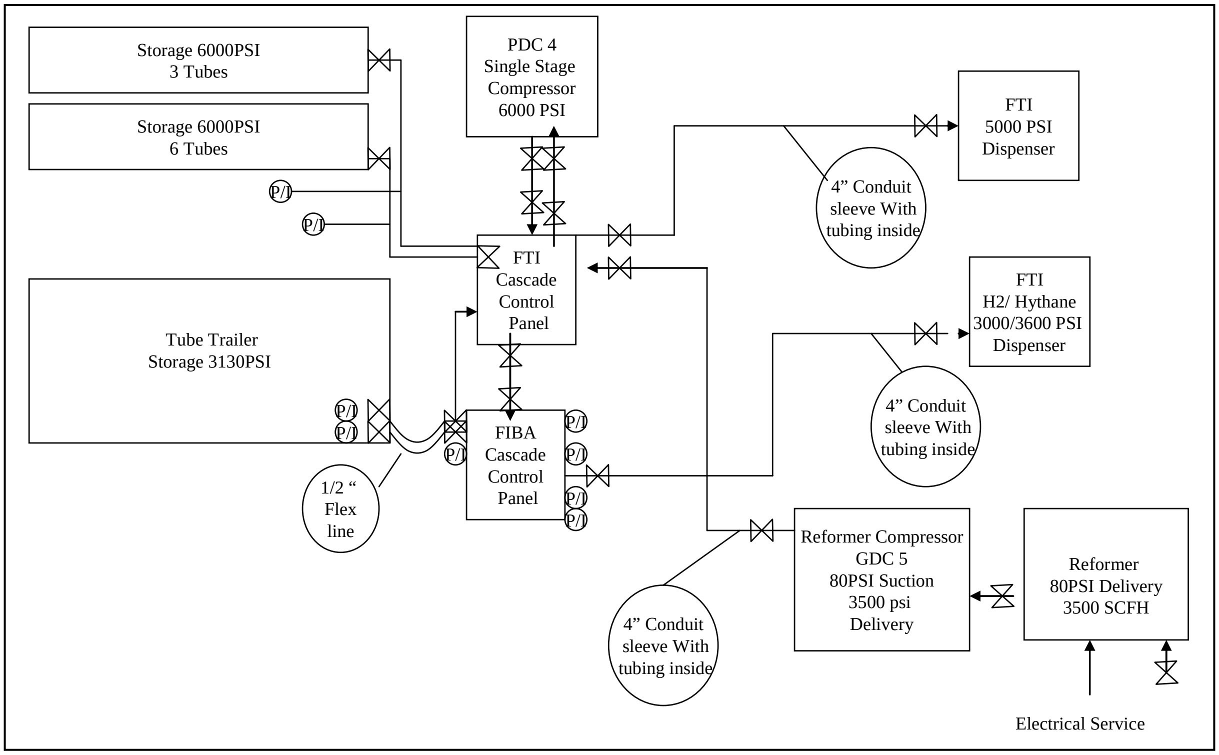
STATION FUELING AND MAINTENANCE

With the addition of the new FC hydrogen bus, and the schedules of the buses, some low hydrogen fills were noticed. A schedule for fueling was implemented to accommodate the fueling and ensure complete fills for the buses. SunLine conducted an evaluation to see what upgrades were needed. These upgrades to the station were planned to get the station at or near commercialization with equipment that can be purchased today, without the use of prototype units. The station upgrades were funded by both AQMD and FTA consist of a new commercial reformer along with a six year maintenance agreement, upgrades to the booster compressor, a dedicated dispenser bus hose, additional hydrogen storage, and a card reader to make the station publicly accessible after hours and weekends without an attendant.

- A new commercial reformer was chosen and procured during the first part of 2006. Several different types of reformers and manufacturers were considered. Prototype units and one of the systems were eliminated from the selection process due to the stage of commercialization they were in.
- The current PDC booster compressor is a production unit. The compressor was originally purchased as a single stage compressor with the option of an upgrade to duplex. By making the unit a duplex compressor, recovery time will be decreased from a four hour recovery time (60 scfm) to a two hour recovery time (120scfm) in-between bus fills.
- The FTI hydrogen dispenser is not a certified production unit. SunLine is currently working with California Weights and Measures to see what will be necessary to certify the dispenser system. It was installed in 2004 as part of a station expansion with funding from AQMD. The dispenser was purchased as a single hose dispenser with the option of an upgrade to a two hose dispenser. Currently the dispenser can fill small hydrogen vehicles with a California Fuel Cell Partnership (CaFCP) compliant interface or a non-communication fill at ¼ kg per minute. This is an adjustable feature that has to be changed when ever small vehicles are fueled and then switched back up to higher flow rates for nightly fueling of the buses. By equipping this dispenser with a dedicated bus hose no more manipulation of the dispenser will be needed for smaller vehicles.
- An additional hydrogen higher pressure storage system (60 kg) will be installed to the existing 180 kg of storage at the tank farm. This storage system will work to increase the final stage of the cascade system to ensure adequate fueling of the buses at night.
- A card reader system and video trainer will be installed as part of this upgrade. This is a regular production unit from Fuel Force that many fleets and our CNG station currently use. It matches the card reader system used by Sunline CNG station and will make billing and tracking of the fuel used by SunLine and public customer more efficient and convenient

Several maintenance procedures have taken place this reporting period on the SunLine Thousand Palms hydrogen station compressors. The high pressure booster compressor (PDC4) experienced diaphragm "O" ring failures during February 2005 at 691 hours and once again in March 2005 at 716 hours. To date, these were the only major repairs done on the booster compressor system. A new diaphragm was installed on the 2^{nd} stage of the (PDC5) compressor at 1110 hours. This is the primary compressor from the reformer unit. The diaphragm is expected to last at least 4000 hours. The premature failure was caused by a broken spring for the discharge check valve. No other damage was noticed at the time of repair. These compressors continue to be operated and serviced by SunLine personnel.

SUNLINE HYDROGEN STATION FLOW DIAGRAM



SECURITY

SunLine continues to provide gated security and video surveillance to the hydrogen station. To date no reports of vandalism or damage have occurred to the station's equipment or property. No safety incidents have occurred since the first commissioning of the station in April 2000 to date.

OTHER HYDROGEN FLEET TESTING

In late 2005, the SunLine Thousand Palms hydrogen facility was identified as one of the "California Hydrogen Highway" fueling stations. The station continues to be used by several car manufactures and hydrogen users in Southern California. The SunLine Thousand Palms hydrogen facility continues to operate and provide hydrogen for the SunLine bus program and other hydrogen cars in Southern California. A formal letter from the state is expected to address the hydrogen station as an official "California Hydrogen Highway Station" in 2007.

During this evaluation period, the SunLine Thousand Palms hydrogen facility has continued to provide hydrogen for various hydrogen vehicles in the Coachella Valley. All hydrogen is internally produced by the Hyradix natural gas reformer. In August 2004, AQMD had a hydrogen fuel cell conference in the Palms Springs area. Several hydrogen car manufactures participated in the ride and drive. All vehicles were fueled at the SunLine Thousand Palms hydrogen station.

Several hydrogen vehicle manufacturers’ have used the facility, including Ford Motor Co. during their calibration phase of their HICE program, and during the Palm Spring Clean Cities 2005. In August 2005, Ford conducted hot weather testing on their HICE test program. Ford Motor Co. will be delivering 100 units in 2006 to several sites located throughout the country. Four of those units may be tested by a local Indian Gaming Casino. To date no vehicles from Ford have been delivered in the Coachella Valley. American Honda also continues to utilize the hydrogen station with their leased vehicle (20 cars) program. Honda FC vehicles come periodically to the Coachella Valley on business either from AQMD, City Los Angeles Municipal car pool and the Los Angeles Water District.

PUBLIC OUTREACH

Tours have been conducted and continue to provide valuable information to the general public as well as visitors from around the world on Hydrogen and Alternative fuels. Each semester our local community college provides a tour of the facility for the several environmental classes conducted during the semester. There has continued to be a host of both private and government agencies to visit the every day working hydrogen station that has been continually developed with help from DOE, AQMD, CARB and other governmental agencies.

CONCLUSION AND RECOMMENDATIONS

The success of this program can be measured in miles driven by new state of the art public transportation buses and kilograms of hydrogen produced. It has been by the vision of SunLine Transit Agency along with the DOE, FTA and all other collaborators that this program still continues to offer a view of what the future may hold in store for the United States and is prosperity and hope for a cleaner and brighter future with out the dependence on foreign oil.

SunLine recommends continued support from the DOE to programs like these for hydrogen infrastructure and commercialization of hydrogen technology to move the United States to it ultimate goal for a sustained, safe and economical energy source for a free and clean air America.

Attachment A
Hyradix AQMD Report

HyRadix, Inc., SunLine Transit Agency and

SunLine Services Group

Hydrogen Refueling System Demonstration Project

AQMD Contract Number 03200

27 July 2005

Table of Contents

Executive Summary

The South Coast Air Quality Management District (AQMD) is the local agency with primary responsibility for regulating stationary source air pollution in the South Coast Air Basin in the State of California. In January, 2003 the AQMD contracted with SunLine Services Group (SSG) to provide a turn-key hydrogen production and refueling station for use with alternative fuel vehicles and fuel cell vehicles (Contract No. 03200). The location of the refueling station is at the SunLine Transit Agency (SunLine) site in Thousand Palms, California.

As called for in the contract, the station is an integrated system with hydrogen generation, purification, compression, storage and dispensing. The hydrogen generation and purification systems were developed by HyRadix, Inc. (HyRadix) at their facilities in Des Plaines, Illinois. Autothermal Reforming (ATR) and Pressure Swing Adsorption (PSA) were the technologies of choice to convert commercial natural gas into a high purity hydrogen fuel product.

The compression, storage and dispensing infrastructure was designed by SSG for SunLine. Prior to the contract, SunLine had been operating a commercial hydrogen and natural gas refueling station for several years. It incorporated a FIBA Technologies cascade type system to store and dispense hydrogen. In this system, hydrogen is stored at three different pressures; low-pressure (3000 psig) intermediate-pressure (5000 psig) and high-pressure (6000 psig) and dispensed at two (3600 psig and 5000 psig). The hydrogen inventory was replenished by an on-site electrolyzer or by trucking the DOT trailer that served as low-pressure storage to an off-site vendor for filling. In addition to this equipment, SSG selected a PDC Machines, Inc. two-stage diaphragm compressor to compress the 100 psig hydrogen product from the HyRadix hydrogen generator to the low-pressure storage.

The effectiveness of the integrated system in converting commercial natural gas to fuel grade hydrogen, compressing and storing the hydrogen fuel and then quickly dispensing to 5000 psig storage tanks onboard alternative fuel vehicles and fuel cell vehicles was demonstrated during the April, 2004 to May, 2005 period.

An initial one month test run of the Adéo™ Hydrogen Fuel Generator (HFG) was completed in April, 2004. The goal of the demonstration run was to operate the Adéo HFG at 90% of its rated capacity (90 nm^3/h) for ten consecutive days within a 30 day period. A product hydrogen purity greater than 99.5 vol% and carbon monoxide concentration less than 1 vppm were to be maintained during the run. The ten day run started on 17 April 2004 and completed on 30 April 2004. Several shutdowns due to external utility problems occurred during this period. Since they were due to external sources the shutdowns were not considered relevant to the continuous operation. The hydrogen generator was immediately restarted after each shutdown and the demonstration run was resumed after the plant was lined out. During the demonstration run the average product hydrogen purity was 99.68 vol% and the carbon monoxide concentration was less than 1 vppm. The average feed and product flow rates were 47.0 Nm^3/h and 91.7 Nm^3/h, respectively.

The one year demonstration run covered the period from 17 April 2004 through 16 April 2005. The Adéo™ was operated for a total of 4395 hours over the course of the 12 month demonstration run. During this period it produced 189,967 Nm^3 of 99.95+ purity hydrogen from 106,072 Nm^3 of natural gas. Of the total hydrogen produced SunLine used or sold 51,900 nm^3. The balance of the hydrogen was vented. Much of this vented product hydrogen occurred during the December through February period. During this time, SunLine was using the Adéo unit to perform a paid study for a third party.

In addition to the grant provided by the AQMD, additional funding for this project was provided by the U.S. Department of Energy, through a State Energy Program grant with the State of Illinois Department of Commerce and Economic Opportunity (Grant #03-57501). The SunLine Transit Agency and HyRadix, Inc. also supplied funds for the execution of this project.

Background

HyRadix, Inc (HyRadix) and SunLine Services Group (SSG) are partners in the installation and test operation of a hydrogen refueling system for use with alternative fuel vehicles (AFV) and fuel cell vehicles (FCV) operated by SunLine Transit Agency (SunLine). HyRadix, SSG and SunLine participated in the project through a contract with the U.S. Department of Energy, through a State Energy Program grant with the State of Illinois Department of Commerce and Economic Opportunity (Grant #03-57501) and a grant from the South Coast Air Quality Management District (Contract No. 03200).

The objective of the project was to demonstrate the effectiveness of a hydrogen refueling station that combines HyRadix's Adéo hydrogen generation technology with compression, storage and dispensing facilities designed by SSG and SunLine. The project consisted of three phases. The work breakdown structure for these phases may be seen in Appendix A.

Phase I of the project involved the development and fabrication of Adéo Hydrogen Fuel Generator (HFG) by HyRadix and a hydrogen compression, storage and dispensing system by SSG and SunLine. The Adéo HFG, as specified in the grant, was to produce 100 nm^3/h of 99.0+ vol% hydrogen product with less than 1vppm carbon monoxide. The hydrogen dispensing and storage system needed to be capable of compressing the hydrogen product to storage pressure as well as refueling a bus with 40 kg of hydrogen to 5000 psig within 15 minutes or an automobile in 3 – 5 minutes.

Phase II addressed the installation and commissioning of the hydrogen refueling station equipment.

