2009 Hydrogen Program

Annual Merit Review Meeting

PEM Electrolyzer Incorporating an Advanced Low Cost Membrane

Monjid Hamdan

Giner Electrochemical Systems, LLC

May 20, 2009

Project ID# pd_21_hamdan

Overview

Timeline

- **Project Start:** May 2008
- **Project End:** May 2011
- **Percent Complete:** 30

Budget

- **Total Project Budget: $2.49M**
  - **DOE Share:** $1.99M
  - **Cost Share:** $0.51M
- **FY08 Funding**
  - **DOE: $650K**
  - **Cost Share : $162K**
- **FY09 Funding**
  - **DOE: $230K**

Barriers

Hydrogen Generation by Water Electrolysis

- **G. Capital Cost**
- **H. System Efficiency**

Targets

DOE TARGETS: Distributed Water Electrolysis			
Characteristics/units	**2006**	**2012**	**2017**
Hydrogen Cost ($/kg-$H_2$)	4.80	3.70	<3.00
Electrolyzer Cap. Cost ($/kg-$H_2$)	1.20	0.70	0.30
Electrolyzer Efficiency %LHV (%HHV)	62 (73)	69 (82)	74 (87)

Partners

- **Parker Hannifin Corporation** – System Development
- **Virginia Tech University** – Membrane Development

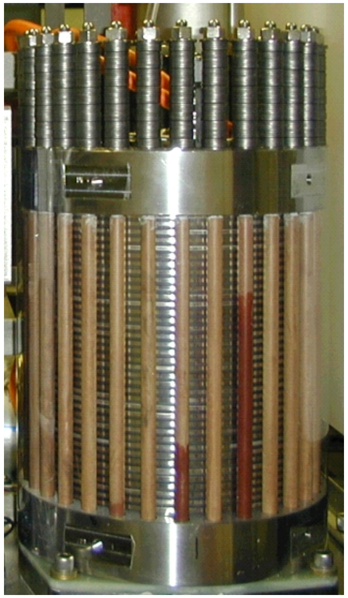
Project Objectives

Overall Project Objectives

- Develop and demonstrate advanced low-cost, moderate-pressure PEM water electrolyzer system to meet DOE targets for distributed electrolysis.
  - Develop high efficiency, low cost membrane
  - Develop long-life cell-separator
  - Develop lower-cost prototype electrolyzer stack & system
  - Demonstrate prototype electrolyzer system at NREL

FY08-09 Objectives

- Develop Low-Cost, High-Efficiency, High Strength Membrane
  - Electrochemical performance comparable to thin Nafion® (N1135)
  - High strength to allow operation at 300 psig and 80-90°C
- Initiate cell-separator development
- Complete preliminary system design and development of lower-cost components



Milestones

FY08 Go/No Go Decision Points (May 09)

Milestones	Progress Notes	% Complete
Membrane: Demonstrate DSM™ membrane performance comparable to or better than that of Nafion® 1135 at 80°C	**DSM™:** Completed 1000 hrs @ 80°C. Testing indicates low membrane degradation rate, high life expectancy Performance DSM™ > Nafion®1135; ~Nafion® 112	**100%**
Demonstrate electrolyzer lifetime with DSM™ membrane (80°C ≥ 1000 hrs)	**BPSH:** Cell Voltage Performance > Nafion®112	**100%**
Cell-Separator: Demonstrate performance comparable to dual-layer Ti separator	Life testing and H_2-embrittlement tests confirm longevity of Carbon/Titanium cell-separators.	**100%**
System Development: Complete preliminary design review	P&ID Diagram √ Process Flow Diagram (PFD) √ Control Diagrams √ Safety Review √ System Layout and Packaging CDR	**56%**

Membrane Development Approach

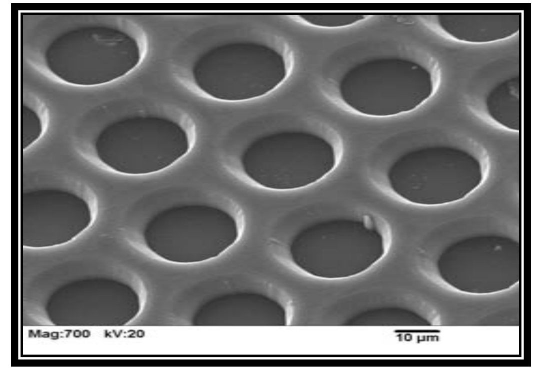
- Further develop and combine two approaches under development for PEM fuel cell membranes:
  - DSM™ high-strength, high-efficiency membranes -GES
    - PFSA ionomer incorporated in an engineering plastic support
    - Evaluate 2D and 3D supports
  - Advanced hydrocarbon membranes- Virginia Tech
    - Bi Phenyl Sulfone, H form (BPSH)
    - Random or Block copolymers

