IV.A.2 Development of a Turnkey Hydrogen Fueling Station

David E. Guro
Air Products and Chemicals, Inc.
7201 Hamilton Boulevard
Allentown, PA 18195
Phone: (610) 481-4625; Fax: (610) 481-4260; E-mail: gurode@apci.com

DOE Technology Development Manager: Arlene Anderson
Phone: (202) 586-3818; Fax: (202) 586-9811; E-mail: Arlene.Anderson@ee.doe.gov

DOE Project Officer: Carolyn Elam
Phone: (303) 275-4953; Fax: (303) 275-4788; E-mail: Carolyn.Elam@go.doe.gov

Subcontractors:
H_2Gen Innovations, Inc. – Alexandria, VA
Pennsylvania State University – University Park, PA
QuestAir Technologies Inc. – Burnaby, BC, Canada (engineering services contract)

Contract Number: DE-FC36-02AL67613

Start Date: 01 January 2002
Projected End Date: 31 March 2006

Objectives

To demonstrate the potential for an economically-viable stand-alone, fully-integrated hydrogen (H_2) fueling station based upon the reforming of natural gas by working to:

- Develop a cost effective solution to the reforming of natural gas to produce a reformate stream
- Build on the experience gained at the Las Vegas H_2 Fueling Energy Station project
- Develop an efficient, cost-effective means to purify the hydrogen-rich reformate to pure hydrogen employing pressure swing adsorption (PSA)
- Develop an optimum system to compress, store, meter, and dispense hydrogen into vehicles
- Efficiently integrate the process steps mentioned above into a safe, user-friendly, cost effective fueling station
- Demonstrate the operation of the fueling station at Penn State University (PSU)
- Maintain safety as the top priority in the fueling station design and operation
- Obtain adequate operational data to provide the basis for future commercial fueling stations

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Hydrogen, Fuel Cells and Infrastructure Technologies Multi-Year Research, Development and Demonstartion Plan:

- A. Fuel Processor Capital Costs
- C. Operation and Maintenance (O&M)
- F. Control and Safety

Technical Targets

The following DOE target (identified in the "Hydrogen, Fuel Cells and Infrastructure Technologies Multi-Year Research, Development and Demonstration Plan," Table 3.1.2) that is addressed in this project:

- Cost H_2: $3/kg in 2005

Approach

This project is being managed in three phases, with Stage Gate reviews between each phase.

- Phase 1 - conceptual design and preliminary cost evaluations for each major sub-system in the fueling station.
- Phase 2 - sub-system R&D will be performed to test the concepts put forth in Phase 1. Technical viability and fueling station costs will be validated.
- Phase 3 - fabrication, installation, and testing of the full-scale H_2 generator and dispenser at PSU. This H_2 fueling station will be designed to deliver 50 nm^3/hr H_2.

During the past year, the Program Team progressed within and completed Phase 2 (Subsystem R&D) and began Phase 3 (System Deployment). Phase 2 was managed as a comprehensive development project, wherein work was organized by process sub-system (reformer, PSA, compression, storage, and dispensing). A combination of simulation, laboratory R&D, real-world component testing, collaboration with vendors, and engineering design work was integrated to enable significant progress towards the DOE Targets and Barriers. Due to DOE funding constraints Phase 3 was broken into 2 pieces:

- First, much of the H_2 refueling station equipment was installed and commissioned, including: the liquid H_2 tank, H_2 compression system, hydrogen storage system, hydrogen dispenser, CNG/H_2 blend skid, and the CNG/H_2 blend dispenser.
- Second, the hydrogen generator, including the reformer, syngas compressor, and H_2 PSA purifier, will be installed in October 2005.

Accomplishments

- Completed Phase 2 development work, as outlined below.
- Initiated Phase 3 system deployment work, as outlined below.
- Met DOE overall system efficiency target for 2005 - calculation.
- Met DOE 2005 target of $3.00/kg H_2 dispensed - calculation.

Future Directions

<u>Phase 3 – System Deployment</u>

Scale-up and detailed engineering design of all equipment will be completed. Fabrication of all equipment and installation at Penn State will follow. Finally, the fueling station will be started up and put into operation at Penn State University. This will include 6 months of operation and testing.