Phase III entailed a demonstration of the integrated hydrogen refueling station. This included a 10 day demonstration of the Adéo^{TM} HFG ability to perform at 90% of its rated capacity as well as a one year integrated demonstration run.

HyRadix, Inc.

HyRadix, based in Des Plaines, Illinois, is dedicated to the development and commercialization of hydrogen generation technology for hydrogen vehicle refueling, industrial applications and for fuel cells. Using an innovative combination of process technology and equipment, HyRadix's Adéo hydrogen generating appliances produce high purity hydrogen from the common infrastructure fuels such as pipeline natural gas and commercial grade LPG.

The HyRadix Fuel Processor Program was initiated in 1998 and follows a well-established process for new technology development. HyRadix begins with product conceptualization, during which time HyRadix researches existing hydrogen generation chemistry and technology to develop a fundamental understanding of the issues, which lead to several proposed alternative technical solutions. From there computer modeling and process simulation tools are applied to determine an optimal process solution. These computer-modeling tools are refined throughout the development program to continuously guide efforts. After developing an optimal computer-generated solution, pilot plants are constructed to complete proof-of-principle experiments to verify computer model predictions. After pilot plant testing, prototype units are fabricated which represent the actual fuel processor product HyRadix will deliver to the marketplace. Each successive prototype includes iterations on the design of the overall process as well as iterations on individual pieces of equipment.

The rigor of this development process has produced a state-of-the-art auto-thermal reforming (ATR) process design with a unique heat integration scheme and superior hydrogen purification technology. This has resulted in the development of a hydrogen generation system capable of providing high purity hydrogen product at high efficiency and with a short startup time

SunLine Transit Agency and SunLine Services Group

The SunLine Transit Agency is a recognized leader in demonstrating alternative fuel options for public transportation. Since 1999, SunLine has worked with the U.S. Department of Energy (DOE), U.S. Department of Defense (DOD) and the U.S. Department of Transportation (DOT) to develop and test hydrogen infrastructure, fuel cell vehicles and alternative fuel vehicles.

SunLine has cultivated a rich history of testing and demonstrating equipment for leading industry manufacturers in a pre-commercial environment. Visitors, from around the world, to SunLine's "Clean Fuels Mall" have included government delegations and agencies, international journalists and media, industry leaders and experts, and environmental and educational groups.

SunLine has been operating a commercial natural gas refueling station since 1993 and a commercial hydrogen and natural gas refueling station since 1999. During this time it has accumulated significant technical and operating experience.

Systems Description

Hydrogen Fuel Generator

The HyRadix Adéo™ On-site Hydrogen Fuel Generator incorporates auto-thermal reforming on bi-functional, monolithic catalysts and CO shift reaction to produce a hydrogen-rich reformate. When coupled with Pressure Swing Adsorption (PSA), the system produces 100 nm^3/h of 99.95 vol% hydrogen product with less than 1 vppm carbon monoxide at 90 psig from 52 nm^3/h of natural gas feedstock. The hydrogen product from the PSA is subsequently compressed and delivered to storage. The waste gas from the PSA is sent to an onboard Waste Gas Burner to recover heat.

Natural gas feed for the Adéo HFG was obtained from SunLine's 250 psig supply. The feed pressure was reduced to less than 125 psig prior to entering the unit. Odorants and other sulfur compounds were removed from the natural gas feed using HyRadix's patented sulfur removal technology. The sulfur removal adsorbent is sufficient for nine months operation at design feed rate. The analysis of the natural gas feed is shown in Table 1.

Component	Average Concentration
Methane	96.24 vol%
Ethane	1.54 vol%
Propane	0.23 vol%
Butanes	0.08 vol%
Pentanes	<0.01 vol%
C6 Plus	0.02 vol%
Nitrogen	0.43 vol%
Carbon Dioxide	1.46 vol%
Total Sulfur	< 25 vppm
Heating Value	1013 btu/scf (HHV)

Table 1
Natural Gas Feed Analysis for 17 April through 30 April 2004

Some of the features included with the Adéo™ hydrogen generation unit are:

- Monolithic ATR and shift catalysts.
- Ambient temperature feed desulphurization
- Advanced PSA designed to process reformate with elevated nitrogen levels

- Fully automated startup.

- An onboard air compressor to supply process air for the auto thermal reforming reaction. Air for the low pressure combustion of process waste gas in a heat recovery Burner was provided by an onboard blower.

- Process water was provided by a HyRadix supplied reverse osmosis system. The system was capable of delivering 2 gal/min of process water with a specified conductivity of < 0.5 µS/cm.

- A HyRadix supplied treated cooling water system was used to provide cooling water for the Adéo^{TM} unit. The cooling water is used to cool reformate before it is directed to the PSA. It is also used to regulate the temperature of the control system components in hot environments.

Nitrogen is used in the Adéo HFG startup sequence and as a purge whenever the plant is shut down. Since a ready supply of nitrogen was not available at the test site, cylinder nitrogen was used for this purpose. Approximately 1100 scf of nitrogen is required for each startup-shutdown cycle.

The Adéo HFG is a skid mounted design with a ventilated metal enclosure. Its physical dimensions are 22 ft. x 8 ft. x 8 ft. (L x W x H). The installation is illustrated in Figure 1.

Figure 1
HyRadix Adéo^{TM} Hydrogen Fuel Generator Installation at SunLine Transit Agency

Hydrogen Fuel Storage and Dispensing

Preexisting Storage and Dispensing Infrastructure

SunLine has been operating a commercial hydrogen and natural gas refueling station for several years prior to this project. It uses a FIBA Technologies cascade type system to store and dispense hydrogen. In this system, hydrogen is stored at three different pressures; low-pressure (3000 psig) intermediate-pressure (5000 psig) and high-pressure (6000 psig) and dispensed at two (3600 psig and 5000 psig). The low-pressure hydrogen is blended with compressed natural gas for use in Hydrogen-Compressed Natural Gas (HCNG) powered vehicles. It is also used as the first stage in a cascade to refuel higher pressure fuel cell powered vehicles. In the cascade, as the pressure in the receiving vessel approaches the pressure of the low-pressure supply, the dispensing system switches to the intermediate-pressure hydrogen supply. Likewise, as the receiving vessel pressure approaches the intermediate- pressure, the dispenser switches to high-pressure hydrogen to top off the vehicle hydrogen pressure to about 5000 psig.

The low-pressure hydrogen storage is comprised of a 16-tube DOT trailer. The DOT trailer can store up to 104,300 scf of hydrogen at a MAWP of 3130 psig. In addition to supplying the low-pressure hydrogen requirements described above, it is used to supply feed for the intermediate and high-pressure storage. Prior to the acceptance of the Adéo™ HFG, the low-pressure hydrogen supply was replenished by an on-site electrolyzer or trucking the trailer to an off-site vendor for filling.

A single-stage PDC Machines, Inc. diaphragm booster compressor is used to inventory the higher pressure systems. The ASME tube tanks used in both systems consist of carbon steel cylinders, each with a rated maximum allowable working pressure of 6250 psig. The intermediate-pressure storage consists of six of the ASME tube tanks with a total capacity of 55,100 scf of hydrogen at 5000 psig. The high-pressure storage makes use of three ASME tube tanks with a total capacity of 33,100 scf of hydrogen at 6000 psig.

Figure 2 - Hydrogen Storage at SunLine Transit Agency

New Storage and Dispensing Infrastructure

A new compressor was required to compress and deliver the hydrogen product from the Adéo™ HFG unit to the 3000 psig DOT storage trailer. SunLine selected a PDC Machines, Inc. two-stage diaphragm compressor for this service. As noted above, it currently uses this compressor in conjunction with existing processing equipment and is satisfied with its operation and reliability. An advantage offered by this type of compressor is its ability to provide contamination free gas as required by today's fuel cells.

When the hydrogen pressure drops to a predetermined level in the low-pressure storage, a SunLine operator will start the Adéo HFG in preparation for filling. After the hydrogen product purity reaches the desired value (3½ hours to 99.95 vol% H_2 purity for a cold start), the operator confirms that it is ready for export to storage, starts the hydrogen product compressor and sets the Adéo HFG feed rate to produce the desired amount of hydrogen product. Prior to product export, the compressor is run through an automated purge cycle to remove air. After purging is completed, the 90 psig hydrogen product from the Adéo HFG is automatically lined up with the compressor. The product is then compressed and sent to the low-pressure storage. When the pressure in the storage reaches 3000 psig a signal is sent to shut down the compressor and place the Adéo™ HFG in idle.

Site Conditions

The demonstration site is located at SunLine's facilities in Thousand Palms, California. It is a desert environment, subject to occasional sandstorms. Average site temperature data are provided in Table 2.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High (°F)	70	75	80	88	95	104	108	107	101	91	78	70
Low (°F)	44	47	51	56	63	70	76	76	71	61	50	43

Table 2
Average Temperature Data for Thousand Palms, California
(source: http://weather.yahoo.com/climo/USCA1145_f.html, 17 June 2004)

Project Implementation

An explanation of the execution and completion of the tasks in the Statement of Work and the Project Accountabilities, shown in Appendix A, is provided below.

Phase I - Development/Testing/Fabrication

Task 1 Fabrication of Demonstration Reformer/Pressure Swing Adsorption Unit (PSA)

Tasks 1.1 – 1.2 Engineering Design and Design Approval

The detail design for the Adéo™ HFG unit was completed in March, 2003. The design package included a Process Specification, detailed hydraulic calculations, Piping and Instrumentation Diagram, Mechanical Flow Diagram, equipment, control and instrumentation specifications and fabrication drawings. A thorough hazards and operability analysis (HAZOP) was part of the design package, as well, and its recommendations were included in the design.

The following codes were used in the design of the Adéo HFG:

1. Pressure vessels and heat exchangers were fabricated and certified per ASME Code Section VIII Division 1 AO2 Addenda
2. Pipe was fabricated per ASME B31.3
3. Electrical specifications followed the NEC code
4. NFPA and OSHA requirements were adhered to in the design
5. Material certificates, calculations and QA/QC manuals are maintained

Task 1.3 Fabrication of a Demonstration Reformer

Fabrication of the Adéo HFG was started in early April, 2003 and was completed in June, 2003. The fabrication was performed in an Illinois fabrication shop under HyRadix guidance. Two weeks were spent on pre-commissioning activities after completion of the fabrication.

The Adéo system was shipped to SunLine on 18 July 2003. The cooling tower was delivered directly to SunLine from the manufacturer.

Task 2 Development, Testing and Fabrication of Compression, Storage and Dispensing System

Tasks 2.1 – 2.5 Engineering Design through Equipment Delivery

As previously noted, SunLine was operating a commercial hydrogen and natural gas refueling station for several years prior to the start of this project. The sub-tasks 2.1 through 2.5, pertaining to the process design and equipment design and selection, had already been completed by SSG and SunLine. Most of the equipment was already installed and operating. In the case of the product hydrogen compressor, the PDC Machines equipment was purchased earlier for use with a different fuel reformer, but, was never installed.

Task 2.6 Permitting

Permits for the installation of the storage and dispensing systems were obtained by SSG from the Riverside County Fire Department.

Phase II - Installation and Commissioning

Task 3 Reformer Installation and Commissioning

Task 3.1 Install Reformer at Demonstration Site

The Adéo^{TM} HFG arrived on site on 22 July 2003. All of the catalysts and adsorbents were shipped uninstalled to prevent damage during shipping. The catalyst inventory consisted of monolithic catalyst for the ATR, Shift Reactor and Waste Gas Burner. Pelletized adsorbent was supplied for the sulfur removal system and the PSA. Catalyst and adsorbent loading began on 6 August and was completed the next day.

The utility line installations were completed during August, 2004. These included:

- 480 VAC, 3-phase power
- ½" natural gas line, pressure reducing regulator and pressure relief valves
- makeup water line to the RO system
- process water line from the RO system to the HFG
- makeup cooling water line to the cooling tower
- cooling water supply and return lines
- HFG vent and relief valve extensions
- analyzer sample lines
- product hydrogen and hydrogen export to storage lines
- nitrogen purge line

The full plant installation was completed on 5 September 2004.

Tasks 3.2 and 3.3 Test and Commission Reformer at Demonstration Site

Throughout the fabrication and installation of the Adéo HFG, continuous improvements in heat exchange technology and performance were being made at HyRadix's Des Plaines facility. In early September it was decided to incorporate these improvements into the Adéo unit. These modifications were completed by the first week of October, 2003.

First gas to the unit occurred on 9 October 2003. For the next month, the Adéo HFG was continuously operated and all systems were tuned to optimize performance. The controller operations as well as the automated startup and shutdown functions were tested and verified. Analytical equipment was brought online and calibrated. The PSA was commissioned and the unit consistently produced hydrogen product with a purity of 99.95 vol%.

The October-November testing produced data that was used to further upgrade the performance of the heat exchange design. The new modifications were completed by the end of March, 2004. The Adéo HFG was started up on 6 April 2004 and successful pre-demonstration run testing was performed through 16 April 2004.

Task 3.4 Training of System Operators

Classroom and hands-on training methods were used to instruct SunLine personnel in the operation of the Adéo^{TM}. This training was completed in September, 2004.

Task 3.5 Security

A security fence surrounds the entire SunLine compound except the dispensing area. Access to the compound is through a guarded and monitored gate. The Adéo unit, product compressor and hydrogen storage are located within the compound.

Task 3.6 Equipment Installation Permits

The Adéo HFG was installed as a replacement for another hydrogen fuel generator and required no new permitting for installation.

Task 4 Installation and Commissioning of Compression, Storage and Dispensing System

Task 4.1 Install Compression, Storage and Dispensing System at Demonstration Unit

The SunLine hydrogen storage and dispensing system had been installed prior to the start of the project. The product compressor was installed on a concrete pad next to and north of the Adéo unit. The installation was completed in early July, 2003.

Task 4.2 Commission Compression, Storage and Dispensing System

Shortly after its installation, the product compressor was run on nitrogen to ensure all of its systems worked. As noted in Task 4.3, the commissioning of the product compressor occurred in November, 2003. A slipstream of hydrogen from the Adéo HFG was introduced to the compressor, compressed and vented to atmosphere.

