Development of a Turnkey Commercial Hydrogen Fueling Station

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Pennsylvania State University - University Park, PA
QuestAir Technologies Inc. - Burnaby, BC, Canada

Objectives

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

- Develop a cost-effective solution to the reforming of natural gas to produce a reformate stream;
- Develop an efficient, cost-effective means to purify the hydrogen-rich reformate to pure hydrogen employing pressure swing adsorption (PSA);
- Develop a commercially acceptable 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;
- Maintain safety as the top priority in the fueling station design and operation; and
- 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 Program Multi-Year R,D&D Plan:

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

Approach

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

- In Phase 1, conceptual designs and preliminary cost evaluations for each major sub-system in the fueling station will be completed. Options will be developed and compared for the reformer system, PSA system, compression, storage, and dispenser.
- In 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 will include fabrication, installation, and testing of the full-scale hydrogen generator and dispenser at Penn State. This fueling station will be designed to deliver 50 nm^3/hr of hydrogen.

Accomplishments

- Completed Phase 1 study. Held Stage-Gate meeting between U.S. DOE and Air Products management. Decision made to proceed with the project.
- Initiated Phase 2 development work, as outlined below.

Future Directions

- Complete Phase 2 - Subsystem Development. In this phase, the most promising subsystem designs assessed in Phase 1 will be further developed. Lab testing of certain components will be carried out. Recommendations for the optimal fueling station components will be made. Phase 2 is currently underway.
- Execute Phase 3 - System Deployment. 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 all three Phases is outlined in the table below:

Task	Date
Phase 1 Pre-Contract Technical Development	Oct 2001 - March 2002
Cooperative Agreement Award	29 March 2002
Phase 1 Conceptual Design and Economic Evaluation	April 2002 - June 2002
Phase 2 Subsystem Development	July 2002 - July 2003
Phase 3 System Deployment	August 2003 - June 2004
Phase 3 System Deployment - Operation & Testing	July 2004 - December 2004

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 onsite hydrogen generation to institute a pervasive 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 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, as the overall project manager, is responsible for the total system integration and final development of the installed equipment. As the system integrator, Air Products will ensure that the system is fully optimized and that all of the individual components are compatible to deliver the lowest cost hydrogen fuel. This nine-quarter 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. Air Products has worked with H2Gen and other reformer suppliers to develop and to evaluate the applicability of auto-thermal reforming (ATR), partial oxidation (POX), and steam methane reformer (SMR)-based reforming systems. At the end of Phase 1, Air Products confirmed the team's ability to reach the cost targets via a confirmed definition of scope and execution costs and identified the partners for further development of components in Phase 2.

In Phase 2, currently underway, the most promising subsystem designs assessed and selected in Phase 1 will be further developed. Lab testing of certain components will be carried out. Recommendations for the optimal fueling station components will be made. Air Products engineers, working with the selected reforming partner, will optimize the design of the reformer and build and test components of this reactor in a laboratory. Air Products will be directly responsible for the design of the dispenser, which will be tested in a shop prior to installation on site. Because of the partners' relationships with the automotive manufacturers, we will solicit their assistance for inclusion of commercial features such as vehicle communication. Finally, Air Products will act as the system integrator to pull together the various pieces into a comprehensive turnkey unit and to minimize the total cost of delivered hydrogen.

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 Penn State University. This will include 6 months of operation and testing. Finally, we will validate the cost of hydrogen delivered from the installed fueling station, and we will estimate the impact of mass-producing components.

Results

General:

Phase 1 work completed. Presentation made to DOE headquarters representatives on August 7, 2002. Major conclusions of Phase 1 report:

- Project schedule validated – on target.
- Project budget validated – on target.
  - Completed general process specifications for all major equipment.
  - Obtained quotes and updated cost estimates.
  - Re-validated development costs with principal investigators for each area of the fueling station.
- Cost-effective route to production and delivery of hydrogen from a commercial fueling station identified.
  - Cost of hydrogen from stations improves with mass production and with scaling to larger station sizes.
  - $1.50/gallon gasoline equivalent is a stretch goal, but attainable.
  - Stand-alone hydrogen station is technically and economically feasible.

Phase 2 kicked-off. Of critical importance to the success of this project is the availability of vehicles (or other hydrogen demand) at the Penn State site to validate the performance of the installed fueling station. Penn State (PSU) and Air Products recognized that fuel cell hydrogen buses will not be available by January 2003, the targeted commissioning date for the hydrogen fueling station. A team was established to develop a plan for the station and for making vehicles available. The team met in January, February, and March 2003 and consisted of representatives from Air Products, PSU Hydrogen Institute, DOE (Philadelphia Regional Office), State of Pennsylvania Department of Environmental Protection (DEP), Center Area Transport Authority (CATA), PSU Pennsylvania Transportation Institute, and PSU Office of Physical

Plant (OPP). The team's recommended plan is for the PSU Hydrogen Institute to take the lead in a project to:

1. convert several CATA compressed natural gas (CNG) buses to run on a H_2/CNG blend,

2. convert several PSU OPP utility vans from CNG to H_2/CNG blend,

3. purchase for PSU OPP one hydrogen internal combustion engine utility van,

4. upgrade the CATA and PSU facilities for operation with a H_2/CNG blend,

5. provide required training, and

6. run and maintain the fueling station for a period of 3 years.

