Overview

Timeline
Project start date 1 April 2004
Project end date 30 Dec. 2005
Percent complete 90%

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

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

Partners
SUNY Albany
Nanotech
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

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

Utilities Key Points:
- $2 / kg
- clean H2
- scalable

Oil & Gas Companies Key Points:
- fueling vision
- global reach
- systems expertise

Cost of Hydrogen, $ / kg
- Energy cost
- BOP capital
- Stack capital

Today Target

System Cost-Out Through GE Process
Optimizing H2 Cost Drives Tradeoffs

Voltage / Current Tradeoffs

Baseline IV curve

Current Density, A/m²

0 500 1000 1500 2000 2500 3000 3500

1.5 1.6 1.7 1.8 1.9 2 2.1

Cell Voltage

Efficiency

82% 77% 72% 68% 65% 62% 59%

m² to make 1 kg/hr H₂

H₂ Cost, $ / kg

Total Cost

Energy Cost

Capital Cost

Lowest cost operating point varies with cost of electricity and specific cost of material
Technology Plan for Stack Cost

High surface area electrodes minimize stack size

Advanced materials enable low assembly costs
Alkaline Electrolyzer Design Basics

**Cathode (-):**

\[ 2\text{H}_2\text{O} + 2\text{e}^- \rightarrow 2\text{OH}^- + \text{H}_2 \]

**Anode (+):**

\[ 2\text{OH}^- \rightarrow \text{H}_2\text{O} + 2\text{e}^- + \frac{1}{2}\text{O}_2 \]
Electrode Concept Selection

Wire arc Raney meets targets
Wire Arc Single Cell Data

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

- 5 x 153 cm² cells
- 500W input power
- 10 grams H₂ / 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**

+ $V_{cell}$

- $V_{cell}$

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**O2 bubbles mask anode, increasing overpotential**

**H2 bubbles mask cathode, increasing overpotential**

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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

Effect of gas coverage

H₂ volume fraction

Current density

Optimize Passage Height

Experimental Validation

Cell voltage, V

Predicted
Experimental

i, mA/cm²

0 0.5 1 1.5 2

i, mA/cm²

0 0.5 1 1.5 2

height, mm

Optimize Passage Height

slow flow
medium flow
fast flow
50 kW Stack Manufacturing

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

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

Diaphragm requirements:

- resists gas bubble crossover
- highly wettable
- low specific electrical resistance

<table>
<thead>
<tr>
<th>Membrane Material</th>
<th>Pore Size (um)</th>
<th>Bubble Point (psi)</th>
<th>Water Flux (ml/min/cm2 @10psid)</th>
<th>ASR (ohm*cm²)</th>
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<tbody>
<tr>
<td>Polypropylene</td>
<td>7 μm - non weave</td>
<td>0.14</td>
<td>123</td>
<td>3.655</td>
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<tr>
<td>Polypropylene</td>
<td>0.22</td>
<td>15</td>
<td>3</td>
<td>397.8</td>
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<tr>
<td>Polyethersulfone</td>
<td>0.22</td>
<td>60</td>
<td>33.2</td>
<td>1.8 +/-0.1 (n=3)</td>
</tr>
</tbody>
</table>
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
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

3D electrochemical CFD capability enables fast geometry optimization
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
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:


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.