

2005 DOE Hydrogen Program Review

Low-Cost, High-Pressure Hydrogen Generator

Cecelia Cropley

Giner Electrochemical Systems, LLC

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This presentation does not contain any proprietary or confidential information

Overview

Timeline

- Project Start: Jan 2003
- Project End: Dec 2005 (to be extended due to slow funding)
- Percent Complete: 40

Budget

- Total Project Budget: \$3.026M
 - DOE Share:\$1.499M
 - Cost Share:\$1.527M
- FY04 Funding
 - DOE: \$245K
 - Contract awarded April 04
- FY05 Funding
 - Anticipate \$400K
- Cost Share Funding to Date: \$819K
 - Jan 03- Mar 04

Barriers

- DOE Technical Barriers for Hydrogen Generation by Water Electrolysis
- Q. Cost- capital cost, O&M
 - R. System Efficiency- replace mechanical compressor with electrochemical compression
 - S. Grid Electricity Emissions
 - T. Renewable Integration
 - U. Electricity Costs

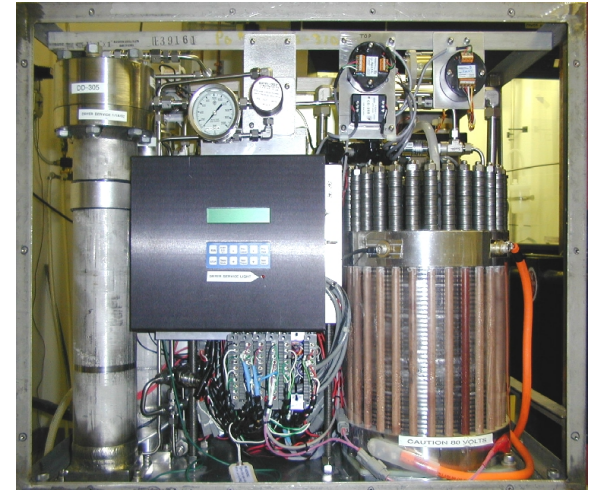
Partners

- General Motors
- Center for Technology Commercialization- Public Outreach and Education

Project Objectives

Overall Project

- Develop and demonstrate a low-cost, high-pressure water electrolyzer system
 - Increase electrolyzer hydrogen discharge pressure
 - reduce amount of mechanical compression required
 - Reduce capital costs to meet DOE targets
 - Demonstrate a 3,300 scfd high-pressure electrolyzer operating on a renewable energy source
 - Public outreach and education



Approach

- Incrementally increase operating pressure through advanced seal and endplate design
 - 1000 psid in 2002; 2000 psid in 2003
 - Possible further increases to 3500 and 5000 psid
- Replace high-cost stack components with lower-cost materials and fabrication methods
- Increase operating current density to reduce cell active area (reduce stack cost) while retaining high efficiency
- Incrementally increase the system operating pressure
- System innovations to replace high-cost, high maintenance components
- Emphasize safety in design and operation



Objectives- Past Year

- System Economic Analysis
- Continue Development of Lower-Cost Stack Components
 - anode Side Membrane Support Structure (ASMSS)
 - cell frames
- Increase Operating Current Density
 - initiated development of an advanced high-efficiency, high-strength membrane
 - demonstrate stack life using thinner (Nafion 115) membrane
- Demonstrate System Operation at 2000 psig - EP2
- Initiate Design of Lower Cost BOP

