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

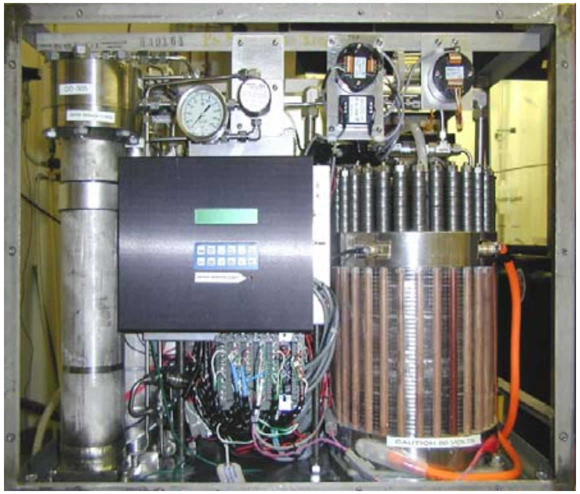
DOE Technical Barriers for Hydrogen Generation by Water Electrolysis

- 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

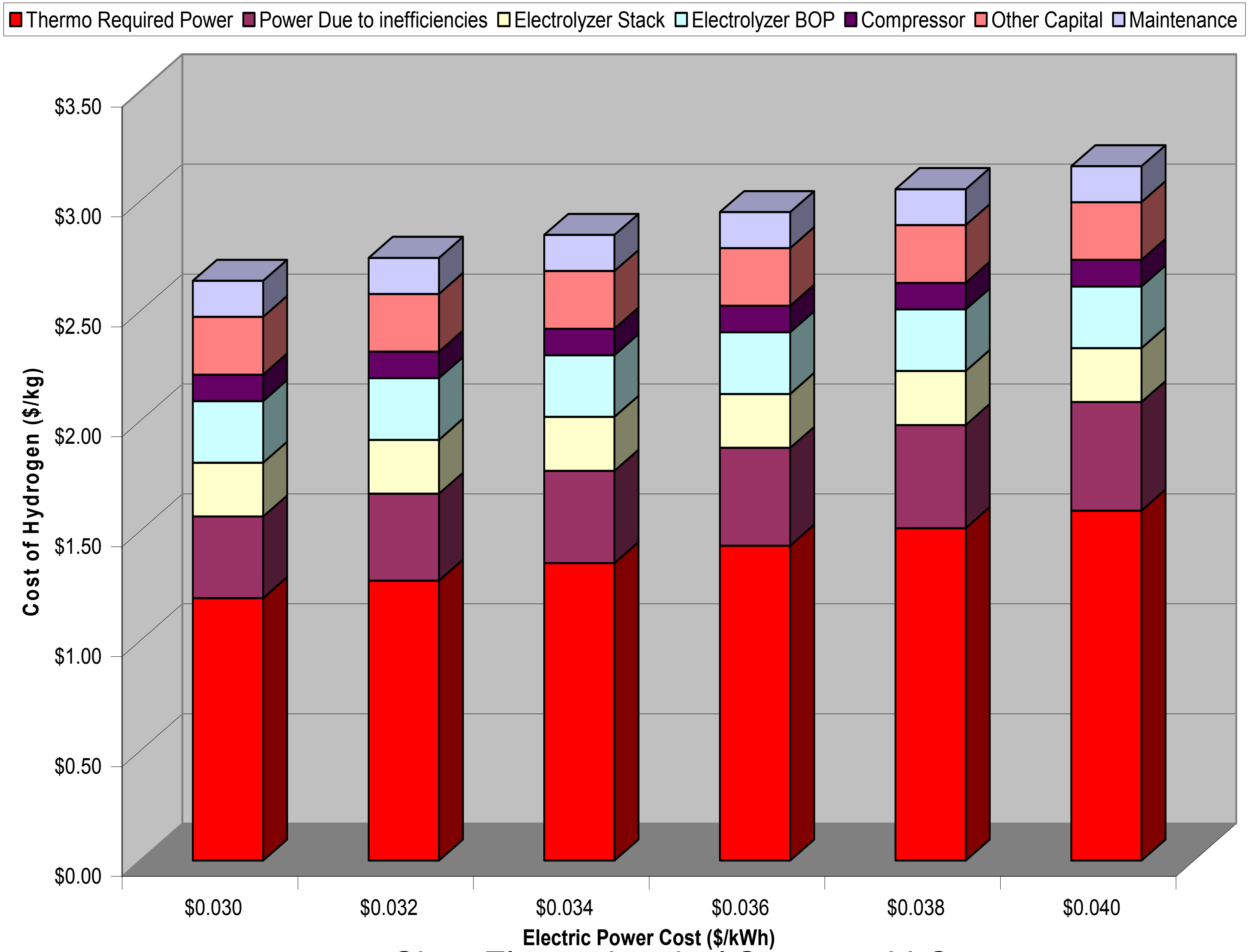
Objectives- Past Year

- 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



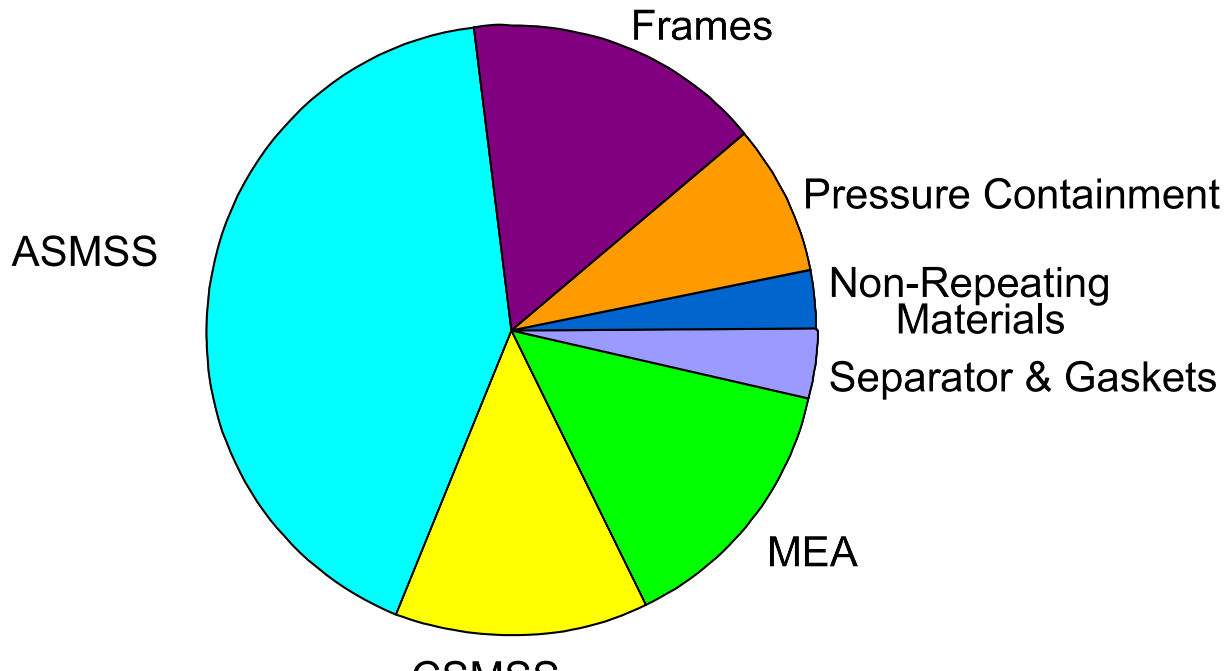
- To meet DOE target of $2.85/kg H_2
  - Electricity < $0.036/kWhr
  - Installed equipment cost < $1100/kW
  - Plant operated at 90% capacity
  - 10 year life
- To meet installed equipment cost target