DSM™ Membrane

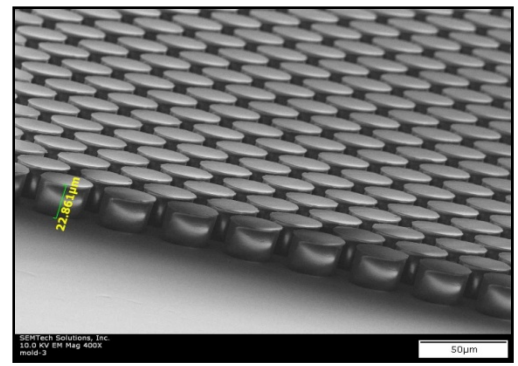
Supported Membrane Approach

- ***GES*** DSM^{TM} high-strength, high-efficiency membranes
  - PFSA ionomer incorporated in an engineering plastic support (2D & 3D)
    - 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
  - Optimize membrane
    - Ionomer EW and thickness
    - Scale-up fabrication methods and techniques

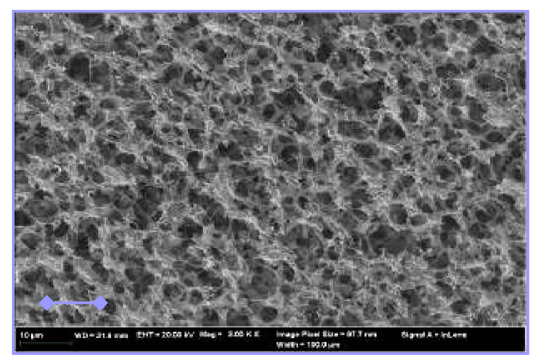
DSM^{TM} Supports



2D “Laser”



2D “Cast”



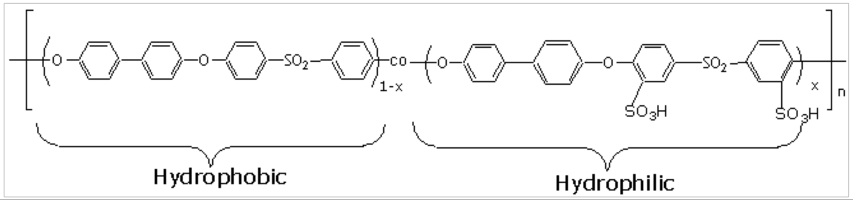
3D “Commercial”

Scanning Electron Microscope (SEM) micrograph of the polymer membrane support structures

BPSH Membrane

Advanced Hydrocarbon Membranes Approach

- ***Virginia Tech*** Bi Phenyl Sulfone, H form (BPSH)
  - Wholly aromatic
    - Strong acid resistance
  - Inexpensive starting materials
  - Form disulfonate monomer, then random or block copolymerization
  - Determine optimum sulfonation level
    - Trade-off between conductivity and mechanical properties
    - 35 mole% disulfone units provides conductivity comparable to N112
    - Evaluate up to 50 mole% disulfone
  - Consider incorporating BPSH into DSM™ supports



❖ **Acronym: BPSH-xx-*Mx***

Bi Phenyl Sulfone: H Form (BPSH)

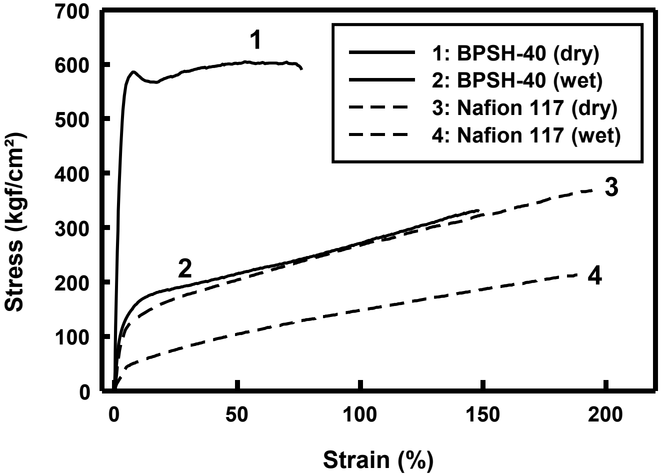
xx= molar fraction of disulfonic acid unit, e.g., 30, 40, etc.

Mx: Acidification method, e.g., *M1*, etc.

❖ **Acidification Treatment**

Method 1: 1.5M H_2SO_4, 30°C, 24hrs, then deionized H_2O, 30°C, 24hrs.

Method 2: 0.5M H_2SO_4, boil, 2hrs, then boiled deionized H_2O, 2hrs.



