# Low Cost Hydrogen Production Platform

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*Diversified Manufacturing Inc, Lockport, NY*

## Objectives

- Examine opportunities for on-site production of hydrogen at low cost using existing technologies (steam methane reforming, pressure swing adsorption), with the following parameters:
  - 1,000 - 5,000 scfh
  - Small, compact, single skid system
  - 10-15 year system life
- Establish a benchmark for current technology
- Design and fabricate a prototype on-site hydrogen production 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 R,D&D Plan:

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

## 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

- Preliminary detail and process design completed
- 3D computer models of components and system completed

- Design for Manufacture and Assembly (DFMA) preliminary analysis completed
- System economic model completed
- Significant hydrogen cost reductions determined to be achievable

### Future Directions

- Complete preliminary detail design and engineering models
- Complete DFMA analysis on total system
- Design, construct and test system components
- Verify component performance and overall system life
- Complete final detail design
- Develop, install and test prototype system
- Continue to update business and economic models

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## Introduction

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 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 1,000 - 5,000 scfh (28-140 $Nm^3$/hr). The design is based on existing SMR technology and existing chemical processes or technologies to meet the design objectives. Consequently, the system baseline design consists of a steam methane reformer, a 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.

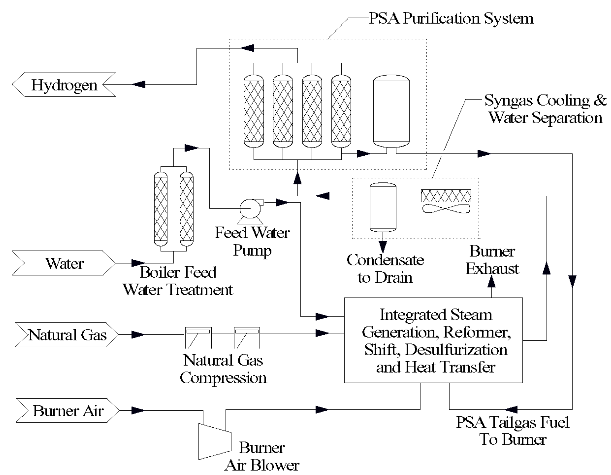


**Figure 1.** Low-Cost Hydrogen Production Platform Process Flow Diagram

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 plant designs, more than 75% of the cost of hydrogen is associated with capital costs. The project approach is to apply DFMA design 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 concepts that involve 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 potential concepts. The analysis showed that no fundamental design flaw exists with the concepts, but additional simulations and prototypes would be required to verify the design(s) prior to fabricating a production unit. These identified risks will be addressed in detail during 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 system, including PSA, compression, controls, water treatment and instrumentation was developed and evaluated. The overall design and specifications were then used to develop accurate hydrogen costs for the optimized system. Potential areas for further cost reductions were also identified and will be investigated in future phases of the program.

A market and business analysis was also conducted as part of Phase I. A study of the current available and potential future hydrogen production technologies was compared with the design concepts developed in this project. An analysis of the potential market, with respect to number of units, feedstocks and capacity was also conducted.

## Results

The capital and product costs were estimated for 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 1,000 and 2,000 scfh plants at 100 units produced per year were approximately $24/MMBtu and $19/MMBtu (HHV), respectively. With increased volume production to 1,000 units per year, the hydrogen costs are reduced by about 12% to $21/MMBtu for the 1,000 scfh unit and $17/MMBtu (HHV) for the 2,000 scfh unit. For the 5,000 scfh plant, the cost of hydrogen ranged from $14 to $17/MMBtu (HHV) 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 $7.50/MMBtu (HHV).

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 the Figures 2 and 3.

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 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 is shown in Figure 4.

