IV.D Biomass Reforming

IV.D.1 Startech Hydrogen Production*

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Projected End Date: October 4, 2005

**Congressionally directed project*

Objectives

The purpose of this project is to evaluate the viability of integrated hydrogen production from waste materials using a plasma converter and a StarCell multistage ceramic membrane hydrogen separation system. Specifically, this project will achieve the following:

- Field test integrated hydrogen production on a pilot scale using plasma gasification and ceramic membrane hydrogen separation.
- Evaluate commercial viability and scalability through extended operation under representative conditions.
- Characterize the performance of the integrated Plasma Converter and StarCell™ Systems for hydrogen production and purification from abundant and inexpensive feedstocks.
- Compare integrated hydrogen production performance to conventional technologies and DOE benchmarks.
- Run pressure and temperature testing to baseline StarCell's performance.
- Determine the effect of process contaminants on the StarCell™ 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 published in February 2005:

- C. Operation and Maintenance (O&M)
- D. Feedstock Issues
- F. Control and Safety

- M. Impurities
- R. Testing and Analysis
- V. Feedstock Cost and Availability
- W. Capital Cost and Efficiency of Biomass Gasification/Pyrolysis Technology

Technical Targets

The Startech hydrogen production program includes both hydrogen production through advanced gasification and separation of hydrogen through microporous membrane separation. This research is advancing the state-of-the-art in both of these technology areas.

Table 1. Technical Targets: Microporous Membranes for Hydrogen Separation and Purification

Performance Criteria[a]	Units	2003 Status	2005 Target	Current Status	2010 Target
Flux Rate[b]	scfh/ft^2	100	100	TBD	200
Membrane Material and All Module Costs[c]	\$/ft^2 of Membrane	450-600	400	TBD	200
Durability[d]	hr	<8,760[e]	8,760	TBD	26,280
ΔP Operating Capability[f]	psi	100	200	TBD	400
Hydrogen Recovery	% of total gas	60	>70	TBD	>80
Hydrogen Quality[g]	% of total (dry) gas	>90	95	TBD	99.5

[a] The membranes must be tolerant to impurities. This will be application specific. Common impurities include sulfur and carbon monoxide.
[b] Flux at 20 psi hydrogen partial pressure differential with a minimum permeate side total pressure of 15 psi, preferably >50 psi and 400°C.
[c] The membrane support structure cost is approximately three times more than membrane material costs.
[d] Intervals between membrane replacement.
[e] Hydrogen membranes have not been demonstrated to-date, only laboratory tested.
[f] Delta P operating capability is application dependent. There are many applications that may only require 400 psi or less. For coal gasification 1,000 psi is the target.
[g] Based on current available PEM fuel cell information, the tentative contaminant targets are: <10 ppb sulfur, <1 ppm carbon monoxide, <100 ppm carbon dioxide, <1 ppm ammonia, <100 ppm non-methane hydrocarbons on a C-1 basis, oxygen, nitrogen and argon cannot exceed 2% in total, particulate levels must meet ISO standard 14787.

As of the time of this writing, the current work scope is entering its final testing phase that is to be completed by 30 September 2005. The efforts have been applied to the design, fabrication, procurement, and assembly of equipment for the plasma converter system gasification/hydrogen separation process. The objectives of the upcoming testing phase will be to establish the current status baseline information indicated in the table above. Accordingly, at the time of this writing it is not possible to quantify the current status cost basis for the process, and TBD (to be determined) has been entered in the table.

Approach

This project aims to benchmark plasma conversion as an advanced fuel-flexible reformer technology, reduce fuel processing costs by implementing single-step gasification and reforming, broaden feedstock flexibility by gasifying mixed waste (municipal solid waste), and determine gas polisher efficiency and suitability of synthesis gas for subsequent processes. Advantages of the plasma conversion system are competitive capital and O&M costs, fewer water and feedstock issues than in other processes, and improved gasification safety due to ambient pressure, continuous feed, and improved process control.

