IV.A.10 Low Cost Hydrogen Production Platform (LCHPP)

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

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

Subcontractors:
Boothroyd-Dewhurst Inc., Wakefield, RI
Diversified Manufacturing Inc. Lockport, NY

Start Date: April 1, 2001
End Date: February 28, 2007

Objectives

- Low cost on-site production of hydrogen.
  - Existing technologies (steam methane reformer 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. Fuel Processor Manufacturing
- C. Operation and Maintenance (O&M)
- D. Feedstock Issues
- F. Control and Safety

Technical Targets

- Energy efficiency: 69% (LHV) – Production only
- Cost of hydrogen: $2.00/kg – Production only
- Life of unit: 15 years
- Single skid, easily installed unit

Approach

- Review existing technologies
- Develop preliminary design and engineering models
- Assess economics of 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 (Phase II: 06/04 – 05/05)

<u>Updated system design as required</u>

- Design for manufacturing and assembly (DFMA) review of system conducted
  - Number of parts and overall complexity reduced

<u>Tested system and components</u>

- Developed of test plans
- Constructed test apparatuses
  - Lab-scale reformer tester
  - Full-scale component tester
  - Full-scale cold flow models
- Tested components
  - Catalysts tested for
    - Containment
    - Configuration
    - Packing density
  - Materials tested
    - Several high-temperature alloys tested
    - Preferred materials chosen
  - Full-scale component tester coming on-line third quarter 2005

<u>Updated computer models</u>

- Computational fluid dynamics (CFD) models
- Process models
- Heat transfer models

Future Directions

- Complete construction of component prototype test apparatus
- Test additional components
  - High temperature component
  - Catalysts
  - Materials
  - Auxiliary components
- Test paramenters

  - Performance
  - Component life
  - Operability and control
  - Fabrication of components
  - Cost of components
- Develop computer models
  - Process flows
  - Burner design
  - Catalyst
  - Complete 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

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 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 and 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 flow rates. 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. 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 70% of the cost of hydrogen is associated with capital costs. The project approach is to apply DFMA design techniques to the component and system design 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 by using CFD modeling and component testing.

Along with the models of the high temperature components, a detailed process and 3-D design model of the remainder of 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. The design concept developed in this project was compared to an existing study of the currently available and potential future hydrogen production technologies. An analysis of the potential market, with respect to number of units, feedstocks and capacity was also evaluated.

Results

The part and assembly detail drawings of all the individual components were updated and re-quoted in the early stages of Phase II as documented in last year's report. No significant design modifications to the overall system have been made during this reporting period. The baseline design is a 2,000 SCFH (4.8 kg/hr) single skid hydrogen system as depicted in Figures 1 through 3. The overall system is designed to fit in a parking space at a typical fueling station and has been designed for all domestic U.S. climate conditions. The baseline system does not include compression and dispensing; however, Praxair is involved in several other small hydrogen

