II.A.8 Low Cost Hydrogen Production Platform

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Subcontractors:
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Diversified Manufacturing Inc., Lockport, NY

Start Date: April 1, 2001
Projected End Date: September 30, 2008

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
  - 15–20 year system life
- Benchmark for current technology
- Design and fabrication of a prototype system

Technical Barriers

The Hydrogen, Fuel Cells and Infrastructure Technologies Multiyear Program Plan Production technical barriers (section 3.1.4.2.1) addressed in Phase II of this project include:

(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% (lower heating value) – production only
- Cost of hydrogen: $2.00/kg – production only
- Life of unit: 15–20 years
- Single skid, easily installed unit

Accomplishments (Phase II – 06/05–05/06)

- Updated system design as required
- Testing of system and components
  - Development of test plans
  - Construction of test apparatuses
    - Lab-scale reformer tester
    - Full-scale component tester
    - Full-scale cold flow models
  - Testing of components
    - No significant issues found to date
    - Full-scale component tester on-line first quarter 2006
    - Testing of full-scale burners and reformer system components
    - Complete analytical equipment installed
    - Characterization testing completed
    - Component testing started May 2006
    - Testing expected to be underway throughout 2006
- Computer models updated
  - Computational fluid dynamics (CFD) models
    - Reformer/burner interaction modeling underway
  - Process models
  - Heat transfer 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, pressure swing adsorber (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. 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 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.

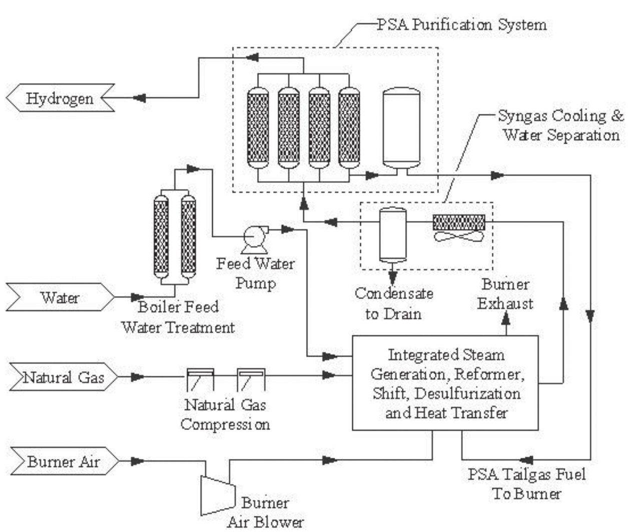

FIGURE 1. Low Cost Hydrogen Production Platform Process Flow Diagram

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, natural gas 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. A study of the current available and potential future hydrogen production technologies were compared with the design concept developed in this project. 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 previous reports. 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/h) single skid hydrogen system as depicted in Figure 2. 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 projects that do include the compression and dispensing scope of supply. These projects are being monitored, and whenever feasible, the experiences and requirements from them are incorporated into the Low Cost Hydrogen Production Platform (LCHPP) design.

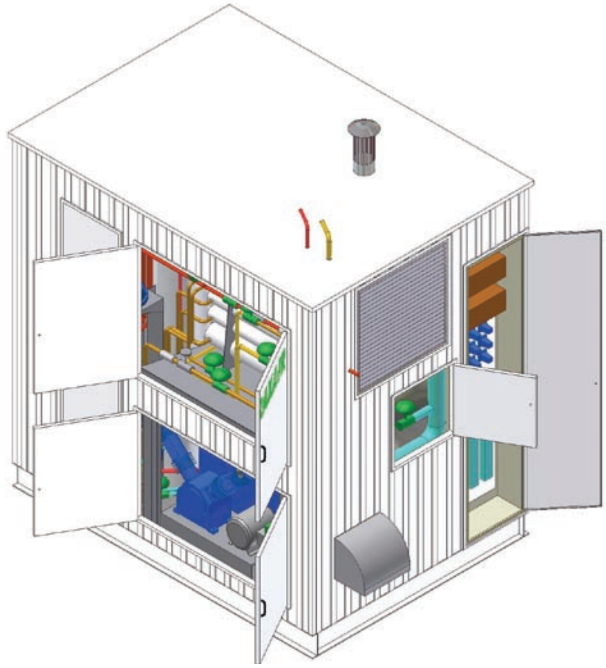

FIGURE 2. Low Cost Hydrogen Production Platform

A patent application regarding the integrated steam generation, reformer, shift, desulfurization and heat transfer component has been submitted.

The integrated high temperature component 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 and updated 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 were constructed and operated. Smaller component tests were also completed for the project as described in the following.