BPSH has a higher Modulus and strength than N117

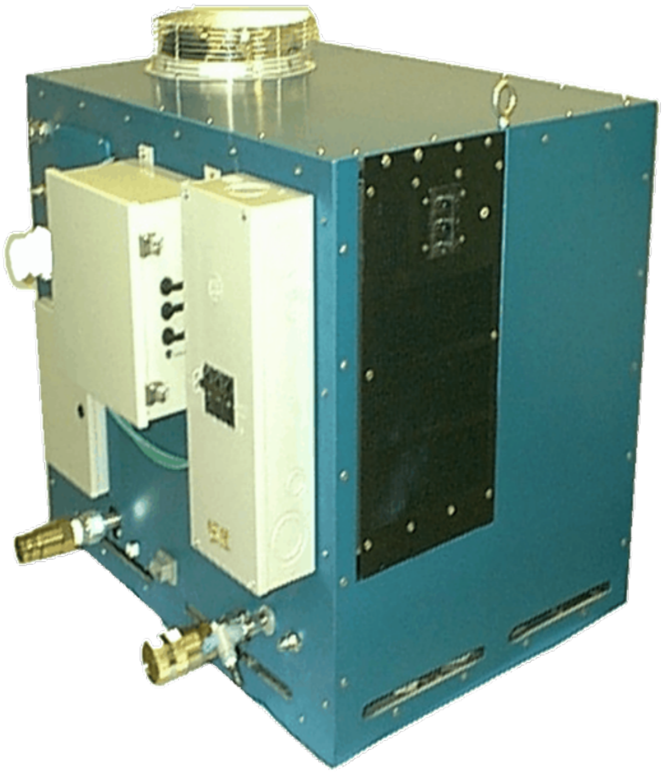
High Durability Cell-Separator Approach

- **Requirements**
  - Gas-impermeable (separates H_2 and O_2 compartments)
  - High electrical conductivity and high surface conductivity
  - Resistant to hydrogen embrittlement
  - Stable in oxidizing environment
  - Low-Cost
- **Legacy Design**
  - Multi-Layer piece consisting of Zr on hydrogen side and Nb on oxygen side
- **Single or Dual-Layer Ti separators have been used**
  - Ti subject to hydrogen embrittlement
