Federal Transit Administration

SunLine Transit Agency

Cooperative Agreement
Project Number CA-26-7022

FINAL REPORT
September 2, 2001

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As previously reported, the XCELLSiS ZEbus arrived at SunLine Transit Agency in Thousand Palms, CA on July 21, 2000. Thousand Palms is located near Palm Springs, CA in the lower Colorado Desert area known as the Coachella Valley. The designated start date for the 13-month test was August 2, 2000. From the program's inception, a Stuart Energy P3 electrolyzer, located at SunLine and funded by a U.S. Department of Energy grant, provided the required high purity hydrogen fuel.

In accordance with our FTA agreement, throughout the program, SunLine participated with XCELLSiS in fueling, training, operating and testing the bus. In cooperation with College of the Desert, SunLine finalized the production and development of a training manual entitled "Hydrogen Fuel Cells and Related Technologies" for technicians. XCELLSiS provided a final report summarizing bus operations at SunLine, a copy of which is attached. The notes below correlate to that report.

Prototype fuel cell vehicles refuel at SunLine Transit Agency's public access hydrogen station in Thousand Palms, CA.

While the report includes data relating to bus performance, it should be noted this demonstration program achieved success far beyond the technical realm. For any new technology to be successful, public opinion must be in its court. Fuel cells, in particular, have received an inordinate amount of attention in recent years, so demonstrating the technology at a transit property familiar with and in total support of clean fuels technology was extremely important to ensure understanding and acceptance.

Through the efforts of the marketing departments at SunLine and XCELLSiS, during its tenure at SunLine, the ZEbus was:

- filmed by half a dozen French, Japanese, Italian and German crews
- reviewed repeatedly by international journalists
- highlighted in brochures and the agency's annual report
- spotlighted in SunLine's new quarterly newsletter, *SunBuzz*
- featured in several "Energy Matters" educational video segments and
- viewed by thousands of people from nearly 20 countries, including groups participating in the CUTE (Clean Urban Transport for Europe) program in Europe and five international groups

- given a special award by the Michelin Challenge Bibendum in Las Vegas in October 2001, following completion of a 275 mile drive from Los Angeles. The Michelin Challenge is an annual international event which showcases clean alternative vehicles.

Thousands of international visitors and industry members saw the ZEbus during its stint at SunLine.

Among those to visit SunLine and see and/or ride the bus were numerous international transit and scientific delegations, international automakers, fuel cell researchers, air quality experts, the November 2000 Hydrogen Technology Advisory Panel (HTAP) meeting, the January 2001 American Public Transportation Association (APTA) Alternate Fuels Committee meeting, representatives from the California Air Resources Board (CARB), California Energy Commission (CEC), Department of Energy (DOE), Department of Transportation DOT), Federal Transit Administration (FTA), South Coast Air Quality Management District (SCAQMD), top-ranking French officials attempting to set hydrogen policy, Canadian Ambassador Gilbert Parent, Israeli Minister of the Environment Tzachi Hanegby and such local organizations as Rotary, Kiwanis, various city managers, the police academy, College of the Desert and others.

In a successful demonstration of technology transfer, SunLine provided mobile fueling and a driver for the ZEbus at the Michelin Challenge Bibendum.

The ZEbus was prominently featured at the Coachella Valley Clean Cities Awards Luncheon, at an Earth Day event at The Living Desert and at a lecture at the Palm Desert Library. However it was most visible in the Michelin Challenge Bibendum at the California Speedway (shown here) and on the road to Las Vegas, where a SunLine driver helped set a new world record for distance and grade in a fuel cell bus. SunLine's fuel cell program was covered in every presentation made by SunLine personnel since the ZEbus arrived. Recent presentations include those made in the Palm Springs area and the Cities of Beijing, Tokyo, New Delhi, Baltimore, Tucson, Chicago, Washington, San Diego and Chula Vista. In addition, the XCELLSiS on-site test engineer and other field reps were filmed by all three local television stations and interviewed by *The Desert Sun* daily newspaper.

As a result of the positive media exposure, thousands of people around the world look forward to the advent of zero-emission hydrogen fuel cell vehicles. As a result of what XCELLSiS learned by conducting its 13-month test at SunLine, future generations of heavy-duty fuel cell engines will be significantly improved. From

SunLine's perspective, the program was therefore an extremely important and successful step in the path toward commercialization of fuel cell vehicles for the transit industry.