Task 4.3 Integration with Reforming Unit

The Adéo HFG and hydrogen product compressor integration logic was successfully tested for the first time on 4 November 2004. The initial integrated operation of the Adéo HFG with the SunLine storage and dispensing system was made on 7 May 2004.

Prior to the start of this project, SunLine has shown that the installed dispensing equipment is capable of meeting contract requirements of filling a hydrogen fueled bus with 40 kg. of hydrogen to 5000 psig within 15 minutes. Likewise, hydrogen powered automobiles take less than 5 minutes to refuel.

Task 4.4 Operating Permits

A permitting letter was issued by the Riverside County Fire Department on 11 June 2004. This correspondence allowed for the continuous and unattended operation of the Adéo HFG (see Appendix E). Prior to acceptance by the fire department, operation of the Adéo unit was allowed only as long as a HyRadix operator was present.

Below is a list of the documentation provided to Riverside County for review prior to issuing the permitting letter:

- Completed unit HAZOP.
- Process Flow Diagram (PFD).
- Summary of plant safety shutdown equipment.
- General description of the plant including a process description, equipment specifications and the codes used in design and construction.

In addition to the documentation review, the Riverside County Fire Marshal made a comprehensive inspection of the installation and installed safety equipment.

Phase III – Demonstration

Task 5 Demonstration of Integrated System

Task 5.1 One Month Demonstration Run

The goal of the demonstration run was to operate the Adéo™ HFG at 90% of its rated capacity (90 nm^3/h) for ten consecutive days within a 30 day period. A product hydrogen purity greater than 99.5 vol% and carbon monoxide concentration less than 1 vppm was to be maintained during the run. SunLine and HyRadix will then continue to operate and monitor the unit for an additional period of 12 months. During this time, long-term data will be collected to verify maintenance requirements and costs, system performance, hydrogen production costs and on-stream availability.

The demonstration run started at 1400 hrs PST on 17 April 2004. The natural gas feed rate and PSA cycle time were chosen to maintain a hydrogen product flow greater than 90 nm^3/h and product hydrogen purity greater than 99.5 vol%. The feed rate chosen for the test was 47 nm3/h. A description of the on-line analyzer used for measuring product hydrogen purity may be found in Appendix F.

The plant operated for almost six days at these conditions until 0730 hrs on 23 April. At this time an unplanned shutdown occurred when the plant lost feed water due to a break in the water supply main at the test site. This, eventually, led to a low process water inventory condition within the Adéo unit which, in turn, resulted in an automatic shutdown of the unit.

The plant was restarted after the maintenance work was completed and ran at test conditions until 1530 hrs on 24 April 2004. At this time it shut down due to a voltage spike in the power supplying the plant. Trouble with the power supply caused unplanned shutdowns at 1130 hrs on 25 April and, again, at 0930 hrs on 26 April. The plant was restarted and brought back to test conditions soon after each shutdown. Since the shutdown cause was external to the Adéo HFG, the run time resumed where it was when the shutdown occurred.

The ten day (240 hour) demonstration run was successfully completed at 1800 hrs on 30 April 2004. A plot of the demonstration run can be found in Figure B.1 in Appendix B. During the run the average product hydrogen purity was 99.68 vol% and the carbon monoxide concentration was less than 1 ppmv. The average feed and product flow rates were 47.0 nm^3/h and 91.7 nm^3/h, respectively.

Also provided in Appendix B are plots of the cold and warm startup performance. A cold startup is defined as one in which all temperatures within the Adéo™ HFG are less than 50°C. A warm startup is one that occurs within one hour after a shutdown while the unit temperatures are still elevated. As shown in Figure B.2, the time needed progress from a cold start to product with a 99.95 vol% hydrogen purity is about 3 hours. In Figure B.3 it is shown that the time required to go from a warm startup to product with a 99.95 vol% hydrogen purity is 1.6 hrs.

Shutdowns
The four unplanned shutdowns experienced during the demonstration run were due to the interruption of utilities to the Adéo HFG. The loss of the process water supply due to unscheduled maintenance was avoidable with better communications between maintenance and operation personnel. The three shutdowns due to power spikes were addressed with the addition of equipment within the Adéo HFG to better condition the external power supplied to it.

Task 5.2 Evaluate One Month Demonstration Run and Modify

Heat Exchangers
Proper selection of heat exchange equipment is important in optimizing the performance of any hydrogen fuel generator. The size limitations, performance requirements and severe operating conditions require a compact and robust heat exchanger design. The exchangers currently in place within the Adéo HFG are meeting these requirements.

Service and Support
While the Adéo HFG is designed for minimum operator intervention, regular maintenance is required to keep it operating at optimal performance. A maintenance manual was provided to SunLine which addresses the maintenance cycle for the Adéo HFG based on the experience gained while operating in the desert environment.

Extended Run
The ten day performance demonstration run for the Adéo HFG was completed 30 April 2004. Work to complete the integration of the hydrogen fuel generator with the SunLine storage and dispensing system was completed on 7 May 2004. After this period, SunLine and HyRadix agreed that it would be in the best interest of both parties to cooperate in the continued operations of the integrated plant during the upcoming one year demonstration run. The current hydrogen requirements of SunLine can be met by operating the plant only a few days per week. HyRadix has agreed to provide operation services when necessary and to monitor the plant, around the clock, in order to accumulate the maximum amount of runtime data.

Task 5.3 One Year Demonstration Run

The one year demonstration run covered the period from 17 April 2004 through 16 April 2005. A summary and presentation of the production data for the period is provided in Appendix C.

The Adéo^{TM} was operated for a total of 4395 hours over the course of the 12 month demonstration run. During this period it produced 189,967 nm^3 of 99.95+ purity hydrogen from 106,072 nm^3 of natural gas. Of the total hydrogen produced SunLine used or sold 51,900 nm^3. The balance of the hydrogen was vented. Much of this vented product hydrogen occurred during the December through February period. During this time, SunLine was using the Adéo unit to perform a paid study for a third party. Weekly production details are provided in Table C.1 and Figures C.1 and C.2.

Hydrogen product was first compressed and exported to storage on 7 May 2004. Only three of the cylinders in the DOT trailer were inventoried in order to isolate the hydrogen from the rest of the storage system prior to sampling and third party certification of purity. Sample results showed that the hydrogen purity exceeded 99.95 vol% with less than 1 vppm of carbon monoxide. Sale of Adéo HFG produced hydrogen began shortly after SunLine's acceptance of the analysis results and the remaining 13 tubes on the DOT trailer were filled by 12 May 2004. The Adéo HFG continues to run as required in order to inventory the DOT trailer.

From 7 May 2004, when the product compressor was first commissioned, through the end of the one year demonstration run the Adéo was the sole source of hydrogen for SunLine operations. Typically, when the hydrogen inventory in the low-pressure storage cylinders dropped to about 2000 psig, the unit was started and run at 40 – 50% design. At this rate the Adéo was able to satisfy the continuing hydrogen demand from SunLine and its customers while slowly replenishing the hydrogen inventory. After several days the storage system would be full and the Adéo would be shut down or operated in the idle state and venting hydrogen until the inventory was again depleted. When operated in the idle state the Adéo will automatically redirect hydrogen product from the vent to the product compressor when the low-pressure storage inventory drops to about 2600 psig.

Shutdowns

A summary of the shutdowns experienced by the Adéo during the demonstration run is provided below in Table 3.

Shutdown Type	% of Occurrences
Planned	18
External	10
Unidentified	5
Tuning and Maintenance	7
Operator Error	5
Equipment	55

Table 3
Summary of Shutdowns that Occurred During Demonstration Run

All of shutdowns identified as planned were made by the operator after the hydrogen storage was filled. As mentioned above, the Adéo^{TM} was operated at a rate intended to match supply with demand. When hydrogen storage was topped off the Adéo would automatically transition to an idle state and vent hydrogen to the atmosphere until the hydrogen inventory was decreased to the low level. If the operator felt that the plant would remain at idle for an extended period due to low hydrogen demand he had the option of shutting down to conserve resources.

The external occurrences refer to shutdowns that were caused by uncontrollable conditions outside of battery limits. These include loss of process water, power interruptions and an upset in the natural gas feed supply. Power interruptions in the form of voltage surges caused most of this type of shutdown. Although the source of the power troubles was never identified, the voltage surges generally occurred during hot weather (over 100°C) and affected the Burner Blowers. Power conditioning equipment was added to successfully address the problem.

5% of the shutdowns are labeled as unidentified. In these cases there were no indications given by instrumentation, alarms or operators as to the cause of the shutdown.

Of the shutdowns identified as due to maintenance and tuning work, the majority occurred during control loop tuning. Additional shutdowns occurred when adjusting valves and swinging nitrogen purge cylinders. In all cases the plant was immediately restarted.

Operator error figured in 5% of the shutdowns. There was no discernable pattern to the errors and none have occurred since August, 2004.

Equipment malfunctions resulted in 55% shutdowns during the twelve months of the demonstration run. In many instances, multiple consecutive shutdowns were caused by a single equipment malfunction and this served to inflate the total number of equipment related shutdowns. A description of the various equipment shutdowns follows.

Problems with PSA valves produced the majority of the equipment shutdowns, usually by dumping tail gas from an adsorber vessel and causing a high Burner temperature. Several additional high Burner temperature shutdowns occurred for which no cause was determined. It is felt that they too may have been due to problems with the PSA valves. These problems were solved after adjustments were made to the PSA valves and their control logic.

Two series of process water level switch malfunctions resulted in several shutdowns. One series happened in early May, 2004, the other in September, 2004 and each series was identified with a unique level switch. The switches were replaced and the problem was solved.

A single series of aborted startup attempts occurred in September 2004 and was caused by a malfunction in the Startup/Waste Gas Burner Igniter. The Igniter was replaced. An additional aborted startup occurred at the end of the demonstration and was the result of damaged wiring.

In October, 2004 two series of shutdowns were recorded due to high ATR catalyst temperature. The cause of these shutdowns is believed to be due to pre-combustion at the top of the ATR. Two additional instances of high ATR catalyst temperature shutdowns occurred in November, 2004 and January, 2005. These were traced to loss of steam due to electrical failures in the Recycle Water Pump. Two high ATR catalyst temperature shutdowns happened in July, 2004 during the startup transition to PSA operation. The cause was a momentary pressure bounce that upset the steam-carbon ratio and resulted in a spike in the ATR catalyst temperature. A similar shutdown in May, 2004 was the result of a pressure bounce when the product hydrogen was switched from vent to the Product Compressor. In each of these cases the problem was eliminated by adjusting control loop tuning.

A few shutdowns are believed to be the result of low ATR air flow caused by excessive water in the ATR Compressor Water Coalescer. The float type discharge valve malfunctioned in July and August of 2004 which prevented the elimination of water from the Coalescer. A cleaning of the discharge valve assembly eliminated the problem.

Programmable Logic Controller (PLC) equipment malfunctions were the cause of two shutdowns. These were quickly identified and the PLC components were replaced.

Operating Expenses

The hydrogen production cost, on a direct operating cost basis, for the Adéo™ HFG is $2.06 USD per kg. of hydrogen product ($0.94 USD/lb.). This includes the cost of natural gas feed, cooling and process water, and the electricity required to operate the Adéo HFG as well as the compression, storage and dispensing equipment. The natural gas feed and utility unit costs may be found in Appendix D. At $0.71 USD/therm, the natural gas price used to calculate the hydrogen production cost is high by historical measures. Using a more historical average natural gas rate of $0.50 USD/therm translates to a direct cost for producing hydrogen of $1.55 USD/kg ($0.70 USD/lb).

Assuming a 90% on-stream factor, a ten year life expectancy, annual maintenance and consumable costs of 5% of capital (similar to what is being observed at SunLine) and combined with the current pricing for a 100 Nm3/h Adéo HFG, the calculated fully loaded cost of hydrogen, with the utility prices in Appendix D, is $4.27 USD/kg ($1.94 USD/lb). Once again, if the historical natural gas price of $0.50/therm is used, the calculated hydrogen production cost is $3.82/kg ($1.73 USD/lb).

Task 5.4 Perform System Repairs

During the One Year Demonstration Run repairs and adjustments were made to the Adéo HFG as required. Details of these instances may be found in Task 5.3 above. In addition, as explained in Task 3.2, modifications were made to the heat exchanger network to incorporate continuous improvements that were made in heat exchanger technology and performance during the project.

Task 6 Data Acquisition, Analysis and Reporting

Tasks 6.1 and 6.2 Data Acquisition and Analysis

The requirements set forth in these two tasks are met in the One Month and One Year Demonstration Run reports found in Tasks 5 above as well as the data presented in the attached appendices.

Task 6.3 Reporting

This task is completed with the submittal of this final report and the accompanying two-page project summary.

Conclusions

All of the requirements set in the project agreement have been met. HyRadix and SunLine have demonstrated the viability of producing fuel grade and fuel cell grade hydrogen from commercial natural gas feedstock using the HyRadix Adéo™ Hydrogen Fuel Generator and dispensing it to fuel cell vehicles and alternative fuel vehicles.

Appendix A – Statement of Work and Project Accountabilities

ATTACHMENT 1
STATEMENT OF WORK FOR
SUNLINE SERVICES GROUP
AUTOTHERMAL REFORMER HYDROGEN FUELING STATION

CONTRACTOR shall perform the following tasks for the AQMD to provide a turn-key hydrogen production and refueling station located at SunLine Transit Agency in the Coachella Valley.