  - Lifetime limited to <5000 hours, depending on pressure and operating conditions
- **Approach**
  - Develop a new low-cost dual-layer structure
    - Evaluate methods of bonding dissimilar metal films
    - Evaluate non-metal substrate with conductive coating

Designing Low Cost Electrolyzer System - Approach

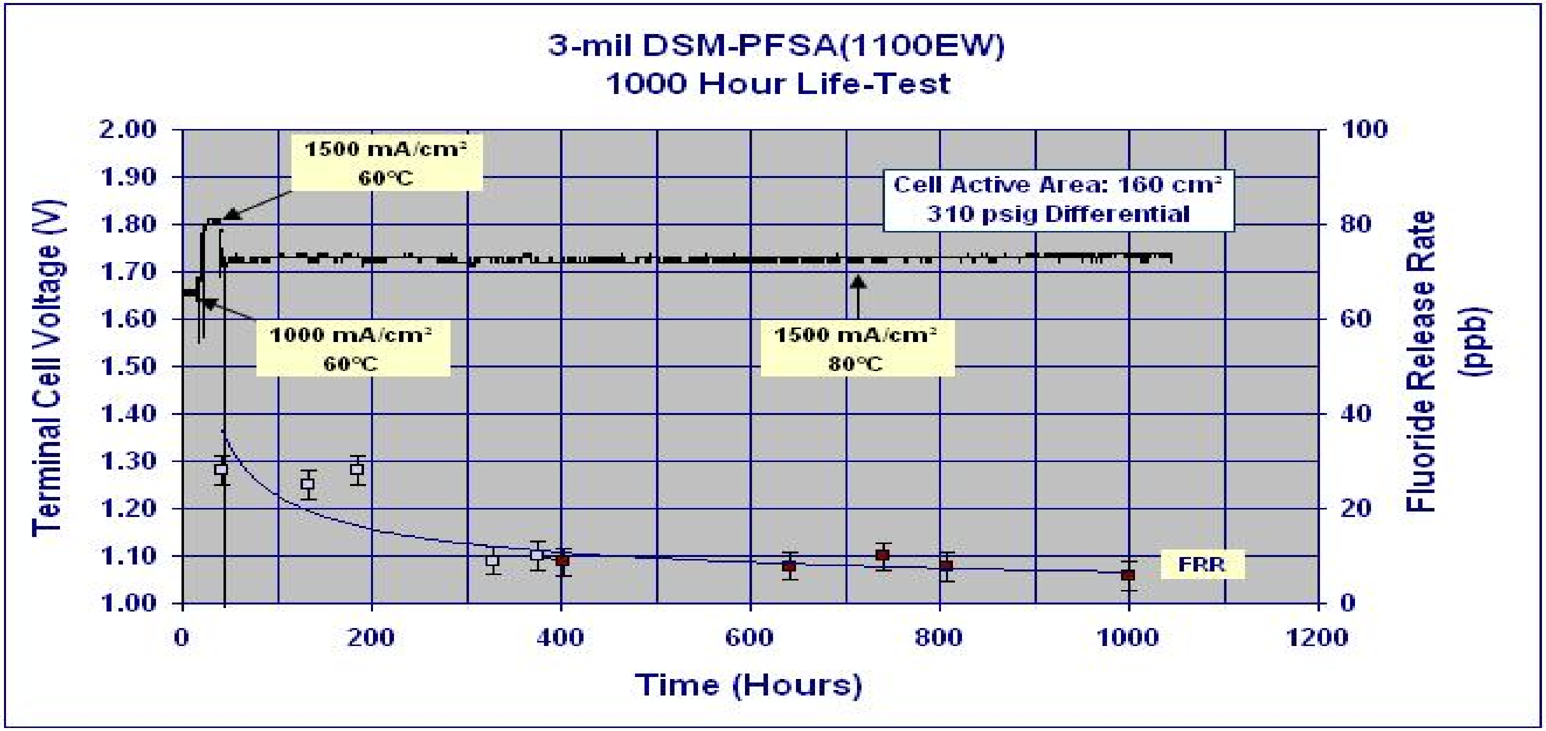
- **Objectives**
  - Reduce BOP capital cost
  - Reduce BOP power consumption
  - Increase stack active area
  - Improve safety and reliability
  - Design for high-volume manufacturing