DATA COLLECTION:

Chief Executive Officer Eduard Michelin (right) with SunLine and XCELLSiS team members at the world's largest alternate fuels road rally.

The information presented in **Figure 1.1 "Basic Vehicle Data"** describes the characteristics of the XCELLSiS P-4 fuel cell bus. This bus is the latest generation of the ZEbus and an improvement of the P-3 buses that were in service in Vancouver and Chicago. The P-4 was sent to the Palm Springs, CA area to determine the effects of extreme temperatures (up to 120 degrees), blowsand and other airborne contaminants on the fuel cell engine. The bus was used on several occasions to provide non-revenue service to a wide variety of people interested in riding. The data presented in the following figures describes the activities involved with testing on the local tracks.

The first project requirement was to maintain a mileage log so events of interest to a transit agency could be captured and evaluated at appropriate data collection points. This was done so elements of reliability and maintainability could be determined or projected. **Figure 2.1 entitled "Mileage"** presents the cumulative mileage incurred since July 20, 2000. In the final quarter, June - August 2001, the bus logged a total of 4,254.6 miles. Bus reliability and availability were greatly improved as a result of improvements made to the overall cooling system. Though the ZEbus was being upgraded throughout this period, it operated a total of 531.4 hours, a major increase in availability and reliability over previous quarters.

The pie chart titled "Accumulated Miles since July 20, 2000" outlines the transit track testing mileage (90%) compared to mileage associated with testing demonstration and training (10%). "Testing demonstrations" represented times the bus was available for riders; "training" targeted operators and mechanics. Both testing and training proved to be valuable tools to operators and mechanics, who are key to the successful implementation of a new technology at any transit property.

Driven from Fontana to Las Vegas, the ZEbus set a new world's record for distance and grade.

The pie chart "Accumulated Hours since July, 20, 2000" reflects the total hours accumulated on the bus' power systems during the test. As a comparison, SunLine's fleet average is between 17 and 19 miles per

hour. This compares favorably with XCELLSiS bus operations of 17.5 miles per hour (range 8.1 to 20.0 average).

It should be noted a number of hours were recorded for static testing to gather additional information on the power systems and duplicate a variety of conditions experienced on the road. Finally, SunLine was limited in the amount of fuel available on board due to elevated temperatures in the valley and a method of refueling (pressure transfer) that operated at less than optimal conditions. This required a careful evaluation of fueling conditions and requirements.

Another area of significant interest to a transit agency is outlined in **Figure 2.2 entitled "Fuel Consumption and Driving Range."** The fuel cell bus exhibited excellent fuel economy and fuel consumption was in the order *of 5.07 miles per diesel gallon equivalent* in the last month of operation. This compares favorably to 2.4 miles per diesel gallon equivalent, achieved with conventional buses operating on natural gas in similar transit service. Further improvements in fuel efficiency are anticipated with the introduction of an improved P-5 fuel cell engine.

Transit agencies are always concerned with support costs associated with bus operations. **Figure 2.3 entitled "Consumables"** summarizes the usage of the different consumables. The Coachella Valley's extreme desert conditions indicated a need to improve cooling efficiency. Changes were implemented to improve cooling performance that produced an increase in engine efficiency, a reduction in the number of purges and overall water consumption, and greater fuel cell reliability. Road calls were virtually eliminated in August and it is anticipated that the frequency of inspections could be further reduced with future fuel cell systems.

Figure 2.4 entitled "Maintenance" addresses maintenance requirements and related support costs, and reflects the maturity of the technology. Increased inspections were planned into this project so appropriate standards could be developed for OEM's. A total of 315.8 hours were deemed necessary for maintenance inspections to run the bus for 15,154.1 miles and 865.3 hours. It is anticipated that these hours will decrease with continued technological improvements.

SunLine and XCELLSiS received special recognition at the Michelin event.

Figure 2.5 "Road Calls" assists transit agencies in identifying the reliability of system hardware. Only one road call was necessary in August and this reflects well on the improvements made to the cooling system. Many of the 24 calls during this period were attributable to erroneous shutdowns and system sensitivity warning lights / alarms. It must also be noted that the desert's summer heat provided the harshest of environments for testing.