CONTRACTOR, in partnership with UOP/Hyratics, will be completely responsible for the turnkey installation of the Autothermal Reformer (ATR) hydrogen generation facility in accordance with this Contract. The station will be an integrated system with a hydrogen generation, purification, compression, dispensing and storage capacity. The station will produce hydrogen at 99+% purity that also meets the standards set by ISO 14687 Hydrogen Fuel Specification. This standard allows a combination of nitrogen, water and oxygen to comprise up to 1.9% of the total, while at the same time, limiting the concentration carbon monoxide to less than three parts per million and sulfur compounds to below the detectability limits, in no case above 1 part per million. The system must be capable of filling on-board storage tanks to 5,000 psia and have the capability to fill 6-8 fuel cell cars each day at 5 kg hydrogen per fill-up. An eight-month installation and training period is projected, ~~followed by thirteen months of operation and analysis~~** During the operational period fuel will be available to trained personnel at the site.

CONTRACTOR shall design, install, and operate the ATR fueling station in accordance with the following tasks:

PHASE I Development/Testing/Fabrication

Task 1 - Fabrication of Demonstration Reformer / Phase Shift Absorption Unit (PSA)

1.1 – CONTRACTOR will complete the engineering design of the demonstration reformer and submit a preliminary design that includes sufficient detail to enable evaluation of the overall design and performance of the proposed system, including piping and instrumentation diagrams (P&IDs), PSA design, mass and energy balance through the system, HAZOP recommendations and equipment layout.

1.2 - CONTRACTOR will present and discuss project design with the designated representative of the U. S. Department of Energy and obtain their approval.

1.3 - CONTRACTOR shall fabricate demonstration reformer and prepare it for delivery to the Thousand Palms site.

**the first thirty days of continuous operation for oepration and analysis. SunLine will provide copies of additional data collected for DOE and CEC during the field verification test will be submitted to SCAQMD thereafter at no cost to SCAQM

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Task 2 - Development, Testing and Fabrication of Compression, Storage, and Dispensing System

2.1 - CONTRACTOR shall develop the process design of the compression, storage and dispensing systems including component specifications and materials list.

2.2 - CONTRACTOR shall complete engineering design of equipment and select equipment and materials needed for fabrication.

2.3 - CONTRACTOR shall fully integrate all component parts and equipment into the reformer system and ensure that all are compatible with the system operation.

2.4 - CONTRACTOR shall solicit bids from well-qualified subcontractors for the installation of the ATR reformer system and its components.

2.5 - CONTRACTOR shall prepare plan, coordinate the delivery of equipment and services from the various partners, engage and supervise construction contractor, and submit project design plan for permit approval.

2.6 - CONTRACTOR shall obtain all required approvals and building permits, and work with permitting agencies' representatives to ensure that all inspections, permit conditions and other requirements have been successfully completed.

PHASE II Installation and Commissioning

Task 3 - Reformer Installation and Commissioning

3.1 - CONTRACTOR shall deliver and install ATR system at demonstration site in Thousand Palms according to the plot plan and design.

3.2 - CONTRACTOR shall perform all necessary activities to prepare for operation of the unit including component functional testing, system troubleshooting and safety verification testing as well and any other actions required to ensure safe, efficient and reliable operation of the system..

3.3 - CONTRACTOR shall commission the ATR reformer system and commence operations at the demonstration site.

3. 4 - CONTRACTOR shall conduct all necessary system operator training to SunLine Services staff responsible for the use and operation of the ATR reformer.

3.5 - CONTRACTOR shall ensure that fencing to isolate and protect the project equipment and components from vandalism, unauthorized tampering or incidental contact is adequate.

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3.6 - CONTRACTOR shall receive sign off for equipment installation from the appropriate permitting agencies.

Task 4 - Installation and Commissioning of Compression, Storage and Dispensing System

4.1 - CONTRACTOR shall install the compression, storage and dispensing system at the demonstration site in the manner described by the design documents and permit application.

4.2 - CONTRACTOR shall commission the compression, storage and dispensing system upon successful installation and testing.

4.3 - CONTRACTOR shall ensure that the ATR and ancillary systems are fully integrated, compatible and operational.

4.4 - CONTRACTOR shall complete the system installation and obtain sign-off and approval from all required permitting agencies for operation.

PHASE III Demonstration

Task 5 - Demonstration of Integrated System

5.1 - CONTRACTOR shall make conduct and complete one-month demonstration run of completed ATR hydrogen generation and fueling system.

5.2 - CONTRACTOR shall evaluate test run operational and production data, perform necessary modifications or corrections to ensure operation according to design specificatons and release for operation.

5.3 - CONTRACTOR shall operate the ATR system for a twelve-month period to complete the demonstration phase and to collect operational and production data.

5.4 - CONTRACTOR shall promptly repair any breakdown of the ATR system to minimize downtime and correct promptly any problems that develop with the compression, storage or fuel deliver system.

Task 6 - Data Acquisition, Analysis and Reporting

6.1 - CONTRACTOR shall periodically acquire data descriptive of hydrogen production and the use of fuel produced on site.

6.2 - ~~CONTRACTOR shall analyze data to show the efficiency of the system and fuel usage on site.~~ Contractor snall report outages, nydrogen prooduction rates, iist or parts replaceo, hydrogen purity ana cost or hydrogen prooduced during the test period.

a:cu136\4sowandpaysch

6.3 - CONTRACTOR shall provide written progress reports at the completion of each activity, or quarterly in the operational part of the program, shall submit draft final report, final report and two-page project summary as detailed in Deliverables and Attachment 3.

	Description	Accountability
Phase 1	***Development/Testing/Fabrication***	
Task 1	**Fabrication of Demonstration Reformer / PSA**	
1.1	Engineering Design	HyRadix
1.2	Design Approval	HyRadix
1.3	Fabrication	HyRadix
Task 2	**Development, Testing and Fabrication of Compression, Storage and Dispensing System**	
2.1	Process Design of Compression, Storage and Dispensing System	SSG, SunLine
2.2	Equipment Design and Selection	SSG, SunLine
2.4	Solicit Bids for Installation	SSG, SunLine
2.5	Equipment Delivery	SSG, SunLine
2.6	Permitting	SSG, SunLine, HyRadix
Phase II	***Installation and Commissioning***	
Task 3	**Reformer Installation and Commissioning**	
3.1	Install Reformer at Demonstration Site	SSG, SunLine, HyRadix
3.2	Reformer System Testing	SSG, SunLine, HyRadix
3.3	Commission Reformer at Demonstration Site	
3.4	Provide Training to System Operator	SunLine/HyRadix
3.5	Security	SSG
3.6	Equipment Installation Permitting	SSG
Task 4	**Installation and Commissioning of Compression, Storage and Dispensing**	SSG, SunLine
4.1	Install Compression, Storage and Dispensing System at Demonstration Site	SSG, SunLine
4.2	Test and Commission Compression, Storage and Dispensing System	SSG, SunLine
4.3	Integrate with Reformer	SSG, SunLine, HyRadix
4.4	Operation Permits	SSG, SunLine, HyRadix
Phase III	***Demonstration***	
Task 5	**Demonstration of Integrated System**	
5.1	Perform One Month Demonstration Run	SSG, SunLine, HyRadix
5.2	Evaluate One Month Demonstration Run and Modify	SSG, SunLine, HyRadix
5.3	Perform One Year Demonstration Run	SSG, SunLine,

		HyRadix
5.4	Perform System Repairs as Required	SSG, SunLine, HyRadix
Task 6	**Data Acquisition, Analysis and Reporting**	
6.1	Data Acquisition	SSG/HyRadix
6.2	Data Analysis	SSG/HyRadix
6.3	Reporting	SSG/HyRadix

Table A.1
Project Accountabilities

Appendix B – Operating Data for the One Month Demonstration Run

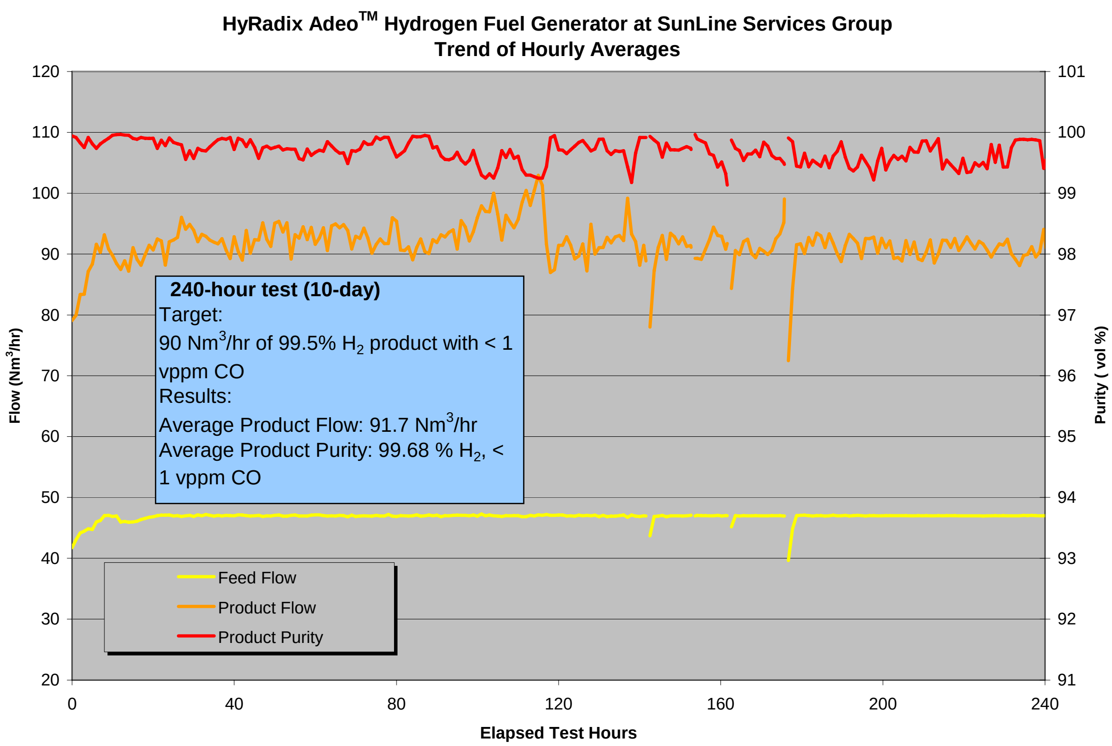


Figure B.1
Plot of Demonstration Run Data for the HyRadix Adéo™ Hydrogen Fuel Generator, 17 April through 30 April 2004

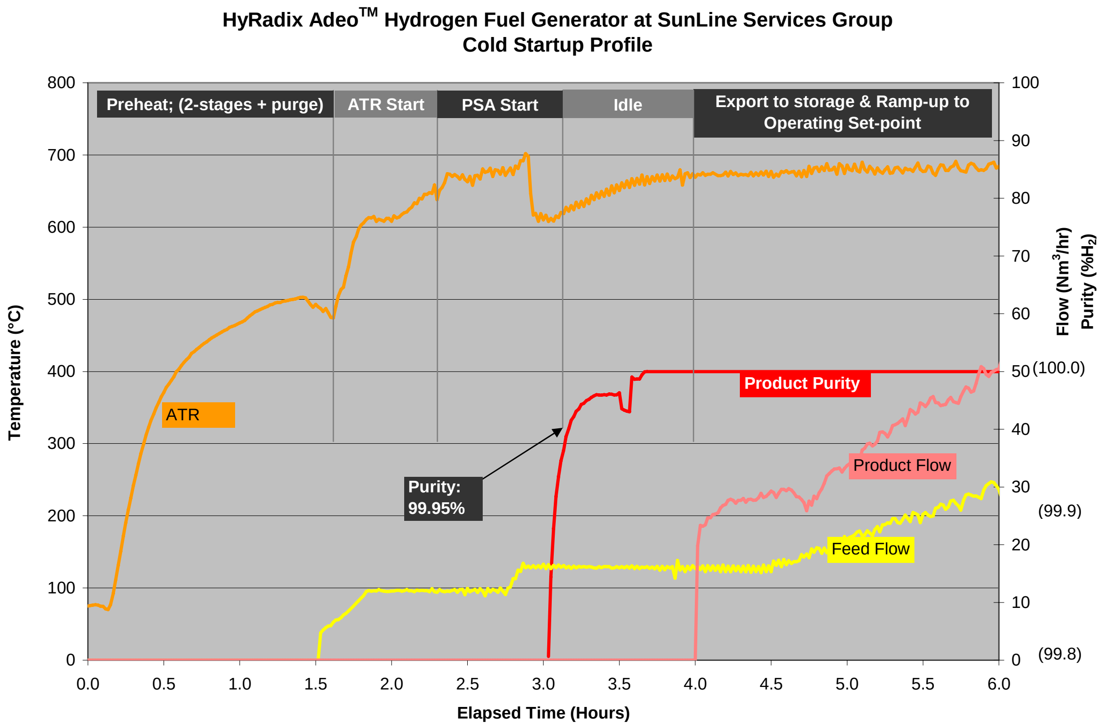


Figure B.2
Plot of Cold Startup Data for the HyRadix Adéo™ Hydrogen Fuel Generator

