New York State Hi-Way Initiative

General Electric Global Research Center
22 May 2005

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Project ID #PDP10

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Overview

Timeline

Project start date 1 April 2004

Project end date 30 Dec. 2005

Percent complete 90%

Budget

Total project funding	M$2.1
• DOE share	M$1.4
• Contractor share	M$0.7
Funding received in FY04	M$1.05
Funding for FY05	M$0.35

Barriers addressed

Q. Capital Cost of Electrolysis Systems

T. Renewable Integration

Technical Targets:

2005: Electrolyzed Hydrogen @ $2.50 / kg

2010: Electrolyzed Hydrogen @ $2.00 / kg

Partners

SUNY Albany
Nanotech

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Objectives

- Develop a commercial strategy for low cost alkaline electrolysis
- Demonstrate a laboratory scale proof of concept electrolyzer
- Address market barriers to hydrogen infrastructure development in New York State

Approach

Quantify Market Requirements
- Establish customer and mission profile
- Determine target product size and configuration

Design System
- Set performance targets to meet customer requirements
- Identify technical barriers in development path

Electrochemical Cell Analysis
- Develop and test materials for low cost electrolyzer stack
- Optimize system cost, performance, and reliability

Bench Scale Testing
- Build and test proof of concept system

Full Scale Installation Concept
- Design reference plant

Marketing Study
- Identify opportunities for H2 business acceleration in NY State
- Identify barriers to hydrogen infrastructure implementation

Customer Pull Driving GE Technology Solution

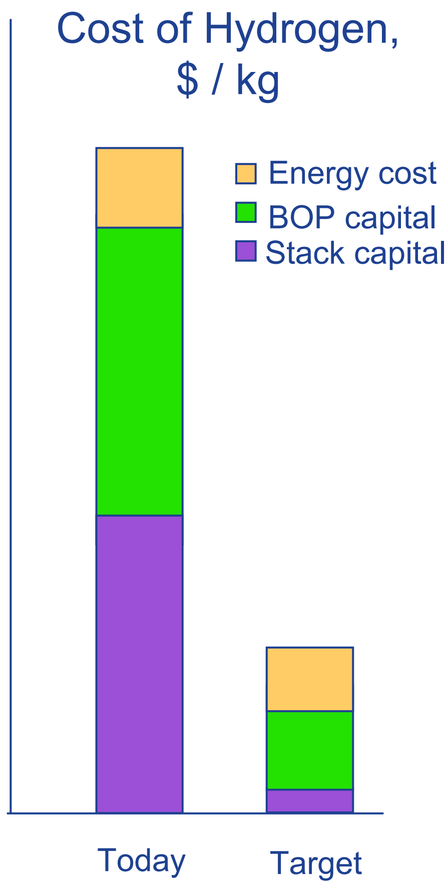
- $2 / kg
- clean H2
- scalable

Utilities

- off-peak asset utilization
- grid support
- distribution growth

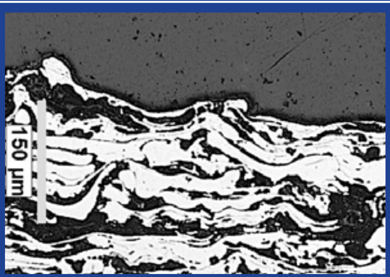
Oil & Gas Companies

- fueling vision
- global reach
- systems expertise



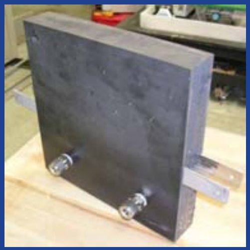
Capital Cost :
Key to Market Entry

Stack Cost-Out Through Technology



high surface electrode

monolithic design



System Cost-Out Through GE Process

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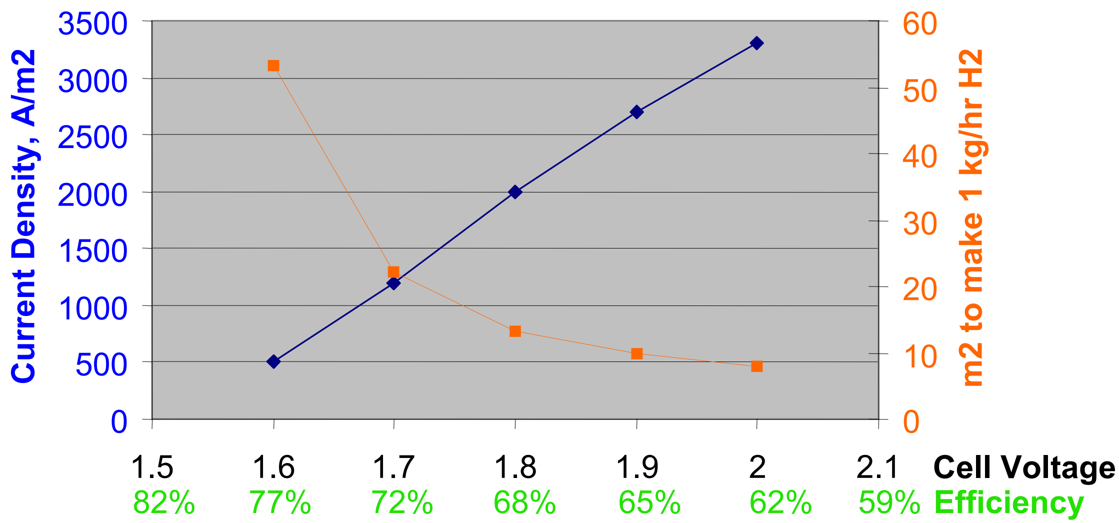
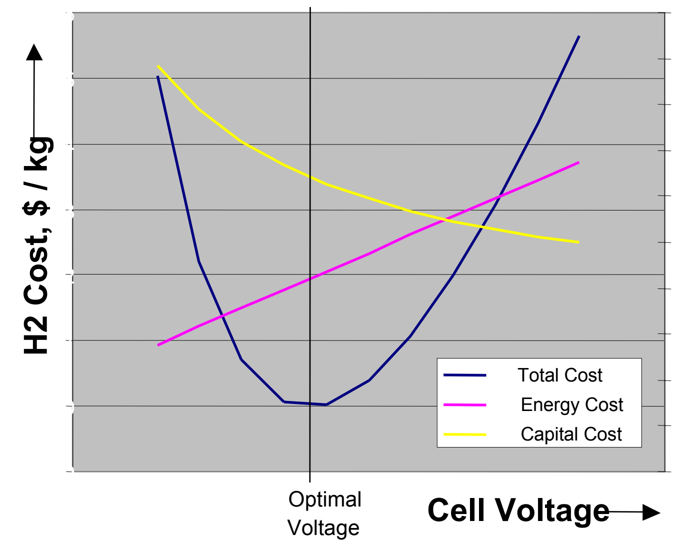
Optimizing H2 Cost Drives Tradeoffs

Voltage / Current Tradeoffs

Baseline IV curve





minimizes energy costs

minimizes capital costs

Lowest cost operating point varies with cost of electricity and specific cost of material

