2008 Hydrogen Program

Annual Merit Review Meeting

Low Cost, High Pressure Hydrogen Generator

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Project ID# PD10

This presentation does not contain any proprietary or confidential information

Overview

Timeline

- Project Start: Jan 2003
- Project End: Dec 2007
- Percent Complete: 100

Budget

- **Total Project Budget: $2.27M**
  - **DOE Share: $1.122M**
  - **Cost Share: $1.147M**
- **FY07 Funding**
  - **DOE: $110K**
  - **Cost Share : $103K**
- **FY08 Funding: $0**

Barriers

Hydrogen Generation by Water Electrolysis

- G. Capital Cost
- H. System Efficiency

Targets

DOE TARGETS: Distributed Water Electrolysis				GES STATUS	
Characteristics/units	**2005**	**2012**	**2017**	**2003**	**2007**
Hydrogen Cost ($/gge)	4.75	3.70	<3.00	7.37	4.76
Electrolyzer Cap. Cost ($/gge)	2.47	0.70	0.30	5.42	2.14
Electrolyzer Cap. Cost ($/kW)	600	400	125	>2500	987
Electrolyzer Cell Efficiency	68	76	77	61	67

Partners

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

Project Objectives

Overall Project

- Develop and demonstrate a low-cost, moderate-pressure PEM water electrolyzer system
  - Reduce stack capital costs to meet DOE targets
  - Increase electrolyzer stack efficiency
  - Demonstrate 1200 psig electrolyzer system

Past Year

- Field test electrolyzer system at NREL

Advantages of GES PEM Electrolyzer

PEM electrolyzers have higher stack efficiency than alkaline systems

- Electricity is the key cost component in electrolyzer systems.
- With advanced membrane demonstrated 1.70V at 1750 mA/cm^2 Stack efficiency = 74% based on LHV).

	Performance	Stack Electric cost ($/gge @ 3.9¢/kWh)
GES PEM	1.70V @ 1750 mA/cm^2	1.74
Alkaline	Typically >1.85V at 300-400 mA/cm^2	~2.50

- Operation at higher current density partially offsets higher cost/area of PEM electrolyzer
- GES PEM differential pressure technology produces H_2 at moderate to high pressure with O_2 production at atmospheric pressure
  - Eliminates handling of high-pressure O_2, reducing system cost & complexity, and improving safety
- Cost is benefited by advances in PEM fuel cell technology

Milestones FY2007

Jan 07

Complete fabrication of low-cost stack components

May 07

Assemble & test modified stack with decreased parts-count per cell

40 to 16 parts/cell

>2500 to <1000$/kW

July 07

Incorporated low cost stack in modified system

Sep 07 – Apr 08

Field testing at NREL

Approach

- Develop lower-cost materials and fabrication methods for cell components
  - Replace high-cost metal components with other materials
  - Develop fabrication methods suitable for large-scale fabrication
  - Reduce parts count/cell
- Increase operating current density to reduce cell active area (reduce stack cost) while retaining high efficiency
  - Evaluate trade-off of efficiency vs. capital cost
  - Develop high-efficiency membrane
  - Reduced catalyst loadings
- System innovations to replace high-cost, high maintenance components
- Emphasize safety in design and operation

Stack Cost Reduction Progress

- *Anode/Cathode Side Membrane Support Structure*
  - Prior ASMSS design consisted of 9 metal parts. which are individually cut, plated, welded, cut again and assembled; CSMSS, similar in design, incorporated expensive valve metals
    - Successfully incorporated single-piece CSMSS metal part
    - A single-piece ASMSS part demonstrated acceptable pressure drop in A 160-cm^2 cell and demonstrated stable electrolyzer performance. Further development required for larger stacks.

