2005 DOE Hydrogen, Fuel Cells & Infrastructure Technologies

Program Review Presentation

Startech Hydrogen Production

STARTECH
ENVIRONMENTAL CORP.

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May 25, 2005

Project ID#: PDP27

Overview

Timeline

- Start: October 04
- Phase 1 End: September 05
- Phase 2 End: September 06

Budget

- Phase 1: $613,174
  - Doe Portion: $490,539
  - Share Portion: $122,635
- Phase 2: $620,000
  - DOE Portion: $496,000
  - Share Portion: $124,000

Barriers

C. Operation and Maintenance
D. Feedstock Issues
F. Control And Safety
M. Impurities
R. Testing and Analysis
V. Feedstock Cost and Availability
W. Capital Cost and Efficiency

Partner

Media and Process Technology Inc.

Project Objectives

- 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 StarCellTM system.

Analytical Approach

1. Utilize StarCell Ceramic Membrane System to purify Hydrogen from a mixed Synthesis Gas.
2. Utilize Plasma Converter Gasification System to generate Hydrogen Rich Synthesis Gas.
3. Measure processing cost and quality of hydrogen production from several representative feedstocks.
4. Characterize plasma gasification and membrane separation as an integrated hydrogen production system.
5. Characterize and baseline integrated operation using MSW surrogate and coal as feedstocks.

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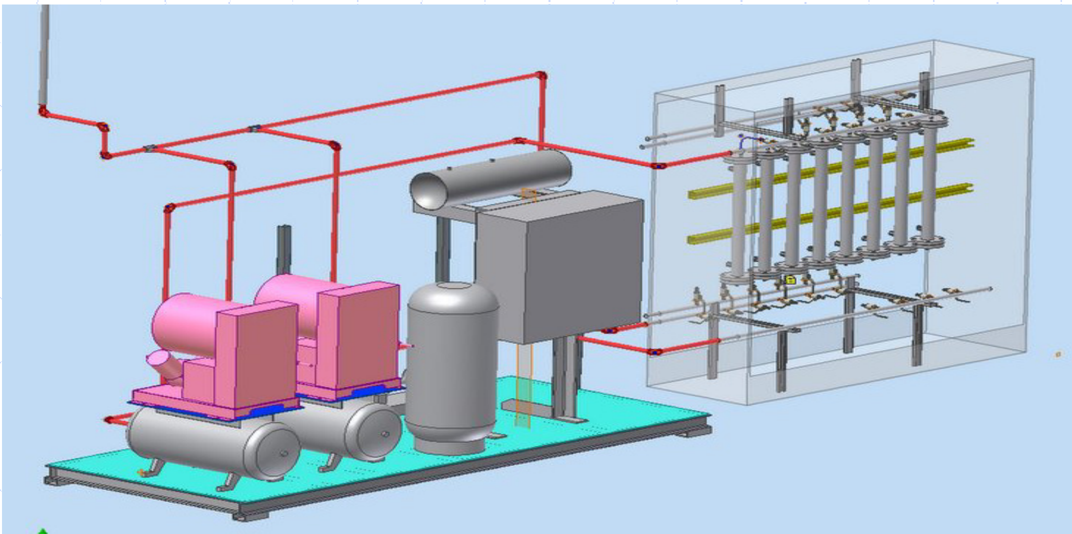
Accomplishments



Accomplishments

- Project Initiated October 2004
- 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.
- PCS pre mod baseline testing December 2004:
  - Commenced general Operational Assessment in preparation for DOE work.

Accomplishments

- 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 H_2 content.

2004 Comments

"Feedstock availability and variety not sufficiently addressed"

- The project scope was intentionally limited to focus on Municipal Solid Waste (MSW) as the most prevalent feedstock and on Coal to yield process comparisons of Plasma Conversion with other gasification technologies. Membrane performance should remain the same regardless of feedstock.
- This is a first pass implementation and analysis of the Plasma Converter System and the StarCell Hydrogen separation system relative to DOE targets. Once the systems are baselined, areas for improvement will be identified and addressed in future work.
- Other feedstocks were proposed such as end of life electronics, and medical waste, but these were viewed as niche feedstocks that did not significantly address the nation's energy needs.
- There is potential to use Plasma Conversion on numerous other Feedstocks once viability of the process is established.