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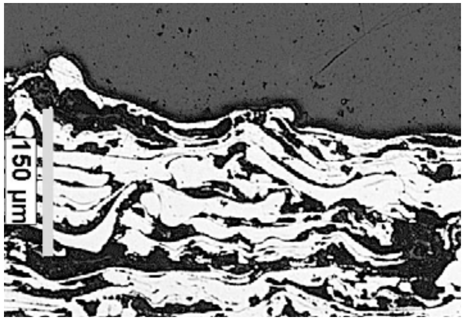
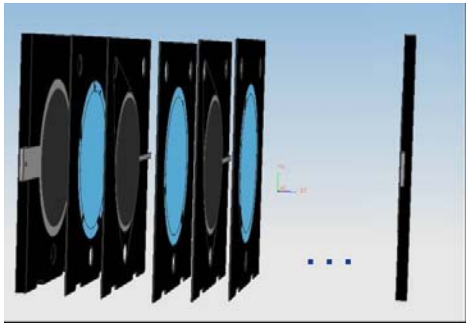
Technology Plan for Stack Cost

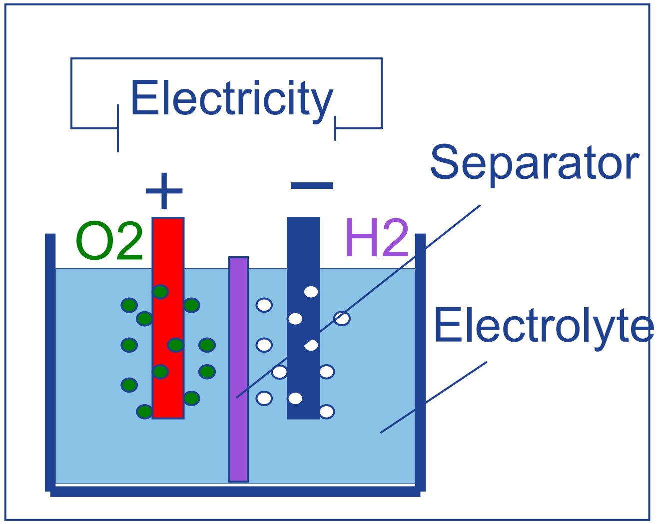
High surface area electrodes minimize stack size



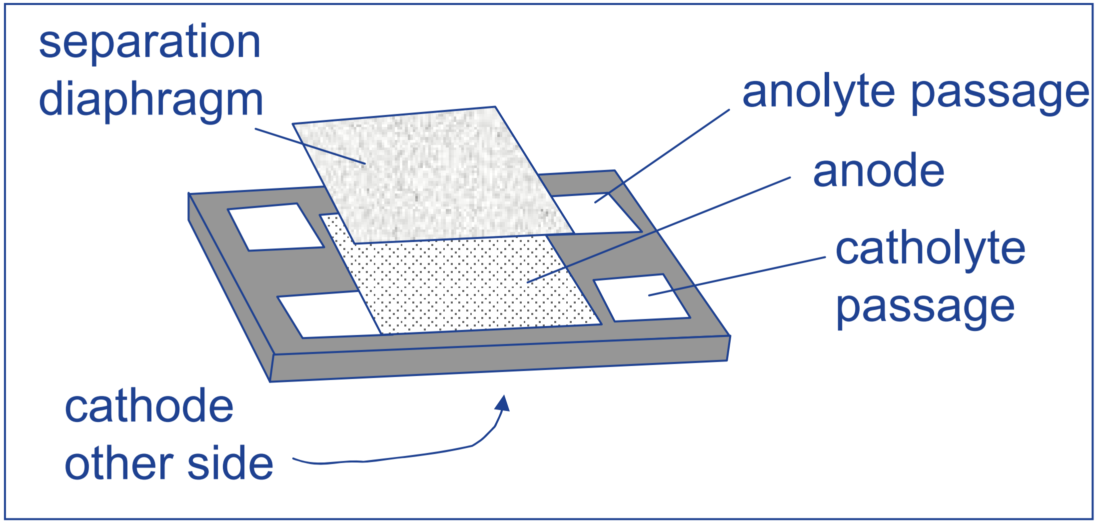
Advanced materials enable low assembly costs



Alkaline Electrolyzer Design Basics



Single Unipolar Cell



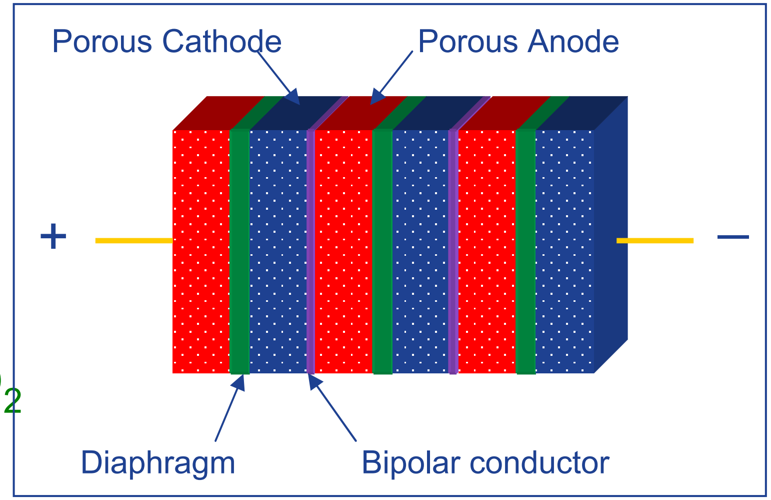
Bipolar type half-cells

<u>Cathode (-)</u>:

$2H_2O + 2e^- \rightarrow 2OH^- + H_2$

<u>Anode (+)</u>:

