II.A.2 Low-Cost Hydrogen Distributed Production System Development

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Subcontractor:
Süd Chemie, Inc., Louisville, KY

Start Date: July 1, 2005
Projected End Date: September 30, 2008

Objectives

- Design, build and test a steam methane reformer system that will achieve the DOE cost and efficiency targets for 2015.
- Demonstrate the efficacy of a low-cost renewable hydrogen generation system based on distributed production of hydrogen from ethanol.

Technical Barriers

Technical barriers from the Hydrogen Production section (3.1.4.2.1) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Reformer Capital Costs
(B) Reformer Manufacturing
(C) Operation and Maintenance (O&M)
(D) Feedstock Issues
(E) Greenhouse Gas Emissions
(F) Control and Safety

Technical Targets

Distributed Production of Hydrogen from Natural Gas

	2010	2015	H_2Gen Status
Production Unit Energy Efficiency, %(LHV)	72.0	75.0	67.4[a]
Production Unit Capital Cost (Uninstalled)	900K	580K	742K[b]
Total Hydrogen Cost $/gge	2.50	2.00	2.33[c]

[a] Based on the current HGM-2000
[b] 1,500 kg/day system at 500/year production rate
[c] Using 7-year MACRS depreciation

Accomplishments

- Collected over 42,000 hours of field test data (multiple units) on the 113 kg/day commercial H_2Gen SMR systems to verify system efficiency and reliability, exceeding the original goal of over 2,500 hours field test experience.
- Based on this extensive test experience at 113 kg/day scale, H_2Gen redesigned the reactor and flow sheet for a 565 kg/hr platform, including:
  - Low pressure drop burner
  - Compact, low stress steam generator
  - Linear combustion air supply system
- Designed the SMR plus PSA skid to industry standards including B31-3, VIII-1, API 618, NFPA 70A, 497, 496 and CSA 5.99.
- Built and tested the major sub-systems including the burner and steam generator systems, and redesigned the boiler system to improve performance.
- Completed fabrication of the first 565 kg/day reformer and PSA system.
- Completed the ethanol catalyst screening tests and successfully demonstrated reforming of neat ethanol in micro-reactor tests.
- Started the long-term (>1,000 hours) catalyst life testing with ethanol, and prepared for testing of ethanol reforming with gasoline additives found in E-95 used in commercial ethanol fuel transport.

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Introduction

Achieving the DOE cost targets will require improved efficiency and also larger hydrogen capacity compared to the current hydrogen generation module (HGM)-2,000 system (2,000 scfh or 113 kg/day capacity). We are also reducing catalyst cost while improving SMR, shift and PSA performance and increasing feedstock diversity.

Approach

To meet these DOE cost targets, the HGM system must be improved both in terms of higher efficiency (to cut down the cost of natural gas) and also in reduced capital cost. Furthermore, the capacity of the HGM must be increased, both to cut the cost of hydrogen (since many HGM components will scale less than linearly with increased hydrogen capacity) as well as to meet the demands of a full service fueling station. We have therefore designed, built and will begin field-testing an HGM-10,000 with five times the capacity of our current system.

While we expect that the HGM-10,000 (565 kg/day) technology scaled to 1,500 kg/day will meet or exceed the DOE 2015 cost targets for the hydrogen production and gas cleanup portion of a fueling station, it will still depend on natural gas. To reach the DOE renewable hydrogen goal, we, working with our catalyst partner, Süd Chemie, will also evaluate the cost and efficiency of reforming ethanol at the local fueling station using the H_2Gen technology. We expect that hydrogen made from ethanol will be the least costly renewable hydrogen option for at least a decade or two.

Results

Water-Gas Shift (WGS) Catalyst Development. Süd-Chemie continued working on the development of improved WGS catalysts which are stable under high pressure conditions of HGM operation, has high activity towards WGS reaction, low activity for methanation and suppress formation of any by-products. Modifications to existing WGS reactors at Süd-Chemie were necessary to operate at H_2Gen pressures of interest. Upgrades to existing equipment included pressure gauges, mass flow controllers, and relief value spring kits. Other modifications included back pressure regulators for the reaction tubes as well as a regulator to step down the pressure before continuing to the analytical equipment.

Süd Chemie ran multiple tests on several WGS catalysts under H_2Gen operating conditions. A number of different supports were also prepared and tested. A new support was identified, and the best support/catalyst combination was optimized by detailed studies of support properties and promoter concentrations and types.

Pre-Reforming Catalyst Development. Süd-Chemie and H_2Gen identified an opportunity to develop a high performance pre-reforming catalyst to extend to fuels such as liquefied petroleum gas (LPG) and ethanol. The pre-reforming of natural gas, LPG and ethanol required a stable fuel flexible catalyst that is matched to H_2Gen's operating parameters. In addition to being stable this catalyst needed to be sulfur and carbon tolerant.

Süd-Chemie has developed stabilized oxide support for the pre-reforming catalysts. The initial sample sent to H_2Gen was prepared on a 100 cc scale using R&D lab equipment. After receiving positive feedback from initial trials at H_2Gen, the scale-up of the material was investigated. Initial trials were not successful in the pilot plant using industrial equipment. Upon further investigation and equipment optimization, successful trials were carried out by making several tens of kilograms. The results need to be confirmed in actual plant equipment.

