

II.A.3 Low-Cost Hydrogen Production Platform

Tim Aaron

Praxair, Inc.

175 East Park Drive

PO Box 44

Tonawanda, NY 14151

Phone: (716) 879-2615; Fax: (716) 879-7567; E-mail: tim_aaron@praxair.com

DOE Technology Development Manager: Arlene Anderson

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

Subcontractors:

Boothroyd-Dewhurst Inc., Wakefield, RI

Diversified Manufacturing Inc., Lockport, NY

Objectives

- Low-cost on-site production of hydrogen
 - Existing technologies [steam methane reformer (SMR)-based]
 - 2.4 - 12 kg/h (1,000 - 5,000 scfh)
 - Small, compact, single-skid system
 - 10-15 year system life
- Benchmark for current technology
- Design and fabrication of a prototype system

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 Research, Development and Demonstration Plan:

- A. Fuel Processor Capital Costs
- B. Operation and Maintenance (O&M)
- C. Feedstock and Water Issues
- E. Control and Safety
- Z. Catalysts
- AB. Hydrogen Separation and Purification

Approach

- Conduct review of existing technologies
- Develop preliminary design and engineering models
- Assess economics versus current and potential future supply options
- Develop and test component prototypes
- Develop final design and verify economics
- Build, install and test complete prototype system

Accomplishments

- Completed detail design of high-temperature component
 - Drawings
 - Process models
 - Mechanical stress models
- Completed system detail design
 - Process & instrumentation diagram
 - Controls for transient conditions (startup and shutdown, turndown)
- Optimized system
 - Reduced mass of system
 - Reduced parts & assembly complexity
 - Increased thermal efficiency
 - Increased primary energy efficiency
 - Reduced product cost
- Developed component test plan

Future Directions

- Build component prototype test apparatus
 - High-temperature component
 - Catalysts
 - Auxiliary components
- Test system components
 - Performance
 - Component life
 - Operability and control
 - Fabrication of components
 - Cost of components
- Develop computer models
 - Process flows
 - Burner design
 - Catalyst
 - Preliminary detail design and engineering models
- Complete final detail design
- Participate in the development of domestic and international design and safety standards related to small hydrogen systems
- Develop, install and test prototype system
- Continue to update business and economic models

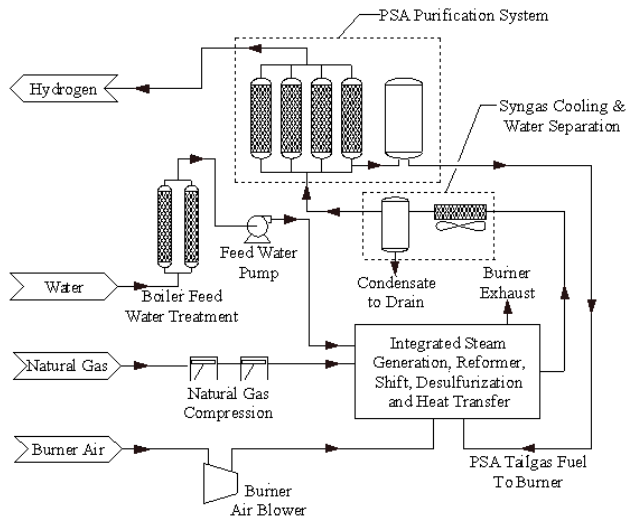


Figure 1. Low-Cost Hydrogen Production Platform Process Flow Diagram

Introduction

Current industrial steam methane reformer (SMR)-based hydrogen production facilities are highly capital intensive because they are custom-designed and are built using one-at-a-time design and fabrication techniques. Capital costs account for 70-85% of the total per unit hydrogen costs for on-site systems in the 48 kg/h (20,000 scfh) and below capacity range. As a result, the opportunity exists for very substantial reductions in product hydrogen costs by introducing advanced design optimization technology. The focus of this project is to develop an integrated system for the turnkey production of hydrogen at 2.4 - 12 kg/h (1,000 - 5,000 scfh). The design is based on existing SMR technology and existing chemical processes/technologies to meet the design objectives. The baseline design therefore consists of a steam methane reformer, pressure swing adsorption (PSA) system for hydrogen purification, natural gas compression, steam generation and all components and heat exchangers required for the production of hydrogen. A process flow diagram of the system is shown in Figure 1. The scope of this project does not include hydrogen compression, storage or fueling station components.