$2OH^- \rightarrow H_2O + 2e^- + \frac{1}{2} O_2$



Multicell Bipolar Stack

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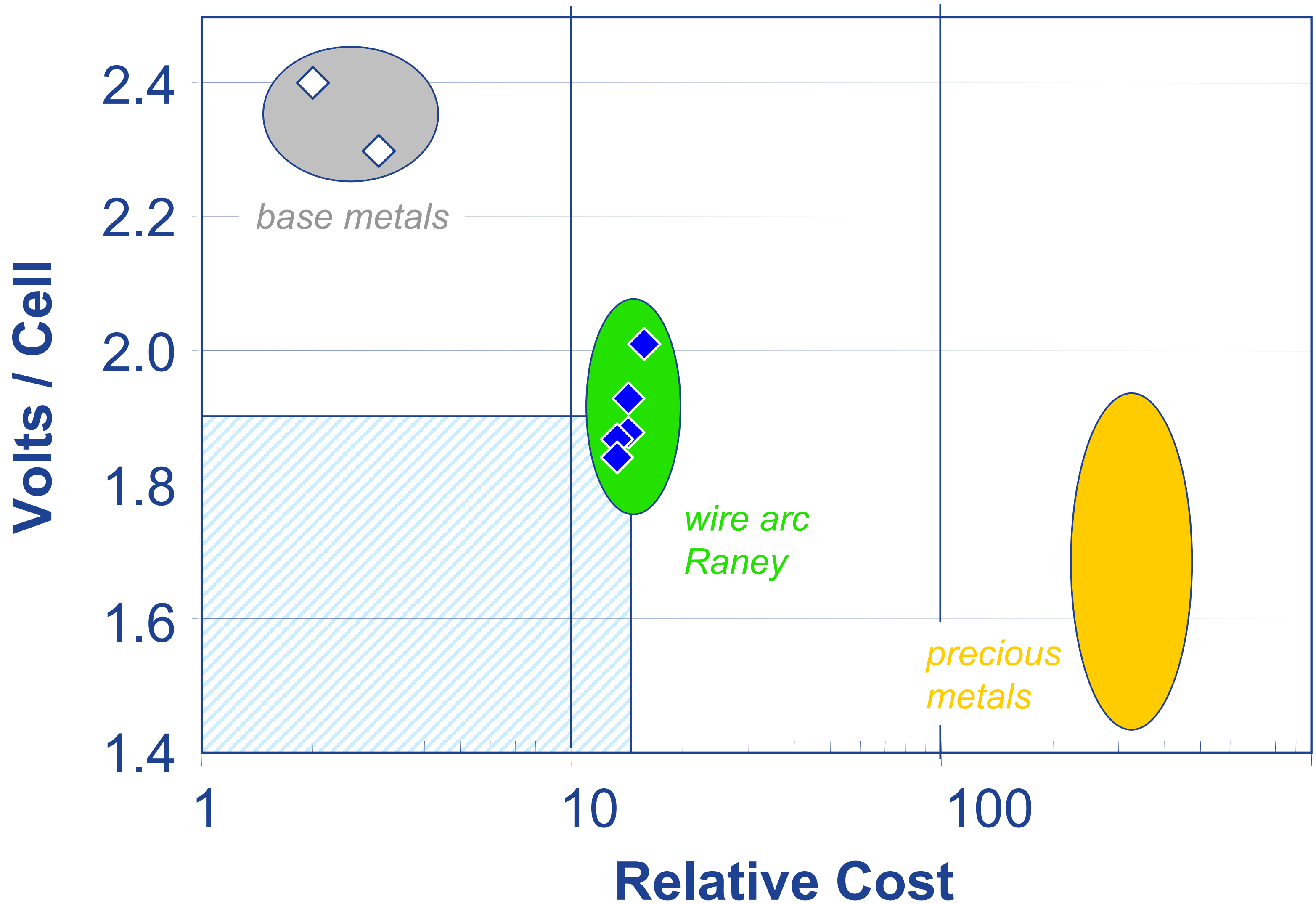
Electrode Concept Selection



Wire arc Raney meets targets

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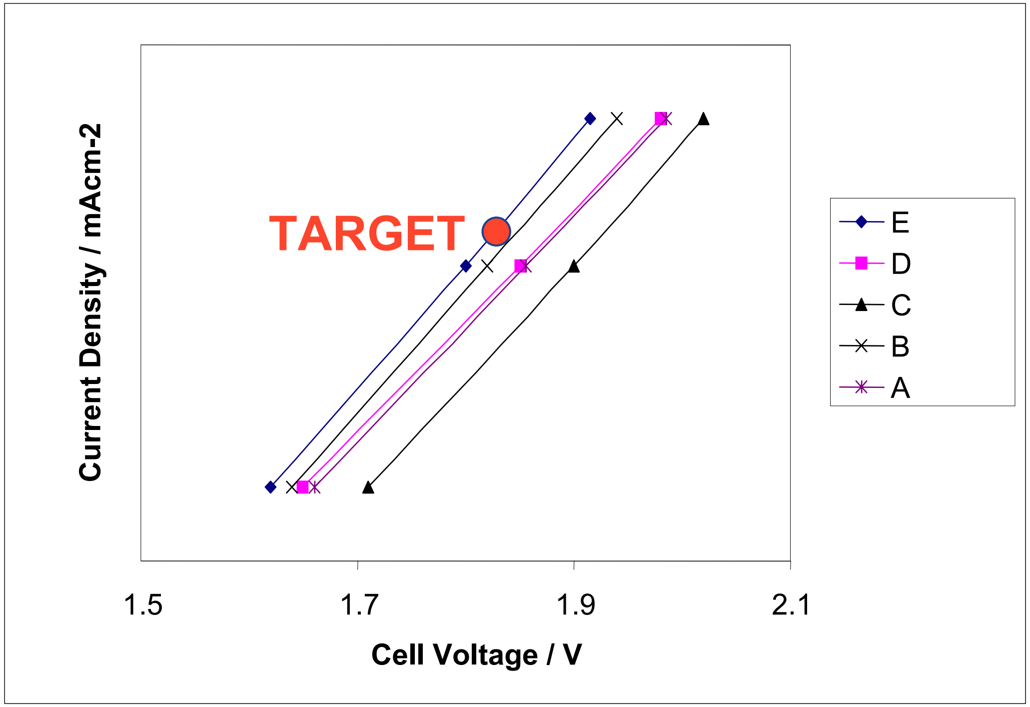
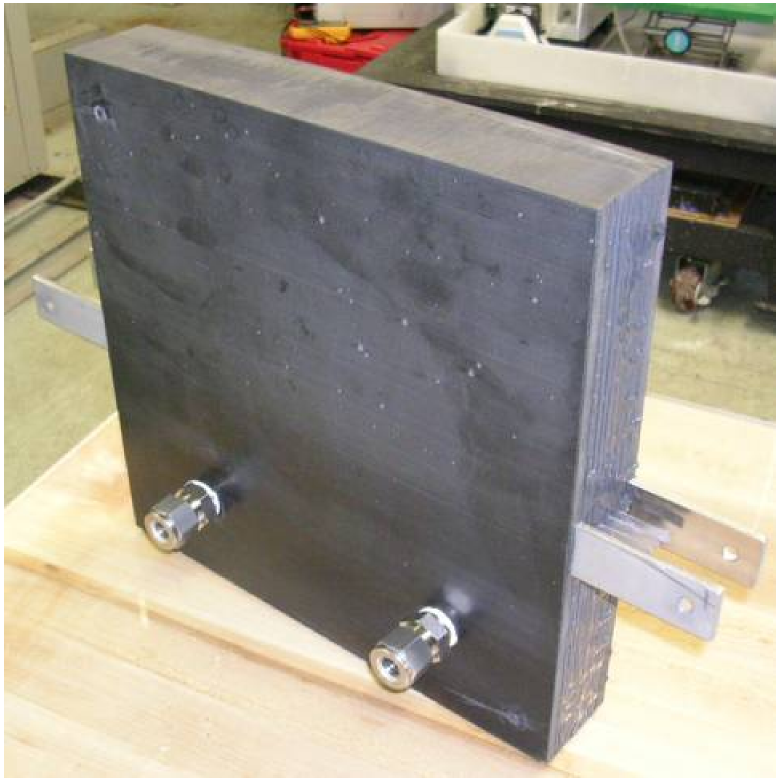
Wire Arc Single Cell Data



single cell test stand

All electrodes at or close to target
Electrode “E” the choice to go forward

Stack Design



- 5 x 153 cm^2 cells
- 500W input power
- 10 grams H_2 / hour output
- GE advanced plastic material
- Plate / epoxy construction
- Wire arc coated electrodes
- Dual inlets to eliminate shunts