The expected schedule for these Phases is outlined in the table below:

Task	Date
Phase 3 System Deployment – Station without steam methane reformer (SMR)/PSA (Completed)	October 2003 – October 2004
Phase 3 System Deployment – SMR + PSA	October 2004 – Sept 2005
Phase 3 System Deployment – Operation & Testing	• Oct 2005 Start-Up of Reformer • Nov 2005 – January 2006 Operation and Testing

Introduction

The transition to hydrogen as a fuel source presents several challenges - one of the major hurdles is the cost-effective production of hydrogen in small quantities. In the early demonstration phase, hydrogen can be provided by bulk distribution of liquid or compressed gas from central production plants; however, the next phase to fostering the hydrogen economy will likely require on-site hydrogen generation to enable widespread infrastructure. Providing inexpensive hydrogen at a fleet operator's garage or local fueling station is a key enabling technology for direct hydrogen fuel cell vehicles (FCVs). The objective of this project is to develop a comprehensive, turnkey, stand-alone hydrogen fueling station for FCVs with state-of-the-art technology that can be cost-competitive with current hydrocarbon fuels. Such a station will help to promote the advent of the hydrogen fuel economy for buses, fleet vehicles, and ultimately personal vehicles.

Approach

The development efforts are expected to build on preliminary work accomplished by the major partners. Air Products and Chemicals, Inc. (APCI), as the overall project manager, is responsible for the total system integration and final development of the installed equipment. As the system integrator, APCI will ensure that the system is fully optimized and that all of the individual components are compatible to deliver the lowest cost H_2 fuel. This project is being managed in three phases, with Stage Gate reviews between each phase.

During Phase 1 of the project, subsystem conceptual designs were formulated and costed. Options were developed and compared for the reformer system, PSA system, compression, storage, and dispenser. APCI has worked with H2Gen and other reformer suppliers to develop and to evaluate the applicability of autothermal reforming, preferential oxidation, and steam-methane reforming systems. At the end of Phase 1, APCI confirmed the team's ability to reach the cost targets via a confirmed definition of scope and execution costs and has identified the partners for further development of components in Phase 2.

In Phase 2, the most promising subsystem designs assessed and selected in Phase 1 were further developed. Lab and field testing of certain components was carried out. Recommendations for the optimal fueling station components were made. APCI engineers, working with the selected reforming partner, have optimized the design of the reformer for use in the hydrogen generator system. APCI completed the design of the hydrogen and CNG/H_2 blend dispensers, which were tested, installed, and commissioned on the PSU fueling station site. Finally, APCI served as the system integrator to pull together the various pieces into a comprehensive turnkey unit and to minimize the total cost of delivered H_2.

During Phase 3, scale-up and detailed engineering design of all equipment will be completed. The engineered system will be analyzed for DFMA® (Design for Manufacture and Assembly) and the assembled system will include instrumentation for data collection and provisions for remote monitoring of operation. Fabrication of all equipment and installation at Penn State will follow. Then, the fueling station will be started up and put into operation at PSU. This will include 6 months of operation and testing. Finally, we will validate the cost of H_2 delivered from the installed fueling station, including a study pertaining to the impact of mass-producing components.

Results

Due to DOE funding constraints, the funding available to this project was reduced. Thus, the team agreed to a creative alternative plan that achieved several objectives:

- Development of the H_2 PSA in FY 2004, and includes the deployment of the H_2 product compressor, H_2 product storage module, and H_2 and H_2/CNG dispensers in FY 2004.
- Continued progress on the reforming and integrated H_2 Generator (reformer + syngas compressor + H_2 PSA), albeit at a slower pace to keep within the budget constraints of FY 2004.
- Opening of a H_2 Fueling Station at PSU in October 2004, in support of PSU's planned vehicle availability.

Per contract amendments we agreed to do the following:

- Slow the reformer work commensurate with the DOE budget constraint. APCI will continue to work with its vendors and will complete the development aspects of the project on the H_2 Generator. This will enable mechanical fabrication, delivery, and start-up of the H_2 Generator in October 2005.
- Complete the testing of the beta PSA prototype at our H_2 production facility, as per the original schedule in FY 2005.
- Install the H_2 compressor, H_2 storage module, and both dispensers (H_2 and H_2/CNG) as per the original amended project plan.
- Install a liquid H_2 tank and vaporizers for H_2 supply to compressor/storage/dispensers.
- Complete the 6-month operational testing and reporting program within FY 2006.

