"FILLING UP WITH HYDROGEN 2000"

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Abstract

"Filling Up with Hydrogen 2000" is a prototyping development program intended to validate the Stuart Fuel Appliance Model for hydrogen infrastructure. Stuart fuel appliances are purpose built on-site electrolytic hydrogen generators for refueling gaseous hydrogen vehicles. Using only electricity and water and having no emissions beyond oxygen, electrolytic fuel appliances can be readily deployed to create a highly distributed fuel supply network. The program is in it final year of Phase 2.

The tasks in Phase 2 of the Stuart/DOE program are to design, build and deploy a variety of fuel appliances. Two types of appliance were built under this program: Fleet Fuel Appliances and Personal Fuel Appliances, both of which target the needs in nascent hydrogen vehicle commercialization. The Fleet Fuel Appliance targets buses, trucks and other centrally fuelled fleet vehicles, where fuel production rates in excess of 400 SCFH (10 Nm^3/h) are required. The Personal Fuel Appliance is geared towards consumers' vehicles at the home or office, and can be powered by the utilities found in the typical North American home. The production rate of these units is in the range of 50 SCFH (1.5 Nm^3/h). Both types of appliances are capable of delivering gaseous hydrogen at high pressure (up to 5000 psig) to the vehicle. The goals of the program are to demonstrate the performance and cost objectives projected in the Phase 1 commercialization plan while introducing a safe and convenient refueling process.

Introduction

As presented in the Phase I Business Plan, the successful development and demonstration of fuel appliance technology will enable a cost effective pathway for building a hydrogen fuel supply infrastructure to support hydrogen vehicles in their early commercialization. The fuel appliance addresses the issue of fuel delivery by providing point of use fuel generation using existing energy utilities. Using the existing electricity grid, a full service infrastructure can be built up as a distributed network of small electricity to hydrogen fuel converters.

Key to meeting the market requirements is reducing the cost of electrolysis. Stuart's patented cell technology is designed to achieve the cost targets demanded by transportation fuels. The CST technology uses low cost polymer and metal sheets, which are easily assembled in a stack. The cell stack replaces the cell-tanks of earlier designed fuel appliances, such as those used in the Ballard/BC transit bus filling station in Vancouver. In addition to cost savings in manufacturing, the CST gas generation system/fuel appliance is one-tenth the size of earlier cell designs. The CST electrolyser can be configured either as a single stack or multi-stack electrolyser. The multi-stack electrolyser, having multiple cells in parallel, can run cell currents up to 30,000 amps and is suitable for large fueler applications. All the prototypes built under "Filling Up With Hydrogen 2000" use CST technology.

"Filling Up With Hydrogen 2000" will provide an experience base with the cell stack technology for later commercialization, and is a cost effective approach for equipment testing in that the user/customer picks up operating costs for the benefit of the hydrogen produced. In addition to testing the cell technology, the prototype development plan provides public exposure to the fuel appliance concept, introducing customers to the idea of distributed on-site hydrogen production as well as providing valuable precedents for the development of codes and standards and hydrogen project risk assessment. The operation of the bus fuel appliance (P3-1A) at SunLine Transit provides public access to the technology through SunLine. The low-pressure fueler (P3-1B LP) provides a demonstration of a system, which can refuel metal hydride gas storage. The high-pressure fueler (P3-1B HP) demonstrates the concept of a distributed "community fueler". The design of the bus fueler, P3-5, demonstrates the large format cell technology which could be used in large bus fleet fueling applications. The P4 prototypes are being used to test different configurations of the cell stack integration with the compressor, including a pressurized stack configuration and integration with a wind turbine in a semi-stand-alone energy system. Prototyping of the personal fuel appliance (PFA P1 Model 25) at major automakers will provide the auto industry the opportunity to evaluate the concept of a small onsite hydrogen generator and potential home based fueling appliance.

