

VIII.C.3 Auto-Thermal Reforming Based Refueling Station at SunLine Services

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Subcontractors:

SunLine Services Group, Thousand Palms, CA

Start Date: January, 2003

End Date: April, 2006

Objectives

- Demonstrate a H₂ refueling station to serve vehicles using hydrogen/compressed natural gas (HCNG) blend fuels and H₂.
- Validate on-site auto-thermal reforming of natural gas.
- Evaluate the cost of hydrogen production vs. the target of \$3.00/gge in 2008.
- Evaluate vehicle fill rates under real-world conditions.
- Provide public education about hydrogen and fuel cells.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production and Technology Validation sections of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Hydrogen Production
 - A. Fuel Processor Capital Costs
 - C. Operation and Maintenance
 - F. Control and Safety
- Technology Validation
 - C. Hydrogen Refueling Infrastructure
 - D. Maintenance and Training Facilities

Contribution to Achievement of DOE Technology Validation Milestones

This project has made a contribution to achievement of the following DOE technology validation milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- *Milestone II: Validate cost of producing hydrogen in quantity of \$3.00/gge untaxed (2008).*
The dispensed cost of hydrogen has been demonstrated at \$3.68/gge (based on natural gas cost of \$4.50/MMBTU and electricity cost of 8.5¢/kWh)

Approach

- Design and test a prototype natural gas fueled hydrogen generator based on catalytic auto-thermal reforming (ATR) technology, advanced sulfur removal technology, and an advanced pressure swing adsorption (PSA) system. (HyRadix)
- Design, fabricate and install a 100 Nm³/h (215 kg/day) reformer at the SunLine facility. (HyRadix and SunLine Services)
- Commission and test the installed demonstration unit.
- Design, procure and install a multi-pressure storage system for cascaded hydrogen dispensing in two forms: hydrogen only and HCNG. (SunLine Services)
- Operate the refueling station for refueling of fuel cell cars and buses, HCNG buses and other hydrogen vehicles as they become available in the future. (SunLine Services)
- Provide public tours and educational opportunities at the refueling station. (SunLine Services)

Accomplishments

- Demonstrated the satisfactory operation of the HyRadix ATR reformer; completed a performance test in April 2004 based on acceptance criteria of 10 days of continuous operation at 90% of rated capacity.
- Validated the operability of a reformer based refueling station in real-world revenue generating service with a lower cost of hydrogen than the next best available source (delivered tube trailers).
- Demonstrated a dispensed hydrogen cost of \$3.68/kg (based on the DOE benchmark costs of \$4.50/MMBTU for natural gas).
- Completed more than one year of operation, with the reformer accumulating more than 5000 hours of operation while providing all of the hydrogen dispensed at the refueling station.
- Provided public tours and public education at the refueling station.

Future Directions

While this project is complete, HyRadix and SunLine Services each continue to pursue other activities related to hydrogen energy.

- HyRadix has commercialized the Aptus and Adéo™ hydrogen generators based on the hydrogen generator used in this project and is actively selling to industrial hydrogen consumers as well as for refueling applications. Development work is continuing to improve efficiency and to expand the product range to other capacities as well as other fuels.
- SunLine Services continues to operate the HyRadix reformer, generating hydrogen to meet all of its hydrogen refueling requirements. SunLine Transit plans to increase the number of hydrogen fueled vehicles that it uses and will continue to offer public education at its facility.

Introduction

The objective of this project was to develop and demonstrate a hydrogen refueling station that combines HyRadix's on-site hydrogen generation technology with compression, storage and dispensing facilities designed by SunLine Services Group. The refueling station is located at the SunLine facility in Thousand Palms, California, and provides low-cost hydrogen fuel for hydrogen internal combustion engine (ICE) buses and fuel cell vehicles. Hydrogen is also blended with compressed natural gas (CNG) to form HCNG, which is used in SunLine's fleet of converted CNG buses.

It should be noted that this project was initiated before the drafting of the *Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan* and was completed before its final publication.