2004 Comments

"Feedstock availability and variety not sufficiently addressed"

- In 2001, ~230 million tons of MSW was produced.
- 56% of this material goes to landfills.
- If a single day's waste were converted to Plasma Converted Gas (~50% H2 and 40% CO), it could produce ~38 million kg H2 (gge) per day.
- CO could be converted to energy to run operations or water gas shifted to augment H2 production.
- This is roughly equivalent to 10% of the US daily requirement for gasoline without water gas shift.
- >72 % of MSW is Bio derived material. Only 11% is plastic or fossil fuel derived material. Remainder is glass, metals, and other.
- Reference: EPA Municipal Solid Waste Basic Facts Website (http://www.epa.gov/epaoswer/non-hw/muncpl/facts.htm)

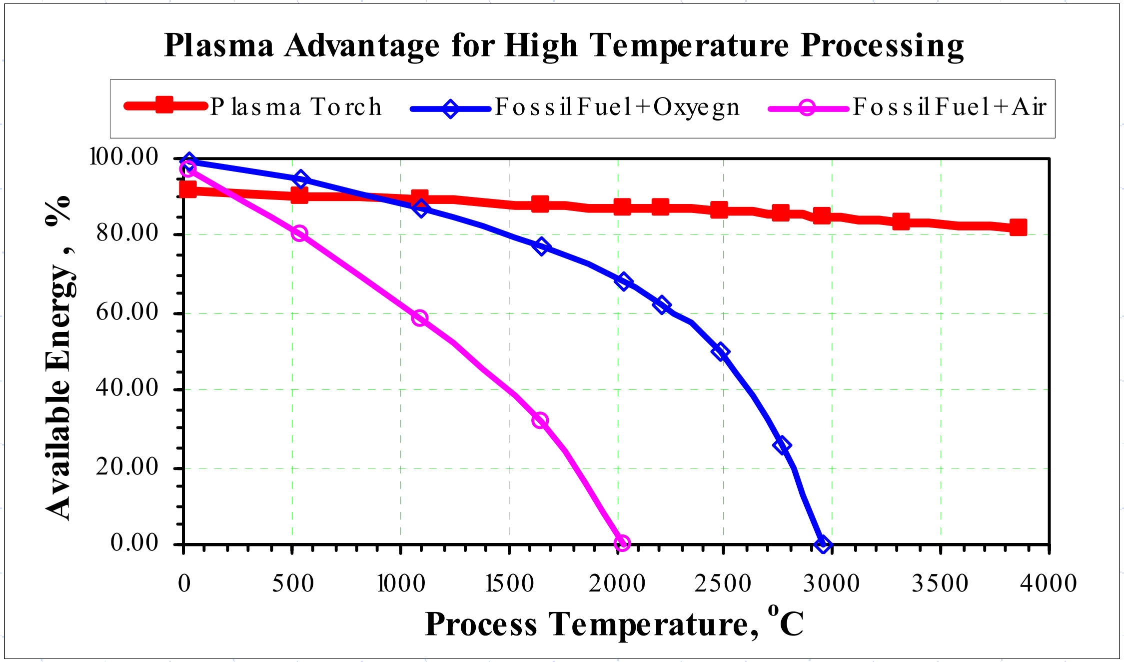
2004 Comments

“Not Clear that a rigorous enough analytical program is in place to assess the impact on efficiency, H2 Volume and purity of using mixed feedstocks.”