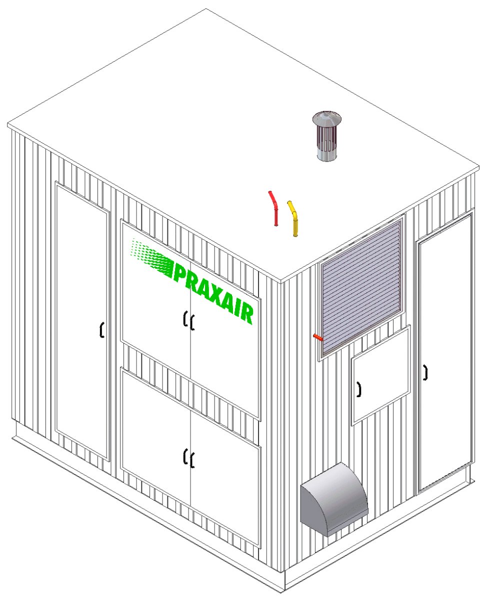


**Figure 2.** Low-Cost Hydrogen Production Platform Skid Design. (All components and controls necessary for the production of hydrogen using natural gas, city water and electricity as utilities.)

**Figure 3.** Low-Cost Hydrogen Production Platform - Skid Cover Off

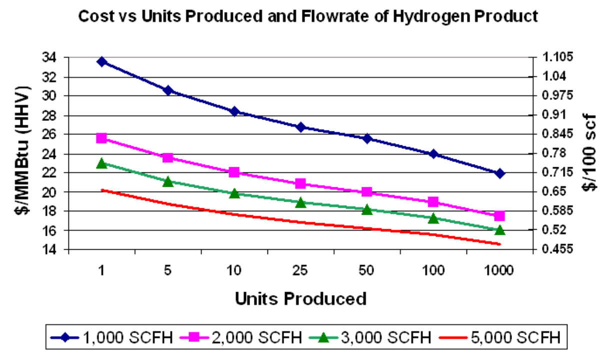


**Figure 4.** Unit Hydrogen Cost Versus Units Produced and System Capacity

A comparison of fuel costs between internal combustion engine vehicles (ICEVs) and fuel cell vehicles (FCVs) shows that if there is no tax on hydrogen, then the hydrogen must be produced at about $19/MMBtu (HHV) (before compression) to be competitive with fully-taxed gasoline at $1.60/gal. If hydrogen is to be competitive with untaxed gasoline ($1.20/gal), then the cost of uncompressed hydrogen should be $12/MMBtu (HHV). Thus, with a cost of $19/MMBtu (HHV) for 2,000 scfh uncompressed hydrogen with production of hydrogen plants at 100 units/year, FCV hydrogen costs will be nearly equal to ICEV hydrogen costs in early years if there is no tax on hydrogen. With the mass production of hydrogen plants as the FCV market grows throughout the U.S., hydrogen cost will need to decrease to $13/MMBtu (HHV) to make it possible to support a fuel tax. Cost models indicate that $13 to $16/MMBtu hydrogen is not achievable with 1,000 scfh plants, but with production plants of 2,000 scfh and higher, these targets are achievable. The design concepts developed in Phase I of this project show significant progress in decreasing the cost to produce hydrogen in production plants of <5,000 scfh. As the demand for hydrogen increases, the capacity required at each site will grow and units in the production range of 5,000 scfh will be more cost effective. Significant effort will be required to validate the design concepts in the subsequent phases of the project and to develop a working prototype of the system. The total remaining duration of the project is estimated to be three to four years.

The transportation sector is likely to continue to be a primary source for the demand of small-scale hydrogen production systems in the future. Our baseline projections for the number of 2,000-5,000 scfh hydrogen plants that Praxair will have opportunity to build are 30 plants/yr in 2010 and 130 plants/yr in 2020. With the recent modifications to California's zero emission vehicle mandate, the market for FCVs will be slow to develop. The cost of fuel cells also remains a significant barrier for the viability of FCVs. 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 demonstrated that significant improvements in cost, plant layout, system integration and overall system optimization are achievable. Therefore, further development efforts will focus on system and component computer modeling and prototype testing. Phase II of the project will focus on demonstrating both the design component testing and economic viability of the concepts developed in Phase I.

## Conclusions

1. Applying DFMA principles to the overall design significantly lowered the cost to produce hydrogen at volumes of 1,000 to 5,000 scfh.
2. A complete hydrogen generating system producing up to 5,000 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 with PSA purification).
4. Preliminary results from the Phase I study will need to be verified in subsequent phases of the project to ensure that the system is safe, robust and meets the overall project goals.

## FY 2003 Publications/Presentations

1. Presentation at the DOE Annual Merit Review Meeting (May 2003)
2. Phase I Final Report (submitted to DOE - June 2003)