To achieve the targets listed above, Startech will implement the following approach:

- Utilize StarCell ceramic membrane system to purify hydrogen from a mixed synthesis gas.

Table 2. Technical Targets: Biomass Gasification/Pyrolysis Hydrogen Production[a]

Characteristics	Units	Calendar Year			
		2003 Status	2005 Target	Current Status	2010 Target
Energy Efficiency[b]	%	44	47	TBD	50
Total Hydrogen Cost	\$/gge H_2	2.10	1.90	TBD	1.75
Detailed Cost Breakdown: These calculations are for guidance only and not necessarily the research targets to achieve the total energy efficiency and cost goals.					
Capital Cost Contribution	\$/gge H_2	0.70	0.60	TBD	0.55
Feedstock Cost Contribution[c]	\$/gge H_2	0.70	0.65	TBD	0.60
Fixed O&M Cost Contribution	\$/gge H_2	0.40	0.40	TBD	0.35
Other Variable O&M Cost Contribution	\$/gge H_2	0.30	0.25	TBD	0.25

[a] Economic parameters: 40 yr. analysis period, 10% IRR after taxes, 100% equity financing, 1.9% inflation, 38.9% total tax rate, MACRS 20-year depreciation. The results in 2000$ were inflated by 6% to yield 2003 dollars. These costs are at the plant gate. The cost target for delivery of hydrogen from the plant gate to the point of refueling at a refueling station in 2015 is $1/gge (See Section 3.2).

[b] Energy efficiency is defined as the energy of the hydrogen out of the process (LHV) divided by the sum of the energy into the process from the feedstock (LHV) and all other energy needed. The electrical energy utilized does not include the efficiency losses from the production of the electricity.

[c] For 2003 and 2005, a biomass feedstock cost of $46/dry ton in 2000$ was used. For 2010, a feedstock cost of $44/dry ton was used. For 2015, a feedstock cost of $42/dry ton was used.

- Utilize plasma converter gasification system to generate hydrogen-rich synthesis gas.
- Measure processing cost and quality of hydrogen production from representative feedstocks.
- Characterize plasma gasification and membrane separation as an integrated hydrogen production system.
- Determine viability for StarCell scale-up and next phase development.

Accomplishments

- First StarCell modules received December 2004:
  - Module configuration locked and flows approximated for StarCell Design
  - Potting process had an unanticipated negative effect on projected membrane flux
  - Membrane manufacturing process to be reassessed to improve bundled performance
  - Membrane delivery date pushed out to May 2005 to allow for additional bundle development
- Plasma Converter System pre-mod baseline testing December 2004:
  - Commenced general Operational Assessment in preparation for DOE work
- StarCell membrane test system design work:
  - Detailed design January 05 – February 05
  - Safety/design review March 05
  - StarCell build completion on schedule for May 05
  - Build completion to coincide with membrane module receipt
- Design Features
  - StarCell configured for optimal process flexibility. Incorporated 3 Stage 1 to Stage 2 changeover modules allowing Stage 1 and Stage 2 configurations of 4 and 4, 5 and 3, and 6 and 2.

- Able to accommodate wide range of potential hydrogen throughputs and selectivities.
- Upgradeable to accommodate additional membrane modules.
- Option to use single compressor to cascade through membrane stages.
- Upgradeable for Stage 2 reject to augment Stage 1 hydrogen content.