TRAINING AND TECHNOLOGY TRANSFER

The final draft of the "Hydrogen Fuel Cell Engines and Related Technologies Manual" was reviewed in December 2001. The manual is the first of its kind and provides an excellent base for training purposes and curriculum development. The updated final copy of the manual is completed and included herein. Please see tab number 5.

INTERNALTRAINING, EVALUATION AND FOLLOW-UP

SunLine mechanic Dino Juarez assigned to this training from June 2001 through September 2001. As previously indicated, other mechanics and supervisors were also included when specific training procedures took place.

CONCLUSION

The project was very useful in establishing operating parameters and environmental testing in extreme heat conditions, and in transferring technology to a transit agency. Data collection is recognized in the operating and support functions as a necessary prelude to the successful introduction of fuel cell transit vehicles. Similarly, operating data will lead to improved components and a P5 fuel cell engine with greater power, energy efficiency and reliability.

At the end of the 13-month test period, the bus ran flawlessly in the Michelin Challenge Bibendum from Los Angeles to Las Vegas, a 275-mile trek. SunLine refueled the ZEbus in transit in Baker, CA 150 miles from its home base in Thousand Palms, CA. Refueling was a precautionary measure taken in anticipation of extensive idling upon arrival at Las Vegas, given the strong media and public representation. SunLine also provided mobile hydrogen-fueling services to other Bibendum vehicles upon request.

In the Coachella Valley, Los Angeles, Fontana and Las Vegas, all who encountered and/or rode the ZEbus were impressed with its smoothness, low engine noise, absence of odors and emissions, and just loved the ride. The future for the ZEbus looks very bright!

Fuel cell projects are anticipated to continue in California and Europe with the introduction of new buses equipped with Ballard P5 and other fuel cell engines as early as the first-half of 2003. SunLine looks forward to its continuing role as a test site for next generation fuel cells and ancillary systems. Improvements in power, reliability and energy efficiency will be instrumental in reducing harmful emissions and lessening our dependency on foreign oil imports.

Fuel Cell Bus Demonstration

STATUS OF PROJECT REQUIREMENTS/TASKS

Final - September, 2001

				STATUS
FTA Requirements:				
1	Procure and road test a 40' bus, etc.			Completed
2	Demonstrate and test a fuel cell bus w/Xcellsis, etc. (13 mos.)			Completed
3	Provide transit agencies w/information, etc.			End of project
4	Results of testing and demonstration to be disseminated to others			To be provided by FTA per Shang Hsiung
5	Demonstration to provide information as follows:			
		Operations		Completed
		Maintenance		Completed
		Management		Completed
		Traning Issues		Completed
6	Develop training manuals in conjunction w/XCELLSIS, etc.			Completed
7	Demonstration to be coordinated w/other SunLine projects:			
		Construction of solar and wind powered hydrogen generation facility		Completed
		Stuart's P-3		Completed
		RTA, SunLine, SCAG ITS grant		In work
8	Quarterly Reports Required			Completed
SunLine/XCELLSIS Agreement				
	Xcellsis Obligations:			
1	Deliver Bus in the first half of 2000			Completed
2	Conduct some testing in Vancouver (2 mos.) before comes to			
	SunLine			Completed
3	Xcellsis to deliver bus at its cost.			Completed
4	Provide SunLine w/the following:			
		Engineering design and project management support		Completed
		Safety assurance plan integration services and hardware		Completed
		Maintenance services and hardware to include tools,		
		manuals, etc.		Completed
5	Provide a test engineer, mechanical tech and elecrical tech			Completed
6	Make one test manager and one data controller available			Completed
7	Allow SunLine to show bus 4 hrs. per month w/in 50 mi. radius			Was shown to groups at SunLine almost daily
8	Review possiblity of upgrading P4 to P5 engine			Unfunded