FIGURE 3. Photo of Lab Scale Test Apparatus

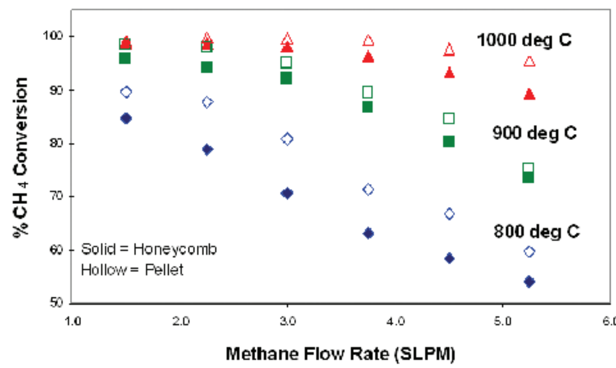

FIGURE 4. Sample of Catalyst Testing Results

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. Initial testing with this apparatus was completed during the reporting period with life testing likely to continue for at least the next four months. Results to date have verified the Phase I reformer component design meets 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. Figures 3 and 4 show addional detail regarding this test appartus and results.

The second test apparatus is a full-scale component tester for the individual high temperature components. The test rig facilitates testing of the reformer, shift reactor, high temperature heat exchangers, natural gas desulfurization, burner and steam generation (Figure 5). This system has been fabricated, installed and initial testing is underway. A delay in the schedule for this test rig was implemented at the request of the DOE. The test apparatus includes a burner tester that facilitates combined and individual high temperature component testing. The skid has a steam system to provide the steam required for the reformer and shift testing. Also, the skid has four electric process heaters for heating various fluids to the desired test conditions. The control and analytical capabilities associated with the system include gas chromatograph gas analysis, over 25 analog inputs, over 85 thermocouple inputs and a fully automated control system with remote capabilities. 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 uses 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 of this test rig was completed and periodic safety reviews of the test rig will be completed throughout the project (Figure 6).

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

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. The cost models have been updated to reflect the cost parameters per the updated DOE technical plan for hydrogen production. The baseline for the cost model is now a 20-year analysis period, 10% internal rate of return after taxes, 1.9% inflation, 75% utilization factor, \$0.08/kWhr cost of electrical power and \$5.00/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. The current estimated cost of hydrogen from the LCHPP system is shown in Figure 7.

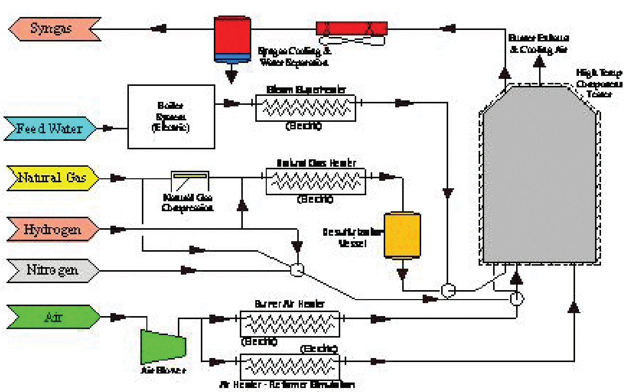

FIGURE 5. Process Flow Diagram for the Full Scale Component Test Apparatus

FIGURE 6. Small Hydrogen System Component Test Apparatus Installed at Praxair

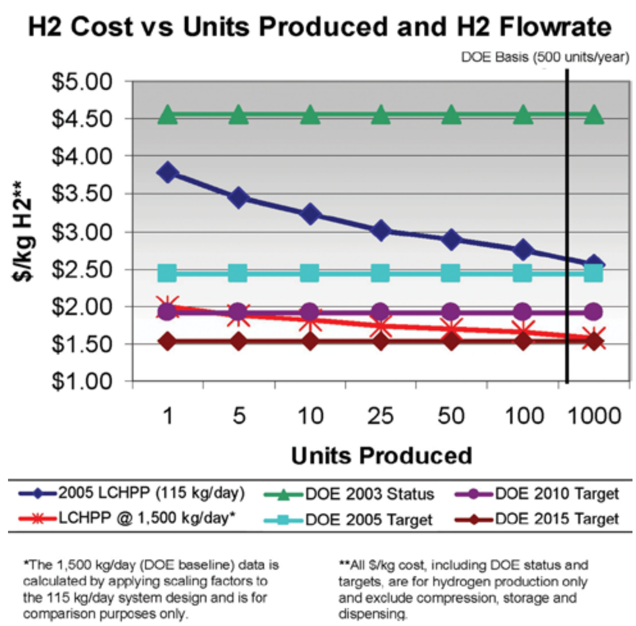

FIGURE 7. Unit Hydrogen Cost Versus Units Produced and System Capacity

Conclusions

1. 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).
2. 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.
3. A new benchmark appears possible for the cost of hydrogen produced from current process technologies (i.e. SMR, and PSA purification).
4. Preliminary results will need to be verified to ensure that the system is safe, robust and meets the overall project goals.

FY 2006 Publications/Presentations

1. A presentation regarding the overall project status was given at the DOE Annual Merit Review Meeting (May 2006).

2. A paper and presentation was given at the 2006 International Forum on DFMA sponsored by Boothroyd-Dewhurst the week of June 19th 2006. The paper is titled "DFMA Approach to Reducing the Cost of Hydrogen Produced from Natural Gas."