First "true monolith" – design details per product concept

500W Bench Scale System

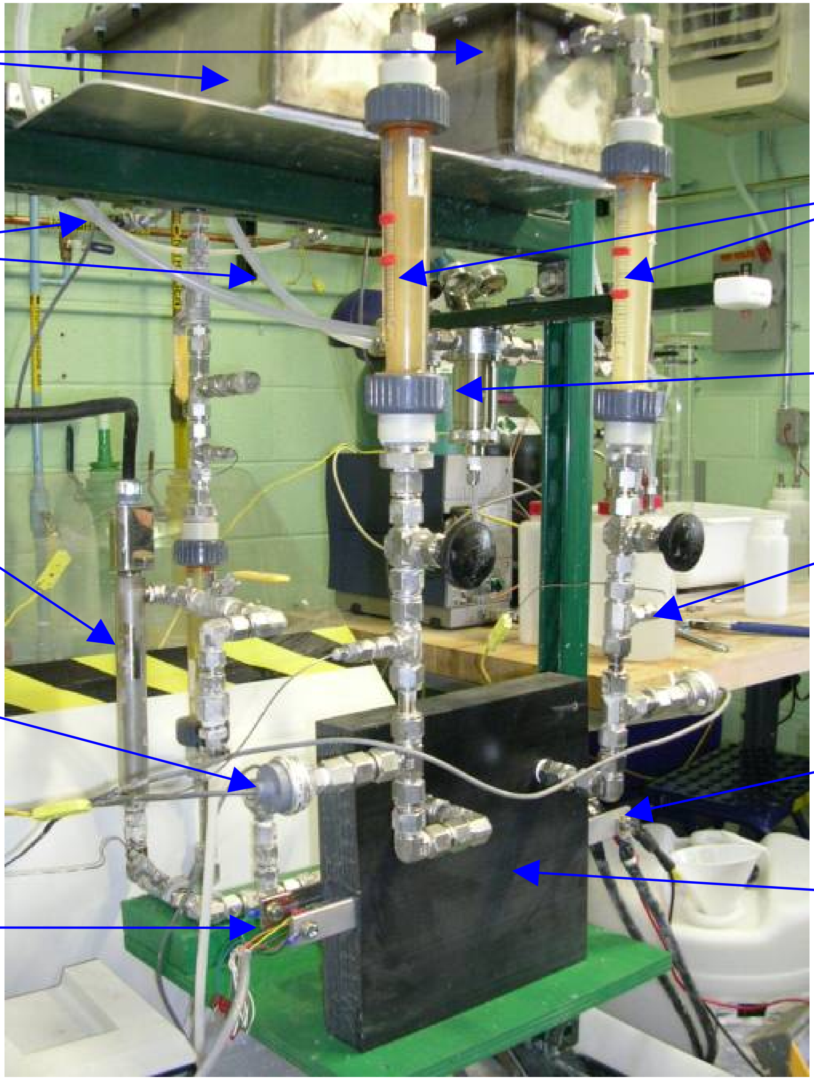
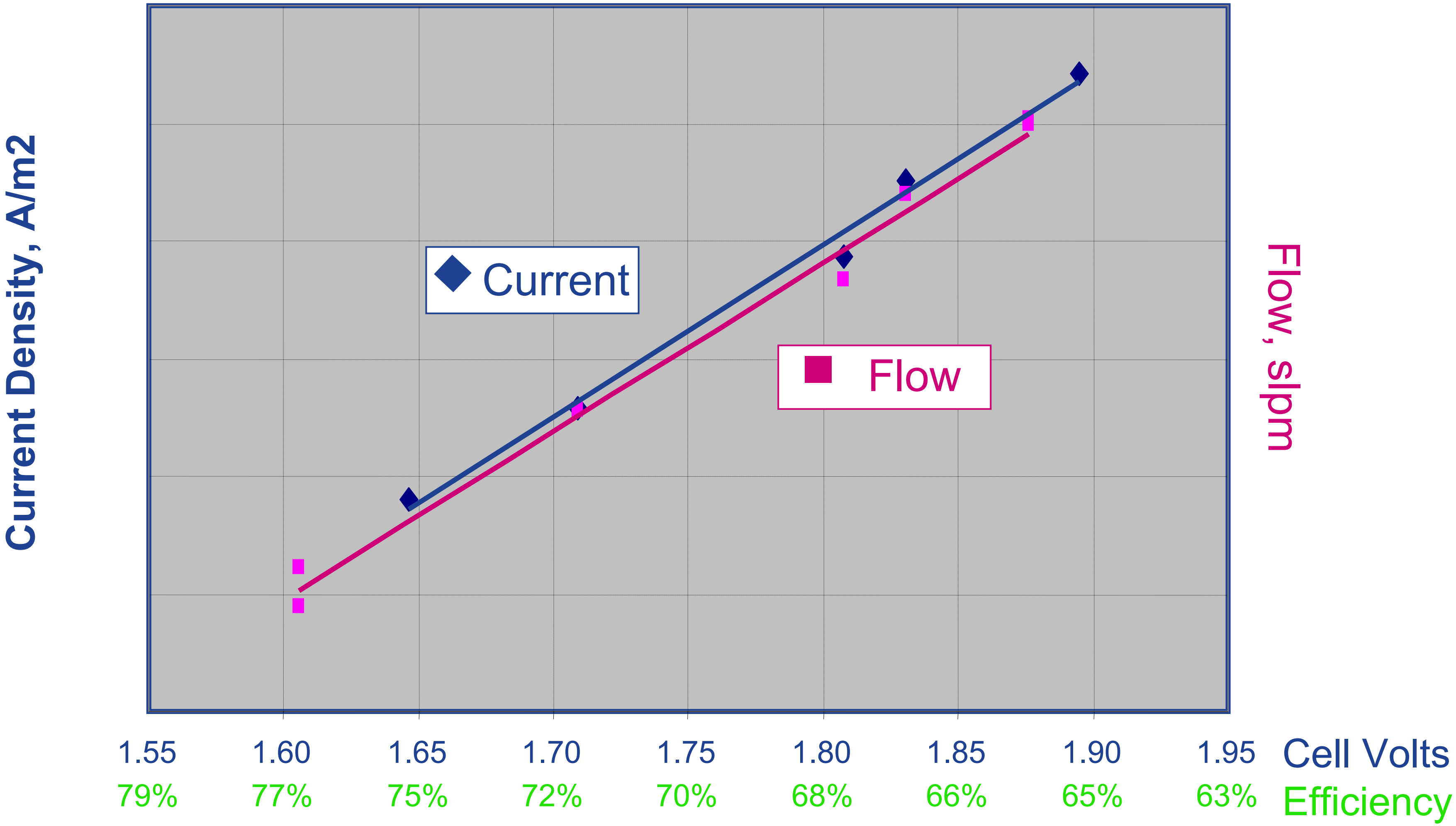