Stack Cost Reduction Progress

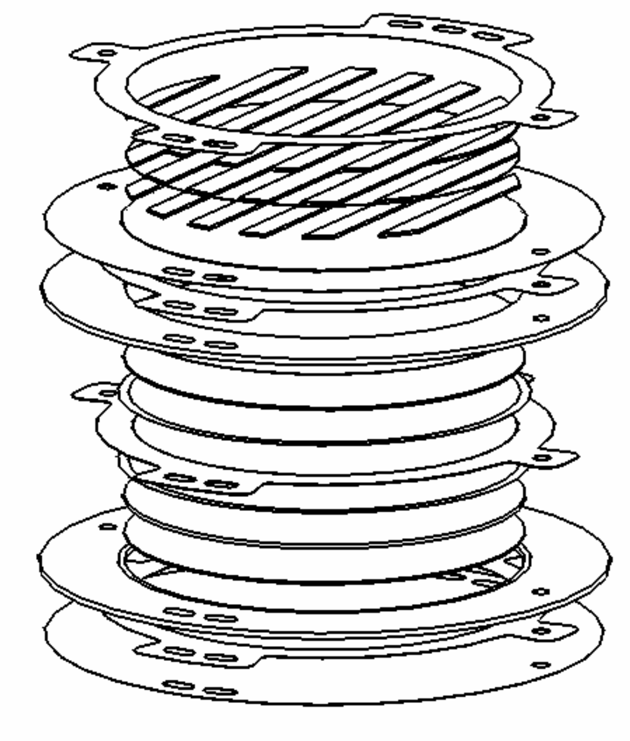
- *Thermoplastic Cell Frame Enhancement*
  - Conducts fluids into/out of active area
  - Aids in pressure containment- highly stressed component
  - Presently these parts are molded and machined; machining accounts for 95% of part cost
    - GES developed molding process, low-cost fabrication method that eliminates machining.
    - Molding process reduces cell cost by 40%

Stack Cost Reduction Progress

- *Cell Separator*
  - Key component that must be compatible with high-pressure hydrogen on one side and oxygen at high potential on the other
  - Previous technology was a very expensive part consisting of two different valve metals
  - Evaluated several approaches for lower-cost part
    - Carbon coating on a titanium separator to reduce hydrogen embrittlement
      - Difficult to obtain an impervious, pinhole-free coating
    - Metal oxide coatings on titanium to reduce hydrogen-embrittlement
    - Short-term solution is a two-piece titanium separator
      - Projected to have lifetime of 5000 hours
      - Longer life separator needs to be developed

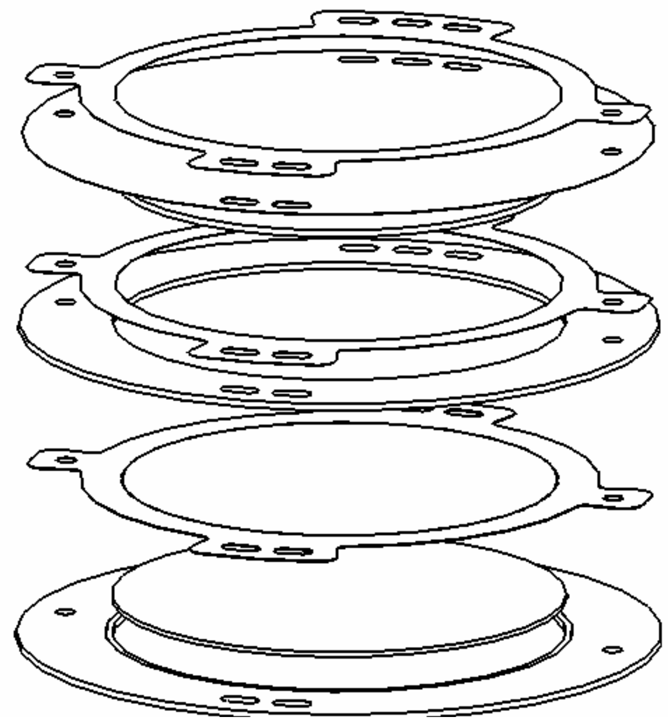
Progress in Part Count Reduction

2002



40 + Parts

Present Goal (2006)



16 Parts

Increasing Operating Current Density - Progress

- High-current-density operation reduces stack active area, and therefore stack cost
  - Thin membranes have low resistance, allowing efficient operation at high current densities. Thinner membranes operating at higher temperatures are required to achieve the DOE efficiency
  - Drawback is poor mechanical properties, limiting operation to moderate differential pressures

    - GES has reduced the thickness of the Nafion membrane used from 10 mils to 7 mils, and has demonstrated performance and short-term life of a 5 mil Nafion membrane in a short stack at 400 psid

