Proceedings of the 2000 Hydrogen Program Review
NREL/CP-570-28890

# "FILLING UP WITH HYDROGEN 2000"

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## Abstract

"Filling Up with Hydrogen 2000" is Stuart Energy's prototype deployment program to develop Hydrogen Fuel Appliances, purpose built on-site electrolytic hydrogen generators for refueling gaseous hydrogen vehicles. The general objective of this prototype deployment program is to demonstrate that electrolysis based hydrogen generators can meet market cost and performance targets. The program is in year 2 of Phase 2.

In Phase 2 of the Stuart/DOE program Stuart Energy will deploy two types of appliances called Fleet Fuel Appliances and Personal Fuel Appliances. 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 supported by the utility infrastructure of 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 will be 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 accomplishing a safe and convenient refueling process.

## Introduction

The objectives of the past year were to demonstrate operation of Stuart's new CST electrolytic cell stack technology in large-scale application as part of a hydrogen bus refueling station at SunLine Transit in 1000 Palm, California and in small sizes through the prototyping program for the personal fuel appliance. The CST cell stack is key to achieving the cost targets in both product lines. The experience from the demonstrations will provide an experience base for the cell stack technology for later commercialization, and is a cost effective approach for equipment testing in that the user picks up operating costs.

In addition to testing the cell technology, Stuart's 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 hydrides. The high-pressure fueler (P3-1B HP) demonstrates the concept of a distributed "community fueler". 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.

While the design and manufacture of the P3 prototypes provides a proving ground for component technology, primarily the cell stack, the design emphasis in the next 12 months will be development of the P4 systems. The P4 prototypes will realize a projected 50% reduction in appliance footprint and will be the basis for achieving manufacturing cost targets.

### 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 of less than 3 cents/kWh, which will make hydrogen from fleet fuel appliances competitive with other transportation fuels. 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 2003. The ultimate cost target for the fleet fuel appliance is $3000 per scfm hydrogen production/refueling capacity. Relationships with bus operators and hydrogen bus companies will be developed during the prototype deployment period from 1999-2001. Commercialization will occur from 2001 to 2004 and will probably be led by fuel cell urban buses.

### Fleet Fuel Appliance Cost Targets

Through the building of prototypes, practical experience has been gained to give a more accurate system analysis of the fleet fuel appliances. The data gained from factory testing the units has aided in establishing reliable, unattended operation. Also from this experience, a more accurate account of the costs in mass manufacturing has been acquired. These revised cost models show

$400 per kW can be achieved for the entry bus fueler (10 buses) and $300 per kW for 30 bus fleets. The electricity consumption would be 60kWh per kg of hydrogen produced.

## P3 Fleet Fuel Appliance Progress

### *Prototype P3-1A*

Following testing reported in last years report an extensive redesign of the cells of the P3-1A prototype was undertaken, involving the eventual replacement of the cell blocks. P3-1A demonstrates Stuart's new MW-CST or multi stack electrolyser cell technology, which is targeting bus fleets and large retail outlets. The new cells were factory tested up to full current (12000 amps) or a hydrogen production rate of approximately 1500 scfh. Not only were hydrodynamic stabilities corrected but so were earlier reported problems with foaming in the cell. The foaming was identified to be due to contamination in the cell assembly. The unit was delivered to Sunline Transit in 1000 Palms, California on February 24, 2000. Within 24 hours of landing in SunLine the unit was producing and pumping gas, demonstrating the quick deployment feature of the Stuart fuel appliance concept.


**Figure 1 – The P3-1A Fleet Fuel Appliance at SunLine**

The unit has been 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 dispenser was designed by Stuart and built by Fueling Technologies Inc. High-pressure hydrogen is delivered through one hose and high pressure Hythane, a mixture of 20% by volume hydrogen in natural gas, from the other. Gas mixture is controlled dynamically by mass flow sensors and mixture is checked using a thermal conductivity sensor. The P3-1A will continue to fill buses and trucks at the SunLine site for a three year process evaluation. The hydrogen bus fleet consisting of one fuel cell bus and two Hythane buses are expected to enter revenue service in late summer 2000.


