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"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, a purpose built on-site electrolytic hydrogen generator 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.

Entering Phase 2 of the 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

A major barrier to successful commercialization of direct hydrogen fuel cell vehicles is the lack of a cost- effective infrastructure. Stuart Energy believes the refueling needs of direct hydrogen vehicles can be met using a distributed network of on-site hydrogen production and refueling stations. In Phase I of the Project, Stuart Energy USA presented a business plan for commercialization of hydrogen appliances using Stuart's 3rd generation electrolysis technology.

The business plan for Stuart Fuel Appliance Co. indicated breakeven after five years with annual revenues climbing to $17 million over this same period. Financial forecasts are based on market projections for direct-hydrogen vehicles and rely on assumptions that direct hydrogen vehicles in the form of buses and cars will be the first fuel cell vehicles to be successfully demonstrated, and that competing with battery electric vehicles, direct hydrogen will become accepted in ZEV mandated areas. (SBC Bunting Warburg and Morgan Stanley Dean Whitter 1998)

Phase 2 of the project, focussing on product development of the fuel appliance, builds on Stuart's earlier experience developing packaged electrolytic hydrogen generators for vehicle refueling at Xerox Clean Air Now! (1995) and BC Transit (1997).

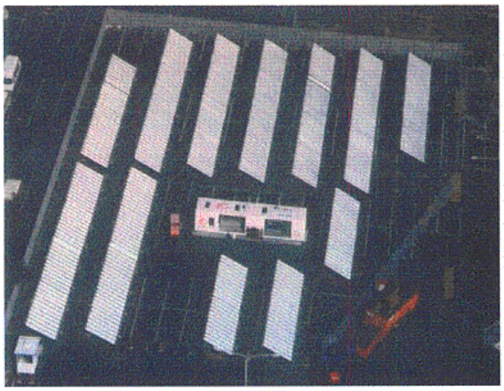


Figure 1 (a)
Xerox Clean Air Now (1995)
(400 scfh @ 4200 psig)

Figure 1(b)
BC Transit Port Coquitlam (1997)
(2500 scfh @ 3600 psig)

Why Hydrogen Fuel Appliances?

The underlying rationale for hydrogen fuel appliances refueling PEM fuel cell vehicles is derived from comparing the three commonly regarded fuel pathways: hydrogen, methanol and gasoline. The native fuel of the PEM fuel cell is hydrogen; for the hydrocarbon fuels a fuel processor must be carried on the vehicle to extract hydrogen. In Table 1 the two competing fuels, gasoline and methanol, are compared with hydrogen according to three key dimensions: underlying energy infrastructure, sustainability, and the investment required.

By using electricity the Stuart fuel appliance is uniquely positioned to not only provide fuel almost anywhere, (wherever there is an electricity infrastructure) but to grow in an environmentally sustainable way which can be progressively tied, through conversion of the electricity supply, to renewable and less carbon intense sources. Looking at the financial investment required the Hydrogen Fuel Appliance infrastructure should be less than gasoline or methanol based on the costs of developing the fuel processor on the vehicle or fuel appliance on the ground, and the changes required in upstream energy supply systems.

An earlier study performed for Ford Motor Company (Directed Technologies 1996) indicated that factory built fuel appliances could achieve cost targets of $6.00 per mscf ($2.50 per kg)-H_2

from gasoline to hydrogen and a small fleet of Neighbourhood Electric Vehicles converted to hydrogen.