Future Directions

- Membrane Work
  - Incorporate and prove next generation membrane materials
  - Water-gas-shift evaluation: Evaluate potential to incorporate the water-gas-shift reaction into the membrane
  - Process control, analysis, and optimization
- Optimization of Hydrogen Production
  - Challenge loading the hydrogen production system: Identify contaminants of particular concern and evaluate performance on challenge loads
  - Establish a broad feedstock specification to expand the applicability of the process to many more materials
  - Gas clean-up (specifically for catalyst preservation)
  - Carbon sequestration evaluation

Introduction

In Startech's plasma converter system (PCS), organic wastes and other feedstocks are dissociated and reformed to create a synthesis gas of predominantly hydrogen and carbon monoxide. The synthesis gas produced in the dissociation process of these materials, particularly the hydrogen component, has an expanding commercial demand. Single step gasification and reforming of feedstocks utilizing the PCS is one potential answer to both distributed and large-scale hydrogen production. The economics of the gasification process are especially favorable when gasifying organic waste including pesticides, tires, medical waste, and municipal solid waste into high purity hydrogen fuel.

To enhance the hydrogen production capability of the PCS, Startech has invested considerable resources into the development of StarCell™, a ceramic membrane technology for the isolation and purification of hydrogen from a mixed gas stream. This technology has far reaching applications in the emerging hydrogen economy for virtually any hydrogen purification application. Inherent advantages of the ceramic membrane technology over other hydrogen purification technologies include the following:

- Excellent material temperature and chemical stability/flexibility
- Microporous material yields much higher throughputs versus nonporous polymeric membranes
- Cost efficient gas separation can be achieved at low pressures, i.e., 50 to 100 psi.

The objective of the Startech Hydrogen production project is further development in two hydrogen infrastructure technology areas. Single-step plasma gasification of the various feedstocks into a hydrogen rich synthesis gas furthers the DOE goal of distributed hydrogen production. Using StarCell, a systemized ceramic membrane technology, to separate the hydrogen from the gas generated by the gasifier and subsequently purifying the hydrogen component will also yield performance data that will be crucial to the future scale-up and commercialization of this technology. Test results obtained during this testing will be compared with DOE cost targets for gasification and membrane performance.

Approach

A key element to this research is the characterization of plasma conversion and StarCell hydrogen purification through real time operation on a pilot scale rather than theoretical projections of laboratory or bench scale testing. Very little modification was done to the PCS as it will first be characterized in light of DOE's objectives to identify the strengths and weaknesses of the technology. In addition to measuring the efficiency and efficacy of the plasma converter, the synthesis gas produced by the plasma converter will be analyzed to verify its suitability for downstream process such as hydrogen purification and water-gas-shift for additional hydrogen production. A significant portion of the research effort will be focused on laboratory analysis of the plasma converted gas. This portion of the research is especially critical as the majority of gasification technologies, especially those linked with separation technologies, have performed their testing on low contaminant feedstocks (i.e., low sulfur coal and clean natural gas) that are not viable solutions for fossil fuel independence. It is important to identify contaminants in diverse feedstocks and understand their effects on downstream components.

StarCell system construction was a major accomplishment of this research effort as it is a very flexible tool for pilot scale membrane characterization in general. Instrumentation on the StarCell provides continuous data logging of process temperatures, pressures, flows, and gas composition at points of interest in the purification system. StarCell was constructed to accommodate tubular membranes bundled together in modules, though planar stacks and other configurations could easily be incorporated. It also has two stages of compression to evaluate various multistage module configurations. Some of the operational configurations are as follows:

- Single-stage compression cascading through multiple stages of modules.
- Dual compression for instances where Stage 1 permeate pressure is too low to drive Stage 2 separation.

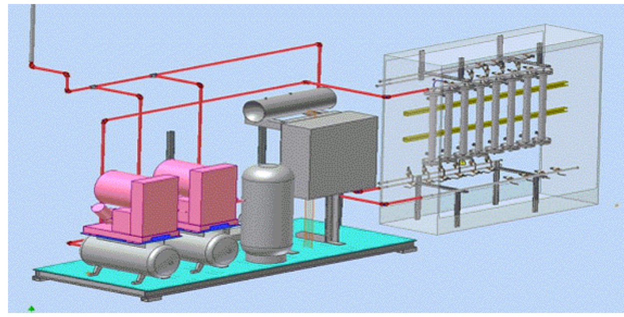

Figure 1. StarCell 3D Design, February 2005

- Stage 1 to Stage 2 switching to allow Stage 1 to Stage 2 configurations of 6 and 2, 5 and 3, or 4 and 4 as conditions and membrane performance require.