- **Approach**
  - Team with large volume commercial manufacturer (domnick hunter group of **Parker-Hannifin**)
  - Redesign system to eliminate or replace costly components
  - Laboratory evaluation of lower-cost components and subsystems
    - Design & test high efficiency H_2 dryer
  - Develop higher efficiency power electronics



Membrane Progress

Supported Membrane

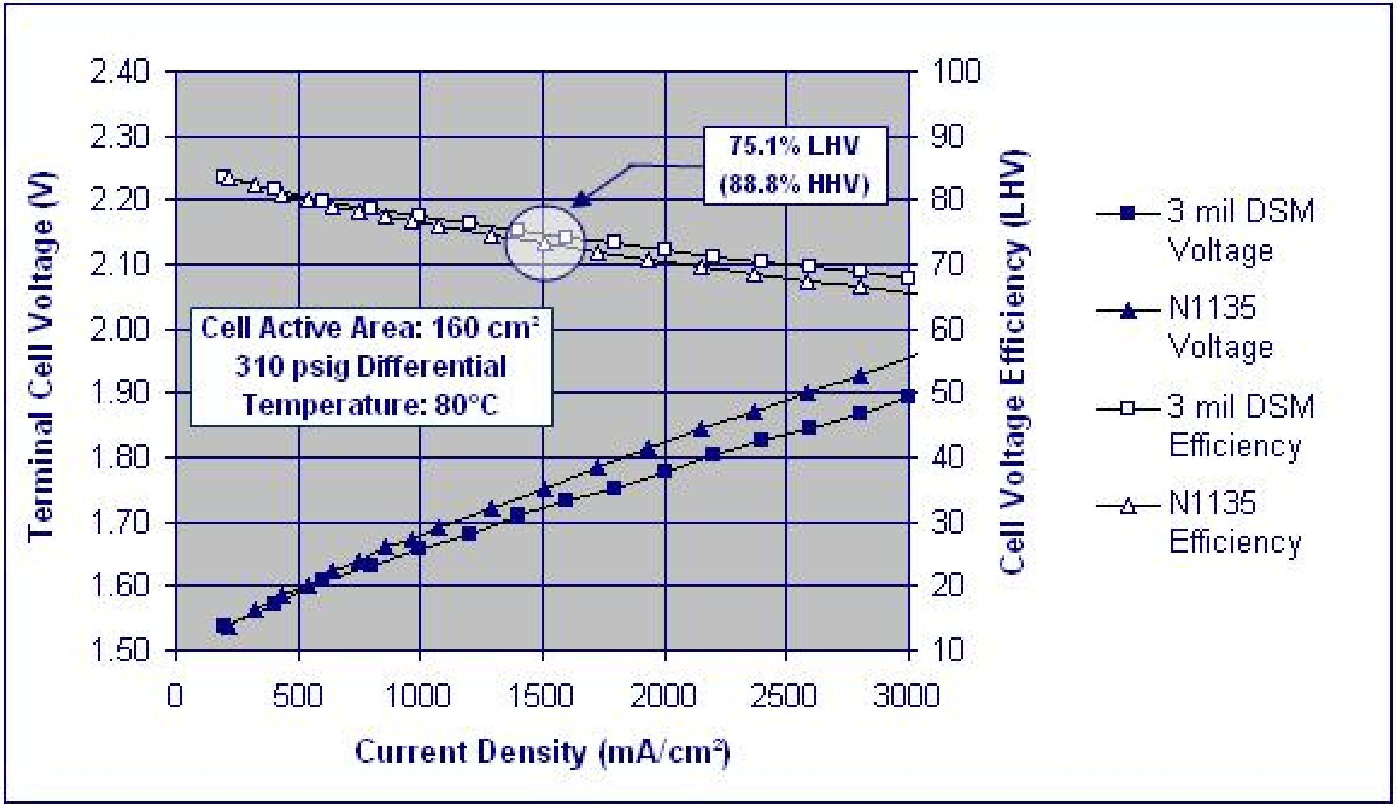


- **Membrane Performance**
  @ 80°C & 240Amps(1500 mA/cm²)
  - Voltage:1.71-1.73V
  - Efficiency: 75.1% LHV (88.8% HHV)
  - Completed 1000 Hour Life Milestone
- **Membrane Degradation**
  - F ion Release Rate: 3.7 µg/hr
  - Life Time Estimate: 45-55,000 hours

Membrane Progress

Supported Membrane

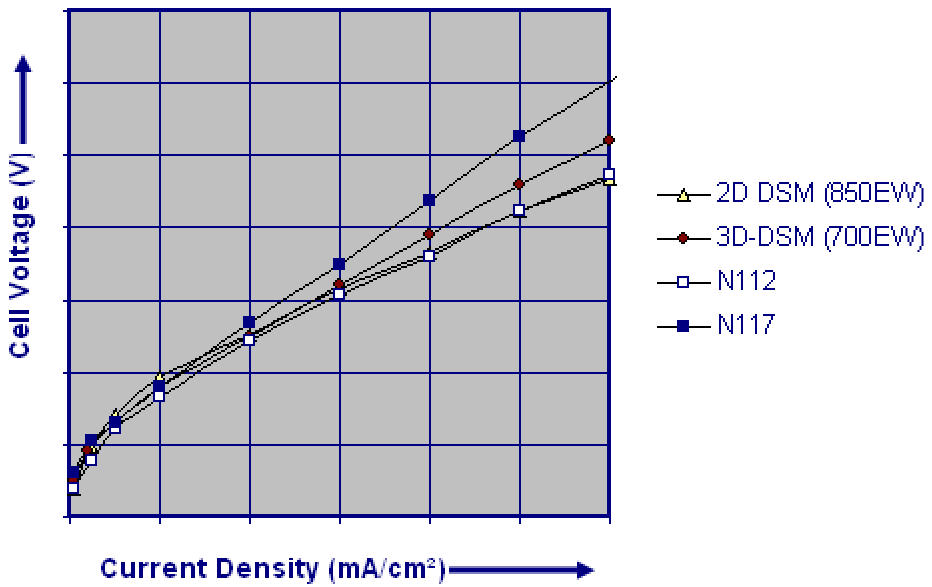
Performance Milestone
3-mil DSM™ (PFSA-1100EW) vs. Nafion® 1135