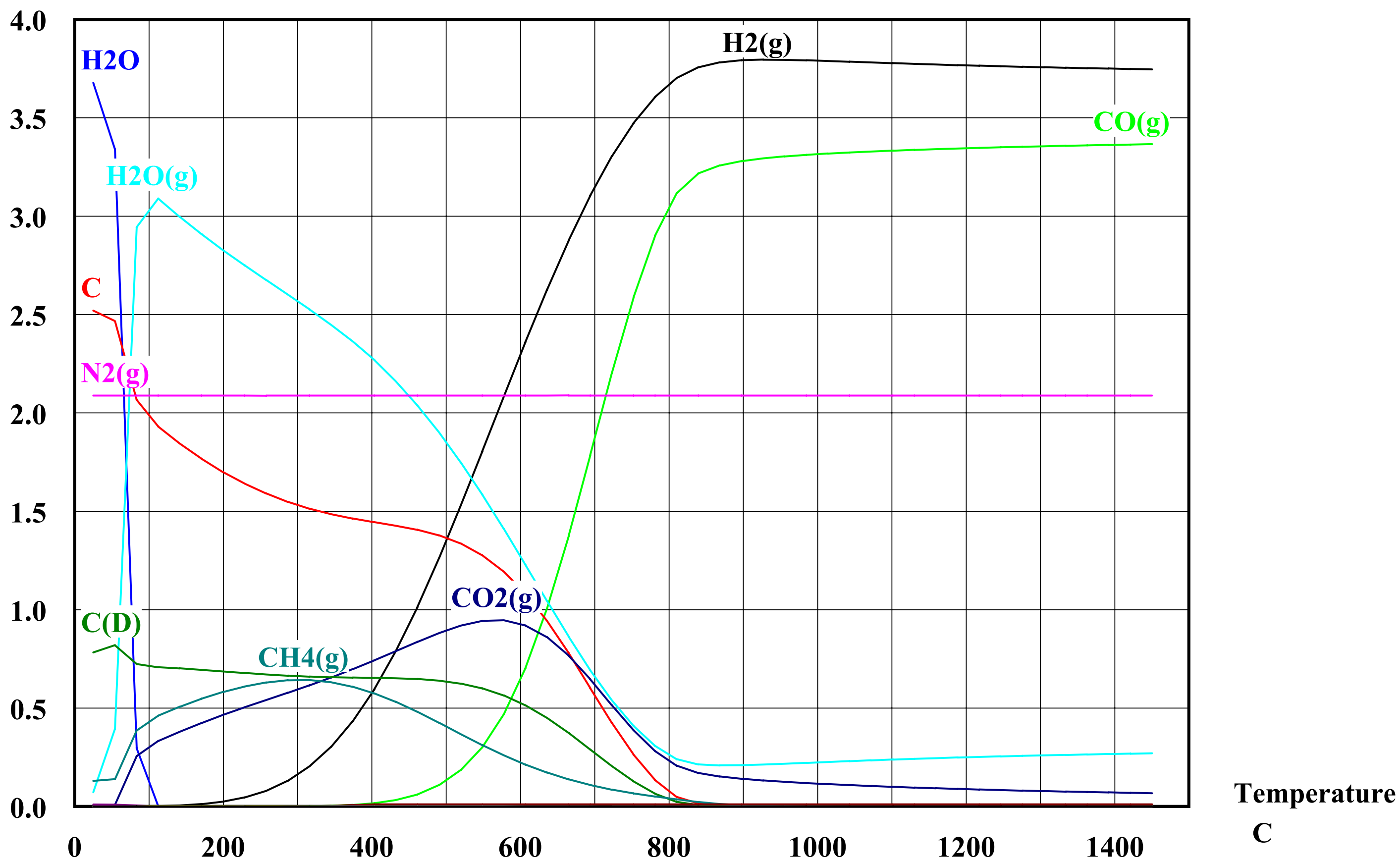
1. >60% of the program funds are to be spent on integrated system operation, testing, and reporting.
2. Fully instrumented Plasma Converter System and StarCell Systems report continuous data on flows, temperatures, and other process parameters to facilitate energy and gasification efficiency calculations.
3. Continuous Gas Analysis will be done for CO, CO2, O2, NOx, H2, and CH4 directly off of the Plasma Converter
4. Grab type samples from various stages of the PCS and StarCell Systems will be analyzed internally and by independent labs.