**Figure 2 -** ***The Hythane/Hydrogen Dispenser at the SunLine Public Filling Station***

### *Prototype P3-1B LP*

The low pressure fleet fuel appliance, P3-1B LP, delivers a rated hydrogen output of 400 scfh at 200psig. It uses Stuart's new H-CST single stack electrolyser technology on a standard design platform. In factory testing the P3-1B LP fueler has operated continuously for over 750 hours (32 days) at 120% of rated output (Figure 3). In total, the unit has operated for over 2800 hours. Subsequent disassembly and examination of the cell stack showed no significant deterioration of cell parts. The hydrogen purity is better than 99.99% with less than 20ppm of oxygen. The water vapour dew point of the delivered hydrogen is better than –70C expanded meeting the purity requirements for metal hydride gas storage ($M\text{-}Ni_{4.5}A_{l.5}$). In the coming year, the hydrogen from the prototype will be used to demonstrate refueling hydrogen vehicles in underground mining applications.

### *Prototype P3-1B HP*

Construction of the P3-1B HP fleet fuel appliance has been completed. Based on the same platform as P3-1B LP the unit uses H-CST technology. The commissioning of the unit was completed recently and testing has started. The hydrogen production rate is rated at 400scfh at a maximum pressure of 5000psig with plans to increase pressure to 6000 psig. Once factory tests have been completed, the unit will be deployed at a customer site.

### *Prototype P3-5 Cell Stack Assembly*

The construction of the P3-5 fuel appliance, capable of fueling 5 buses or approximately 10000 scfh has been taken to the design stage of the cell stack assembly only. The cell stack assembly will be constructed in 2- block cell platforms. The blocks are mounted back to back so that in an assembly the units from a U shaped bank, which can be assembled in an enclosure. The cell stack assembly design will be used in future bus fueler prototypes.


**Figure 3 – P3-1B-LP Factory Test**

**Figure 4 – P3-1B-HP Prototype**

## P4 Fleet Fuel Appliance Future Goals

The design of the P4 prototypes are underway; the build schedule is shown below. Among the improvements will be the use of a new process, which pressurizes the stack and eliminates the need for a water seal. A P4 stack similar to that being used in these appliances has been under test for about 500 h.

Other improvements to be built into the P4 series of prototypes will be: reducing the number of cell stacks in H-CST appliances from two to one by increasing the size of the stack and increasing current density, reducing dryer costs by using an interstage drier, and using a switching mode power supply rather than conventional rectifier to reduce size and improve power factor. Once constructed the unit will be factory tested and eventually deployed in the field at a prototyping partner site.

**Table 1. Schedule for Fleet Fuel Appliance Prototypes**

| PROTOTYPE | PROTOTYPING PARTNER | DELIVERY DATE |
|---|---|---|
| Fleet Fuel Appliance | | |
| P3-1A | SunLine Transit | Q1 2000 |
| P3-1B (High Pressure) | CA Fuel Cell Partnership* | Q4 2000 |
| P3-1B (Low Pressure) | Fuel Cell Propulsion Institute* | Q4 2000 |
| P4-1 | TBA | Q1 2001 |
| P4-10 | TBA | Q4 2001 |
| Personal Fuel Appliance | | |
| PFA-P1-99 | Ford Motor Company | Q4 2000 |