The focus of the project emphasizes packaging, system integration and an overall step change in the cost of capital required for the production of hydrogen at low volumes. To assist in this effort,

subcontractors were brought in to evaluate the design concepts and to assist in meeting the overall goals of the project. Praxair supplied the overall system and process design for the concepts, and the subcontractors were used to evaluate the designs from a manufacturing and overall design optimization viewpoint. Design for manufacturing and assembly (DFMA) techniques and computer models were utilized to optimize the concepts during all phases of the design development.

Approach

The means for achieving low hydrogen costs from small systems is through capital cost reductions, integrating components and reducing the number of parts required for an SMR-based hydrogen production system. For conventional small SMR-based plant designs (<50 kg/h), more than 75% of the cost of hydrogen is associated with capital costs. The project approach is to apply DFMA techniques to the component and system designs from the early concept phase of design to the completion of the design effort. The reduction in number of parts and the resulting integration and simplification of the plant layout significantly reduces the capital cost and the overall plant size. Praxair has defined a concept that involves the integration of steam generation, reforming, shift reaction and all high-temperature components into a single, highly integrated package. The PSA purification system as well as the overall skid layout and integration have also been designed using the DFMA approach. This effort shows the potential to significantly reduce the capital cost required for a small hydrogen system and thereby greatly reduce the overall cost to produce hydrogen.

A risk analysis was conducted to identify any design deficiencies related to the highly integrated system concept. The analysis showed that no fundamental design flaws exist with the design, but additional simulations and prototypes will be required to verify the design prior to fabricating a production unit. The identified risks are being addressed in the current Phase (Phase II) of the development project.

Along with the models of the high-temperature components, a detailed process and 3D design

model of the remainder of the system, including PSA, compression, controls, water treatment and instrumentation, was developed and evaluated. The overall design and specifications were then used to develop detailed hydrogen costs for the optimized system.

A market and business analysis was also developed. Currently available and potential future hydrogen production technologies were compared with the design concept developed in this project. The potential market was evaluated with respect to number of units, feedstocks and capacity.

Results

The capital and product costs were estimated for 2.4, 4.8 and 12 kg/h (1,000, 2,000 and 5,000 scfh) plants at production rates of 1, 10, 100 and 1,000 units built per year. With the low-cost SMR approach, the product hydrogen costs for 2.4 and 4.8 kg/h plants at 10 units produced per year were approximately \$3.90 and \$2.95 per kilogram of hydrogen, respectively. With increased volume production to 1,000 units per year, the hydrogen costs are reduced by about 25% to \$2.90 for the 2.4 kg/h unit and \$2.26 per kilogram of hydrogen for the 4.8 kg/h unit. For the 12 kg/hr plant, the cost of hydrogen ranged from \$2.34 (@10 units) to \$1.85 (@ 1000 units) per kilogram of hydrogen depending on number of units built per year. These costs represent a significant improvement and a new benchmark in the cost to produce small-volume, on-site hydrogen using existing process technologies. The cost models also show that the utility costs (natural gas @ \$4/MMBtu (HHV), electricity and water) total \$0.81 per kilogram of hydrogen.

The capital and product costs are based on a skid package designed to be a complete, operationally verified system prior to being shipped to the site for installation. Computer models of the completed system skid assembly are shown in Figure 2.

The skid has been designed to easily fit within a standard parking space. All mechanical devices such as valves, pumps, compressors, motors, and controls are located on the periphery of the skid, with doors providing easy access to these items. The skid is also designed to be ventilated during operation by using