  - Large cell active area- reduces number of cells and parts count
  - Moderate pressure (400 psig) 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/cm^2 to 1 mg/cm^2
- 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

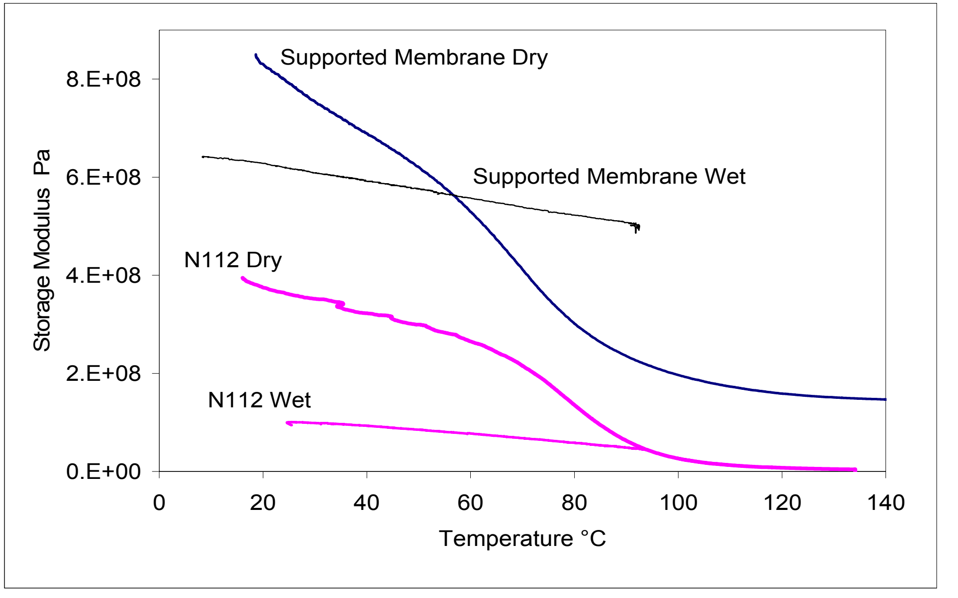
- *Thermoplastic Cell Frame*
  - Conduct fluids into/out of active area
  - Aids in pressure containment
  - Presently these parts are molded, then extensively machined; machining accounts for 95% of part cost
  - GES is working with a Tier 1 automotive component supplier to design new frames and manufacturing 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