    - 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 wet/dry or freeze-thaw cycling
  - Much Stronger Resistance to tear propagation
  - Superior to PTFE based supports
    10x stronger base properties
- Ease of MEA/Stack configurations
  - Direct catalyst inking onto membranes
  - Possible to bond support structures into bipolar frame to eliminate sealing issues
- Customized MEAs
  - Provide more support at edge regions and/or at ports

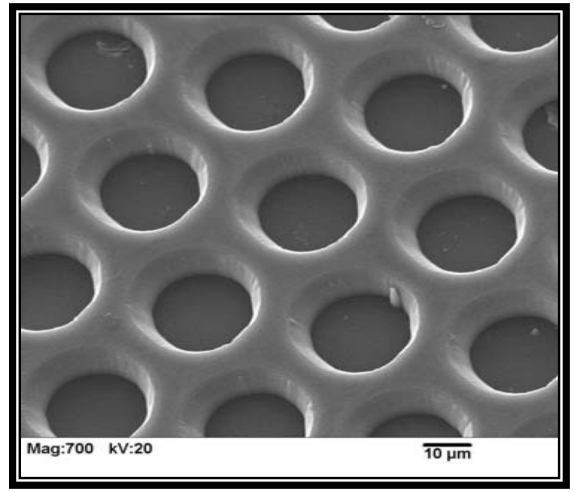


Figure 1. Scanning Electron Microscope (SEM) micrograph of the polymer membrane support structure with definable straight hole pattern

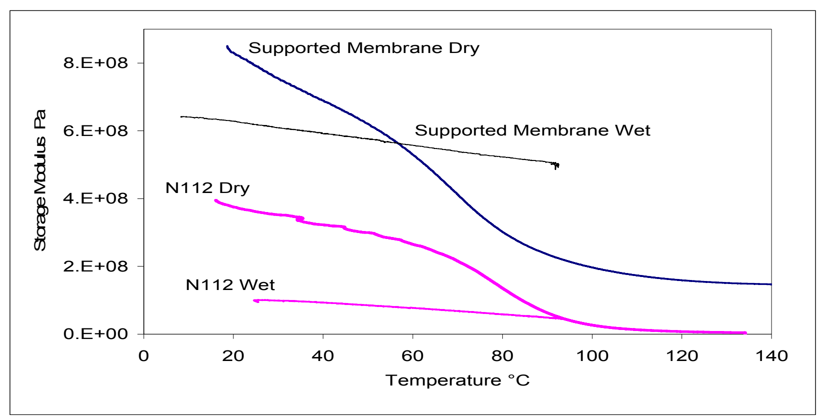
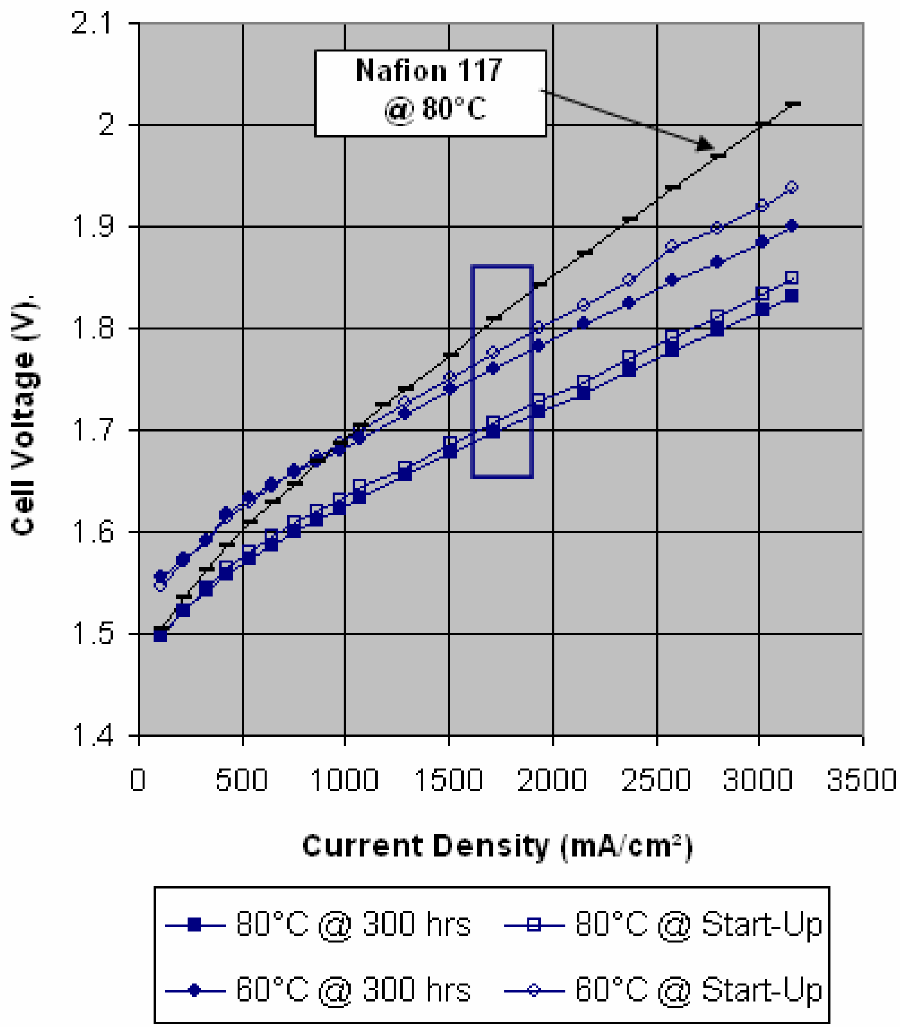