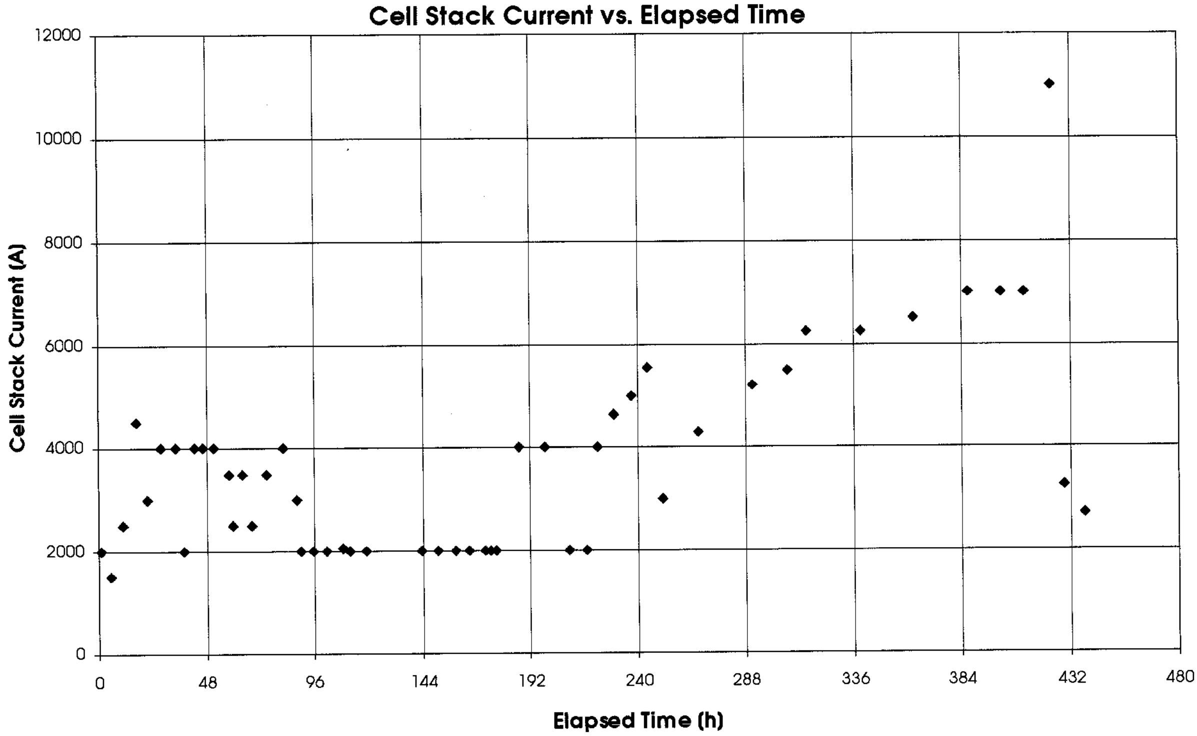


Figure 3 - P3-1A "First 40 Days of Operation"

A list of future prototypes to be built over the deployment period appears in Table 2.

Table 2. Fuel Appliance prototypes

Prototypes	Capacity (Nm^3)	Build Date
P3-1B	Up to 40 Nm^3	Q3 1999
P3-10	Up to 500 Nm^3	Q2 2000
P4-10	Up to 500 Nm^3	Q3 2000
P4-1	Up to 40 Nm^3	Q1 2001
Mark 0	Up to 40 Nm^3	Q1 2001

The next prototype(s) P3-1B will be smaller than P3 but can potentially fill a small bus or a half dozen light duty vehicles. The design of P3-1B is complete, Figure 4, and production of the first of two prototypes has been released with an expected delivery to testing before the end of Q3 1999.

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 be probably be led by fuel cell urban buses.

Fleet Fuel Appliance Cost Model Targets

Cost models for the appliance have been developed based on materials and direct labor. Based on a 30 bus Fleet Fuel Appliance the gas generator cost, including stack, rectifier and controls will be \$160 per kW (power in) (\$1560 per scfm) with the balance-of-plant (compressor, purifier, enclosure) being \$140 per kW (power in) (\$1340 per scfm). Assuming a capacity factor of 50%, the plant operates half the time, 10% maintenance charge on capital equipment and capital return factor of 16% the cost of hydrogen would be \$2.50 per kg of hydrogen at an electricity rate of 2.5 cents/kWh. The electricity rate is believed to be realistic for a utility recallable load in non-peak electricity demand periods.