Figure 5: Bench Scale Test Stand

5-Cell Stack Test Data

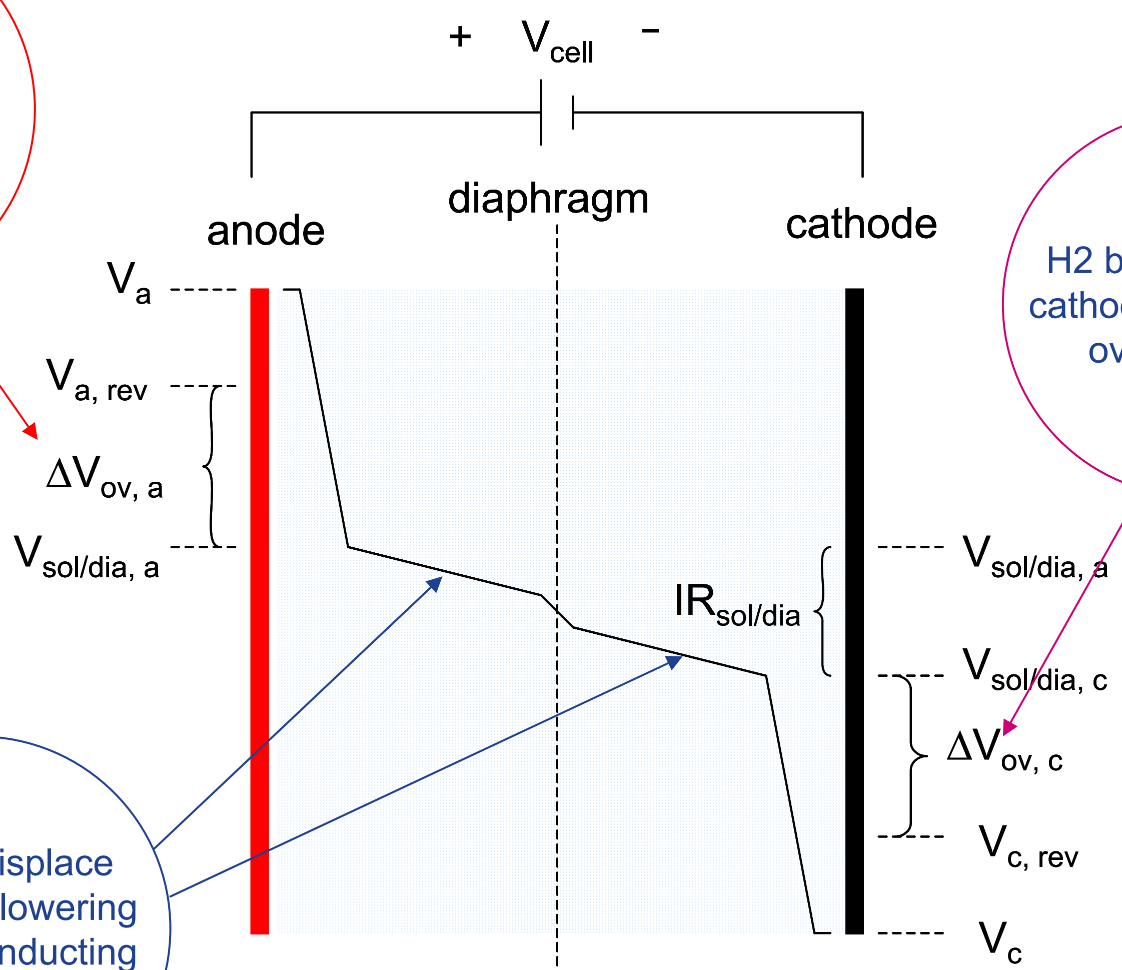


Cell tests show entitlement to reach performance target
H2 production rate 99% of input current equivalent

Bubble Effect on Cell Performance

Voltage Waterfall

O2 bubbles mask anode, increasing overpotential



H2 bubbles mask cathode, increasing overpotential

Bubbles displace electrolyte, lowering effective conducting area.

Challenge: Model Bubbles in a Working Cell

Highly non-linear problem requiring development of advanced models

- Multi-phase turbulent flow
- Porous media
- Electrochemical reactions
- Electron/Ion transport
- Dissolved species

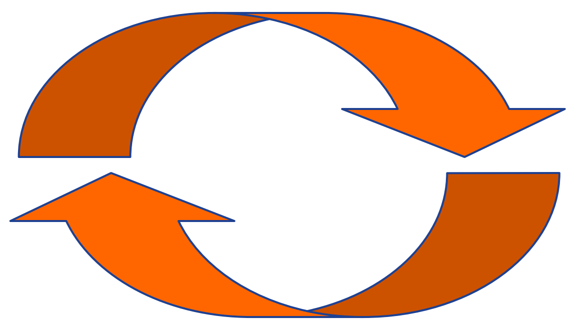
Governing Eqs.