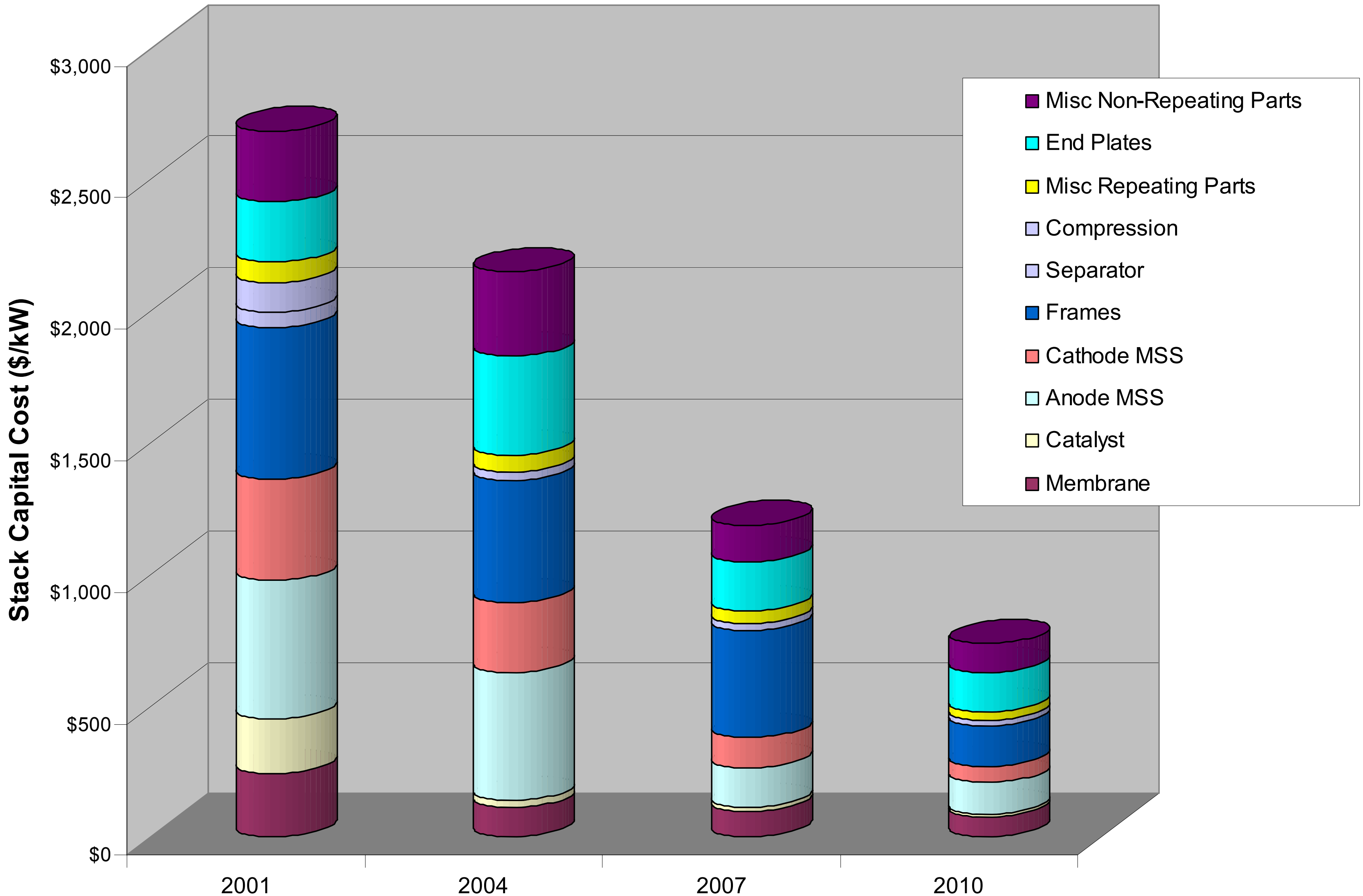
Figure 2. Dynamic Mechanical Analysis (DMA) shows the modulus of the novel supported membrane is ~10 X higher than the N112 membrane.