Fuel Cell Bus Demonstration

STATUS OF PROJECT REQUIREMENTS/TASKS

Final - September, 2001

9	Provide Monthly reports		Completed
	Basic Vehicle Data		Completed, see attached
	Operation Data		Completed, see attached
	Mileage		
	Fuel and other consumable		
	Vehicle range		
	Maintenance interval, labor hours, parts		
	Brake wear		
	Road Calls		
	Fuel Cost		
	Reliablity - am pull-outs met		
	[SunLine to assist w/this data]		
10	Allow SunLine and U.S. government to disclose the data		Agreed
11	Cooperate w/SunLine in training, maintenance and development of		
	training program.		Completed
	SunLine Obligations		
1	Supply hydrogen		Completed
2	Cooperate w/XCELLSIS to obtain license to operate in California		Completed
3	Supply a bus maintenance bay and shelter		Completed
4	Provide utilities		Completed
5	Provide operators		Completed
6	Upgrade facilities for hydrogen safety to include sensors and a fire		
	suppression system		Completed
7	Provide bus consumable, I.e., tires, brakes, etc.		Completed
8	Provide maintenance, labor and materials		Completed
9	Perform road test, under direction of XCELLSIS		Completed
	Phase II: SunLine and Xcellsis Obligations		
1	Develop specs for a fuel cell bus chassis		Completed
2	Apply for funding to assist the selected OEM in the development phase		Done in cooperation w/A.C. Transit, Oakland
3	Select an OEM, execute contract, etc.		In process in cooperation w/A.C. Transit, Oakland

PART REPLACEMENT

Report period from July 20, 2000 to August 31, 2001

Bus ID: P4T-1

Date	Tag ID	Part Name	Type Of Work
10-Jul-01	PC:E01	Inverter	Troubleshooting
25-Jun-01	HUM:S01	humidifier	Maintenance
25-Jun-01	HUM:S02	humidifier	Maintenance
25-Jun-01	HUM:S04	humidifier	Maintenance
25-Jun-01	FCS:S04(D)	stack	Maintenance
25-Jun-01	FCS:S06(F)	stack	Maintenance
16-Jun-01	PC:E01	Inverter	Troubleshooting
27-May-01	HEX:Y01	Fluid oil cooler	Upgrade
24-May-01	PC:E01	inverter	Repair
22-May-01	CMP:A02	Turbo	Repair
16-May-01	PT:H01	Pressure Transducer	Repair
27-Apr-01	FLT:H02	Hydrogen particulate filter	Maintenance
26-Apr-01	FLT:D06	DI filter assy	Upgrade
14-Apr-01	HUM:S02	humidifier	Repair
14-Apr-01	FCS:S04(D)	Stack	Repair
6-Apr-01	CVM:S04(D)	CVM Board	Repair
4-Apr-01	SOV:H08	H2 valve	Repair
31-Mar-01	FCS:S04(D)	stack	Repair
14-Mar-01	FLT:D02	COND. DI Filter	Maintenance
14-Mar-01	FLT:D01	SEP DI Filter	Maintenance
9-Mar-01	PSE:H01	Burst disk	Maintenance
6-Mar-01	HUM:S04	humidifier	Repair
6-Mar-01	FCS:S06(F)	stack	Repair
2-Mar-01	FLT:A01	Air intake filter	Maintenance
1-Mar-01	PC:E01	Inverter	Troubleshooting
26-Feb-01	HUM:S01	Humidifier	Repair
26-Feb-01	HUM:S02	Humidifier	Repair
23-Feb-01	XM:A01	Oil Indicator	Repair
20-Feb-01	HUM:S03	humidifier	Maintenance
20-Feb-01	FCS:S05(E)	stack	Maintenance
29-Jan-01	PC:E01	Ingverter	Troubleshooting
20-Jan-01	PC:E01	Inverter	Troubleshooting
19-Jan-01	PC:E01	inverter	Troubleshooting
20-Nov-00	HUM:S01	humidifier	Repair
20-Nov-00	HUM:S02	humidifier	Repair
20-Nov-00	HUM:S03	humidifier	Repair
20-Nov-00	HUM:S04	humidifier	Repair
7-Oct-00	BAT:E01	12V battery	Maintenance
7-Oct-00	BAT:E02	24V battery	Maintenance
3-Oct-00	LS:D01	DI header tank level switch	Repair
30-Sep-00	XM:A02	Air filter restriction indicator	Repair
14-Sep-00	FLT:A02	Module 1 air inlet filter	Maintenance
13-Sep-00	FCS:S04(D)	Stack	Maintenance
8-Sep-00	FLT:L01	Oil Particle filter	Maintenance
8-Sep-00	FLT:L02	Particle filter	Maintenance
7-Sep-00	DBISO:S01	Stack vibration isolator	Upgrade
2-Sep-00	XM:M01	Gear for Air brake	Maintenance
17-Aug-00	XM:Q01	AC hose and fitting	Other
4-Aug-00	XM:Q01	AC filter drier	Upgrade
4-Aug-00	XM:Q01	AC hose and fitting	Upgrade
4-Aug-00	XM:Q01	R22 expansion valve	Upgrade
29-Jul-00	PMP:D01	DI pump housing	Repair
29-Jul-00	PMP:D01	DI pump impeller	Repair
25-Jul-00	PMP:D01	DI pump housing	Maintenance
25-Jul-00	PMP:D01	DI pump impeller	Maintenance
25-Jul-00	PMP:G01	Glycol pump impeller	Maintenance