The technical approach of this phase of the project was to get the systems interfaced and operational and then to operate the systems to obtain analytical data and establish a performance baseline. It is recognized that significant progress continues to be made in membrane development and we continue to find and conquer new impediments in the incorporation of the membranes into pilot size modules. Establishment of a performance baseline is an essential step in measuring technical improvements under representative conditions.

Results

As indicated in the Technical Targets section, at the time of this writing, testing of the integrated system has just begun and results of that testing are not available at this time. Testing and reporting is expected to be complete in time for the end of the contract period of performance (October 4, 2005). The results of the testing and the technical status of the project will be reported under separate cover upon test completion.

The design, assembly, and integration of the StarCell system are complete. We have included photo documentation of the system that is to be tested (Figures 1-4)

Figure 2. StarCell Construction, April 2005

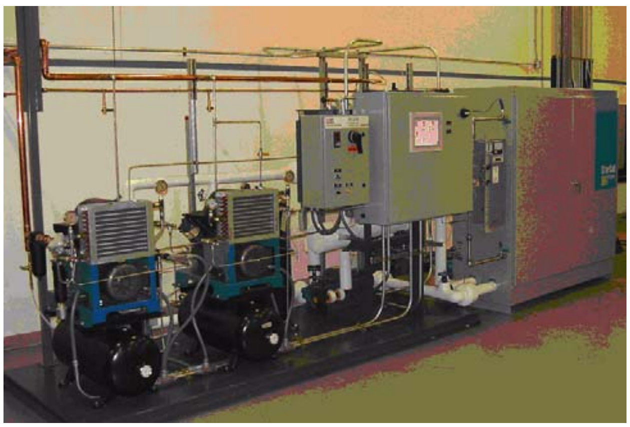

Figure 3. Installed StarCell System, July 2005

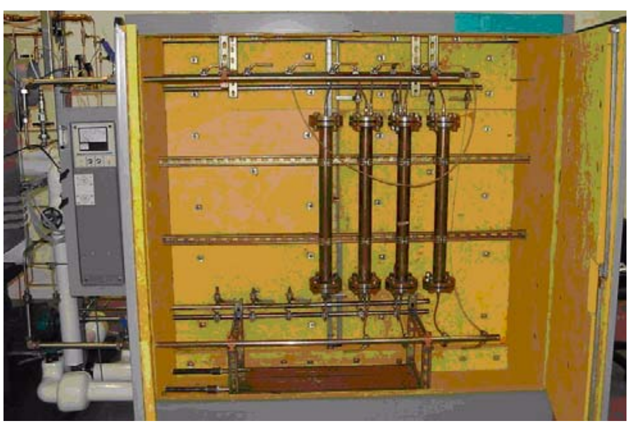

Figure 4. Four Modules Installed in StarCell, July 2005 Module Performance Verification Underway.

Conclusions

Technical results on the PCS, StarCell system operation, and membrane module performance data is not yet available. However, there is little doubt that the StarCell membrane module system will be an important tool for verifying membrane module performance of various membrane configurations. Having the StarCell plumbed into the Startech Plasma converter allows virtually limitless opportunity for module performance testing across various temperatures, pressures, and in the presence of numerous contaminants in various concentrations. The PCS in the same facility has the capability of producing hydrogen-rich synthesis gas from such diverse feedstocks as petroleum wastes, biomass, bio-derived fuels, municipal solid waste, and coal. The data to be obtained in the Startech hydrogen production testing will be critical in identifying and resolving synthesis gas production issues and membrane hydrogen purification across many technology platforms on the path to fossil fuel independence.