Mass

Momentum

Species

Energy



Additional Physics

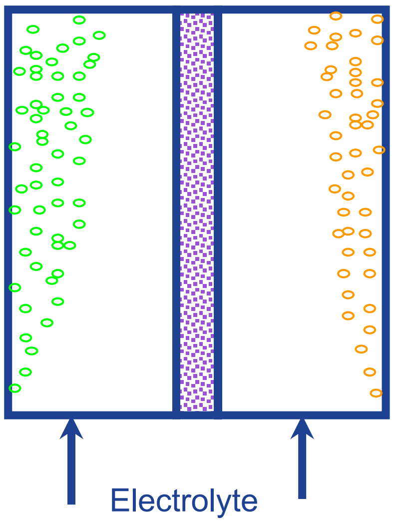
Butler-Volmer Kinetics

Ionic Potential Field

Species Sink/Source

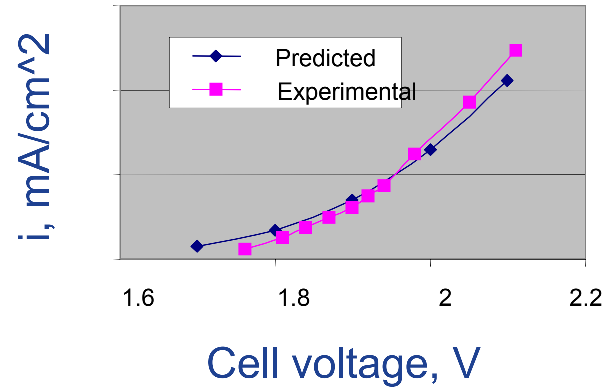
Energy Sink/Source

2D CFD Results

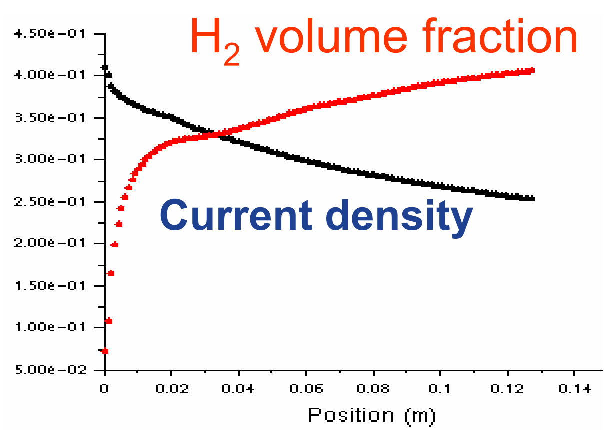


Simplified model / experimental geometry

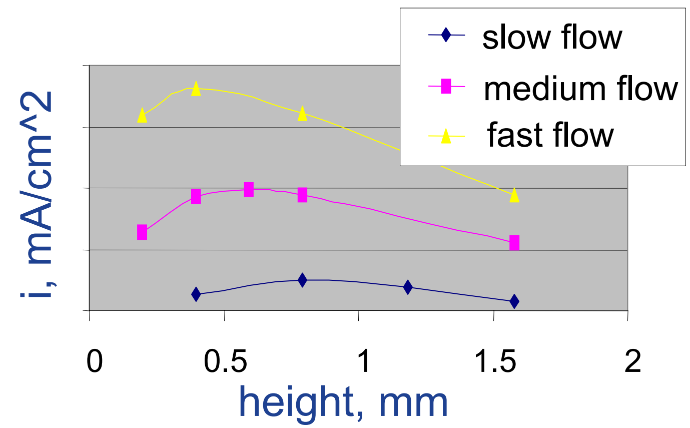
Experimental Validation



Effect of gas coverage



Optimize Passage Height



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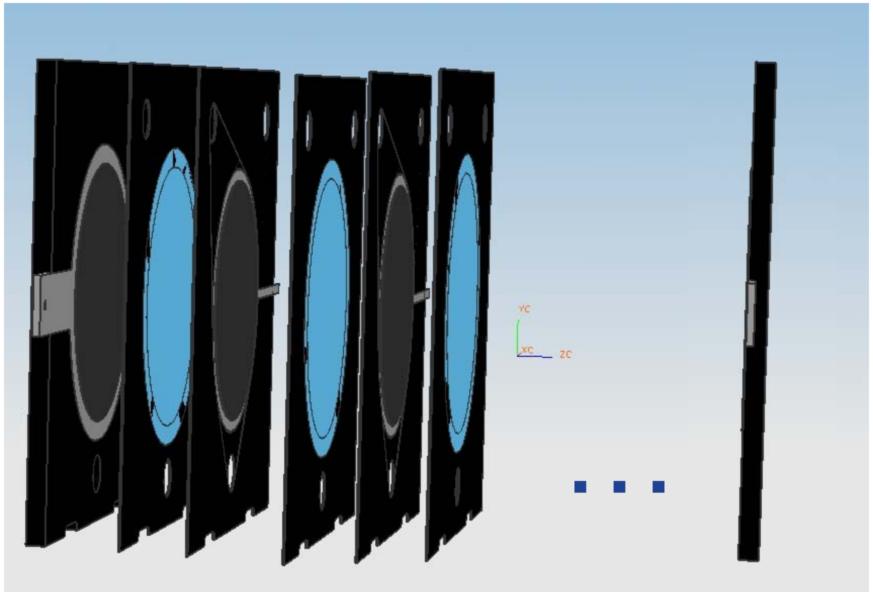
50 kW Stack Manufacturing



molded automotive product

2005 stack: “one-off” construction
Advanced joining methods by GEAM

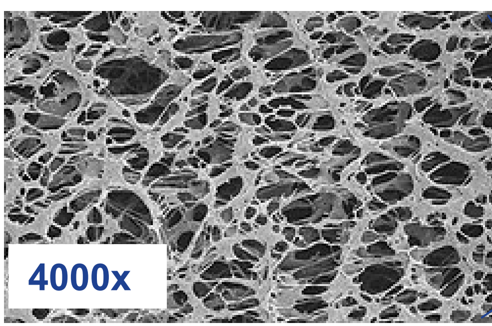
Molding becomes method of choice at 100’s of units / year

Diaphragm Characterization Testing

single cell test stand

Diaphragm requirements:

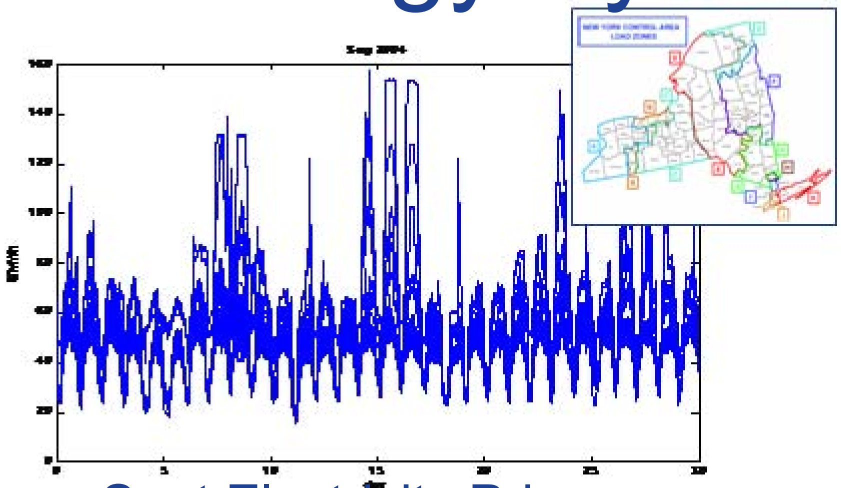
resists gas bubble crossover
highly wettable
low specific electrical resistance



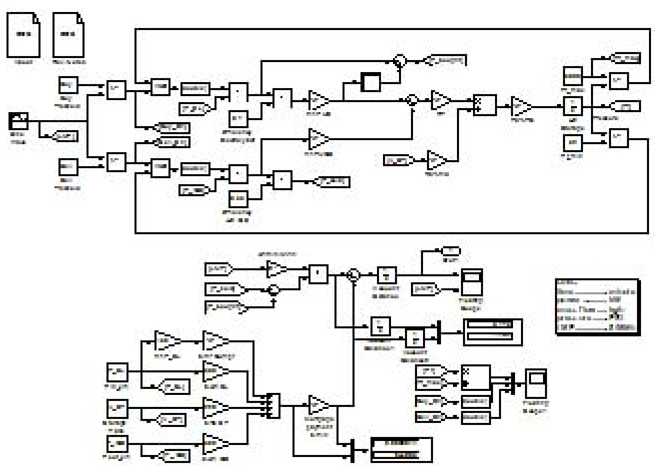
Membrane Materia	Pore Size (um)	Bubble Point (psi)	Water Flux (ml/min/cm2 @10psid	ASR (ohm*cm2)
Polypropylene	7 um - non weave	0.14	123	3.655
Polypropylene	0.22	15	3	397.8
Polyethersulfone	0.22	60	33.2	1.8 +/-0.1 (n=3)