ROAD CALL

Report period from July 20, 2000 to August 31, 2001

Bus ID: P4T-1

Date	Incident/Problem Description	Description On Correction
20-Oct-00	CVM alarm shutdown.	Restart & rev idle to 1500RPM for 2 minutes.
20-Oct-00	DI HDR TANK LOW, DATALINER SHARE ALM MSG	Refilled DI header tank.
31-Oct-00	Bus coach batteries were drained (recorded in earlier snag). Possible cause: Landau operator periodically started bus to increase air tank pressure, to keep air springs inflated, to keep chains tight between bus and Landau. Coach has air leak which can bleed completely in 2-3 days of parking. This occurred during shipment of bus.	Batteries had to be charged.
2-Nov-00	CVM ALM shutdown	Cycled power and restarted.
2-Nov-00	CVM ALM shutdown	Restarted.
2-Nov-00	CVM shutdown	Restarted.
2-Nov-00	CVM ALM shutdown during 2nd startup attempt.	Reset main power and attempted to start again.
3-Nov-00	Bus ran low on DI-water resulting in shutdown and road call.	Topped up DI water header tank.
8-Nov-00	"DI Header tank Low" msg on dataliner. Bus shutdown.	Refilled DI header tank.
17-Nov-00	HI DI OUTLET TEMP ALM	Topped up DI water header tank and restarted successfully.
9-Feb-01	Bus shutdown. Re: DC over current alarm.	Checked fault history and restarted bus.
14-Feb-01	Failed startup after DI header tank low level alarm. CVM warning will not clear during startup.	Bus would not restart.Bus pushed back into bay.
11-Apr-01	Bus shutdown due to low DI water in header tank	Added DI water in tank (6 L); Re-started.
4-May-01	Low DI HDR TNK Alarm shutdown. Shutdowns: 1st at 15:00h DAQ clock. 2nd at 15:07h DAQ clock.	Refilled DI HDR tank, restarted bus successfully.
7-May-01	LOW DI HDR TNK shutdown- level was below readable scale.	Road call, refilled DI water
11-May-01	Bus shutdown due to lack of DI water.	Filled DI water tank and re-started.
11-May-01	Bus shutdown due to low DI water.	Re-filled DI header tank and started bus.
12-May-01	Bus shutdown due to (Hi Air/H2 Delta Pressure) - (Hi DI Inlet Pressure)	Re-started bus.
15-Jun-01	Bus shutdown Re: DI header tank low level	Refilled DI header tank and restarted bus.
18-Jun-01	Bus shutdown Re: CVM Alarm.	Restarted bus.
18-Jun-01	Bus shutdown Re: CVM Alarm	Restarted bus.
20-Jun-01	Hi inlet air temp alarm. Hi RAD out temperature.	Re-started Bus.
21-Jun-01	Bus shutdown due to CVM alarm	Re-started bus.
1-Aug-01	Bus shutdown due to H2 roof sensor failure.	Replaced roof H2 sensor. Recalibrate sensor.

FOR A COPY OF THE COMPLETE MANUAL,

PLEASE CONTACT

SUNLINE TRANSIT AGENCY

AT 760-343-3456, EXT. 336