Fleet Fuel Appliance Results & Future Goals

The first prototype, P3-1A, has been designed built, and is currently undergoing tests at Stuart Energy prior to deployment at SunLine Transit at their bus garage in 1000 Palms, CA. The P3-1A fueler, shown in Figure 3, uses Stuart's 3rd generation electrolyser in a multi-stack configuration. The unit is designed to operate at up to 1500 scfh (40 Nm^3/h) and delivers gas up to a pressure of 4000 psig with a dewpoint of -40 C. P3-1A demonstrates the essential features of the fuel appliance design being a completely contained plant including feed-water treatment, gas compression and purification; all that is needed to operate is water and electricity.

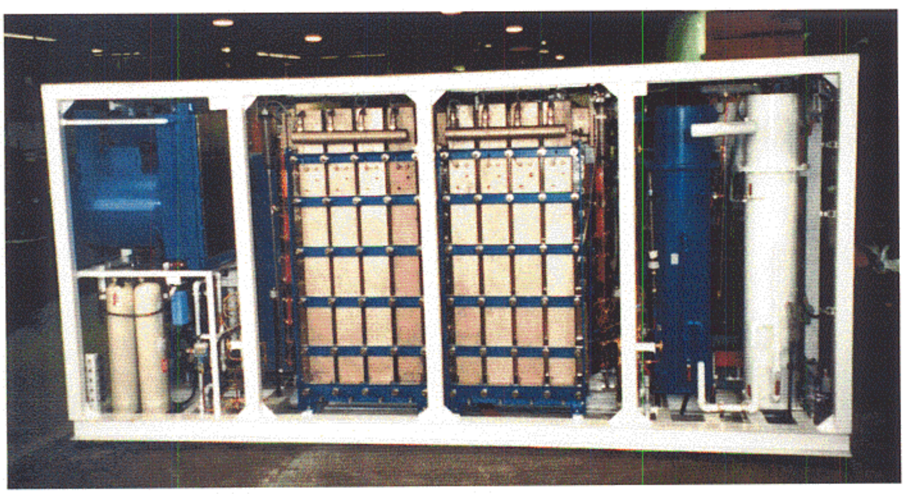
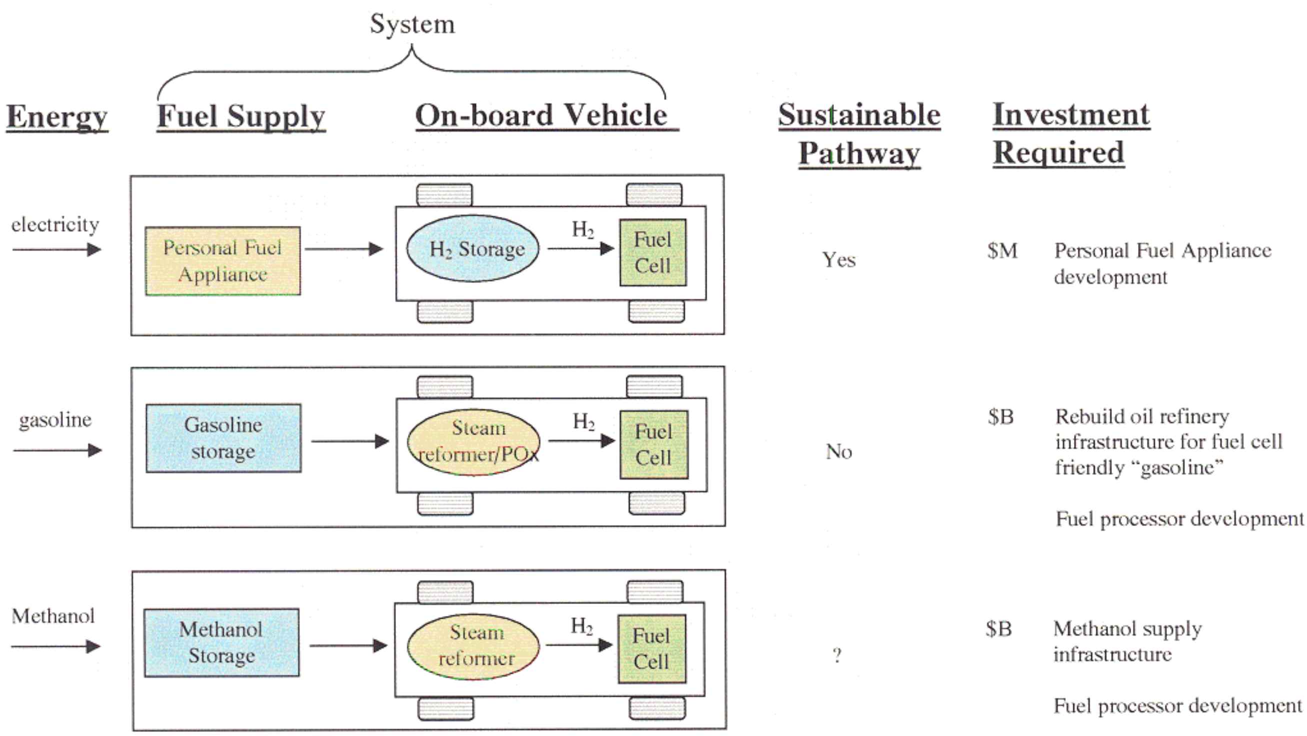