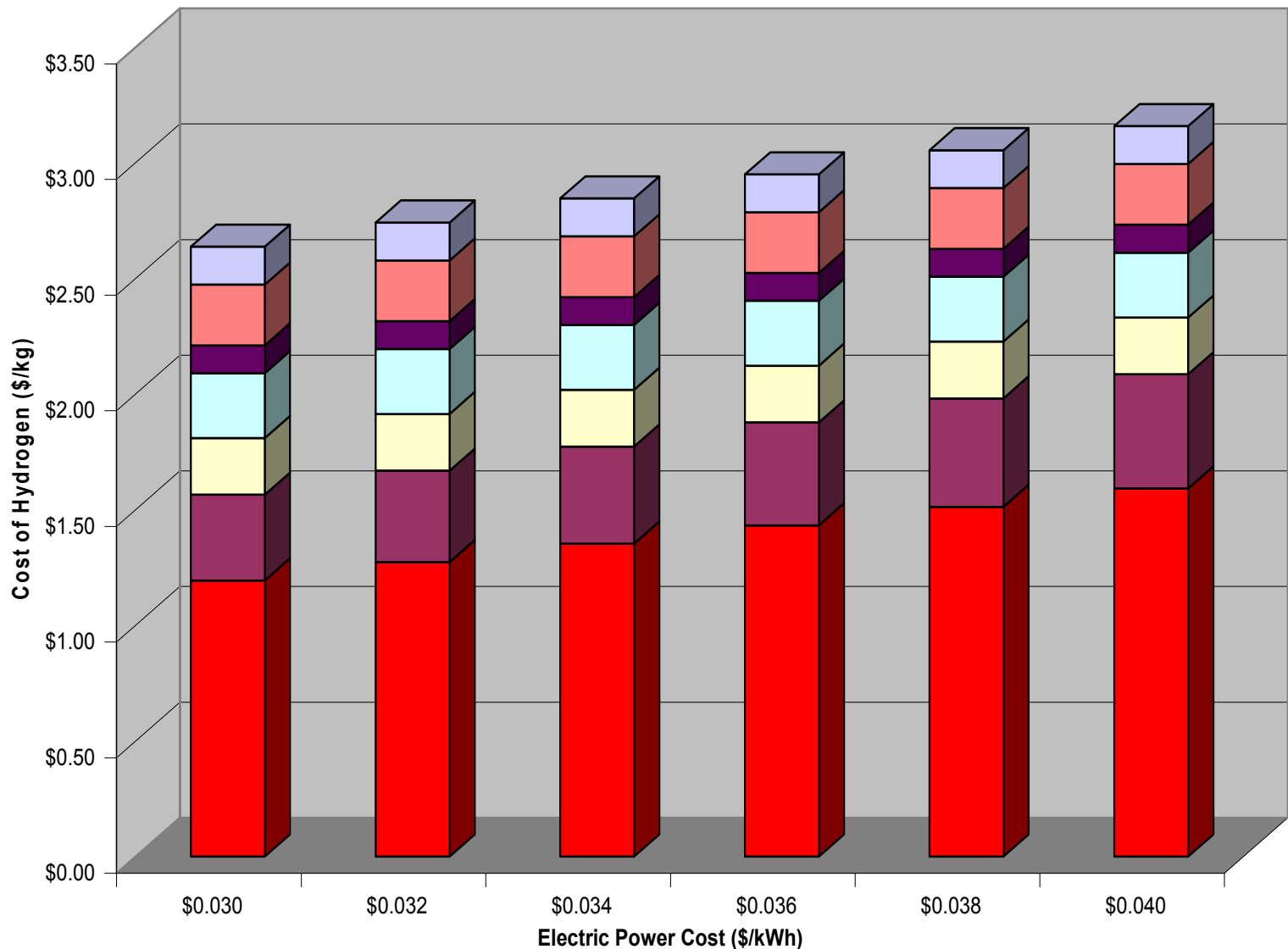
Technical Accomplishments

■ *Electrolyzer Economic Analysis*

- Developed an economic model of electrolyzer capital and operating costs to guide development efforts
- Based on 432 kg/day production rate (DOE neighborhood refueling station scale)
- Electrical load approx. 1 MW
 - Cost of electricity is key factor
- System capital cost is also a major factor

Cost of Hydrogen from Electrolyzer Plant Vs Power Cost

■ Thermo Required Power
 ■ Power Due to inefficiencies
 ■ Electrolyzer Stack
 ■ Electrolyzer BOP
 ■ Compressor
 ■ Other Capital
 ■ Maintenance