Important to the success of this project is the availability of vehicles at the PSU site to validate the performance of the installed fueling station. It was recognized by PSU, APCI, and its partners, that fuel cell H_2 buses would not be available by January 2004, the targeted commissioning date for the station. Thus, a team was established to synthesize a plan forward for the station and for making vehicles available. The team meets regularly and consists of representatives from APCI, PSU H_2 Institute, DOE (Mid-Atlantic Regional Office), State of Pennsylvania Department of Environmental Protection, Centre Area Transit Authority (CATA), PSU Pennsylvania Transportation Institute (PTI), and PSU OPP. The PSU H_2 Institute has taken the lead in developing a follow-on project to: (1) convert several CATA CNG buses to run on a H_2/CNG blend, (2) convert several PSU OPP utility vans to H_2/CNG blend, (3) purchase for PSU Office of Physical Plant (OPP) one H_2 internal combustion engine utility van, (4) upgrade the CATA and PSU facilities for operation with a H_2/CNG blend, including required training, and (5) operate and maintain the fueling station for a period of three years. PSU PTI has secured funding from two Pennsylvania state agencies for the first year of its program.

Progress towards Phase 2 goals is outlined below:

Reformer

- Process engineering development work optimized the reformer system, including desulfurization, shift, steam generation, heat exchange, and valving.
- Lessons learned from the operation and maintenance of the Las Vegas H_2 Refueling Station DOE-sponsored program were fed directly into the design and development work on this program.
- Process flow diagram issued; process and instrumentation diagram developed.
- Engineering development work completed.

H_2 PSA Purifier

- APCI's adsorbent development complete. Novel structured adsorbents and advanced beaded adsorbents show significant improvement in bed size and H_2 recovery. PSA cycle development work concluded – it was used to fully utilize the advanced adsorbents' capabilities. Laboratory experiments completed.
- Rotary valve testing completed at APCI's and its supplier's labs.
- APCI fabricated its "beta" H_2 PSA test unit. The unit was then sent to a commercial Air Products hydrogen production facility and run. Data has been collected and tests completed on the operation of the unit.

H_2 Compression, Storage, and Dispensing

- APCI has completed engineering work to determine the optimum configuration and selection of components for the H_2 dispenser.
- Laboratory equipment to test H_2 flow meters for use in the dispenser has been commissioned. Testing is completed and proves that a single coriolis meter is most suited to the demands of "fast-fill" hydrogen refueling applications.

Currently, Phase 3 work is ongoing. Accomplishments are outlined below:

- Completed design, fabrication, and installation of the liquid H_2 tank, H_2 compression system, hydrogen storage system, hydrogen dispenser, CNG/H_2 blend skid, and the CNG/H_2 blend dispenser.
- Completed commissioning of all installed equipment.

Conclusions

Work progresses on Phase 3 of this aggressive project to determine the viability of a commercial turnkey H_2 fueling station. Over the past year, the team completed its Phase 2 goals, initiated Phase 3, and achieved several significant milestones:

- A cost-effective route to production and delivery of H_2 from a commercial fueling station was identified.
- The cost of H_2 from stations improves with mass production and with scaling to larger station sizes.
- The H_2 PSA system efficiency has been demonstrated through operation and testing to be >82%.
- The $3.00/kg H_2 DOE 2005 target is achievable.
- Stand-alone H_2 station is technically and economically feasible.

FY 2005 Publications/Presentations

1. Annual Program Merit Review presentation was made by David Guro of Air Products at the DOE meeting held in Washington, D.C., in May 2005.
2. Program Review meeting was held in February 2005. Attendees included DOE HQ program management team and APCI team.

Special Awards

1. David Guro of Air Products received an R&D Award from Steve Chalk of DOE at the Annual Review meeting in Philadelphia, PA, in May 2004. The award was for achieving the DOE 2005 Target for H_2 Purification/Separation efficiency of 82%.