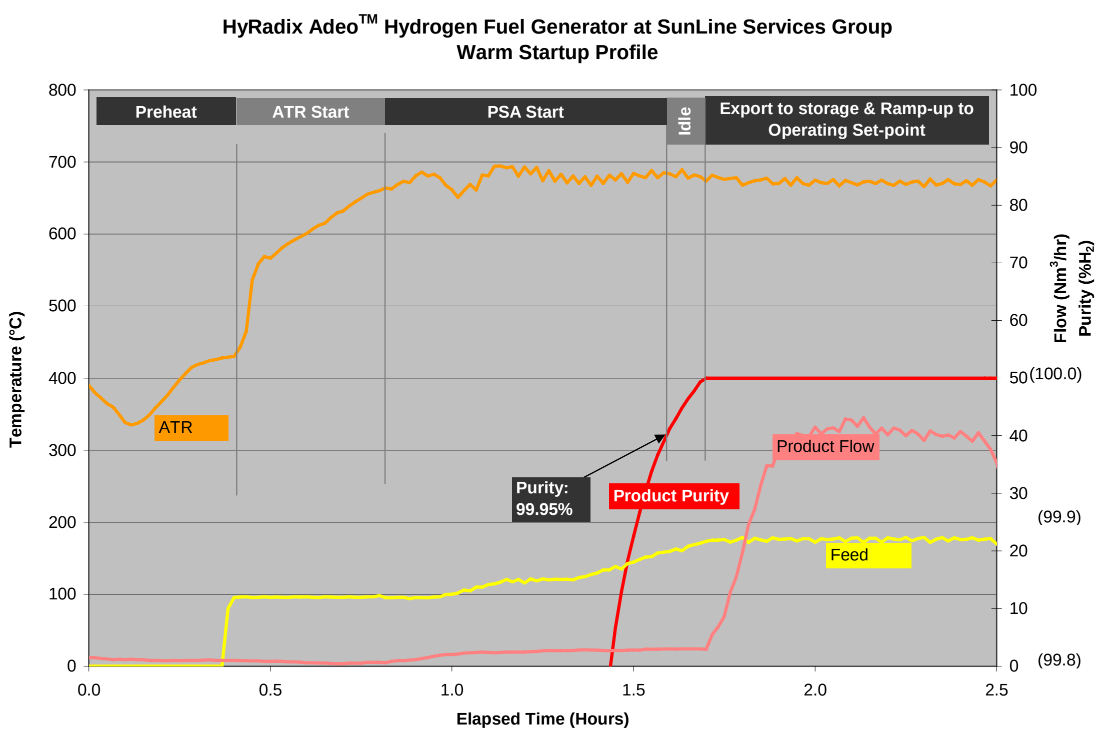


Figure B.3
Plot of Warm Startup Data for the HyRadix Adéo™ Hydrogen Fuel Generator

Appendix C – Operating Data for the One Year Demonstration Run

Table C.1
Weekly Operational Summary of the HyRadix Adéo™ Hydrogen Fuel Generator

	WEEKLY TOTAL			CUMULATIVE TOTAL		
Week Ending	NG Usage (Nm^3)	H2 Production (Nm^3)	Hours Online	NG Usage (Nm^3)	H2 Production (Nm^3)	Hours Online
04/17/04	1,038	1,967	23	1,038	1,967	23
04/24/04	6,779	13,173	155	7,818	15,140	178
05/01/04	5,169	9,606	135	12,987	24,746	313
05/08/04	238	343	16	13,225	25,090	329
05/15/04	589	958	26	13,815	26,047	355
05/22/04	1,757	3,019	78	15,572	29,067	433
05/29/04	2,197	3,935	83	17,769	33,002	516
06/05/04	0	0	0	17,769	33,002	516
06/12/04	4,138	7,588	101	21,907	40,589	617
06/19/04	2,522	4,514	74	24,428	45,104	691
06/26/04	2,762	5,015	94	27,190	50,118	785
07/03/04	2,126	3,876	77	29,316	53,994	862
07/10/04	2,929	5,201	99	32,245	59,195	961
07/17/04	3,469	6,329	122	35,714	65,524	1,083
07/24/04	4,973	9,025	165	40,687	74,549	1,248
7/31/04	3,259	5,841	114	43,946	80,391	1,362

	WEEKLY TOTAL			**CUMULATIVE TOTAL**		
Week Ending	**NG Usage (Nm^3)**	**H2 Production (Nm^3)**	**Hours Online**	**NG Usage (Nm^3)**	**H2 Production (Nm^3)**	**Hours Online**
08/07/04	2,538	4,686	89	46,484	85,077	1,451
08/14/04	3,437	5,973	119	49,921	91,049	1,570
08/21/04	3,930	6,754	157	53,851	97,803	1,727
08/28/04	3,125	5,092	135	56,975	102,895	1,862
9/4/04	2,333	4,103	140	59,308	106,998	2,002
9/11/04	1,739	2,808	111	61,047	109,806	2,113
09/18/04	0	0	0	61,048	109,806	2,113
09/25/04	1,717	2,893	115	62,765	112,700	2,228
10/02/04	46	78	2	62,811	112,778	2,230
10/09/04	0	0	0	62,811	112,778	2,230
10/16/04	2,635	4,694	131	65,446	117,472	2,361
10/23/04	1,895	3,008	111	66,861	119,602	2,451
10/30/04	45	15	8	66,906	119,617	2,459
11/06/04	2,895	5,204	155	69,801	124,822	2,614
11/13/04	3,148	5,691	163	72,949	130,513	2,777
11/20/04	2,574	4,632	137	75,523	135,144	2,914
11/27/04	1,251	2,297	59	76,774	137,441	2,973
12/04/05	0	0	0	76,774	137,441	2,973
12/11/05	0	0	0	76,774	137,441	2,973
12/18/05	640	1,173	31	77,414	138,614	3,004

	WEEKLY TOTAL			CUMULATIVE TOTAL		
Week Ending	**NG Usage (Nm^3)**	**H2 Production (Nm^3)**	**Hours Online**	**NG Usage (Nm^3)**	**H2 Production (Nm^3)**	**Hours Online**
12/25/05	3,360	6,161	168	80,774	144,775	3,172
01/01/05	2,540	4,415	108	83,314	149,190	3,280
01/08/05	1,477	2,636	66	84,791	151,826	3,346
01/15/05	3,190	5,659	140	87,982	157,485	3,486
01/22/05	2,068	3,776	105	90,050	161,261	3,591
01/29/05	2,796	5,107	141	92,845	166,368	3,732
02/05/05	2,877	5,145	128	95,722	171,513	3,860
02/12/05	2,398	4,380	121	98,121	175,893	3,981
02/19/05	854	1,555	45	98,975	177,448	4,026
02/26/05	482	823	26	99,456	178,271	4,052
03/05/05	0	0	0	99,456	178,271	4,052
03/12/05	0	0	0	99,456	178,271	4,052
03/19/05	2,235	3,927	116	101,691	182,197	4,168
03/26/05	1,118	2,045	58	102,809	184,242	4,226
04/02/05	0	0	0	102,809	184,242	4,226
04/09/05	1,557	2,602	82	104,366	186,844	4,308
04/16/05	1,706	3,123	87	106,072	189,967	4,395

1. Week base Sunday through Saturday.
2. Start date 17 April 04, Day 1 of Acceptance Test.
3. Units for NG and H2 are Nm3.
4. NG and H2 based directly on flowmeter readings w/o correction factor.

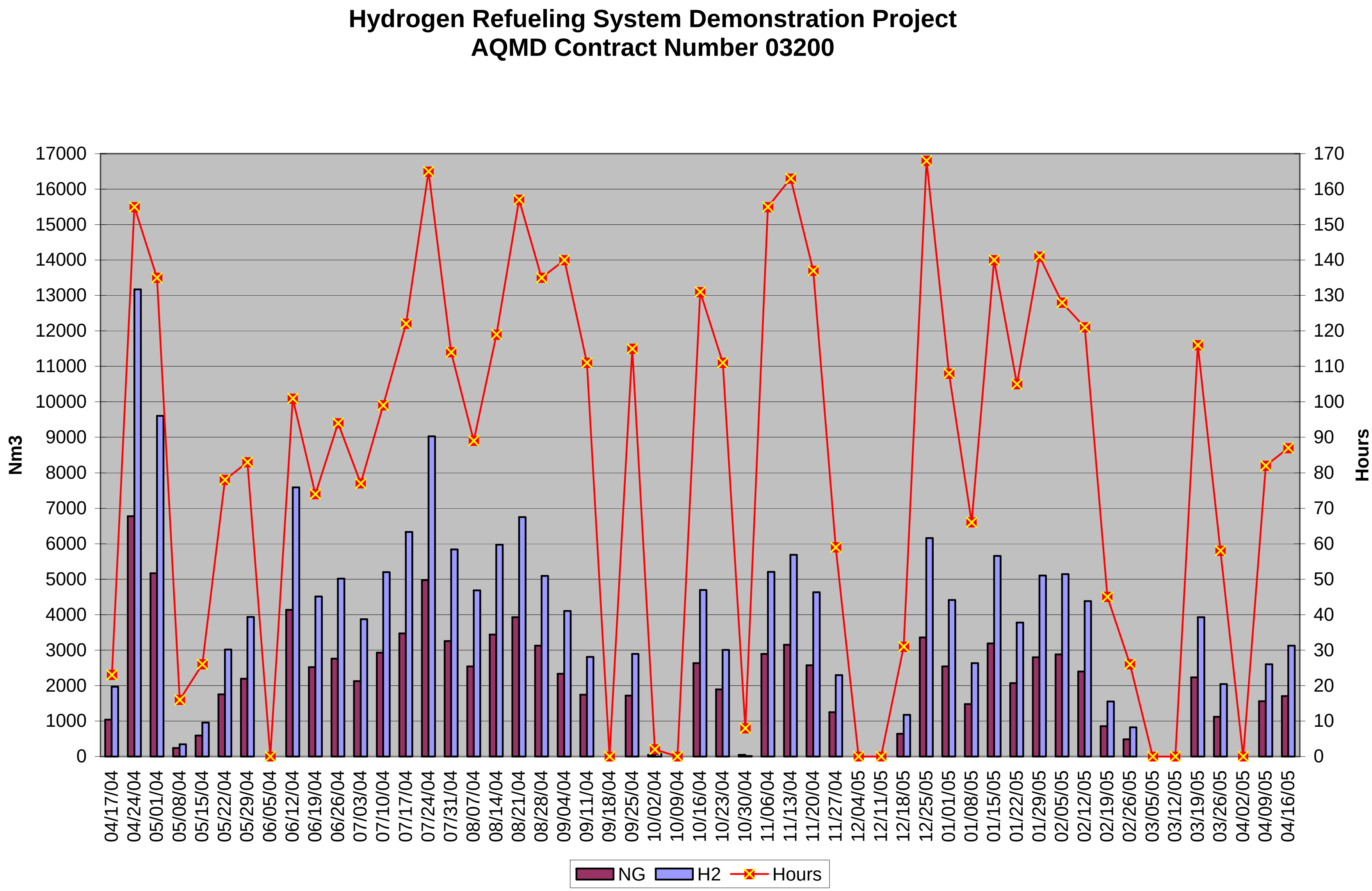


Figure C.1
Plot of Weekly Production Data for the HyRadix Adéo™ Hydrogen Fuel Generator

Hydrogen Refueling System Demonstration Project
AQMD Contract Number 03200

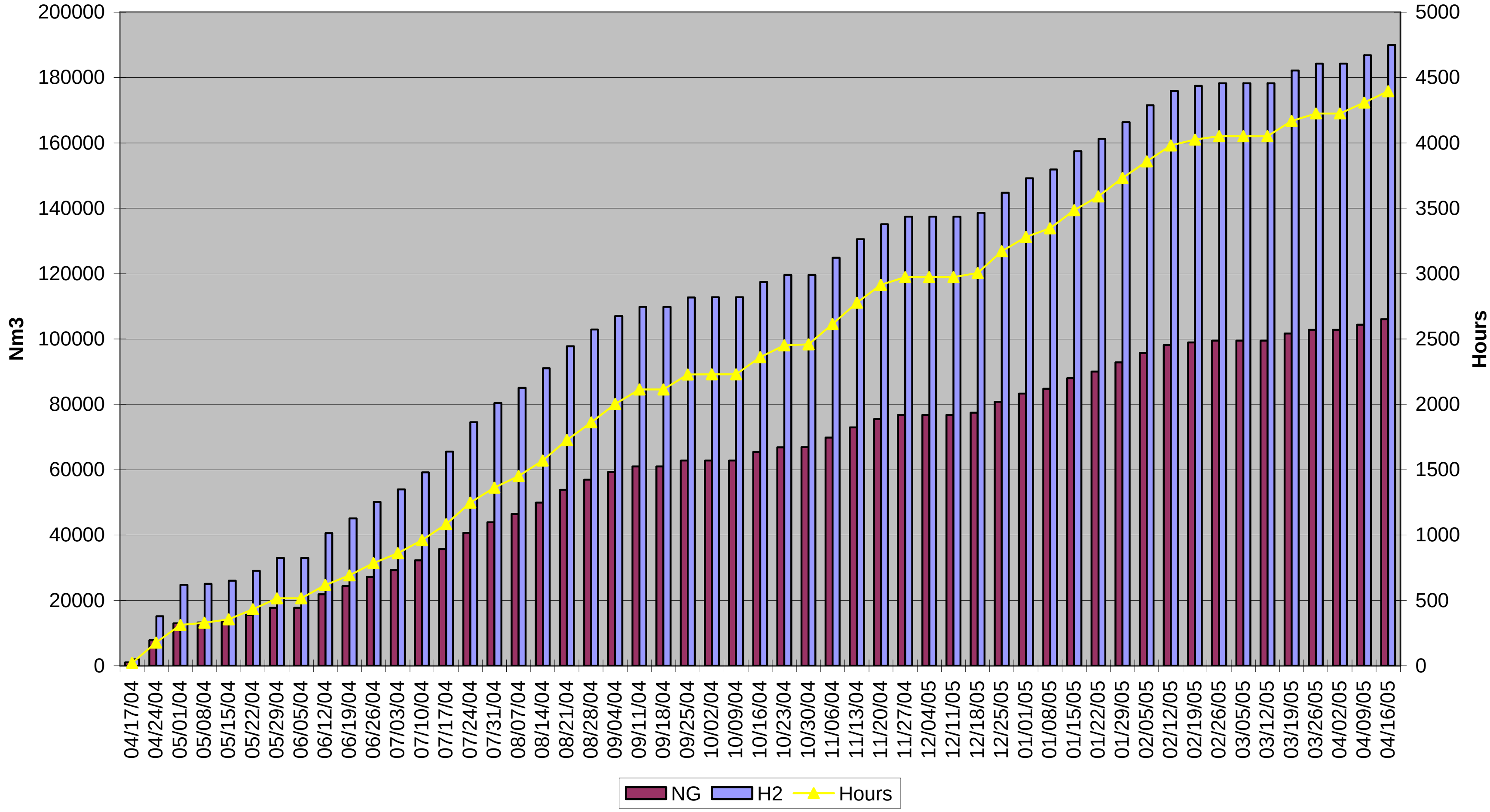


Figure C.2
Plot of Cumulative Production Data for the HyRadix Adéo™ Hydrogen Fuel Generator

Appendix D – SunLine Utility Costs

Utility	Cost
Natural Gas	$0.71 USD/therm
Makeup Process and Cooling Water	$3.67 USD/1000 gal
Electricity	$0.115 USD/kW-hr

Table D.1
SunLine Utility Costs during Report Period

Appendix E - Permits

RIVERSIDE COUNTY FIRE DEPARTMENT
In cooperation with the
California Department of Forestry and Fire Protection

82-675 Highway 111, 2nd Fl., Indio, CA 92201 • (760) 863-8886 • Fax (760) 863-7072

Tom Tisdale
Fire Chief

Proudly serving the unincorporated areas of Riverside County and the Cities of:

Banning
Beaumont
Calimesa
Canyon Lake
Coachella
Desert Hot Springs
Indian Wells
Indio
Lake Elsinore
La Quinta
Moreno Valley
Palm Desert
Perris
Rancho Mirage
San Jacinto
Temecula

Board of Supervisors

Bob Buster, District 1
John Tavaglione, District 2
Jim Venable, District 3
Roy Wilson, District 4
Marion Ashley District 5

June 11, 2004

Hyradix, Inc.
Attn: Lance Anderson
175 W. Oakton St.
Des Plaines, IL 60018-1834

Re: Hydrogen Gas Reformer
SunLine Transit Agency

Fire Department personnel have reviewed the installation of the hydrogen gas reformer at the SunLine Transit Agency in Thousand Palms, California.