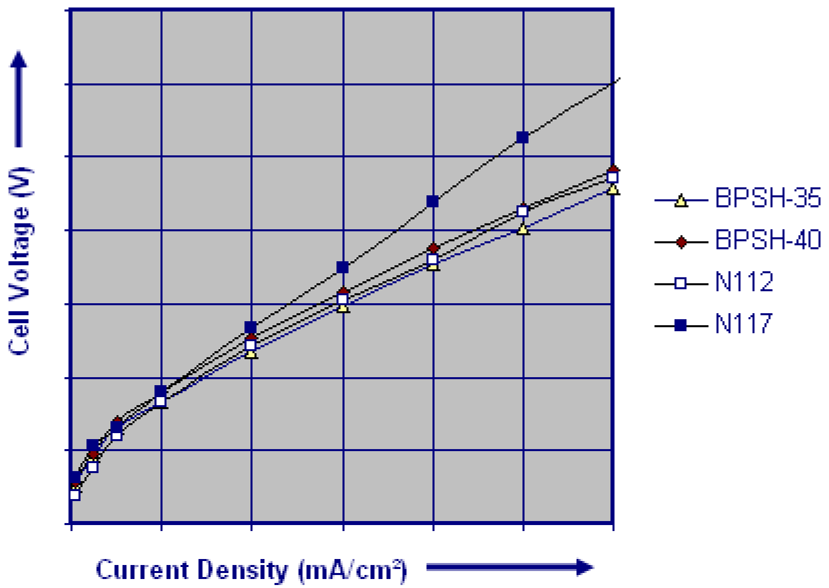
Membrane Progress

Evaluation in 50cm² Hardware

DSM™ Results



BPSH Results

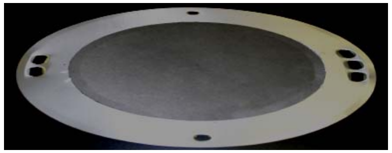


- **Membrane Evaluation**
  - 50cm² Single-Cell Testing, 95°C, 1200 mA/cm²
  - Performance
    - 2D DSM™ Performance equivalent to Nafion® 112
    - 3D DSM™ equivalent to Nafion® 115
    - BPSH35 > Nafion® 112

Cell-Separator Progress

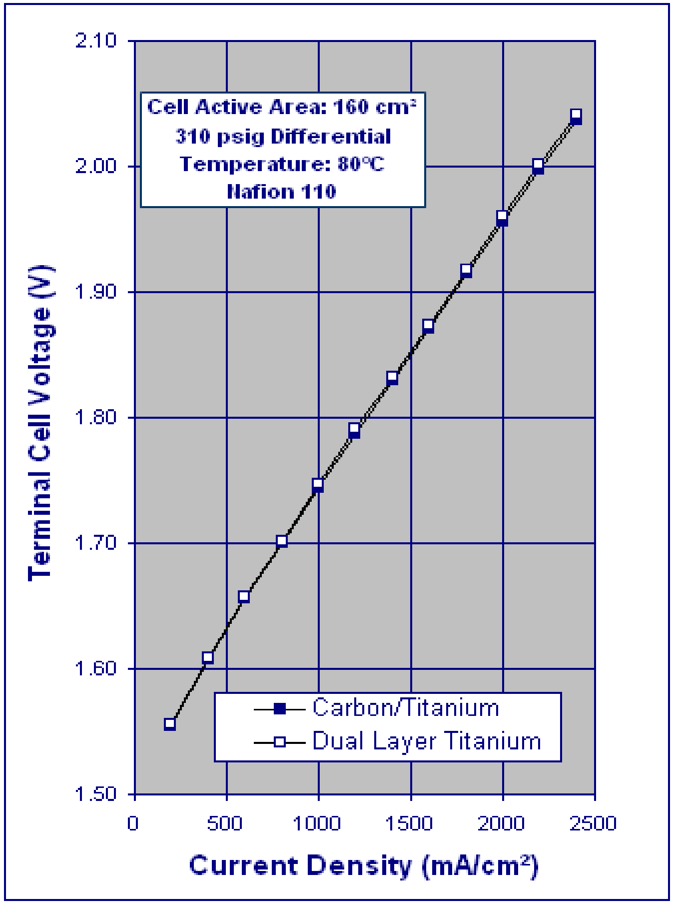
Separator Fabrication & Evaluation

Zr/Ti & ZrN/Ti



Carbon/Ti

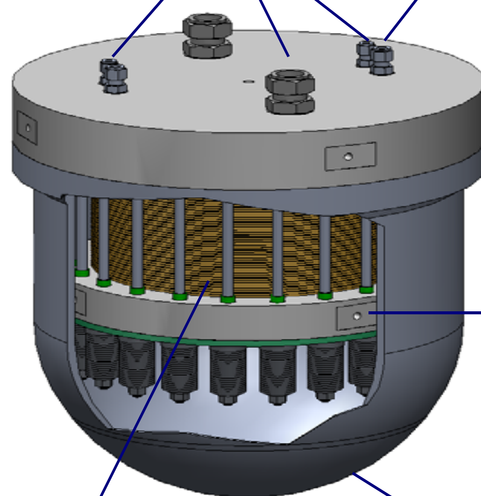
- Properties
  - Conductivity (S/cm) > 300
  - Low Porosity
    - POCO Pyrolitic Graphite (Surface Sealed)
- Evaluation (500 hrs)
  - Zr/Ti & ZrN/Ti coating loss
  - Water Quality
    - Zr/Ti & ZrN/Ti: 1.5 MΩ
    - Carbon/Ti: 14.7 MΩ
  - Hydrogen embrittlement analysis
    - Zr/Ti & ZrN/Ti: 140 & 31ppm H_2
    - Carbon/Ti: 64ppm H_2
    - Dual Layer Ti: 1105 ppm H_2