* proposal under consideration

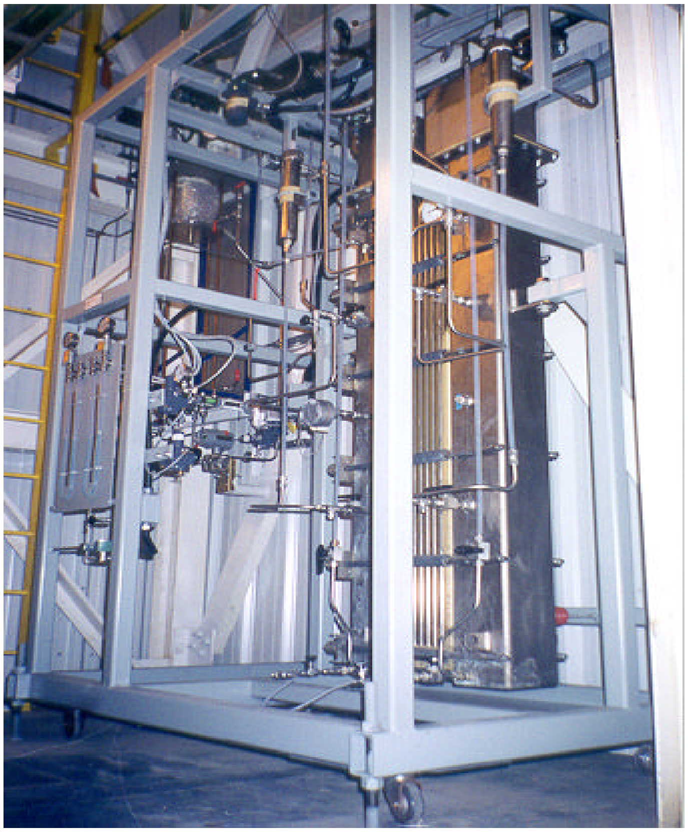


**Figure 5 – Phase 4 Prototype Cell Under Test**

## Personal Fuel Appliance

### 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. The product development program will be completed by 2003 at an expense of 15.2 million dollars. Commercialization will occur from 2003 to 2004.

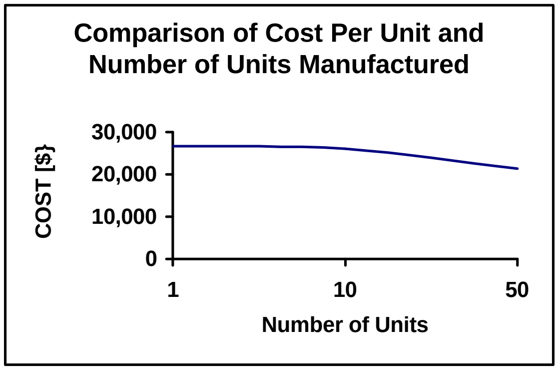
The Personal Fuel Appliance family of products can be marketed as part of a hydrogen vehicle purchase, as a choice of an alternative fuel supply, or as a portable hydrogen maker for more than just a car. This concept of a widely dispersed hydrogen fuel supply infrastructure presents new energy control alternatives and prepares the way for extensive integration of renewable sources into the power mix.

### Personal Fuel Appliance Cost Model Targets

Near-term cost projections for the prototypes are shown below. These are on track with cost projections presented in earlier studies to achieve a cost of $1500 at production volumes of

100,000 per year. The near term plan calls for assembly of a fleet of ten prototypes for limited release to automakers and strategic fleet operators.

**Table 2 – Near-Term PFA Costs**




## Personal Fuel Appliance Results and Future Goals

PFA P1 1999 Unit E delivers 3600psig hydrogen at a rate of 40 scfh. In December of 1999 it was demonstrated to the auto industry at Ford Motor Company at the Dearborn headquarters for the Think group and Daimler Chrysler at Auburn Hills, and at the beginning of this year at National Hydrogen Association Annual Meeting in Washington DC.

The second unit, PFA P1 1999 Unit D, is improved from Unit E in several ways. The system is much more reliable, and approximately 120 pounds lighter. This unit is currently on a tour of California, CARB, SCAQMD, and at SunLine Transit.

Ford Motor Company, Dearborn will be ready to accept a unit for testing in Q3 2000. The evaluation of this unit by a major automaker is the last deliverable of the PFA segment to this project.


**Figure 6 – P1 Model 25 Refueling NRG Hythane Vehicle at the NHA Meeting, Washington, DC**

**Figure 7 – Model of 2003 PFA**

## Conclusion

The objectives for next year are to deploy all three of the P3 type prototypes and begin field evaluation of the cell stack technology. In the next year we hope to complete the design, and build a P4 appliance incorporating improvements to the cell stack, higher current density and incorporate the new pressure controls, which will elevate pressure in the cell and eliminate water seals in the process. For the personal fuel appliance program, through joint evaluation with major North American automakers, we hope to prove the fuel appliance concept.

## 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

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