Documentation has been received to verify that the equipment has been installed and tested in accordance with the manufacturers' specifications. Safety measures and procedures are in place and operational accordingly.

Riverside County Fire Department hereby permits the full operation of the hydrogen gas reformer.

Should there be need for further information and/or clarification, please contact the undersigned.

Sincerely,

FRANK KAWASAKI
Chief Fire Department Planner

By

Walter Brandes
Fire Safety Specialist

Cc: Sunline Transit Agency

H:\PEZWP Data\County\PROJECTS\Sunline\Hydrogen reformer doc

EMERGENCY SERVICES DIVISION • PLANNING SECTION • INDIO OFFICE
82-675 Highway 111, 2nd Fl., Indio, CA 92201 • (760) 863-8886 • Fax (760) 863-7072

Appendix F – Analytical Equipment

Hydrogen product purity was continuously monitored by an on-line analyzer. The analyzer used was a Rosemount Model 7C. This instrument measures the concentration of hydrogen in a sample stream by comparing its thermal conductivity with that of a standard stream. USP hydrogen was used for the standard stream and to zero the instrument at 100 vol% hydrogen. The instrument was spanned for two different ranges. A calibration gas consisting of 99.8 vol% hydrogen and the balance argon and nitrogen was used for the high purity product. A mixture of 99.0 vol% hydrogen with an argon and nitrogen balance was used for lower purity product.

Attachment B
HICE Quarterly Report

Hydrogen Hybrid Internal Combustion Engine (HHICE) Bus

-- Quarterly Progress Report --

Period of Performance, September through December 2004

Participating Organizations:

California Energy Commission
CMT-00-01

Natural Resources Canada/Vehicle Technology Centre

South Coast Air Quality Management District
Contract 04027

SunLine Transit

U.S. Dept. of Transportation, Federal Transit Administration
Cooperative Agreement FTA C-10

CALSTART

ISE Corporation
7345 Mission Gorge Road, Suite K
San Diego, CA 92120
619-287-8785, x140 pscott@isecorp.com

Summary:

This quarterly report describes the continued testing of a hydrogen fueled hybrid electric internal combustion engine (HHICE) powered bus, the delivery to SunLine and the introduction into revenue service.

- Early testing revealed massive discrepancies between expected and actual performance. Data analysis suggested changes to the physical design and to software interfacing parameters, which resulted in step by step improvements which resulted in meeting design objectives.
- The Drive System Test and Initial Operation phases were completed in November, and the bus was driven from the San Diego ISE facility for delivery to Sunline the last day of November.
- The SunLine "Rollout" of the bus December 16 was followed by immediate introduction into revenue service.
- The bus has accumulated over 3000 miles in revenue service in the last two weeks of December, with no service calls.
- Continuing tasks and concerns include heating of the engine damper, which leads to premature failure, implementation of the RDU (Remote Data Unit) operation, occasional backfire at starting and/or shutdown and continued refinement of driver displays.
- Planning continues for the winter testing of the bus in Manitoba during the mid-January through mid-March period.
- The Experimental Permit for operation of the HHICE bus has been received from the Air Resources Board.

Task by Task Review:

Task 1 – Order Long Lead Components.
This task is complete.

Task 2 – Drive System Design
This task is complete.

Task 3 – Drive System Kit Construction
This task is complete.

Task 4 – Construct Bus Chassis
This task is complete.

Task 5 – Drive System Installation
This task is complete.

Task 6 – Drive System Test and Optimization

The drive system is complex and involves use of software to control and interface several systems:

1. The fuel supply system includes provisions for fail-safe[1] shutoff of fuel when bus key is off. An STW (System Technik Wiedemann) controller allows electronic monitoring and selection of fuel tanks.
2. The engine is controlled by Ford Power Products software.
3. Siadis software, provided by Siemens, serves to monitor and control the generator, charging of the ultra-capacitors, and to provide power commands to the engine.
4. The bus has a PLC system which monitors critical parameters and provides information and warnings to the driver.
5. ISE software provides the "glue" to interface the systems together and provide the master control algorithim

The initial focus was on getting the Siemens, Ford and ISE software to work together to the point of providing full engine power and vehicle drivability. This has been a challenge in itself, compounded by unexpectedly severe engine demands for fuel and airflow.

Siemens worked with ISE to provide the software modifications to allow the engine to be test run statically at powers up to 100 kW, using the braking resisters as a load. With the aid of this improvised dynamometer the operation of specific components (spark plugs and ignition coils, for instance) could be evaluated.

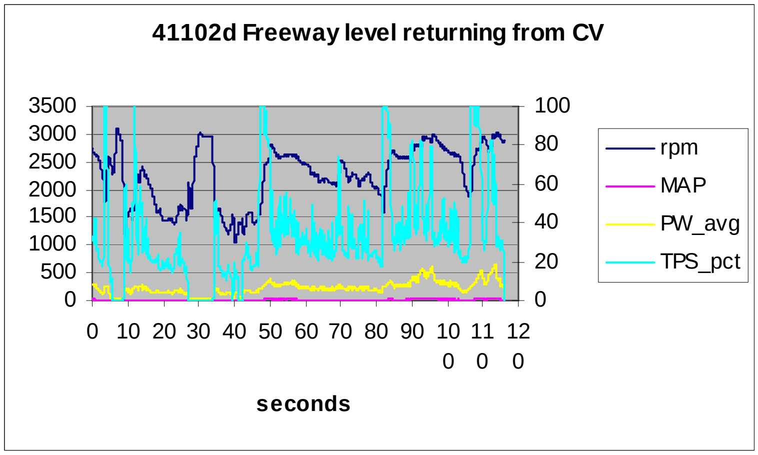
The Ford Power Products (FPP) software for engine control was developed by E-Controls, which (thanks to some strategic encouragement from FPP) worked closely with us in adapting the software to our application. This culminated in use of an internet connection which allowed the engine parameters to be varied by E-Controls staff based in Texas while the engine ran in the static bus at the ISE facility (operation parameters were transmitted from the San Diego site to Texas, allowing a full parameter display of the operation).

The air requirements of the turbocharged engine are double that of the gasoline fueled version, and thus the inlet and exhaust systems were redesigned to reduce pressure drops. Fuel system changes were also implemented to improve engine operation.

To improve to the design power of 140kW, it was necessary to use the bus as a moving test bed with multiple computers doing datalogging and monitoring and changing parameters. It proved to be very difficult to get responsive operation without surging, oscillatory behavior. However, suitable combinations of parameters and operational profiles were found to allow both stop and go, low power operation and still allow the engine to be wound up to full power, using the turbocharger to add one atmosphere boost

[1] Each tank has a shutoff valve open only with key on, and a secondary shutoff solenoid valve near the engine shuts off fuel flow at key off

for hill climb or freeway operation. A single data record, at right, indicates the tendency of the system to operate with wide variations of the TPS (throttle position sensor) and power as roadway demands change. Note the operation at 30 seconds, on a down grade leading to engine braking at 3000 rpm with the throttle closed, as compared to the full throttle accelerations and with the climbing operation at 94 seconds with near 3000 rpm and injector PW approaching 20 ms. This record was from operation on 2 Nov., subsequently we have achieved a much more smooth operation.



Task 6 is complete, but it is apparent that further improvement in the software-hardware interface will allow improved operation, and may yield significant benefits in reduced emissions and improved fuel efficiency.

Task 7 - Initial Operation in Chula Vista

This task is complete. The support of Jack Dickens, Larry Shroyer and others that teamed together to provide fuel from the Chula Vistia Transit facility is gratefully acknowledged.

Task 8 - Cold Weather Testing in Manitoba

The Canadian Team, led by Dr. Allister Hickson, have made great progress in completing all the required agreements, arranging for storage of the bus in a special facility, and in working with Stuart Energy to provide fuel for the test program. The bus will ship January 11, and the test program will start 17 January with Manitoba Transit proceeding through the safety testing required for introduction into service. There are key issues to be resolved:

- Will the bus heating be adequate? Conventionally, the buses introduced into winter service have a diesel fired supplemental heater, absent from this bus designed for service in the California desert. The HHICE uses engine coolant, expected to be at temperatures to 160^{o} F, to heat air using a pair of heat exchangers.
- Will the bus service be limited by the capabilities of the electrolyzer (capable of at most 1 kg/hr)? It would appear that the bus will be limited to about 150 miles service/day, well under the range of the bus if fuel tankage is fully filled.
- Will the electronic control systems work at the very low temperatures?

Task 9 – Revenue Service

The HHICE bus has been at SunLine Transit for the Month of December, the first half of the month for evaluation and driver training which culminated in the "Rollout" ceremony December 16. (Illustrated by the photo at right.)

Following the Rollout the bus immediately went into service on Route 50 in Palm Desert. The bus has been in service from dawn through the evening, accumulating over 200 miles in service every day. The only service interruptions have been for planned maintenance and upgrades. At the end of the year the bus had accumulated over 4000 miles, with 80 percent of the mileage having been accumulated in revenue service.

Tasks 10-11 await completion of the above.

Contractual Agreements:

Vehicle Technology Centre (VTC), University of Manitoba
As noted before, the Canadian Ministry of Natural Resources is contributing to the program by funding ISE through VTC for a share of the bus and an on the street demonstration of hydrogen system operation in the cold northern winter. The agreements between the parties (ISE, SunLine, the Government of Manitoba and the VTC as well as the Ministry are complete and we are proceeding to complete papers required for trans-border shipment of the bus on 11 January.

CALSTART/WestStart
The use of hydrogen fuel offers the possibility of vehicles with zero emissions, with only water in the exhaust. However, NOx is generated to the extent that the combustion process proceeds at high temperature. In the operation of the engine being installed in the HHICE bus we nearly eliminate the NOx as well by running very lean, so that the combustion processes can proceed at a low temperature and almost no NOx results.

There are reasons to believe that the last traces of NOx, and even residual CO and hydrocarbons that either enter through the ambient air or from lubricating oil, can be eliminated by after-treatment, although the means used in gasoline engines are not applicable to hydrogen engines. CALSTART and ISE have completed agreement for support of engine dynamometer testing to develop the capability of approaching ZEV emission levels (where here we define the ZEV goal as there being less NOx, CO in the exhaust than commonly, in city traffic, in the intake). This is more of general interest to future HHICE buses, it is not contemplated that this effort will impact the design or operation of this prototype bus. However, it will add to the increasingly rich body of knowledge as to how to operate HICE equipment such that the vision of a "fuel cell surrogate" is achieved.

A hydrogen engine to be used for this testing has been received at the ISE facility.

Financial Summary: Budget Cost Breakdown:

Mile-stone No.	Description	Budget	Cost to AQMD	Cost to CEC	Cost to SunLine	Cost to DOT-FTA	Cost to NRCAN	Cost to ISE	Total Cost
1	Order Long Lead Parts	$210,000	$0	$210,000	$0	$0	$0	$0	$210,000
2	Drive System Design	$150,000	$100,000	$0	$0	$50,000	$0	$0	$150,000
3	Drive System Kit Construction	$100,000	$60,000	$0	$40,000	$0	$0	$0	$100,000
4	Construct Bus Chassis	$240,000	$0	$0	$140,000	$0	$100,000	$0	$240,000
5	Drive System Installation	$110,000	$0	$0	$110,000	$0	$0	$0	$110,000
6	Drive System Test/ Optimization	$40,000	$20,000	$0	$0	$20,000	$0	$0	$40,000
7	Initial Operation (Chula Vista)	$30,000	$0	$0	$0	$30,000	$0	$0	$30,000
8	Cold Weather Testing (Manitoba)	$37,275	$0	$0	$0	$0	$12,275	$25,000	$37,275
9	Revenue Service (SunLine Transit)	$60,000	$20,000	$0	$0	$0	$0	$40,000	$60,000
10	Emissions Testing	$50,000	$0	$0	$0	$0	$0	$50,000*	$50,000
11	Final Report	$10,000	$10,000	$0	$0	$0	$0	$0	$10,000
Total		**$1,037,275**	**$ 210,000**	**$210,000**	**$290,000**	**100,000**	**$112,275**	**$115,000**	**$1,037,275**

* CARB in-kind use of chassis dynamometer

Unexpected difficultiess in the Drive System Test and Optimization have led to increased expenditures in this task, as is reported in the following report:

Expenditures through December 31, 2004:

Mile-stone No.	Description	Budget	AQMD	CEC	SunLine	DOT-FTA	NRCAN	ISE	Total Expend-itures
1	Order Long Lead Parts	$210,000	$0	$210,000	$0	$0	$0	$0	$210,000
2	Drive System Design	$150,000	$100,000	$0	$0	$50,000	$0	$0	$150,000
3	Drive System Kit Construction	$100,000	$60,000	$0	$40,000	$0	$0	$0	$100,000
4	Construct Bus Chassis	$240,000	$0	$0	$140,000	$0	$100,000	$0	$240,000
5	Drive System Installation	$110,000	$0	$0	$110,000	$0	$0	$0	$110,000
6	Drive System Test/ Optimization	$40,000	$20,000	$0	$0	$20,000	$0	$142,344	$182,344
7	Initial Operation (Chula Vista)	$30,000	$0	$0	$0	$30,000	$0	$0	$30,000
8	Cold Weather Testing (Manitoba)	$37,275	$0	$0	$0	$0	$12,275	$8,000	$20,275
9	Revenue Service (SunLine Transit)	$60,000	$10,000	$0	$0	$0	$0	$20,000	$30,000
10	Emissions Testing	$50,000	$0	$0	$0	$0	$0	$0	$0
11	Final Report	$10,000	$0	$0	$0	$0	$0	$0	$0
Total		**$1,037,275**	**$ 190,000**	**$210,000**	**$290,000**	**$100,000**	**$112,275**	**$170,344**	**$1072,619**

Supporting Documents:

None.