Why Plasma?

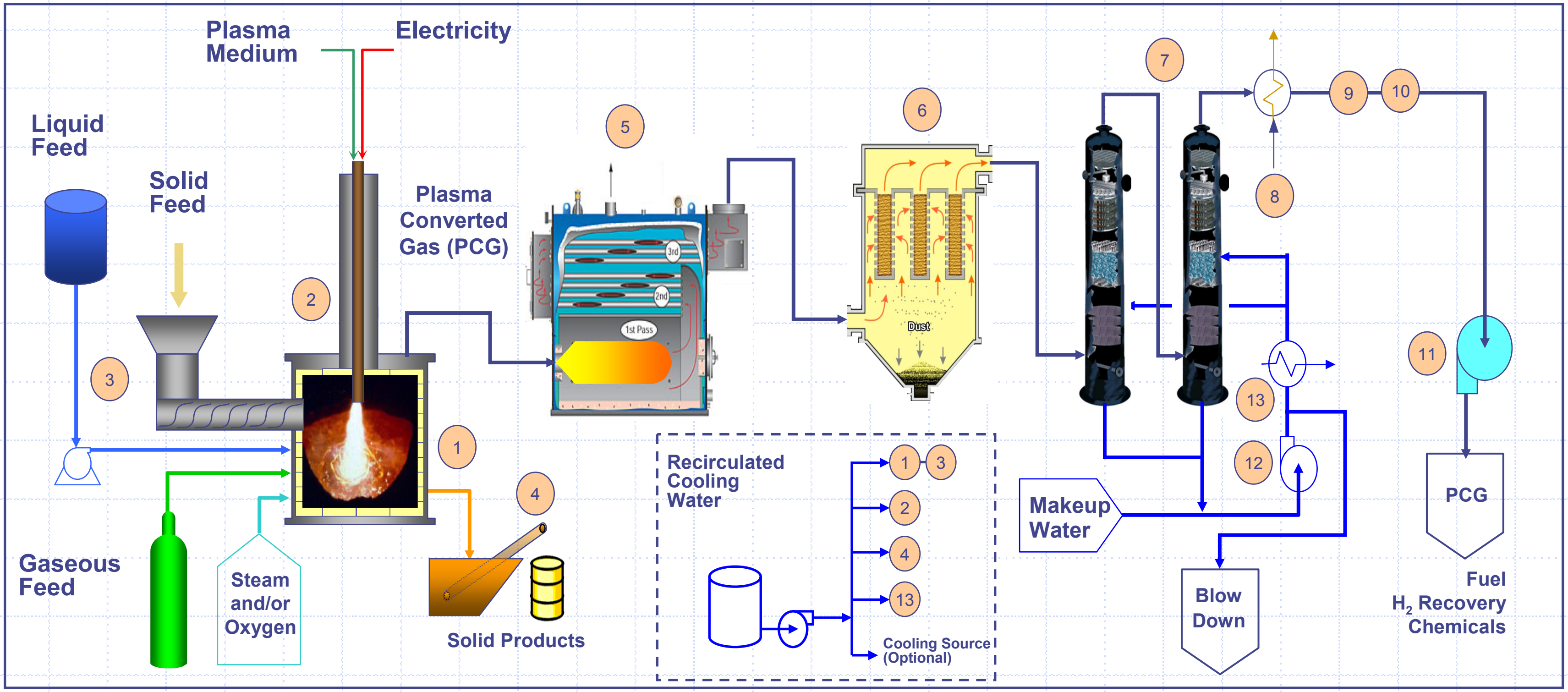
- Superior Environmental Performance
- "Massless Heat"
- High Temperatures
- Commercially Available Equipment
- Low Gas Volumes



EOLE Gasification



Plasma Converter System



Membrane Features

- Applied Research on Advanced H2 Separation
  - Utilize Systemized and Multistage Microporous Membrane Technology for Hydrogen Purification.
  - Membrane performance to be evaluated with various operating conditions and over extended operation.
- Advantage of Ceramic Membrane System
  - Chemical Stability (inert surface)
  - Cost efficient gas separation can be achieved at low pressures, i.e. 50 to 100 psi
  - Hydrothermal stability
  - Intermediate temperature operation, <RT to >350ºC
  - Simpler fabrication of defect free layer