This proposal has met with the approval of PSU and Air Products, and it is being reviewed by Pennsylvania DEP for a funding decision. In order to match station and vehicle availability, the Phase 2 end-date was extended from March 2003 to July 2003, and system startup will be rescheduled from January 2004 to July 2004.

Currently, Phase 2 work is ongoing. Progress towards Phase 2 goals is outlined below:

<u>Reformer:</u>

- Air Products completed a Phase 1 engineering study to update the comparison of ATR, POX, and SMR technologies to determine the optimum route to small-scale H_2 production. The major conclusions were:
  - Advanced Technology SMR's are more cost competitive than the other evaluated technologies for small-scale reforming applications used in hydrogen fueling stations.
  - Of the reformers evaluated, H2Gen's heat exchange reformer and Harvest's regenerative reformer offer the lowest cost of hydrogen. Of the two, H2Gen's system has the greatest potential to provide the low-cost option, but H2Gen's system is also the higher risk option, both technically and economically.
- H2Gen development work continued into the Fall of 2002. Then, a meeting was held between DOE headquarters and Air Products project personnel to determine the best technical path forward on Phase 2 with respect to the reformer development. Conclusions: While H2Gen continued to make progress, they were behind scheduled milestones. A decision was reached to switch to another reformer vendor as the reformer supplier for the remainder of this project.
- Process engineering development work continues on optimization of reformer system, including desulfurization, shift, steam generation, heat exchange, and valving.
- A preliminary process flow diagram (PFD) has been developed.

<u>Hydrogen PSA Purifier:</u>

- Air Products' adsorbent development continued. Novel structured adsorbents and advanced beaded adsorbents show significant improvement in bed size and hydrogen recovery. PSA cycle development work concluded – it was used to fully utilize the advanced adsorbents' capabilities. Laboratory experiments have been completed.
- The lab to test the new PSA rotary valve was completed, and testing has commenced. Thus far, the valve has over 800,000 cycles and is leak-tight. An outside supplier for the valve has been identified and has made the first valve for testing.
- Air Products concluded the successful testing of its "alpha" prototype hydrogen PSA unit at an Air Products hydrogen production facility. The data collected on this PSA unit served to verify several of the significant technical "step-outs" being taken in the new PSA design being developed by the Air Products team. The system ran continuously since July 2002, successfully producing hydrogen at <2 ppm CO with high hydrogen recovery. The system met all engineering targets for hydrogen production, hydrogen recovery, and purity.
- Air Products fabricated a "beta" hydrogen PSA test unit. The unit has been placed next to the "alpha" test unit mentioned above. The "beta"

PSA unit is now in operation, and data is being collected.

- QuestAir completed their Phase 1 work to improve their HyQuestor hydrogen purifier. Preliminary design and cost summaries are done and are included in QuestAir's Phase 1 report to Air Products. QuestAir initiated Phase 2 work.
- QuestAir continued their Phase 2 development work. They have optimized the design of their system and have built their laboratory test rig. QuestAir tested their PSA system and is preparing their Phase 2 summary report.

Hydrogen Compression, Storage, and Dispensing:

- Air Products has completed the preliminary engineering work to determine the optimum configuration and selection of components for the hydrogen dispenser.
- Laboratory equipment to test hydrogen flow meters for use in the dispenser has been purchased, and the lab unit is being fabricated. The test plan is prepared –initiation of testing is anticipated in late Summer 2003.

Conclusions

Work progresses on Phase 2 of this aggressive project to determine the viability of a commercial turnkey hydrogen fueling station. Over the past year, the team completed Phase 1 and derived the following conclusions from its Phase 1 study:

- A cost-effective route to production and delivery of hydrogen from a commercial fueling station was identified.
- The cost of hydrogen from stations improves with mass production and with scaling to larger station sizes.
- The $1.50/gallon gasoline equivalent cost is a stretch goal, but attainable.
- Stand-alone hydrogen stations are technically and economically feasible.

FY 2003 Publications/Presentations

1. Quarterly and Annual Reports to U.S. DOE, as required per the Cooperative Agreement, were submitted by Air Products.
2. Annual Program Merit Review presentation was made by David Guro of Air Products at the DOE meeting held in Berkeley, CA, in May 2003.