Stuart Fleet Fuel Appliance Program

The Fleet Fuel Appliance targets the refueling needs of hydrogen buses, trucks and other centrally fuelled fleet vehicles. Conceived to be a scalable product; 1 to over 30 vehicles can be supported with one appliance. By combining the purchasing power of a number of distributed fuel appliances off-peak power can be purchased at rates less than 3 cents/kWh, which will make hydrogen from fleet fuel appliances competitive with other transportation fuels in the range of $2.50- 3.00 per kg. The development of Fleet Fuel Appliance prototypes follows a four-phase product development program, which is now in its third phase. The 17.7 million-dollar program will be completed by 2004. The ultimate cost target for the fleet fuel appliance is $3000 per SCFM hydrogen production/refueling capacity.

Recent "wells to wheels analysis" has shown, of available hydrogen production pathways, electrolysis powered by renewable or nuclear power is the only process that could reduce transportation green house gas emissions to near zero. Although cost projections for hydrogen production from coal and natural gas are lower than for electrolysis these costs don't reflect cost of CO_2 emissions. Cost comparisons should be refined to include the cost of CO_2 capture and sequestration.

Relationships with auto and bus manufacturers will be developed during the prototype deployment period from 1999-2003. Commercialization will begin in 2003, probably led by auto companies needing fuelers to support vehicle development programs followed by fuel cell bus programs in 2004.

All P3 prototype appliances have been built with exception of P4-10, the large bus fueler.

Table 1. Schedule for Fuel Appliance Prototypes

PROTOTYPE	PROTOTYPING PARTNER	DELIVERY DATE
Fleet Fuel Appliance		
P3-1A	SunLine Transit	Q1 2000
P3-1B (High Pressure)	Powertech Labs	Q1 2001
P3-1B (High Pressure)	California Fuel Cell Partnership	Q2 2002
P3-1B (Low Pressure)	Fuel Cell Propulsion Institute*	Q3 2002
P4-1A	Internal Test	Q2 2001
P4-1B	AQMD/ Wintec Wind Farm	Q4 2002
P4-10	TBD	
Personal Fuel Appliance		
PFA-P1-99	Ford Motor Company	Q1 2001

TBD: to be determined

P3 Fleet Fuel Appliance Program

Prototype P3-1A

P3-1A demonstrates Stuart's new MW-CST or multi stack electrolyser cell technology, which is targeting bus fleets and large retail outlets. The appliance is capable of producing up to 1490 SCFH at full current (12000 amps). The unit is connected to a high-pressure storage system (approx. 100,000 SCF) and an external dispenser, which is part of a public access hydrogen fueling station, the first of its kind in North America. The dispenser was designed by Stuart and built by Fueling Technologies Inc. High-pressure hydrogen is delivered through one hose (up to 3600 psig temperature compensated) and high pressure Hythane, a mixture of 20% by volume hydrogen in natural gas, from the other (up to 3000 psig temperature compensated).

General operating characteristics of the system are summarized below:

Maximum Output	1490 SCFH
Maximum pressure	4000 psig
Cell Voltage efficiency @ 70 C & 95% maximum output	83% WRT hhv
Gas purity (ex. moisture)	99.65%

Over the period from mid-July 2000 to March 31, 2002 the unit has run over 2000 hours (both cells and compressor) producing over 2,300,000 SCF of hydrogen fuel. This fuel has been used to fuel a fleet of hydrogen vehicles including two Hythane buses and a Ballard fuel cell bus. In the fall of 2001 the system was used to provide fuel to the Michelin Bibendum Fuel cell vehicle rally. Hydrogen fuel was delivered to contestants using SunLine's gaseous fuel tanker (capacity 100,000 SCF). Operation of P3-1A at SunLine is planned to continue until March 31, 2003.