Initial characterization of commodity diaphragm materials

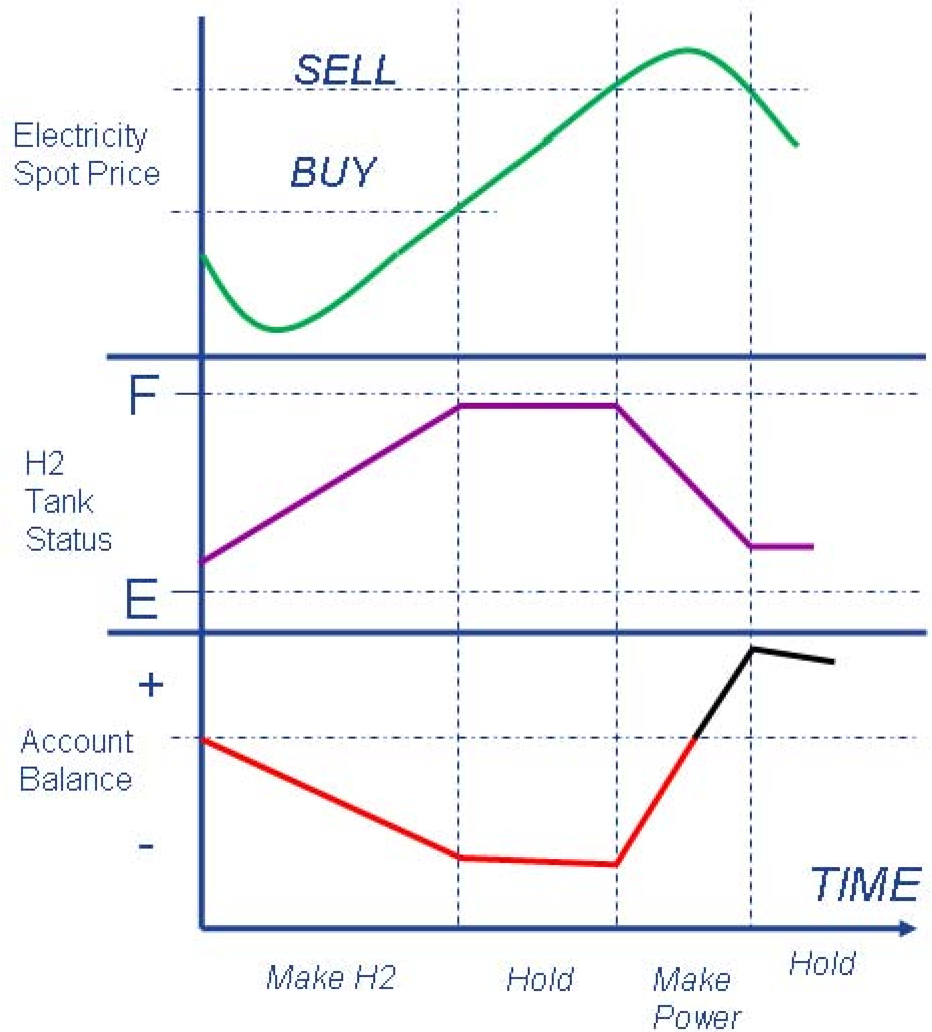
H2 Energy System Optimization



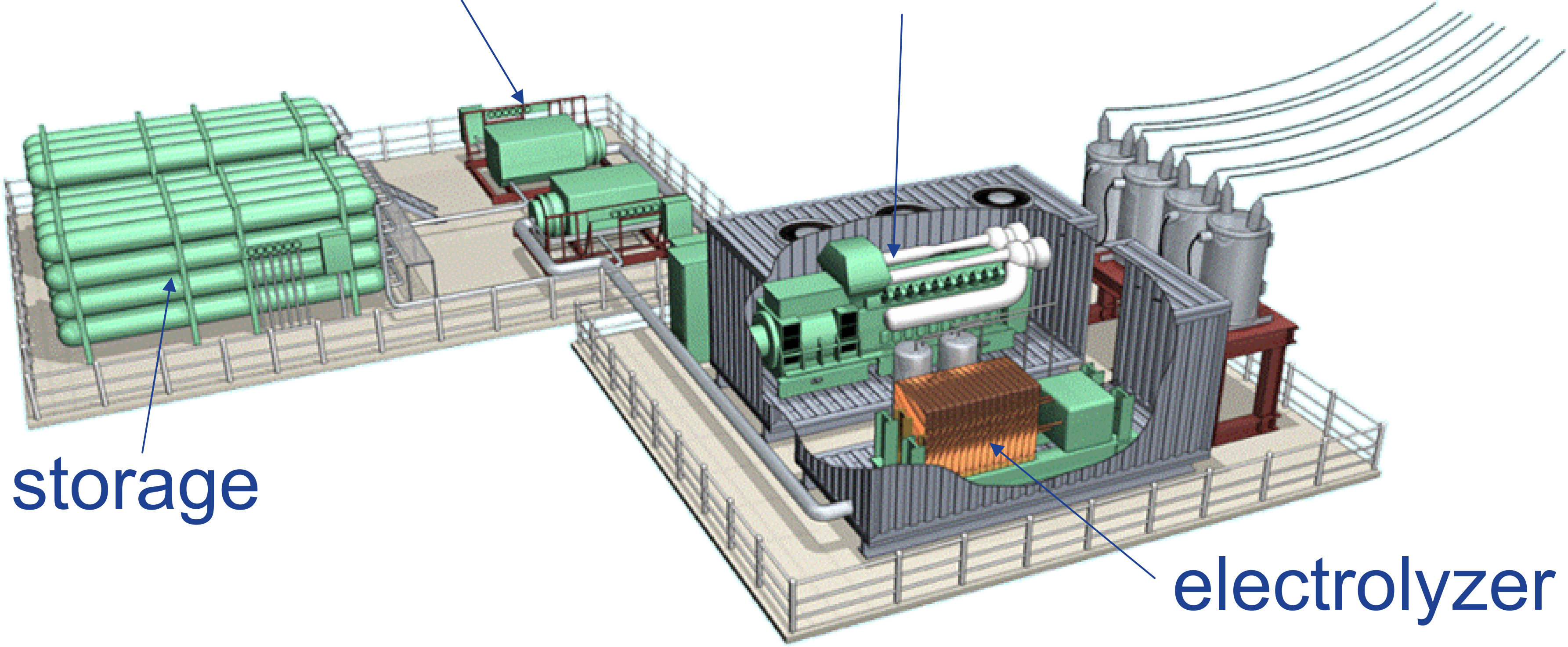
Spot Electricity Price



Electrolyzer / H2 ICE System Model



Reference Power Park Design



MW scale building block for utility or fueling application

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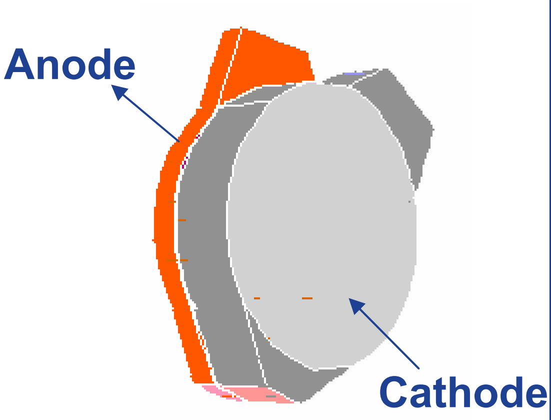
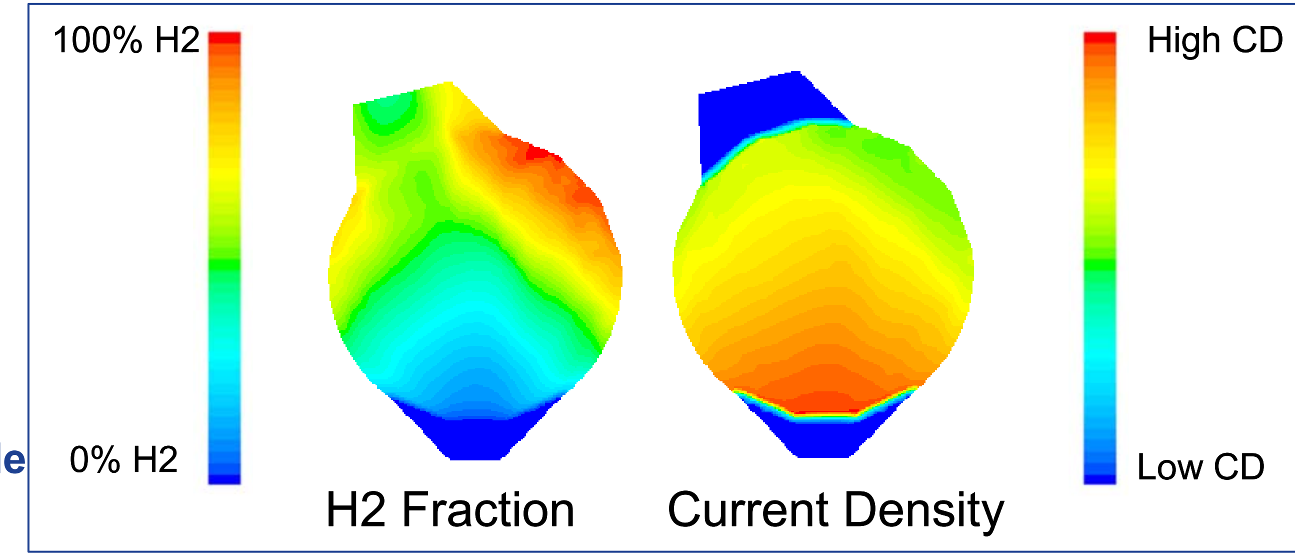
Future Work