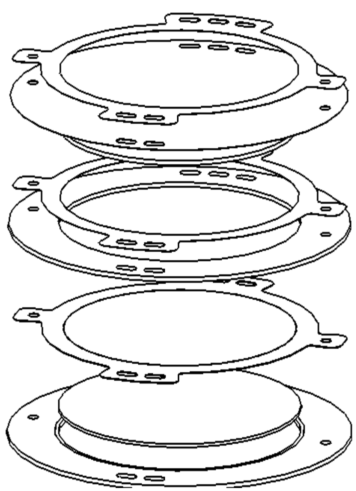


Performance Milestone

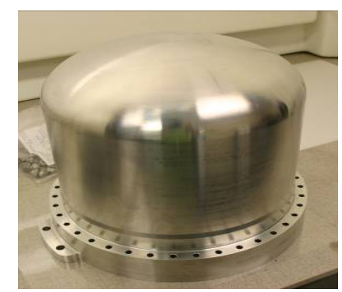
Preliminary Stack Design Progress

- Cell active area increased to 290cm^2
- 22-25 Cells
- Pressurized Safety Dome (300-500 psi)





Repeating Cell Unit

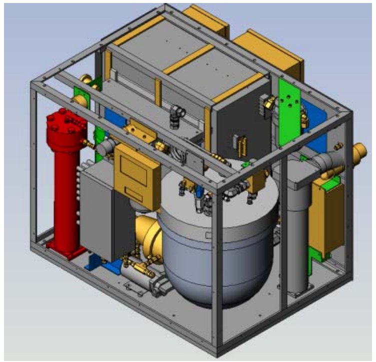


Pressure Dome

Preliminary System Design Progress

- P&ID, PFD, Control Diagrams completed
- Extensive safety review completed
- Component evaluations (Efficiency%)
  - Water Pump: (80%)
    - Multistage centrifugal
    - Larger capacity pumps exhibit higher efficiencies
  - H_2-Dryer: (97%)
    - Dual desiccant w/ vacuum assist
    - Cooling H_2 prior to dryer
  - Rectifier: (93-95%)

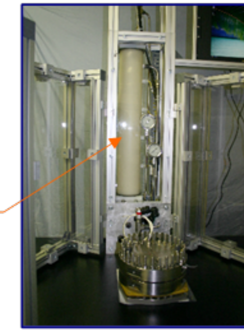
System Design Specifications

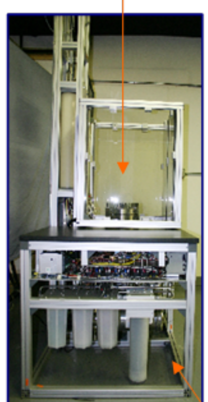


Production Rate	0.5 kg H_2/hr
Operating Pressure	300-400 psid ; H_2 300 psig; O_2 atm
Operating Temperature	50-90°C
Membrane	DSM-PFSA, BPSH, DSM-BPSH
Stack Size	290 cm²/cell, 22-28 Cells
Stack Current Density	1500-2000+ mA/cm²