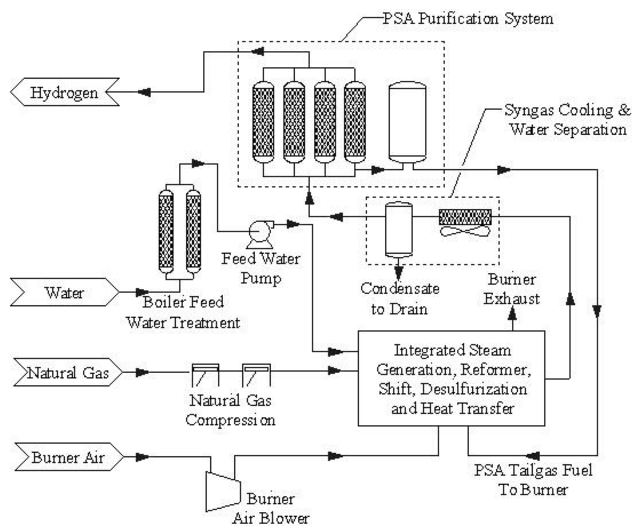

Figure 1. Low Cost Hydrogen Production Platform Process Flow Diagram

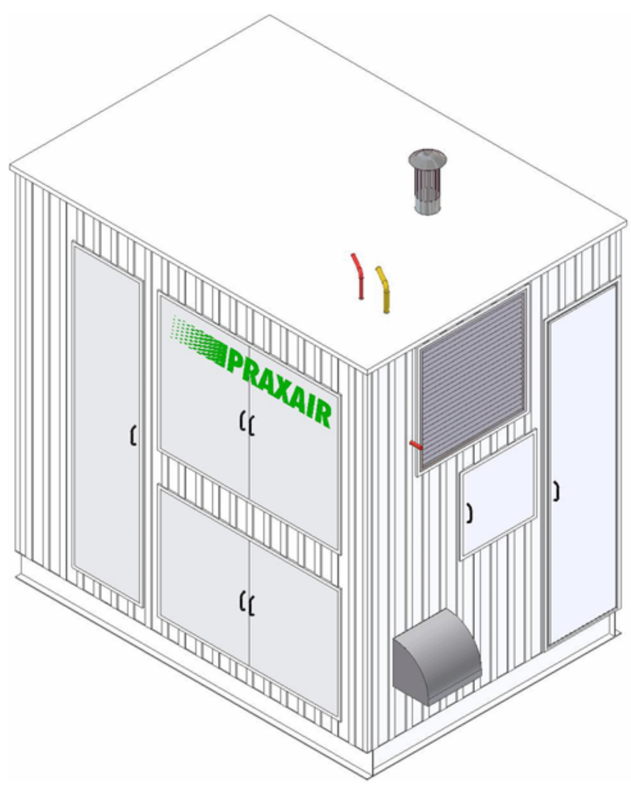

Figure 2. Low Cost Hydrogen Production Platform Skid Design (Doors Closed)

projects that do include compression and dispensing. These projects are being monitored within this project, and, whenever feasible, the experiences and requirements from these projects are incorporated

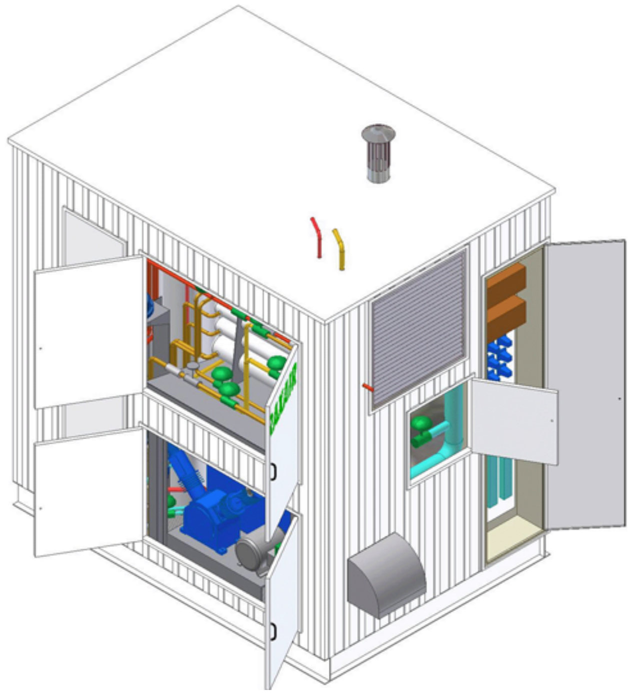

Figure 3. Low Cost Hydrogen Production Platform Skid Design (Doors Open)

Figure 4. Integrated High Temperature Component

into the LCHPP design. A patent application regarding the integrated steam generation, reformer, shift, desulfurization and heat transfer component has been submitted during this reporting period.

The integrated high temperature component shown in Figure 4 contains nearly all of the high temperature operations that are typically accomplished in separate components in a traditional SMR plant. By integrating all of the high temperature operations into a single component, the mass of the system is greatly reduced, the efficiency is increased and overall cost of the unit is significantly reduced. Applying the DFMA methodology to the compact integrated design has resulted in an additional cost reduction. The high level of integration does, however, present a problem for maintenance access to the individual operations. To address this concern, the critical goal of the Phase II testing is to demonstrate the reliability of these internal components to assure that the Phase III and future production systems will meet the overall reliability and maintenance goals.

Computer modeling efforts during this reporting period included the development of process flow and CFD models of the system design and the component testing apparatuses. Detailed models of the heat transfer, process stream compositions and the overall flow characteristics have been developed to support the design of the test rigs.

The main focus during this reporting period was the component testing phase of the project. Two separate test apparatuses, as well as other smaller component tests, are underway for the project as described below.