Figure 2 - Fuel Appliance Prototype P3- 1A (1500 scfh @ 4000 psig)

Results of testing are shown in Figure 3 for the first forty days of operation. The graph logs electrical current flowing through the cell against elapsed hours of operation. When deployed later this year at SunLine, P3-1A will be used to fuel two CNG buses which have been converted to Hythane, a fuel cell bus to be supplied by dbb fuel cell engines inc., a pickup truck converted and more importantly they could play an important role in establishing a direct hydrogen vehicle infrastructure. Cost is not the only issue that the product must overcome to win consumer acceptance. Beyond safety the key consumer issues are operating convenience (it should as easy to use as self-serve CNG refueling) and the size of the appliance (it should occupy a footprint no greater than 10% of the vehicle being fuelled).

Table 1.

Why hydrogen fuel appliances?



($M: order of million $ invested, $B: order of billion $ invested)

Fleet Fuel Appliances

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 refueling capacity.

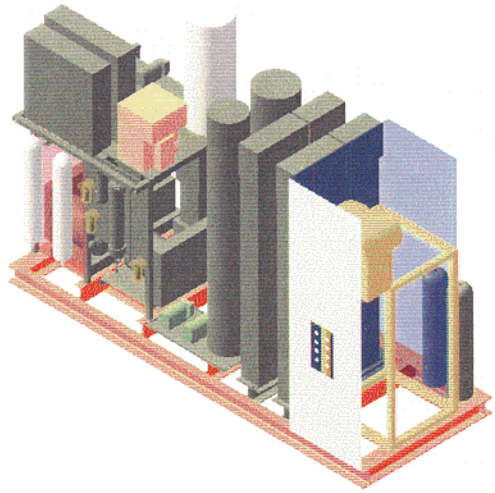


Figure 4 - Model of P3-1B Single Bus Fuel Appliance (400 scfh @ 4000 psig)

Personal Fuel Appliance

Stuart Personal Fuel Appliance Program

The objective of the Personal Fuel Appliance program (PFA) is to provide a convenient and competitive supply of hydrogen fuel to cars at the home or office. The appliance is intended to be easier to install and operate than an electric vehicle charging system. At a refueling rate of 50 scfh the Personal Fuel Appliance will support 1 to 3 cars. 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 market strategy is to have car manufacturers sell fuel appliances in conjunction with fuel cell cars (as now occurring with the natural gas VRA). A non-functioning model of the appliance appears in Figure 4.