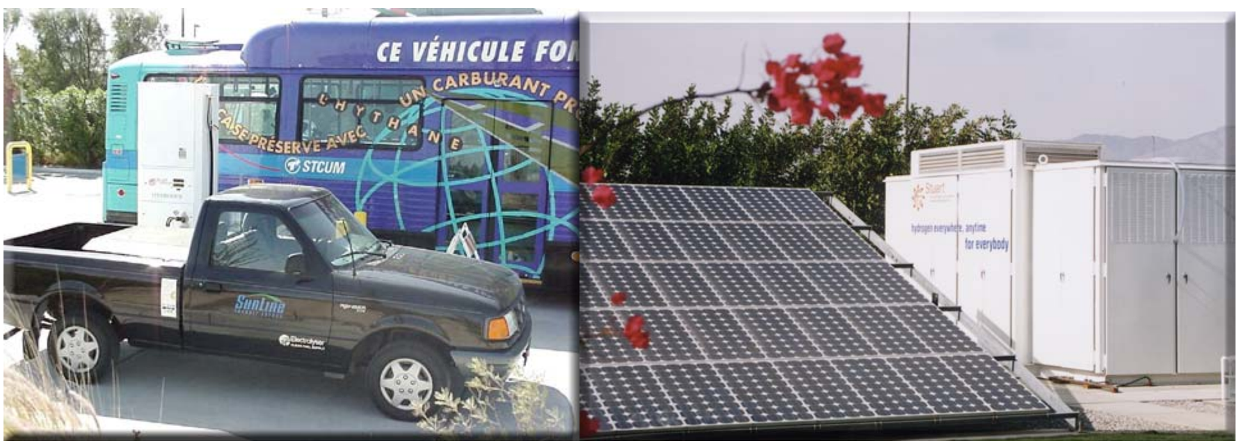

Figure 1: P3-1A Prototype fueling Hydrogen ICE Truck and Hythane Bus at SunLine

Prototype P3-1B LP

The low-pressure fleet fuel appliance, P3-1B LP, delivers a rated hydrogen output of 400 SCFH at 200 psig. In May 2000 this unit successfully completed 3000 hours of in-house testing. In the coming year, hydrogen from this unit will be used to fuel demonstration zero emission underground mining fuel cell vehicles. For this application the cells stacks (2 single stack H-CST cell stacks) will be replaced to test a higher efficiency design. A number of other changes with regard to the dispenser and purification are in process to reflect need to dispense and fill metal hydride, as opposed to compressed hydrogen, storage tanks. The unit will be located in Reno Nevada, where a fuel cell mine locomotive will be tested on a Union Pacific spur line.

Figure 2: Fuel Cell Mining Vehicle to be fueled by P3-1B LP prototype.

Prototype P3-1B HP

The P3-1B HP fleet fuel appliance was delivered to Powertech Laboratories in Vancouver BC where it is being used to fuel a fleet of three vehicles powered by internal combustions engines modified to run on a blend of 51% hydrogen and 49% natural gas. Based on the same platform as P3-1B LP the unit uses H-CST single stack electrolyser technology.

Figure 3: P3-1B HP prototype at Powertech

The unit incorporates the power conditioning system, two cells and two compressors mounted on a linear process design platform that can be readily scaled to larger sizes, up to six cells. The unit has both a catalytic purifier as well as high performance dryer, which is installed inter-stage between the second and third stage of compression. Along with the unit a fast fill dispenser was supplied capable of refueling both hydrogen and Hythane vehicles to 5000 psig. Hydrogen production is rated at 400 SCFH at a maximum pressure of 5000 psig. An external intensifier can take the pressure up to 10,000 psig to allow testing of vehicle tank prototypes at these pressures.

The unit has over 1500 hours and has produced 650,000 SCF of compressed hydrogen. A second unit of the same design has been built for the California Fuel Cell Partnership to be a satellite station at AC Transit in Richmond CA. This unit will be installed along with high-pressure storage, 20,000 SCF at 5000 psig using Type III vehicle tanks, and a fuel dispenser capable of dispensing fuel at either 3000 or 5000 psig.

The operating characteristics of the unit are summarized in the following table:

Production Rate (max)	450 SCFH
Pressure	5000 psig
Purity	99.993%
Moisture	-65 C

Prototype P3-5 Cell Stack Assembly

The P3-5 fuel appliance, capable of fueling 5 buses or approximately 10000 SCFH was taken to the design stage and a cell stack assembly was constructed. The cell stack assembly is built on a 2-block "back to back" platform, with each block consisting of 6 stacks. A P3-5 appliance would consist of a train of three back-to-back modules, aligned in a row, and connected to form a "U" shaped bank, which can be enclosed inside a housing.