The first test rig is designed to verify the feasibility of the reformer catalyst containment and to evaluate the key parameters related to catalyst containment. This test rig is a scaled reformer tester that allows for precise control and testing of the feed gases and the overall configuration of the reformer component. The test apparatus includes a furnace, steam system, analysis equipment and related control components. The gases used in this test include steam, natural gas, hydrogen and CO_2. The product of the test apparatus is syngas. A design and component/hardware safety review of the system was completed prior to the start of testing. Testing with this apparatus has been underway for the last three months with life testing likely to continue for at least the next four months. Results to date have been very positive with the Phase I reformer component design meeting the overall project expectations. The life testing is intended to verify that both the integrity of the catalyst as well as the design of catalyst containment meet the overall system goals.

The second test apparatus is a full scale component tester for the individual high temperature components. The test rig will facilitate testing of the reformer, shift reactor, high temperature heat exchangers, natural gas desulfurization, burner and steam generation. This system is currently being fabricated with the completion date estimated to be the middle of August with testing to commence prior to the end of August. A delay in the schedule for this test rig was implemented at the request of the DOE. The original schedule was to commence testing with this system in the first quarter of 2005. The test apparatus includes a burner tester, steam system, analysis equipment and related control components. The gases used in this test include steam, natural gas, hydrogen, nitrogen and CO_2. The product of the test apparatus is syngas. The test rig will use the burners from the full size design to heat the reformer and related components in a very similar way to the production design. A complete Hazard and Operability Analysis (HAZOP) of this test rig was completed in February and periodic safety reviews of the test rig will be completed throughout the construction and commissioning.

In addition to the tests described above, several other tests and testing projects are either planned or underway as described in the following.

A burner test was completed at the burner supplier in mid-December 2004. The burner test involved a low-cost commercial burner system that is generally fueled by natural gas or propane, but in our case is using a mixture of CO, CH_4, H_2 and CO_2 to simulate the typical burner fuel (tailgas from the PSA) used in an SMR based system. The burner system, using this fuel, functioned very well with even flame distribution and no issues with the simulated PSA tailgas fuel. A full size burner has been purchased and will be installed in the test rig described above.

Tests have been completed related to the materials of construction of the high temperature component. These tests include forming the various alloys in the form of the components and testing them by thermal cycling from ambient to operating temperature. The alloys that met all the requirements of these tests will then be tested for compatibility using simulated process gas at the operating temperature in the component tester as described above.

Tests are also planned to evaluate the auxiliary components that are not part of the high temperature component. These tests include water treatment, natural gas compression, air blower and other auxiliary components. The PSA purification system is being developed as part of another Praxair development project.

The system economic model has been updated continually throughout the reporting period. Modifications to the economics during this period include an increase in raw material costs for the components. Overall, the costs of stainless steel and other alloys have risen in some cases over 20-30% in the past year. The cost models have also been updated to reflect the cost parameters per the updated DOE technical plan for hydrogen production. The baseline for the cost models is now a 20 year analysis period, 10% internal rate of return after taxes, 1.9% inflation, 90% utilization factor, $0.07/kWhr cost of power and $4.50/MMBTU cost of natural gas. Since the system being developed in this project is designed to produce significantly less hydrogen than the DOE baseline system, a second line (red in the graph) has been added to estimate where the LCHPP system would rate at the higher production levels (see Figure 5).

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

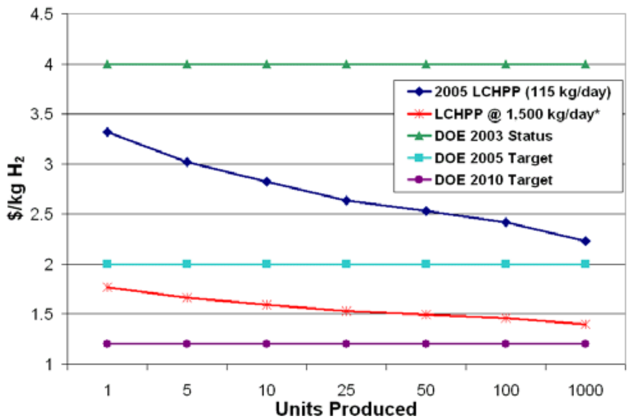

Figure 5. Unit Hydrogen Cost versus Units Produced and System Capacity

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 will need to be verified to ensure that the system is safe, robust and meets the overall project goals.

FY 2005 Publications/Presentations

1. A presentation regarding the overall project status was given at the DOE Annual Merit Review Meeting (May 2005).