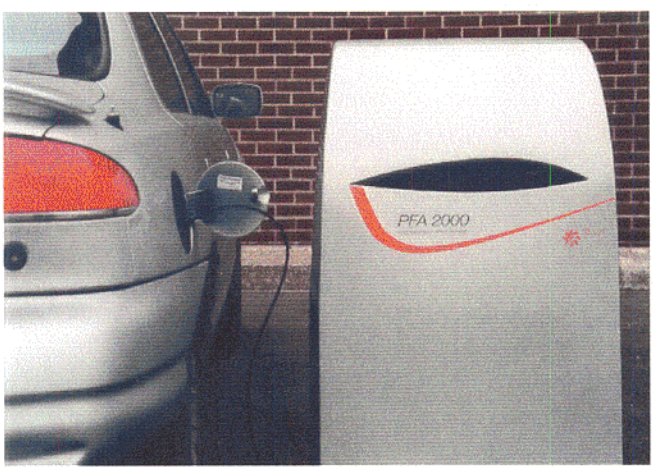


Figure 5 - Model of PFA 2000 Prototype

Personal Fuel Appliance Cost Model Targets

Earlier cost studies indicate the following cost progressions. The first 100 appliances will cost \$15,000. With an increase in volume to 10,000 per year the cost will decrease to \$5,000. Finally, at a production volume of 100,000 units per year the cost target is projected to be \$1,500.

Personal Fuel Appliance Results and Future Goals

The first working model, P1 Model 10, operational by September 1999, demonstrates the essential process, a low-pressure electrolyser (5 psig) coupled to a low cost gas compressor. The compressor is a modified natural gas vehicle-refueling appliance. P1 Model 10 has logged over 300 hours of operation.

Figure 6 - P1 Model 10 Working Model Personal Fuel Appliance (0.5 scfm @ 3000 psig)

The PFA process successfully demonstrated, Stuart Energy USA has entered into a Joint Evaluation Agreement with a major auto-maker for the next 2 years which will see the development of a succession of prototypes moving towards the PFA 2000.

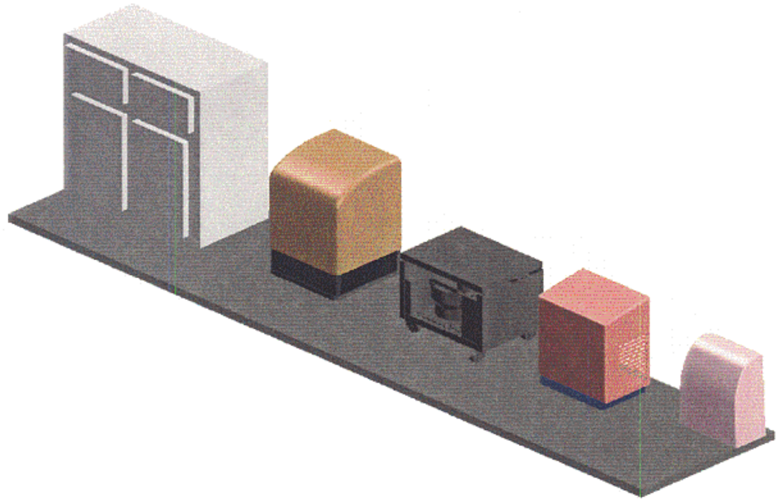


Figure 7 - Planned Progression of Prototypes Under Joint Evaluation Agreement

Conclusion

The goals set out in the prototyping deployment program are achievable, however there are important factors to be determined from the operating experience of the prototypes. System reliability and component lifetime will be key to achieving lifecycle cost targets. Operator acceptance will be crucial, as well as bringing electrical utilities to realize the potential of hydrogen for marketing electricity in non-peak demand periods.

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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