Approach

The HyRadix Adéo™ hydrogen generator is based on auto-thermal reforming on a small scale, producing a reformat stream of 40-50% hydrogen. This gas stream is then purified to 99.95+% hydrogen through a purpose-designed small-scale pressure swing adsorption unit. HyRadix built and tested a prototype 50 Nm³/hr unit – half the output of the final demonstration unit – in order to incorporate learned improvements into the final design of the 100 Nm³/hr demonstration unit. Auto-thermal reforming combines partial oxidation and steam reforming; it makes efficient use of heat but does not require exotic metallurgy.

The compression, storage and dispensing system designed by SunLine compresses the hydrogen to 6250 psi, stores it at that pressure and then dispenses it to the vehicles at a maximum of 5000 psi. The compression system comprises two-stage diaphragm compressors, which maximize energy efficiency, reduce manufacturing costs and increase flexibility, while maintaining contamination-free hydrogen. The two-stage design permits startup under the high inlet pressure of the gas stream coming from the reformer. The storage component consists of high-pressure cylinders rated at a maximum pressure of 7250 psi. The dispenser system is a two-hose

dispenser capable of dispensing at 3600 psi on one side and at 5000 psi on the other side for HCNG and fuel cell vehicles, respectively. The entire dispensing system is rated for 7250 psig.

Results

The HyRadix Adéo™ hydrogen generator and the hydrogen product compressor were installed and commissioned during the fourth quarter of 2003. During initial testing, it was determined that the heat exchanger designs needed to be modified. These modifications were completed during the first quarter of 2004, and the unit was re-commissioned and a performance acceptance test completed in April, 2004.

Subsequent to the successful completion of the performance acceptance test, SunLine Services switched over all of its hydrogen use to that supplied by the reformer. The unit has since been operated for more than a year, during which time long-term data have been collected to verify system performance and hydrogen production costs.

Figure 1 shows representative dispensed hydrogen cost components for the integrated system. While the reformer was designed to deliver a nominal purity of 99.95%, it is routinely operated to produce purities of 99.999%. Routine analysis at off-site laboratories of the hydrogen produced over a range of purities has consistently shown the only impurities to be nitrogen and argon, while CO, CO₂, CH₄, sulfur and other contaminants remain below detection limits.

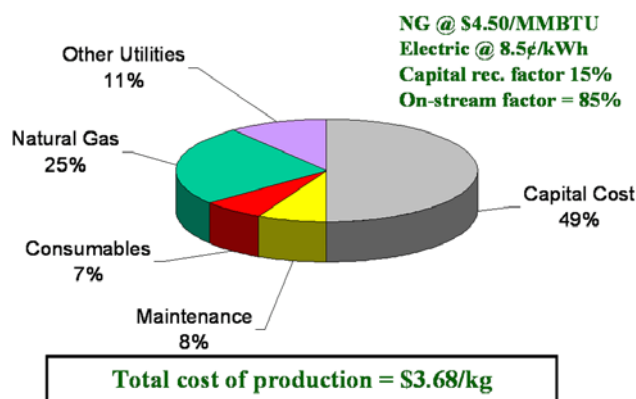


Figure 1. Dispersed Hydrogen Cost Components (2003 basis)

During the past year, SunLine has successfully operated the hydrogen refueling station to service its fleet of HCNG buses as well as a hydrogen ICE hybrid bus that has recently been added to the fleet. In addition, various third party vehicles, both fuel cell and hydrogen ICE, frequently refuel at the SunLine facility while driving through the Coachella Valley.

SunLine has shown that the installed dispensing equipment is capable 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.

Conclusions

This project advanced the Department of Energy's technical objectives in several significant ways:

- SunLine has gained significant experience with and understanding of rate-of-fill factors and the optimization of a cascaded storage and dispensing system for servicing different types of vehicles using hydrogen in different ways.

- The HyRadix Adéo™ hydrogen generator used for this project represents a big step forward in reducing the cost of hydrogen production, and feedback from this project is already providing further product cost reduction for HyRadix as it commercializes this technology.
- This project demonstrates one of the first hydrogen refueling stations in the U.S. using small-scale reforming technology for on-site hydrogen generation. It has been and continues to be a successful real-world validation of hydrogen refueling in a revenue generating application.