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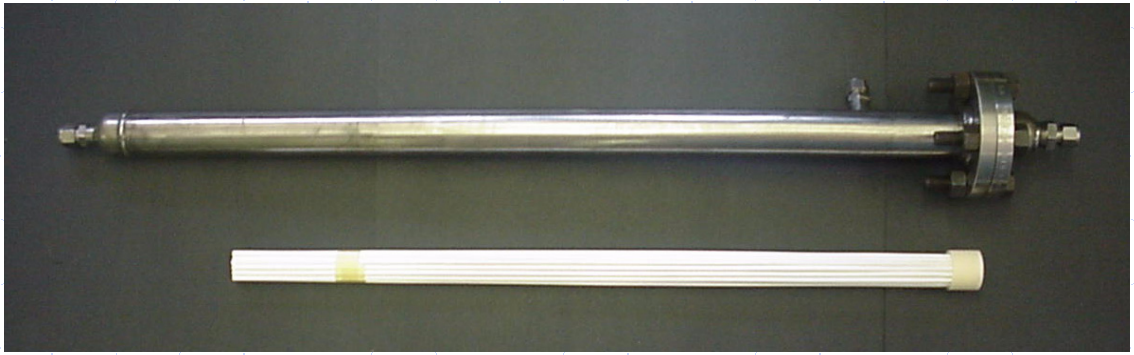
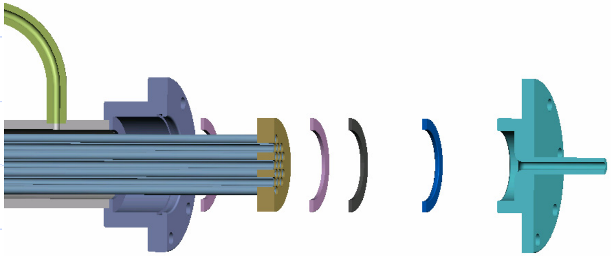
StarCell: How It Works

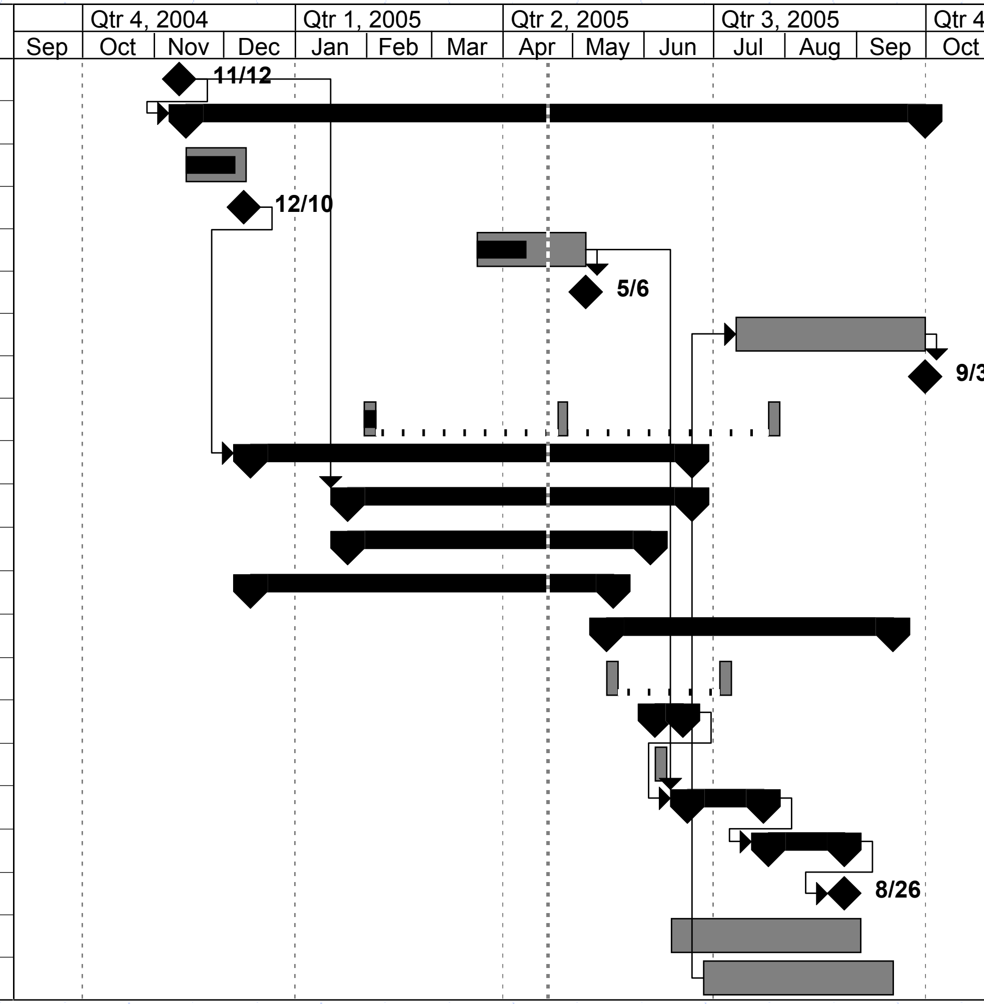
- StarCell Modules are stainless steel housings with Carbon Molecular Sieve tube bundles inside.
- Rated for up to 390ºF and operates up to 150 psig.
- Mixed gas enters through the inlet port and hydrogen permeates through the membrane.
- Hydrogen exits through one exit port and the reject gas exits through another.