Demonstration of Advanced Membrane in 160-cm^2 cell



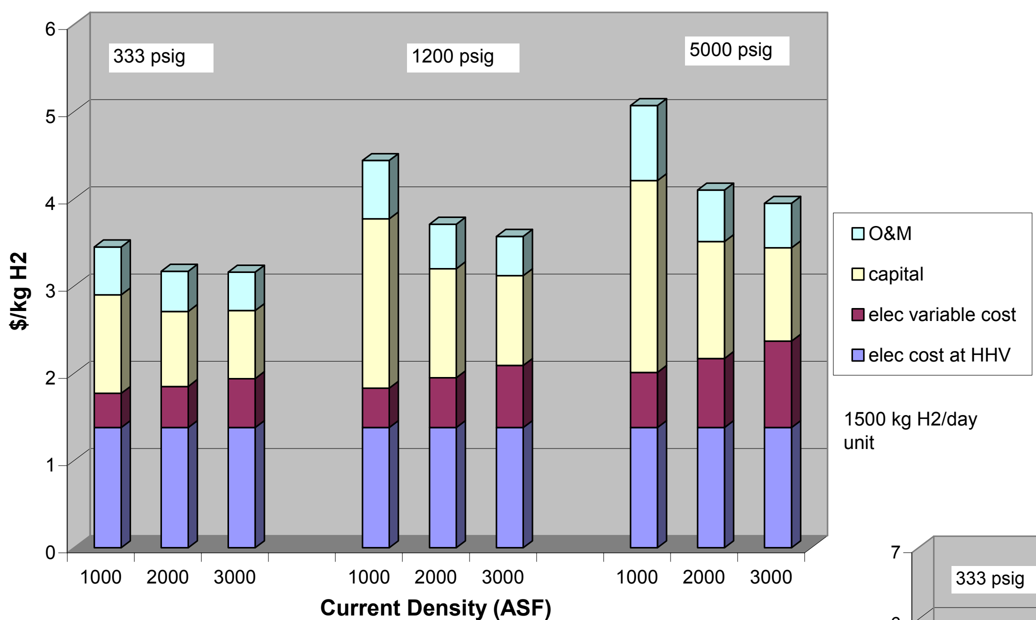
- **Performance of the Advanced DSM is superior to that of Nafion 117**
  - DSM has demonstrated stable short-term operation
  - Membrane is expected to be highly durable; this need to be verified
  - Further development required to decrease fabrication costs

Progress in Stack Cost Reduction



H2A Model Results

H2 Cost Breakdown (elec= $.035/kWh)