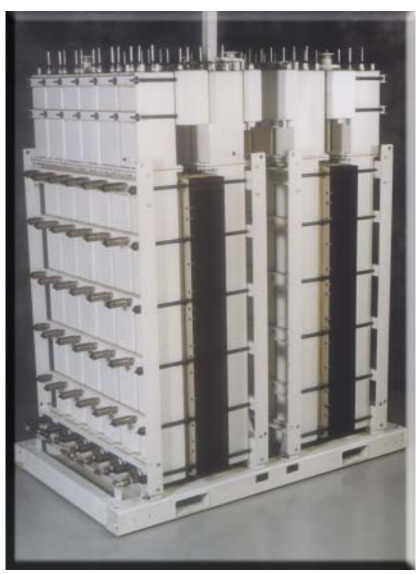

Figure 4: P3-5 "Back to Back" Cell Module

A cell module of this design has been built and tested. The modules as assembled stand approximately 12 feet tall, 8 feet wide, by 6 feet long and weigh 13,000 lb. Combining three modules the cell battery for the P3-5 fueler, with gas and feed water headers connected, will be 14 feet high, 8 feet wide and 20 feet long. The unit would be capable of generating 300 Nm3/h (approx. 10,000 SCFH).

Operating characteristics of the cell module are given ion the following table:

Maximum Output	3700 SCFH
Maximum pressure	5 psig
Cell Voltage efficiency @ 60 C & 85% maximum output	85% WRT hhv
Gas purity (ex. moisture)	99.65%

With amendments made to the Stuart Energy/DOE collaborative agreement at the beginning of this year reflecting the lack of a suitable demonstration site for the P3-5 unit, this task is now complete.

P4 Fleet Fuel Appliance Program

Prototype P4-1A

Construction of the P4-1A prototype is completed and the unit is under test. In this unit a different cell pressure control approach was employed which is based on measuring and controlling the level of electrolyte in the end boxes of the stack rather than using a high-pressure water seal as in P3 prototypes. This method of pressure control has been used on the PFA with good success. An H-CST format stack using this pressure control has also run for 10,000 hours but not directly coupled to a compressor.

Operational issues have arisen because of reliability of sensors and the effectiveness of the degassing process in the cell stack. Further work is needed on material issues before this approach to cell pressure control can be advanced.

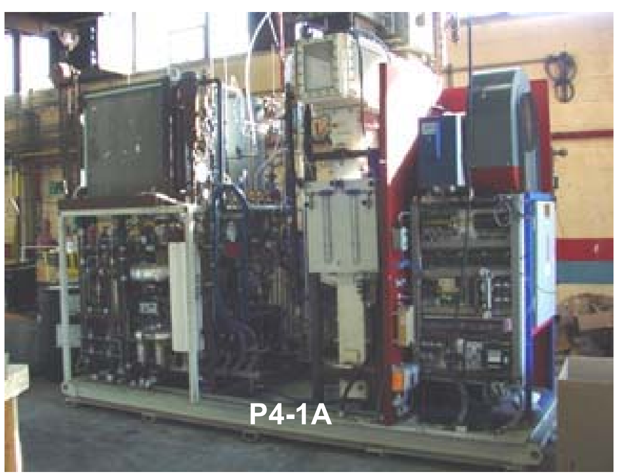

Figure 5: P4-1A Prototype under Internal Test

Prototype P4-1B Renewable Hydrogen Appliance:

P4-1B is a six stack H-platform producing up to 1350 SCFH at 5000 psig. The operating characteristics of the unit are summarized in the following table

Production Rate (max)	1350 SCFH
Pressure	5000 psig
Purity	99.99%
Moisture	-65 C

Working with ISE Research of San Diego, SunLine Transit, and Quantum Technology, the unit will be used in a wind-hydrogen project in the Palm Springs/Coachella Valley. The unit will be connected to three wind turbines at the Wintec wind farm outside Palm Springs; gas production rates will follow the available wind energy. Hydrogen produced by the unit will be used to fuel vehicles at the site and will also be used to fill tankers to transport hydrogen to fueling depots, with the distribution of hydrogen to be handled by SunLine Transit. Delivery of the unit to Palm Springs is planned for the end of this year.