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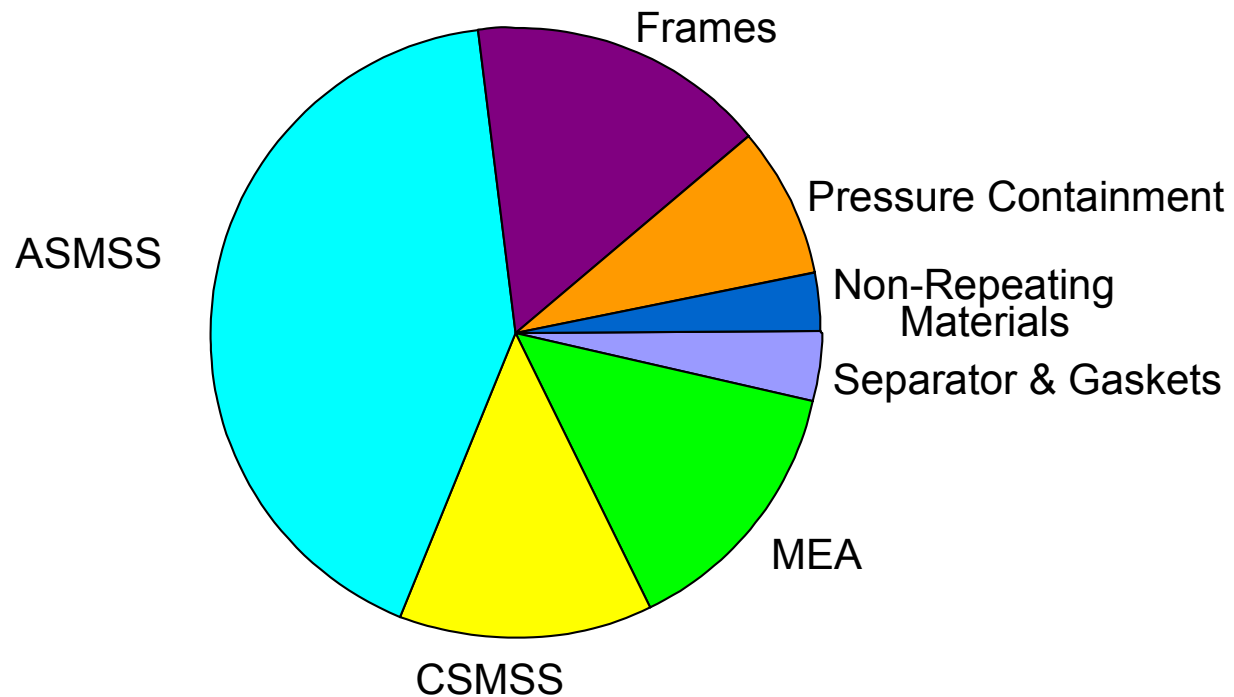
- To meet DOE target of \$2.85/kg H₂
 - Electricity < \$0.036/kWhr
 - Installed equipment cost < \$1100/kW
 - Plant operated at 90% capacity
 - 10 year life
- To meet installed equipment cost target
 - Large cell active area- reduces number of cells and parts count
 - Moderate pressure (400 psig) to high pressure (2000 psig)
 - Requires further evaluation of stack and system cost vs. mechanical compression cost
 - Does not require a breakthrough in compressor technology

Stack Cost Reduction

- Initial stack cost reduction focused on the cathode side membrane support structure (CSMSS)
 - Last year we reported development of a low-cost CSMSS fabricated from a single-piece of a low cost material
 - Replaced a CSMSS hand-fabricated from multiple-layers of expensive metal
- Total noble metal catalyst loading was previously reduced from 8 mg/cm² to 1 mg/cm²
- These cost reductions were incorporated in the EP-2 stack

Stack Cost Reduction

EP-2 Cell Costs by Major Component



Stack Cost Reduction Results

- *Anode Side Membrane Support Structure (ASMSS)*
 - Consists of 9 parts, which are individually cut, plated, welded, cut again and assembled
 - Designed an alternate that consists of 4 parts
 - could be supplied by a vendor as a single complete part
 - Expected to reduce ASMSS cost by 50%; an additional 25% reduction could be realized in high-quantity production