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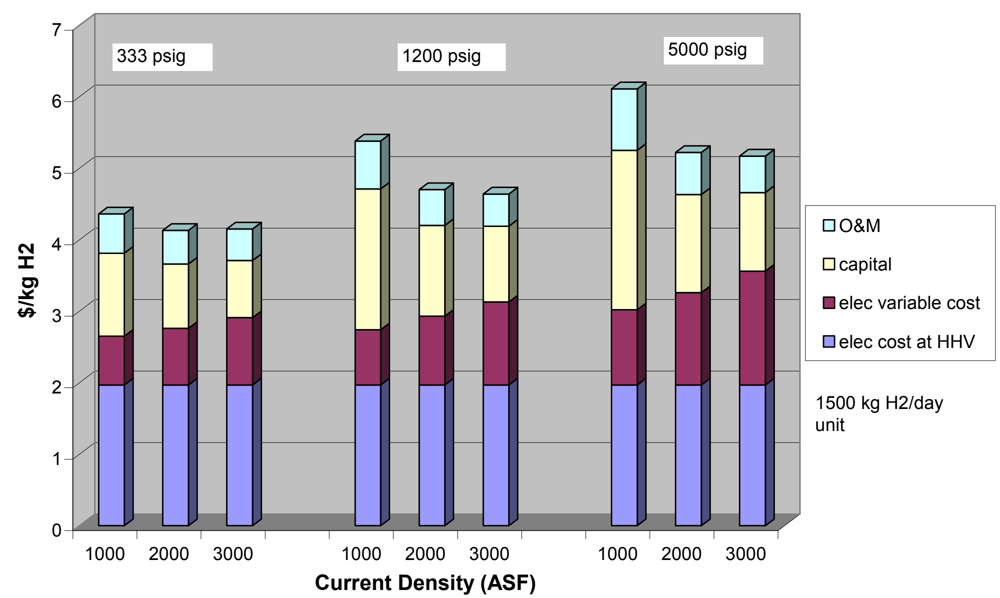
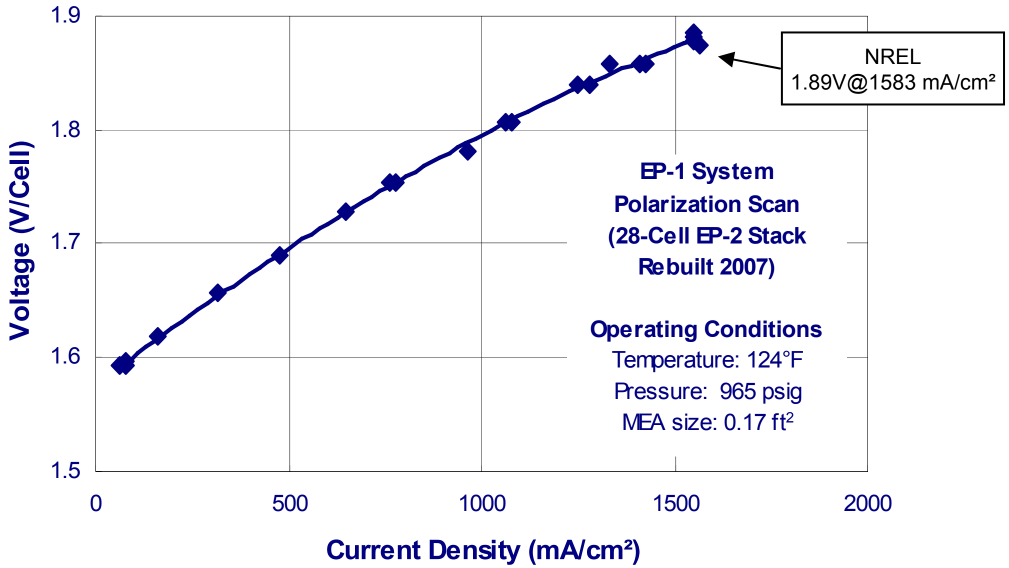


- Lowest cost H_2 at lowest pressure
- Higher pressure requires additional sealing components, smaller diameter
- Lower cost at 2000 - 3000 mA/cm^2 (tradeoff of efficiency vs. capital cost)
- Can achieve ~$3.00/kg at 3.5¢ electricity

Demonstrated System at NREL

- System Evaluation at NREL - Summer 07
- System produces 0.25 kg/hr at 1200 psig
- High –performance stack
  - 28 cells
  - 12.8 kW input power
  - Incorporates the low-cost components developed in this program



Future Plans

- FY2008
  - NREL completing testing of system to verify hydrogen production rate
- Work is being continued under new project
  - Development of low cost, high efficiecy membrane
  - Continued reduction of stack capital costs and stack scale-up to 290 cm^2 active area

Summary

- GES PEM Electrolyzer has potential to meet DOE cost and performance targets
- GES has made significant progress in stack cost reduction
- Further development of a high-strength, high efficiency membrane is recommended
  - Demonstrate reproducibility and durability
  - Decrease fabrication cost
- Development of a low-cost long-life separator is required