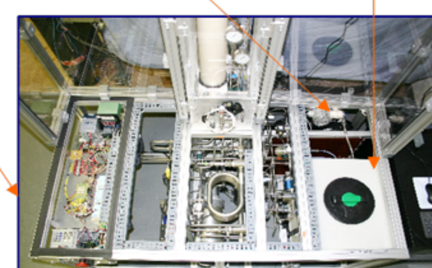
System Progress

Component Evaluation





Side View

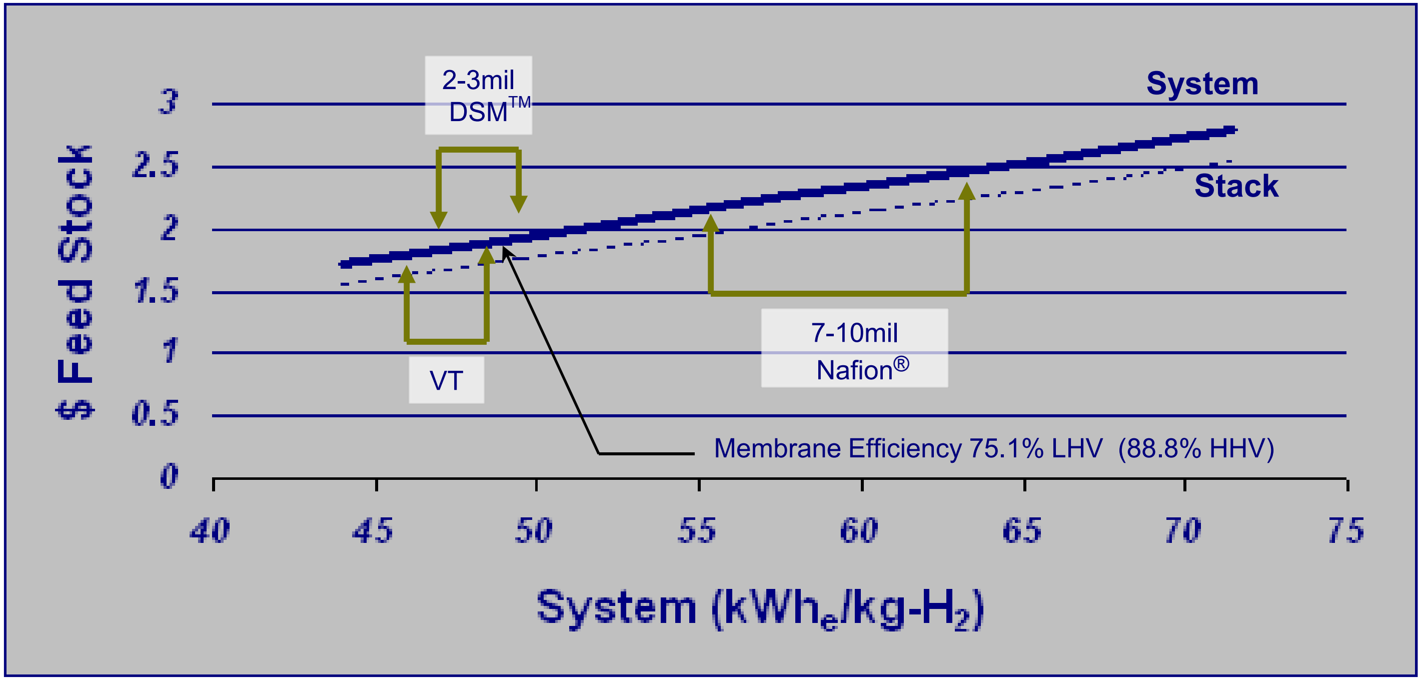


Top (Cover Removed)

Automated Testing

- Stacks; 160-cm² and 290-cm² hardware to 40kW
- Efficiency Evaluation
  - Membrane
  - Subsystems & Components
- Process Evaluation

Membrane vs. Feed Stock Cost



Feed stock costs generated with H2A rev 2.0. Operation @ 1500 mA/cm², 80-90°C. Electric cost = $0.039/kWhr

Projected H_2 Cost

Specific Item Cost Calculation **Hydrogen Production Cost Contribution**				
H2A Model Version (Yr)	Rev. 1.0.11 (FY2007)	Rev. 1.0.11 (FY2009)		Rev. 2.0 (FY2009)
	Includes Delivery			Delivery not included
Capital Costs	$1.78	<$1.47		<$0.86
Fixed O&M	$0.80	<$0.62		<$0.53
Feedstock Costs $1.54 min. @ 39.4 $kWh_e/kg\ H_2$	$2.14 **(N117)**	$1.86 **(DSM^{TM})**		$1.86 **(DSM^{TM})**
Byproduct Credits	$0.00	$0.00		$0.00
Other Variable Costs (including utilities)	$0.04	$0.02		$0.02
Total Hydrogen Production Cost **($/kg)**	**4.76**	**3.97**		**3.28***

* Total cost of delivered hydrogen ($/kg) in H2A Model Rev. 2.0 is $5.20 (Cost of delivery in Rev. 1.0.11 is $0.69; Rev 2.0, $1.92).

H2A Model Analysis Forecourt Model

- Design capacity: 1500 kg H_2/day
- Assume large scale production- costs for 500th unit
- Assume multiple stacks/unit
  - Low-cost materials and component manufacturing
- 333 psig operation. H_2 compressed to 6250 psig
- Operating Capacity Factor: 70%
- Industrial electricity at $0.039/kWhr

Future Plans

- FY2009
  - Continue development of low cost, high efficiency membrane
    - Further exploration of BPSH membrane
      - Random, Block, & Cross-linked copolymers
      - Life-testing of BPSH to determine durability
  - Scale-up of membrane and cell-separator to 290-cm^2
  - Complete electrolyzer stack and system preliminary designs
- FY2010
  - Fabricate deliverable stack
  - Fabricate electrolyzer system

Summary

- GES & VT have made significant progress in membrane development
- GES DSM™ development has
  - Demonstrated reproducibility and durability
  - Improved stack efficiency significantly
- System development efforts are expected to
  - Reduce BOP fabrication costs
  - Increase life of the low-cost, long-life separator
  - Improve BOP components efficiency
- To meet DOE targets for hydrogen production cost, significant cost reductions are still needed in:
  - System
    - Increase Active Area
  - Gas Compression
  - Gas Storage