- *Thermoplastic Cell Frame*
 - Conduct fluids into/out of active area
 - Aids in pressure containment
 - Presently these parts are molded, then extensively machined; machining accounts for 95% of part cost
 - GES is working with a Tier 1 automotive component supplier to design new frames and manufacturing methods
 - Evaluated 3 designs
 - Test coupons successfully hydrostatically tested to 3000 psig
 - Completed design and produced component parts
- Successful development expected to reduce cell cost by 40%

Increasing Operating Current Density

- High current density operation reduces stack active area, and therefore stack cost
 - Thin membranes have low resistance, allowing efficient operation at high current densities
 - Drawback is poor mechanical properties, limiting operation to moderate differential pressures
- GES has reduced the thickness of the Nafion membrane used in the stack from 10 mils to 7 mils, and has demonstrated performance and life of a 5 mil Nafion membrane in a short stack
- Under another program, GES is developing an advanced supported membrane structure
 - Excellent mechanical properties- suitable for high differential pressure
 - High proton conductivity- equivalent to 2 mil Nafion membrane
 - Hydrogen and oxygen permeability equivalent to N112

Supported Membrane

■ Superior Mechanical Properties

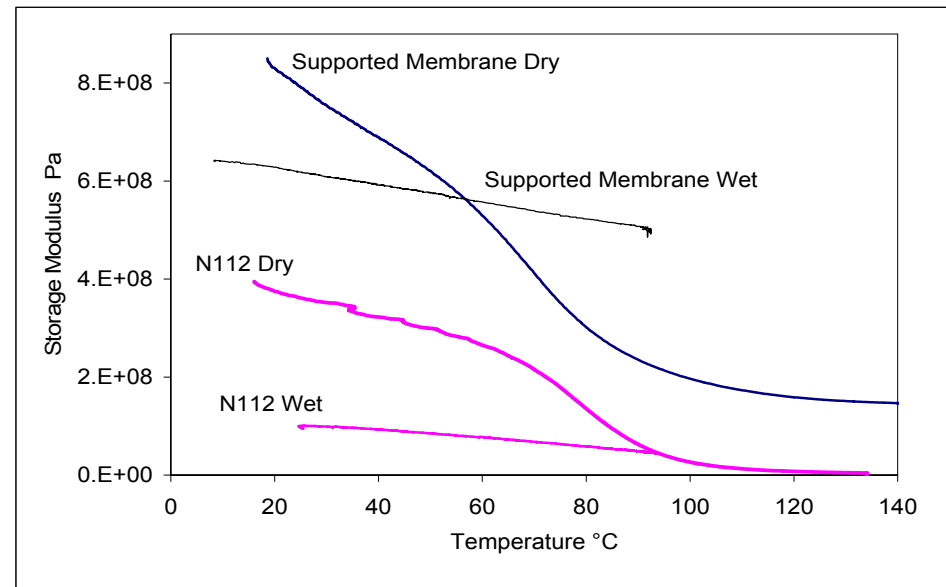
- No x-y dimensional changes upon wetting/drying or freeze-thaw cycling
- Much Stronger, Resistance to tear propagation
- Superior to PTFE based supports 10x stronger base properties
- Allows use of Alternative Electrolyte Materials

■ Ease of MEA/Stack configurations

- Direct catalyst inking onto membranes
- Possible to bond support structures into bipolar frame eliminate sealing issues