Figure 6: Wind Site Location for P4-1B

In the mean time P4-1B will be at South West Research Institute in San Antonio Texas where it will be used to produce fuel for a hydrogen ICE motor generator system being developed by Ford Power Products. After the three month test is complete, the unit will be examined, changes will be made as required and the unit will be shipped to Palm Springs.

Prototype P4-10 Bus Fueler

Work on the P4-10 bus fueler has focused on the packaging of the MW-CST cell blocks inside a housing. The basic cell stack would be similar to the back-to-back unit, which could be packaged as a single row of blocks or as a "back to back" unit. The design and calculations for loading the platform are underway.

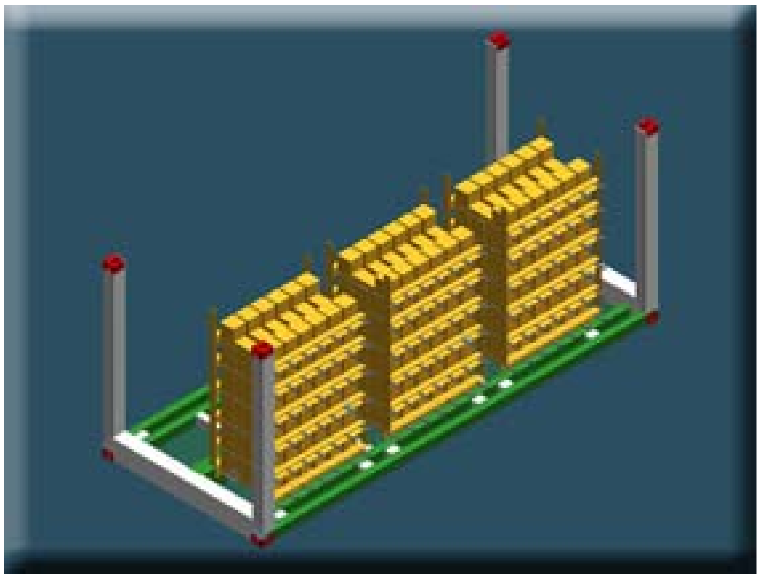

Figure 7: P4-10 Cell Module Packaging Study

Stuart Personal Fuel Appliance Program

The aim of the PFA program is to develop a viable solution to the problem of production and storage of hydrogen for the average consumer's vehicle. The PFA allows refuelling to take place at home or at a place of business, using household utilities, water and electricity and is designed to be as simple to operate as a battery charger. The PFA program includes all necessary equipment for supplying high-pressure fuel for "time filling" hydrogen vehicles. The only inputs are water and electricity; the only outputs are vehicle-ready hydrogen and oxygen

Personal Fuel Appliance Results and Future Work

As reported last year a modified version of the Model P1 25, called the Deca, was built which is significantly smaller than earlier prototypes, 20% smaller than the P1 Model 25 and about a quarter of the size of the P1 Model 10. Five Deca units have been built; the first was supplied to Ford Motor Company with the other four units reserved for public demonstrations. The unit has been extensively demonstrated at hydrogen association meetings in Washington and Vancouver, as well as at the Hanover Fair in Germany, a conference in Beijing China and on numerous occasions with the California Fuel Cell Partnership including the Bibendum in Q3 2001. The unit delivered to Ford has been installed onboard the trailer that carries the Think Hydrogen FCV.

Figure 8: Personal Fuel Appliance in Public Demonstrations

In terms of hardware this task is now complete. We are currently preparing for the next cycle of product development to design a larger fueler able support small fleets and fuel less efficient early FCV's and hydrogen ICE vehicles.

Conclusion

The engineering tasks in this project are nearing completion except for the design and construction of the P4-10 bus fueler. In all seven fleet fuel appliances have been constructed of which five have been put in the field, and eight personal fuel appliances have been built, of which one has been provided for customer evaluation and the others used for internal testing and public demonstration.

References

Stuart Energy USA, *Filling Up With Hydrogen*, 1998, under DOE Cooperative Agreement No. DE-97GO10221

Ford Motor Company, Directed Technologies Inc., Air Products and Chemicals, BOC Gases, The Electrolyser Corporation Ltd., and Praxair Inc. 1997. *Hydrogen Infrastructure Report*, under DOE Prime Contract No. DE-AC02-94CE50389