Project Time Line

ID	Task Name
1	Contract Award
2	**Management and Support**
3	Program Plan
4	Complete Program Plan
5	Test Plan
6	Complete Test Plan
7	Final Test Report
8	Submit Final Test Report
9	Progress Reporting
10	**Fabrication, Assembly, and Integration**
11	**MSW Feed Mod**
27	**Plasma Vessel Mod**
41	**StarCell Integration**
55	**Perform Testing**
56	Test Safety Review
57	**StarCell Baseline**
60	PCS Baseline Testing
61	**Integrated Coal Testing**
68	**Integrated MSW Testing**
76	Complete Testing
77	Sample Analysis
78	Data Compilation



Future Work

- Membrane Work
  - Incorporate and prove out next generation Membrane materials.
  - "Water Gas Shift" evaluation: Potential to incorporate WGS 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

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Hydrogen Safety

- *The most significant hazard with this program is the risk of Oxygen leaking into the PCG (synthesis gas) stream creating an explosive atmosphere.*
- *While this does not pose a significant risk in the Plasma Converter System itself, compressing the PCG containing oxygen could pose risk of an explosion.*
- *The most likely accident scenario has to do with the interface of the feed system with the Plasma Converter as it is a fuel in contact with an ignition source.*
- *There is also a scenario during shut-down where hot material in the Heat Exchanger or the Particle Filter could act as an ignition source if large enough quantities of air leak into the system.*
- *In both of these scenarios, a small fire could result in the area of concern.*

Hydrogen Safety

- *Oxygen content in the PCG is monitored continuously to ensure that the concentration of oxygen remains well below the LEL of 4%. Our safety review evaluated this potential and the compressors will be interlocked with the oxygen analyzer to operate only when the Oxygen content is less than 1%.*
- *Prior to StarCell or Plasma Converter operation, the entire system is purged with Nitrogen so that less than 1% Oxygen concentration remains in the system prior to introduction of synthesis gas or Hydrogen.*
- *All "wetted" parts shall be selected to withstand the temperature, pressure and gas composition for that particular location.*
- *Whenever possible, the use of seamless stainless steel tubing and tube bends will be implemented. Where bending is not feasible, compression fittings will be used*
- *Monitoring and controls insure safe operation and fail safe shutdown during upset conditions.*