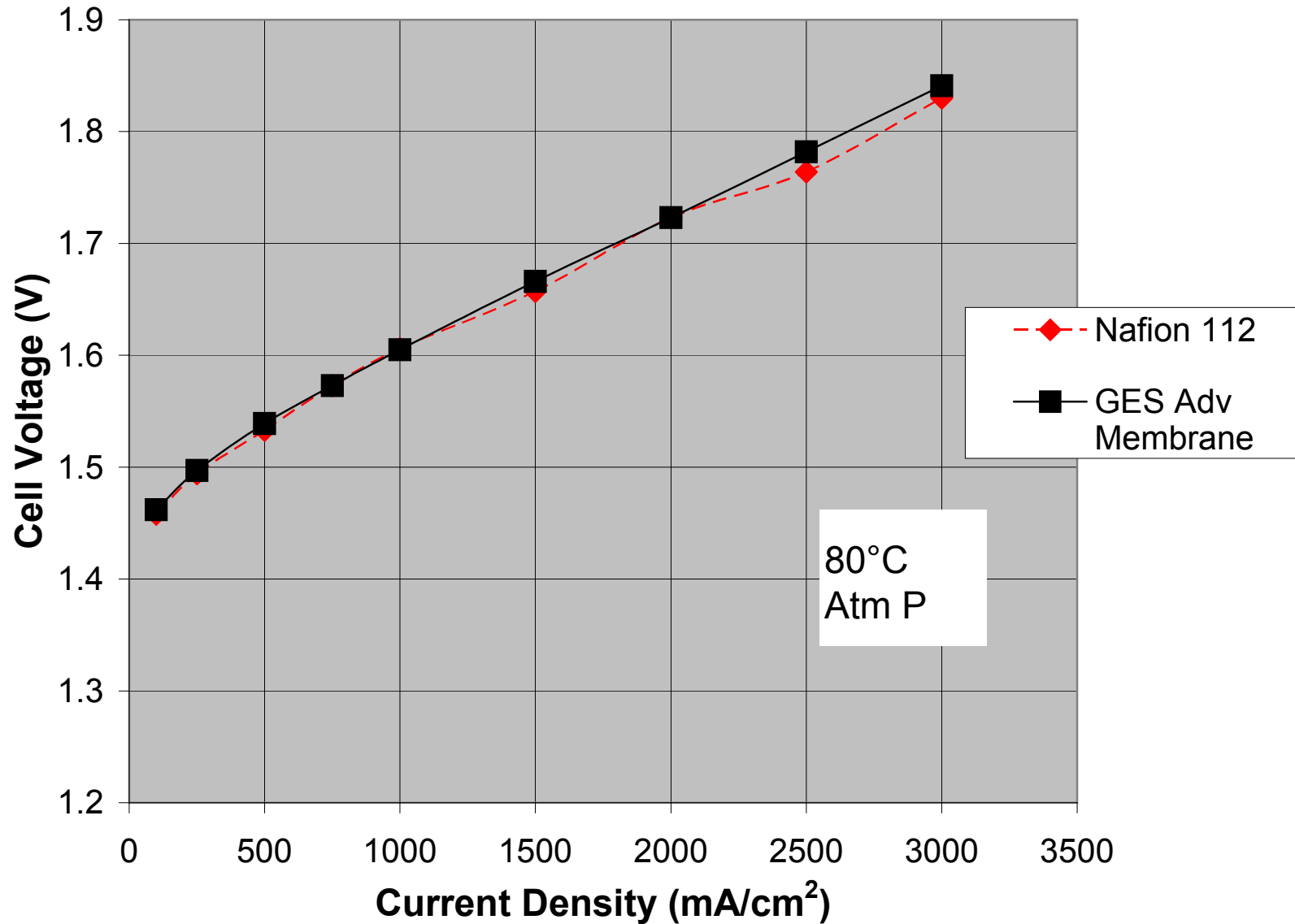
■ Customization of MEA

- Provide more support at edge regions/or at dry inlet ports



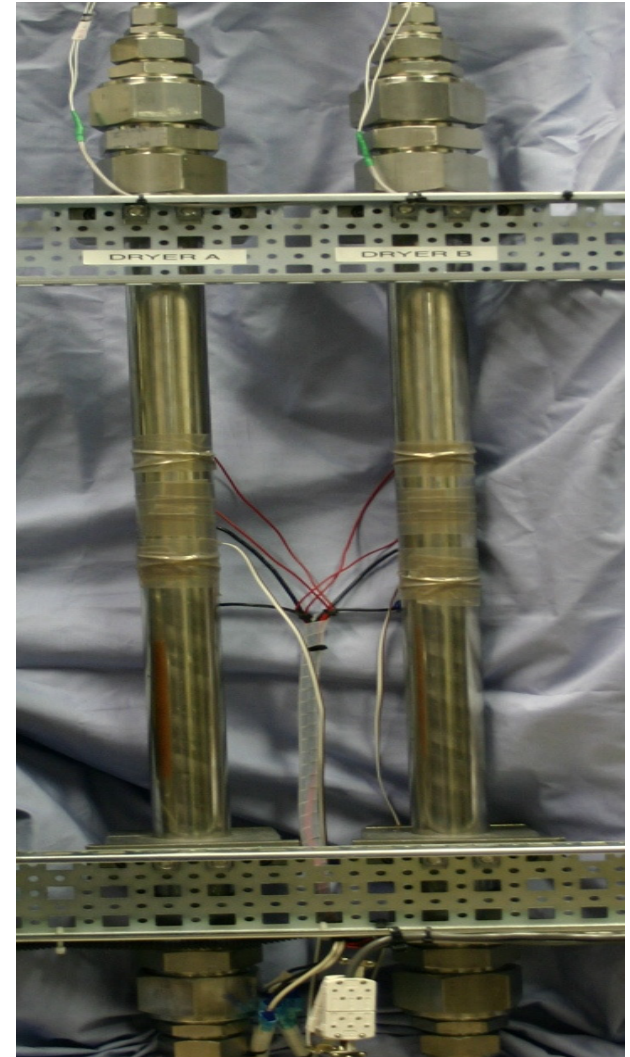
Dynamic Mechanical Analysis (DMA) shows the modulus of the novel supported membrane is ~10 X higher than the N112 membrane.

Performance of Advanced Membrane



System Design- Cost Reduction

- Regenerative Hydrogen Dryer
 - Installed and initiated testing
 - Demonstrated drying of nitrogen to -40 C dew point after regeneration
- However, there are concerns with the dryer, including:
 - High capital cost
 - Inefficient
 - High maintenance
 - poor reliability
- Evaluating modifications to dryer
 - improve efficiency and operability
- Also evaluating an alternative to the dryer



EP-2 System

- Completed system fabrication
- Commissioned system
 - Demonstrated operation at 2000 psig
 - 140 scfd hydrogen at 2000 psig
 - 25 kW system power
- Initiated Process Hazards Analysis



Future Plans

- Remainder of FY 2005
 - Develop lower-cost, long-life cell separator
 - Evaluate methods of minimizing resistance
 - Evaluate alternate sources of low-cost CSMSS material
 - Complete testing of regenerative dryer
 - Continue evaluation of dryer alternatives
 - Complete EP-2 System Hazards Evaluation

Future Plans

■ FY 2006

□ Cost Reduction

- Continue reduction in stack parts count
- Reduce stack costs by additional 35-50%
- Continue membrane development

□ Stack Development

- Design, fabricate and evaluate larger stack active area
 - Increase to 0.3 ft² from present 0.17 ft²

Reviewers' Comments

- Little Collaboration with Other Research Programs
 - First year of program emphasized development of proprietary hardware
 - This year GES worked with a Tier 1 automotive supplier on development of low-cost frames
- Consider Feasibility of Achieving Higher Pressures
 - Development of a 10,000 psi electrolyzer may be feasible, but economics needs to be evaluated
 - GES is evaluating alternative paths to 10,000 psi



Publications and Patents

- "Low Cost Electrolyzer System" (T. Norman and E Schmitt); Provisional Patent Application No. 60/27,788; Filed: October 2004.

Hydrogen Safety

- The most significant hydrogen hazard associated with this project is:

Leak of hydrogen into the laboratory, creating a flammable/explosive mixture, particularly near the ceiling

Hydrogen Safety

- To deal with this hazard we are evaluating several measures, including:
 - Implementing standard operating procedures to minimize potential for hydrogen leak
 - Automatic system shut-down if system loses pressure (or fails to increase pressure at normal rate)
 - Installing multiple hydrogen detectors on the ceiling, with an alarm and automatic system shutdown