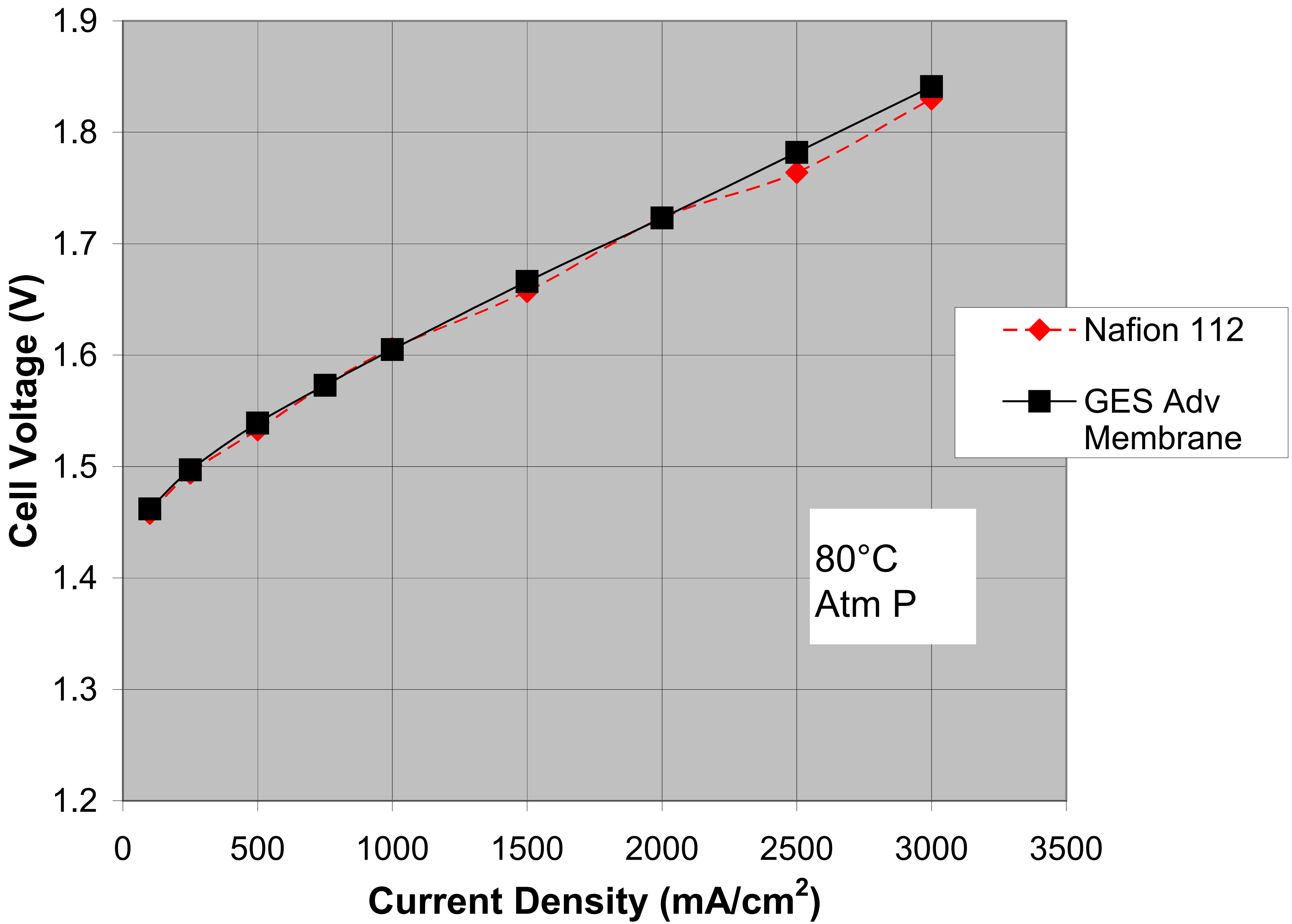
Supported Membrane

- Superior Mechanical Properties
  - No x-y dimensional changes upon wetting/drying or freeze-thaw cycling
  - Much Stronger, Resistance to tear propigation
  - 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



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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 ft^2 from present 0.17 ft^2

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