- Scale up cells for utility-sized stacks
- Study long term effects on electrode performance
- Build a prototype system incorporating full size cells

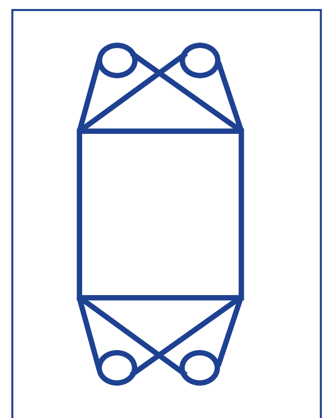
Stack Scaleup to 50 kW system



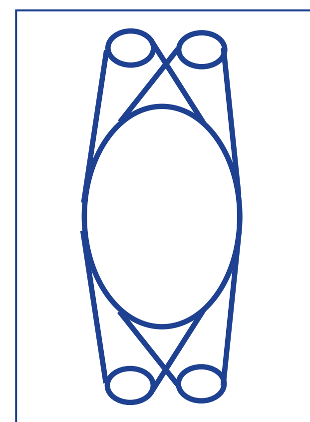


baseline round cell

3D electrochemical CFD capability enables fast geometry optimization



square cell



elliptical

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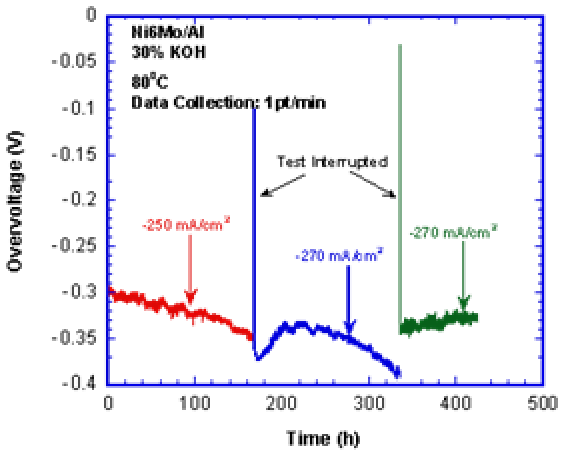
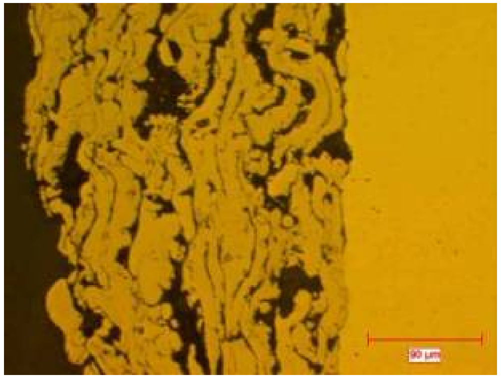
Long – Term Electrode Performance

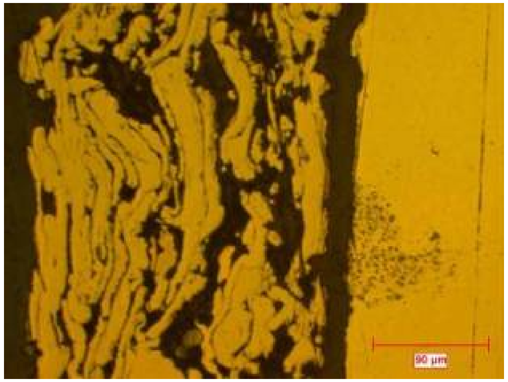
Degradation: study and mitigate change in overvoltage over operating life



Reliability: electrode loss in high current operation



Electrode deposited on substrate, as received



Delamination after highly accelerated stress test

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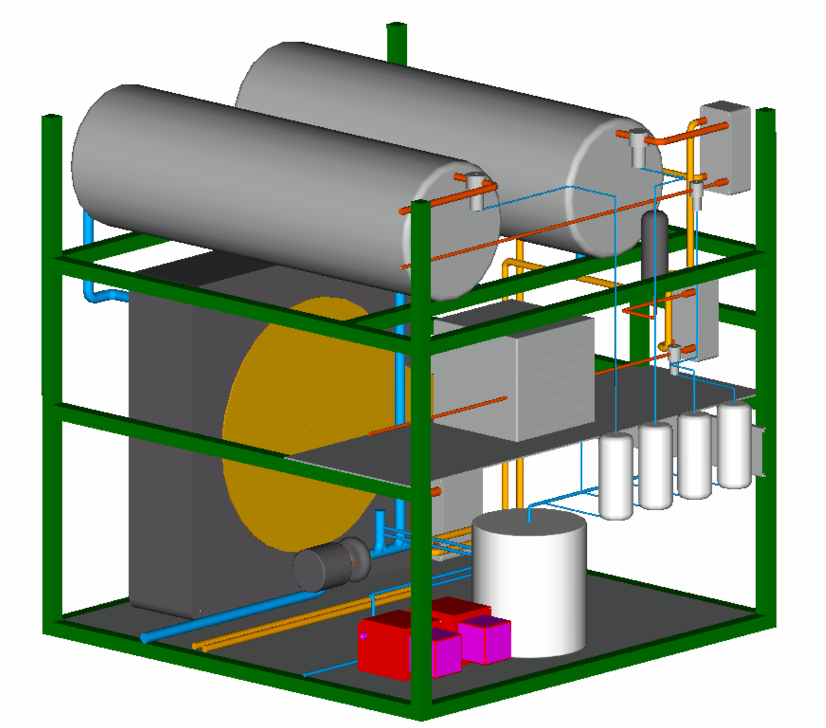
50 kW System - 2005



Capabilities:

- 1 kg H2 / hr production rate
- High pressure operation
- Automated controls
- P, T, massflow, purity measurements

Opportunity for total instrumentation
Study operability & maintenance characteristics

Publications and Presentations

The following papers on hydrogen sensor technology have been accepted for publication:

Z. Zhao, M. A. Carpenter, H. Xia, D. Welch, "All-optical hydrogen sensor based on a high alloy content palladium thin film", Sens. Actuators B., accepted for publication March 2005.

Z. Zhao, M. A. Carpenter, "Annealing enhanced hydrogen absorption in nanocrystalline Pd/Au sensing films", J. Appl. Phys., accepted for publication April 2005.

On 12 April 2005, a the invention of a plastic monolithic electrolyzer stack was filed with the U.S. Patents and Trademarks office.

Hydrogen Safety

The most significant hydrogen hazard associated with this project is the possibility of an abnormal condition resulting in a leak in the hydrogen production system.

If an ignition source is also present such a leak could result in a fire.

Hydrogen Safety

At the GE Global Research Center, the Environmental Health and Safety (EHS) team reviews all experiments. All hydrogen producing systems in this project are contained within laboratory spaces incorporating the following safety features:

- Ventilated hoods
- Flammable gas detectors
- Automatic shutoff on sensing gas or ventilation failure
- Manual emergency stops inside and outside building
- Posted SOP detailing normal and emergency operation
- Required training for all operators

In addition, novel hydrogen sensors are being developed by subcontractor SUNY Nanotech.

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