Attachment C
Hydrogen Purity Analysis

Smart Chemistry, 3401 La Grande Blvd, Sacramento, CA 95823, (916)391-3300, jphsu@smartchemistry.com

Analytical Report on Hydrogen Fuel Quality

Sunline

Smart Chemistry No 6FCP003-01
Sampled on 11/13/2006, 14:00

Constituent	SAE Limits (µmol/mol)	Primary & Secondary Analytical Instrument	Smart Chemistry Detection Limits (µmol/mol)	Concentration (µmol/mol)
Water	5	GC/MS	1	**< 1**
Total Hydrocarbons (C_1 Basis)	2			
Methane		GC/PDHID, GC/FID	0.1	**< 0.1**
Ethane, Ethene, Ethyne		GC/FID, GC/MS	0.6	**< 0.6**
Other Hydrocarbons		GC/MS	0.1	**< 0.1**
Oxygen	5	GC/MS, GC/PDHID	5	**< 5**
Helium, Nitrogen, Argon	100			
Helium		GC/TCD	10	**78**
Nitrogen		GC/PDHID, GC/MS	5	**< 5**
Argon		GC/MS, GC/PDHID	0.8	**< 0.8**
Carbon Dioxide	1	GC/MS	0.4	**< 0.4**
Carbon Monoxide	0.2	GC/PDHID, GC/MS	0.1	**< 0.1**
Total Sulfur	0.004			
Hydrogen Sulfide		GC/MS	0.001	**< 0.001**
Carbonyl Sulfide		GC/MS	0.001	**0.0046**
Methyl Mercaptan		GC/MS	0.001	**< 0.001**
Carbon Disulfide		GC/MS	0.001	**< 0.0005**
Formaldehyde	0.01	GC/MS	0.004	**< 0.004**
Formic Acid	0.2	GC/ELCD	0.06	**< 0.06**
Ammonia	0.1	GC/ELCD	0.04	**< 0.04**
Total halogenates	0.05			
Chlorine		GC/ECD	0.05	**< 0.05**
Hydrogen Chloride		GC/ECD	10[1]	**< 10**
Hydrogen Bromide		GC/ECD	10[1]	**< 10**
Organic Halides		GC/MS, GC/ECD	0.02	**< 0.02**
Particulate Size	< 10µm	Camera, Microscope or SEM	1µm	
Number of Particulate Found with size more than 1 cm				0
Number of Particulate Found with size within 1 mm and 1 cm				1
Number of Particulate with size within 100 µm and 1000 µm				7
Particulate Concentration at 1st Sampling	1µg/L	Balance	0.0025µg/L	**0.0054 µg/L**

Note 1 - The SAE detection limits of Hydrogen Chloride and Hydrogen Bromide can not be reached at this point and more research required.

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REPORT ON SEM/EDS Analysis of Particulates

Introduction

The Teflon filter used for Sunline particulate sampling show no mechanical damage under microscope at magnification of 60 times. The particulates on these filter samples are also bombarded with electron beams under vacuum and electrons emitted from particulates collected to generate particulate image under Scanning Electron Microscope (SEM). In the mean time, the chemical composition information can be also obtained Electron Dispersive Spectrum (EDS).

Procedure

After the pictures taken by camera and evaluation by microscope, particulates for analysis were extracted from the filters using adhesive carbon tabs pressed onto the filter surface, in which the particles sticking to the tab upon removal from the filter surface. The extracted particles were examined in the SEM and qualitative chemical analysis performed using the energy dispersive x-ray spectrometer (EDS) installed on the SEM. No coating of the particle samples was performed, and as a result there was extensive charging of non-conductive particles in the electron beam that obscured surface detail in the SEM images. The SEM was operated at 20 KV accelerating voltage for both imaging and spectroscopy. Secondary electron imaging was used for all of the SEM images in this analysis. Unless otherwise noted, all spectra were obtained with the SEM in spot mode (i.e.: the electron beam parked in one spot during the spectra collection).

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REPORT ON SEM/EDS Analysis of Particulates

Sunline Particulate Filter

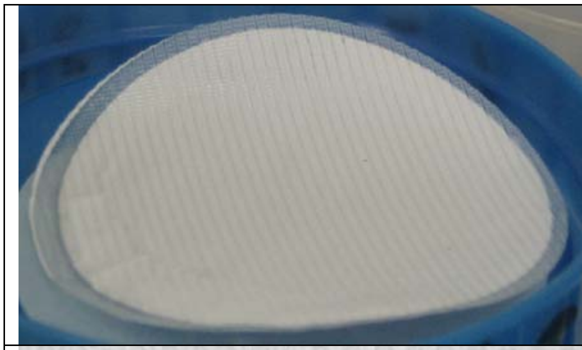

Figure A: Picture of Filter after sampling at Sunline. No visual particulate found.

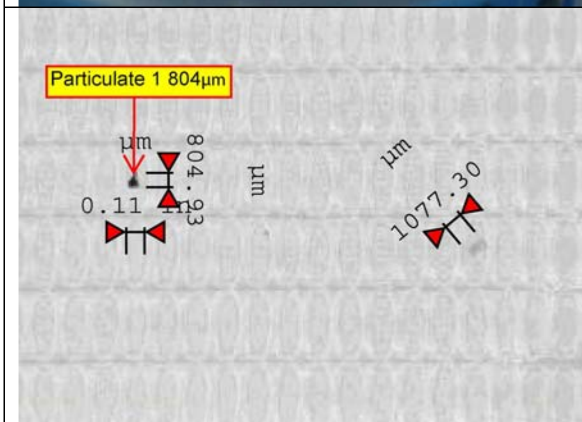

Figure B: Magnification (10X). The sizes of two particulates are 804 and 1077µm.

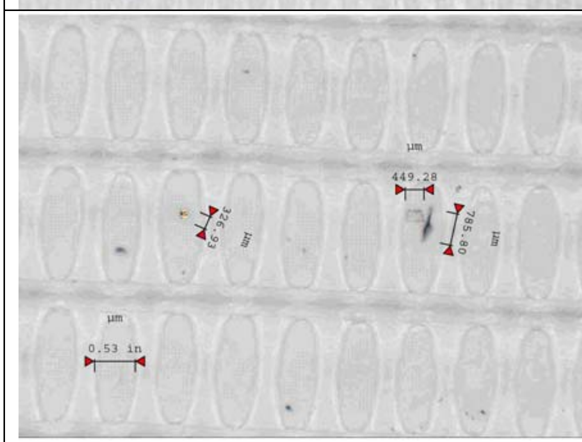

Figure C: Magnification (20X). The sizes of three particulates found are 326, 785 and 429 µm.

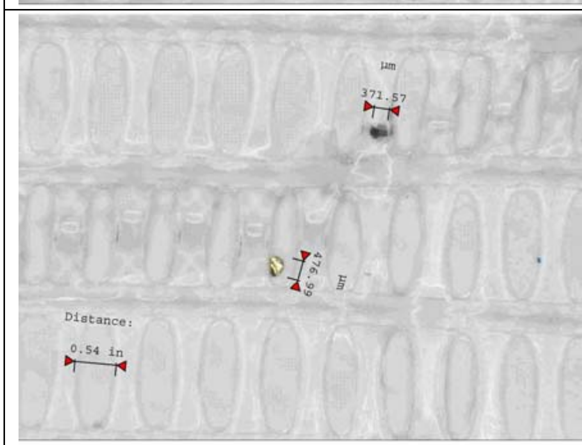

Figure D: Magnification (20X). The sizes of two particulates found are 476 and 372 µm.

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REPORT ON SEM/EDS Analysis of Particulates

SEM and EDS Analysis of Particulates on Sunline Filter

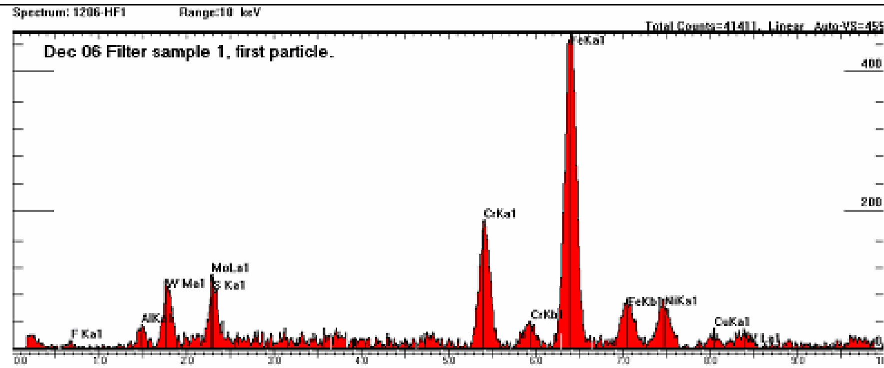

Figure E EDS Spectrum of Particulate 1 (No SEM image recorded). This shows the particulate contains Fe, Cr, Cu, S and Al, which may be stainless steel.

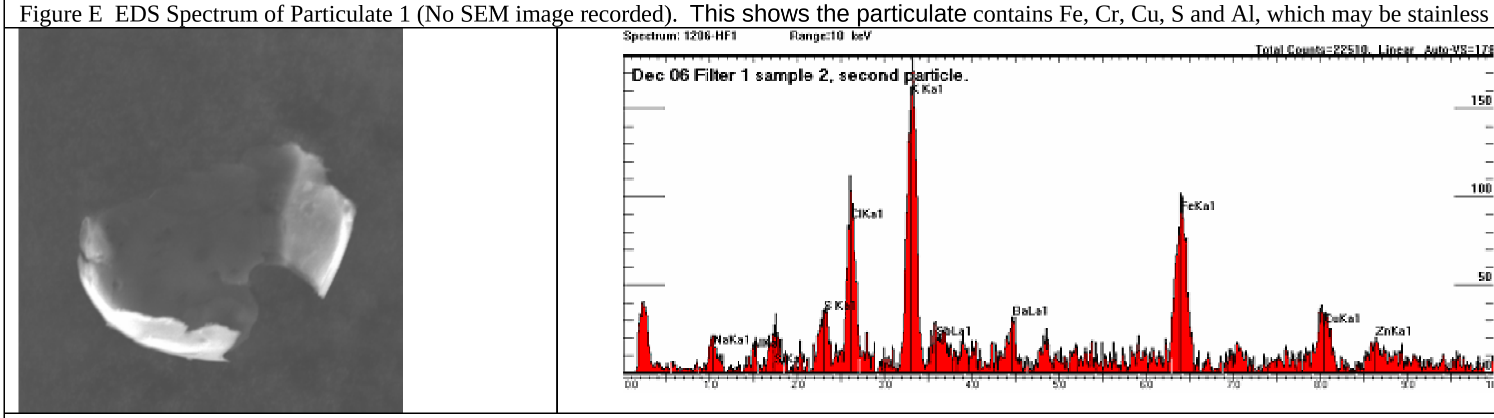

Figure F SEM Image (no size information) and EDS Spectrum of Particulate 2. This shows the particulate contains Fe, Cu, Zn, K, Cl, S and C.

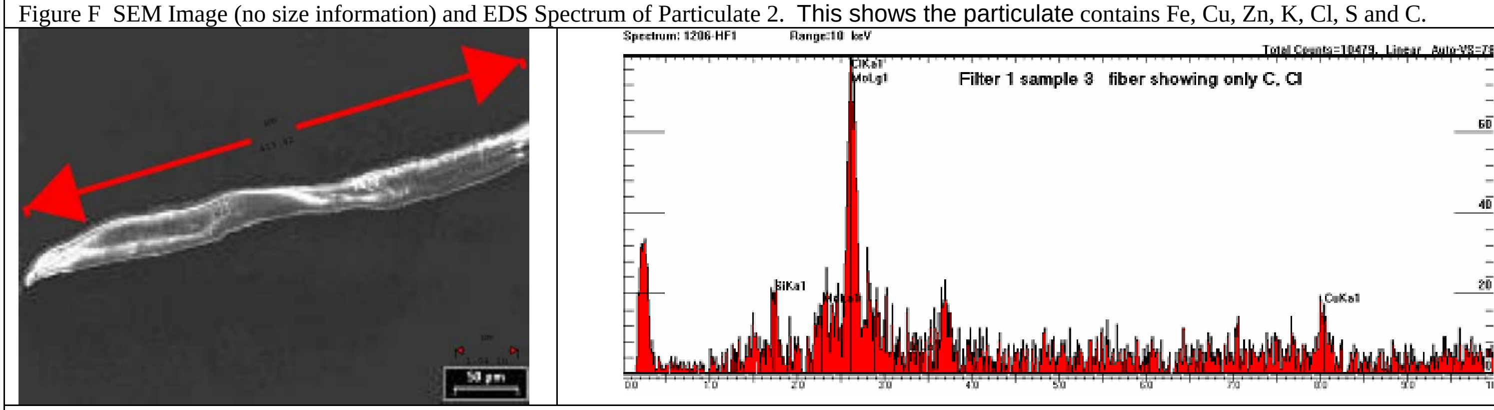

Figure G: SEM Image with size of 413 µm and EDS Spectrum of Particulate 3. This shows the particulate contains C and Cl.