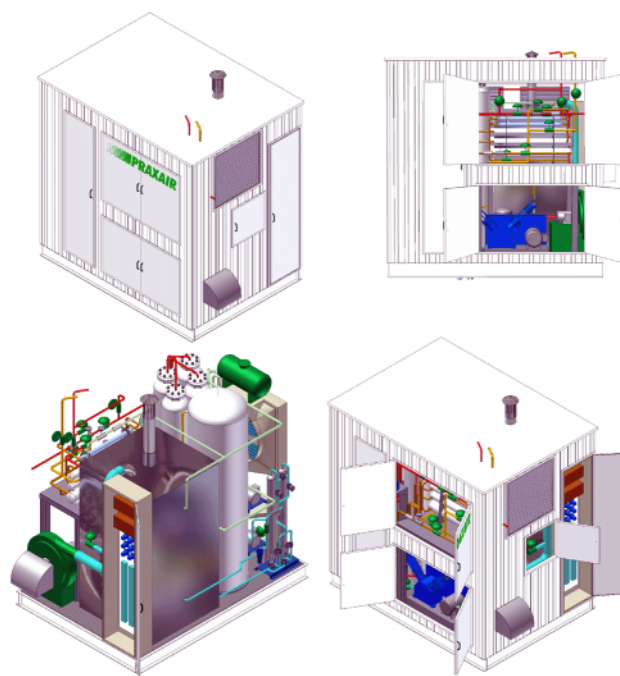


Figure 2. Low-Cost Hydrogen Production Platform Skid Design (All components and controls necessary for the production of 4.8 kg/h (2,000 scfh) hydrogen using natural gas, city water and electricity as utilities.)

the cooling system fan to provide the required air changes. The electrical enclosure is designed to be isolated from the machinery portion of the skid. Atmospheric analysis for combustible and/or hazardous gases has not been designed into the system. It has been calculated that with sufficient air changes, there is no potential of creating a hazardous or explosive environment within, or in the immediate vicinity of, the skid. The predicted cost to produce hydrogen from this system, as well as a comparison with last year's estimated cost, is shown in Figure 3.

The transportation sector is likely to continue to be a primary source for the demand of small-scale hydrogen systems in the future. Our baseline projections for the number of 4.8 kg/h (2,000 scfh) hydrogen plants that Praxair will have opportunity to build are 30 plants/year in 2010 and 130 plants/year in 2020. The cost of fuel cells also remains a significant barrier for the viability of fuel cell vehicles. Therefore, this project is structured to develop an optimized SMR-based system and thoroughly test all aspects of the design prior to entering into a production run. Phase I work has

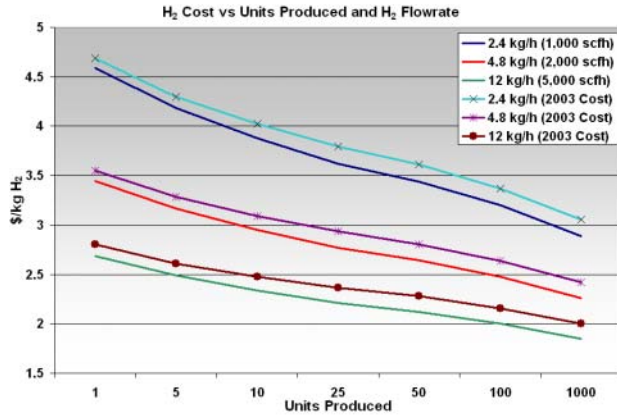


Figure 3. Unit Hydrogen Cost Versus Units Produced and System Capacity

demonstrated that significant improvements in cost, plant layout, system integration and overall system optimization are achievable. Therefore, the Phase II development portion of the project is focusing on system and component computer modeling and prototype testing.

Conclusions

- Applying DFMA principles to the overall design significantly lowered the cost to produce hydrogen at capacities of 2.4 to 12 kg/h (1,000 to 5,000 scfh).
- A complete hydrogen generating system producing 4.8 kg/h (2,000 scfh) can be packaged in a single skid that is small enough to easily fit into a typical parking space.
- A new benchmark appears possible for the cost of hydrogen produced from current process technologies (i.e., SMR, & PSA purification).
- Preliminary results from the Phase I study will need to be verified in Phase II of the project to ensure that the system is safe, robust and meets the overall goals.

FY 2004 Publications/Presentations

1. A paper and presentation titled ‘DFMA Approach to Reducing the Cost of Hydrogen Produced from Natural Gas’ was given to the Society of Automotive Engineers (SAE) in October 2003.
2. A presentation titled ‘Using DFMA to Reduce the Cost of Hydrogen from Small Steam Methane Reformer Based Systems’ was given to the 2003 Hydrogen Production & Storage Forum in Washington, DC in December 2003.
3. A presentation regarding the overall project status was given at the DOE Annual Merit Review Meeting in May 2004.