HGM-10,000 Fabrication. The primary work for 2007 was the full-scale testing of the burner and steam generator sub-systems, completion of the detailed HGM-10,000 design including a new control system architecture, and the fabrication of the first HGM-10,000 that was completed in June 2007.

The HGM-10,000 burner has a much lower pressure drop than the burner used in the HGM-2,000. This lower pressure drop significantly reduces the power draw required from the air blower, which increases the overall electrical efficiency of the SMR system. The burner mechanical design was augmented by a computational fluid dynamic (CFD) analysis of the burner uniformity as shown in Figure 1. This burner system was then fabricated and tested at our Alexandria test facilities as shown in Figure 2.

The full HGM-10,000 system is shown during construction in Figure 3. This system will be shipped to a field test site in July 2007 to begin initial system testing. Our goal is to demonstrate more than 2,500 hours of field operation to gather information on system efficiency and reliability.

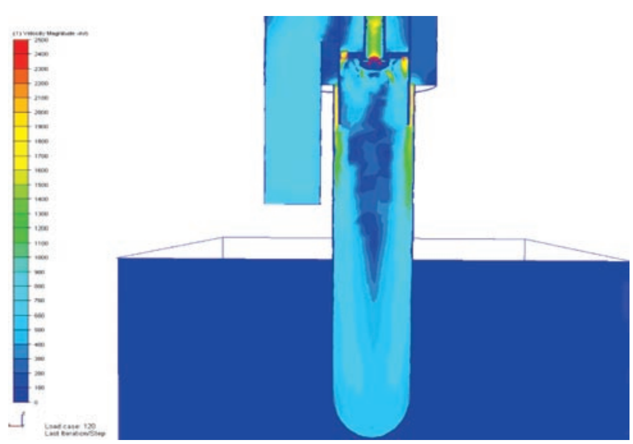

FIGURE 1. CFD Analysis of Mixing Region for HGM-10,000 Burner

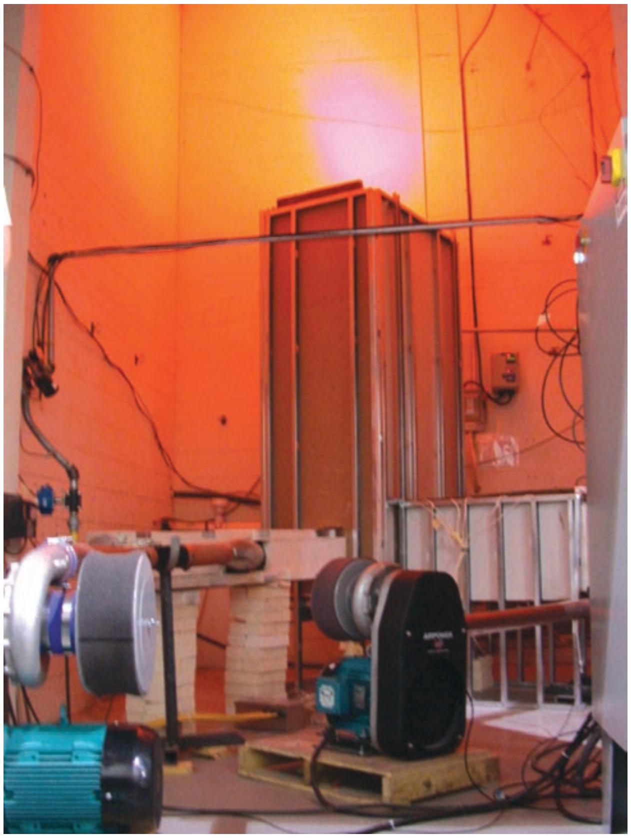

FIGURE 2. HGM-10,000 Burner Test Setup

FIGURE 3. HGM-10,000 During Construction

SMR/PSA Cost Reduction. The total material cost (excluding fabrication labor and general and administrative expenses associated with ordering, shipping and receiving parts) will meet our $350,000 goal without any further cost reductions. Hence, the economies of building multiple units with vendor price reductions should reduce the material costs below our target of $350,000.

The current HGM-10,000 will be optimized through the design for manufacture and assembly processes. In the current unit to save project costs, we used the same reformer tubes that are in our HGM-2,000 reactor. Future costs could be reduced by optimizing the diameter and lengths of these reactor tubes. Other cost savings are anticipated with future designs incorporating the lessons learned in the field test.

Conclusions and Future Directions

To ready the HGM-10,000 for actual deployment in commercial situations, the following key tasks must be completed:

(a) Complete the development of the first version of the operating software for the HGM-10,000, including field testing.

(b) Commissioning procedures, installation, operations and maintenance manuals for the HGM-10,000.

(c) Map the operation of the HGM-10,000 as built, establishing the operating envelope and characteristics.

(d) Identify areas for improvement.

These tasks will naturally lead to the completion of a second prototype plant at the 565 kg/day capacity. This plant will help remedy shortcomings identified in the first plant while the first plant continues to accumulate operating hours to demonstrate durability. A second site has been secured for testing; this second plant and construction and delivery to the site are expected to be completed by Q1 2008.

We will continue screening of ethanol catalysts and complete long-term durability tests. A key focus will be testing with real ethanol blends with impurities present.

Special Recognitions & Awards/Patents Issued

1. We received a 2007 DOE Hydrogen Program R&D Award "in recognition of outstanding achievement in technology innovation" at the annual review meeting.

FY 2007 Publications/Presentations

1. Presentation to the 2007 DOE Annual Peer Review meeting.