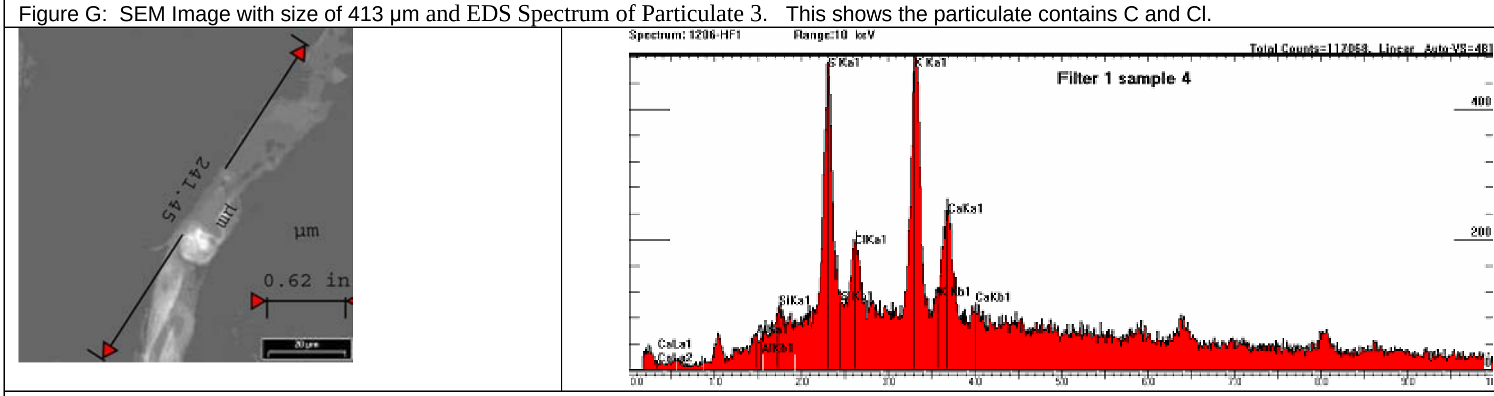

Figure H: SEM Image with size of 241 µm and EDS Spectrum of Particulate 4. This shows the particulate contains Ca, K, S and Cl

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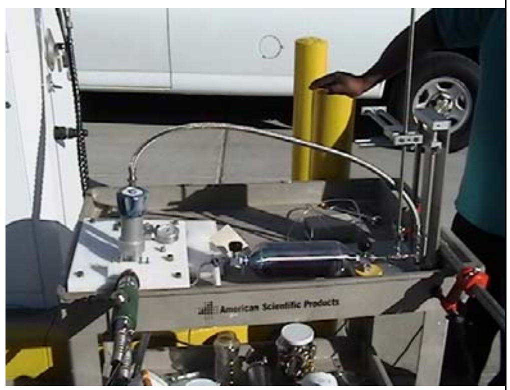
REPORT ON SAMPLING at SUNLINE

1. Particulate Sampling	2. Gaseous Sampling	3. Remove Particulate Filter
		
Particulate Sampling at Sunline Transit, Thousand Palms, CA on 14:00, 11/13/2006. Total hydrogen fuel sampled: 2.004 kg, which was read from station meter. The sampling continued for approximately 5 minutes without stop.	Gaseous sampling at Sunline Transit was performed after particulate sampling. Flash the sample container at 500 psi for 10 minutes. The hydrogen fuel was vented through a 9' 3/8" OD stainless steel pipe perpendicular to ground. Then, the sample container was filling-up with hydrogen fuel by opening inlet valve and closing the outlet valve of sample container. The hydrogen fuel was released by closing the inlet valve and opening the outlet valve of sample container. The process was repeated ten times and then finally filled with hydrogen fuel for sample analysis	The particulate filter holder with Sunline Transit Teflon filter was placed inside an entrance area of a clean glove box while a clean room airs filter fan blowing. The outside door of the entrance area was then closed and the inside door of the entrance area opened to move the filter holder to the main working are of the glove box. The Sunline Teflon filter was removed from the filter holder and placed in a clean labeled plastic container.

Particulate Concentration in Sunline Hydrogen Fuel

Hydrogen Sampled (kg)	**2.004**
Hydrogen Sampled (m^3)	**24**
Filter Number	27
Average Filter Weight Before Sampling (g)	0.09129
Average Filter Weight After Sampling (g)	0.09142
Average Particulate Weight (g)	**0.00013**
Average Particulate Concentration (mg/kg)	**0.066**
Average Particulate Concentration (µg/L)	**0.0054**

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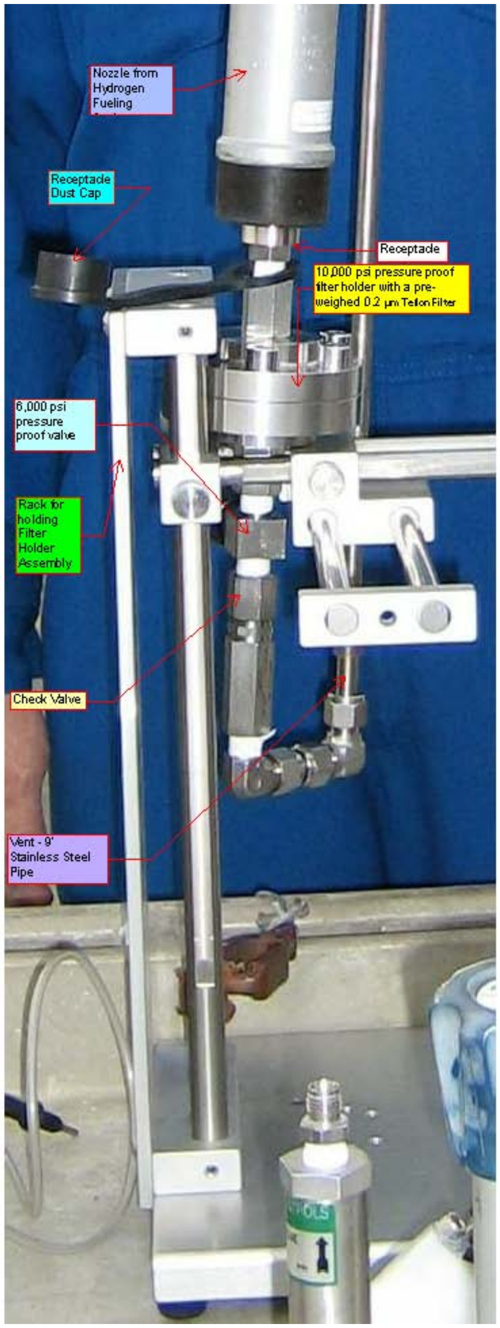
REPORT ON SAMPLING at SUNLINE

Particulate Sampling Procedure

A 47mm OD pre-weighed 0.2 Teflon filter is installed into a 10,000psi pressure proof filter holder inside the glove box with the valve closed. In the field, the filter holder assembly with the exhaustion pipe is secured physically and attached to the suspensor of the hydrogen station, as show in Figure 1. With the hydrogen fuel turned on, perform leak check and then open the valve. The time of sampling is measured and **the weight of hydrogen fuel sampled read from station meter**. The filter holder assembly without the exhaustion pipe is then put into a glove box and the Teflon filter removed and weighed. A check valve is installed to stop the backflow.



Filter Holder Assembly

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REPORT ON SAMPLING at SUNLINE

Hydrogen Fuel Sampling Procedure Using HQSA for Gaseous Analysis

During sampling, sampling personnel shall wear safety goggles and a flame resistant Nomex lab coat.

1. Attach a 1-L 1800psi proved stainless steel sample container to HQSA (Figure 1) and complete assembly as shown in Figure 2. If the sample used for sulfur analysis, a silicone dioxide coated cylinder will be used.
2. Attach station ground wire the bracket of the red valve (V1) of HQSA.
3. The station suspensor is attached to the HQSA receptacle by trained personnel. The **<u>pressure reading of HQSA shall not exceed 500 PSI</u>** after connection.
4. A hydrogen detector will be used to check for hydrogen leaks around all the connections including but not limited to
   - J2600 to receptacle
   - Receptacle to high pressure regulator
   - All connections between high pressure regulator to red valve (Valve V1) shown in Figure 1.

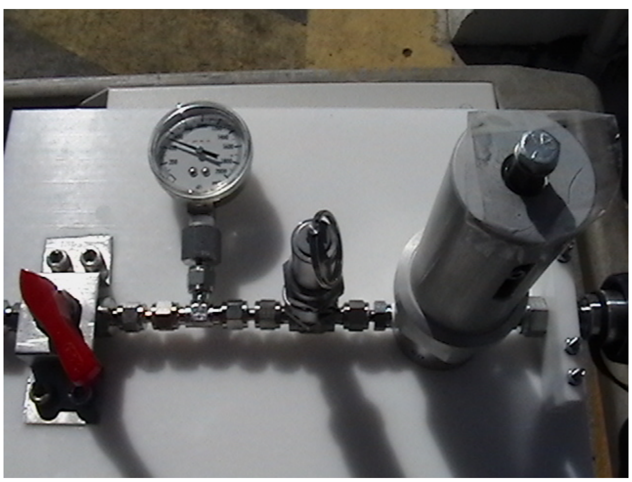
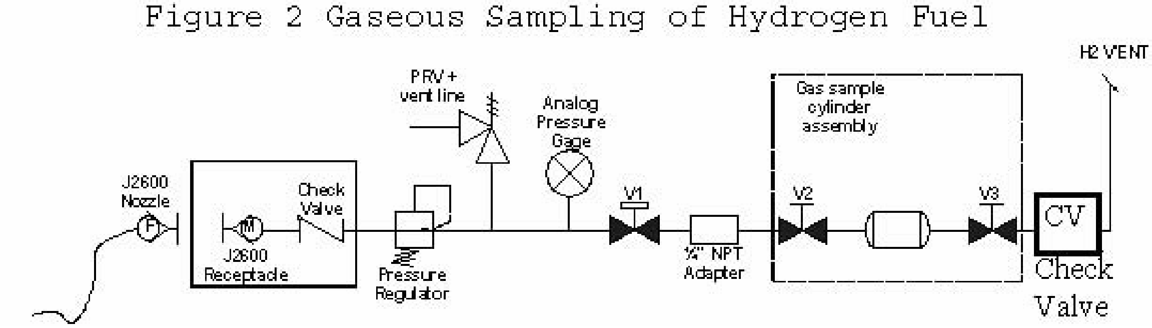


Figure 1 HQSA

Figure 2 Gaseous Sampling of Hydrogen Fuel



5. The red valve (V1) is slowly opened about 20 degree counter-clockwise from top center. Check for leaks between the sample container and red valve (V1). If no leaks are detected, the inlet Nupro valve (V2) of the sample container shall be opened and checked for leaks.
6. If no leaks are detected, inlet valve (V2) is closed and the outlet Nupro valve (V3) of the sample container opened briefly to release most of hydrogen before closing V3.

REPORT ON SAMPLING at SUNLINE

7. Repeat Step 6 ten times.
8. If the station cuts off hydrogen due to the reason of low hydrogen pressure, V3 is closed and immediately followed with closing V2. After hydrogen flow resumes, continue with Step 7.
9. Let hydrogen fuel flowing through the sample container for ten minutes and then close in sequence V3, V2 and V1 valves.
10. Cut off the hydrogen from station and remove J2600 hose. Put dust cap on the hydrogen receptacle of HQSA. Remove hydrogen vent tube and then cap both V2 and V3. Leak-check HQSA and sample container. Restore ground wire and transfer HQSA and sample container to Smart Chemistry Laboratory.

ACRONYMS AND ABBREVIATIONS

AC Transit .... Alameda-Contra Costa Transit District
APTA .... American Public Transportation Association
CARB .... California Air Resources Board
CNG .... compressed natural gas
CTE .... Center for Transportation and the Environment
CUTE .... Clean Urban Transport for Europe
DGE .... diesel gallon equivalent
DOE .... U.S. Department of Energy
DOT .... U.S. Department of Transportation
ECTOS .... Ecological City Transport System
FC .... fuel cell
FCB .... fuel cell bus
FCV .... fuel cell vehicle ft feet
FTA .... Federal Transit Administration
GGT .... Golden Gate Transit
GVWR .... gross vehicular weight rating
HFCIT .... Hydrogen, Fuel Cells, & Infrastructure Technology
HHICE .... hydrogen hybrid internal combustion engine
hp .... horsepower
in .... inches
kg .... kilogram
kW .... kilowatts
kWh .... kilowatt-hours
lb .... pounds
MBRC .... miles between road calls
mpg .... miles per gallon
mph .... miles per hour
NAVC .... Northeastern Advanced Vehicle Consortium
NFCBP .... National Fuel Cell Bus Program
NRCan .... Natural Resources Canada
NREL .... National Renewable Energy Laboratory
PAFC .... phosphoric acid fuel cell
PEM .... proton exchange membrane
psi .... pounds per square inch
RC .... road call
RFP .... request for proposal
rpm .... revolutions per minute
SAFETEA-LU .... Safe, Accountable, Flexible, Efficient Transportation Equity Act: a Legacy for Users
SamTrans .... San Mateo County Transit District
STEP .... Sustainable Transport Energy for Perth
UNDP-GEF .... United Nations Development Program—Global Environmental Facility
VTA .... Santa Clara Valley Transportation Authority
ZEB .... zero-emission