Overview

Timeline
Project start date 1 April 2004
Project end date 30 Dec. 2005
Percent complete 100%

Barriers addressed
Q. Capital Cost of Electrolysis Systems
T. Renewable Integration

Technical Targets:
2010: Electrolyzed Hydrogen @ $2.85/ 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

<table>
<thead>
<tr>
<th></th>
<th>Units</th>
<th>2010 DOE Target</th>
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<tbody>
<tr>
<td>Cell Stack</td>
<td>Efficiency</td>
<td>% (Voltage)</td>
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<tr>
<td></td>
<td>Cost</td>
<td>$/kg H₂</td>
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<tr>
<td>Electricity (System)</td>
<td>Cost</td>
<td>$/kg H₂</td>
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<tr>
<td>O&amp;M</td>
<td>Cost</td>
<td>$/kg H₂</td>
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</table>

Cost

Electricity (System)

O&M

$0.38 / kg H₂

$1.89 / kg H₂

$0.38 / kg H₂
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
Optimizing H2 Cost Drives Tradeoffs

Voltage / Current Tradeoffs

Baseline IV curve

- Current Density, A/m²
- Cell Voltage

Efficiency

- 1.5: 82%
- 1.6: 77%
- 1.7: 72%
- 1.8: 68%
- 1.9: 65%
- 2: 62%
- 2.1: 59%

m² to make 1 kg/hr H2

H2 Cost, $ / kg

- Energy Cost
- Capital Cost

Optimal Voltage

- Total Cost

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

minimizes energy costs

minimizes capital costs

Baseline IV curve

Optimal Voltage

Cell Voltage

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

High surface area electrodes minimize stack size

Advanced materials enable low assembly costs
Electrode Concept Selection

- Wire arc lowest risk solution to meet targets: Electrodeposition next potential cost reduction

**Electrode Concept Selection Diagram**

- **Base Metals**: GE electro-deposited
- **Target Zone**: Dimensionally stabilized anode (DSA)
- **Relative Cost per Unit Area**: 1, 10, 100
- **Precious Metals**: GE spray
Proof of Concept Plastic Stack

5 x 153 cm² cells
500W input power
10 gph output
Noryl plate / epoxy construction
Wire arc Raney electrodes
Dual inlets to eliminate shunts

First “true monolith” – design details per product concept
Figure 5: Bench Scale Test Stand
Bench Scale Test Results

- Operable across wide efficiency range
- Performance meets requirements

TARGET ZONE

Electrode C5
Electrode C4

Current Density, A/m²

Cell Volts

Efficiency

Flow, slpm

79% 77% 75% 72% 70% 68% 66% 65% 63%
Computational Study of Cell Performance

Highly non-linear problem requiring development of advanced models

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

O2 bubbles mask anode, increasing overpotential

H2 bubbles mask cathode, increasing overpotential

Bubbles displace electrolyte, lowering effective conducting area.
Learning from Two Dimensional CFD

Experimental Validation

- Predicted
- Experimental

Optimize Passage Height

- slow flow
- medium flow
- fast flow

Simplified model / experimental geometry

Effect of gas coverage

H$_2$ volume fraction

Current density

Cell voltage, V
Stack Scaleup to 1 kgph system

3D electrochemical CFD capability enables fast geometry optimization
Power Park Conceptual Design

H₂ Production/Energy Storage Subsystem

Electrolysis Product

Configured for <100KW + Small Fuel Cell

H₂ Dispenser

Configured for 50KW to 250KW+

H₂ Compressed and Storage

Configured for 500KW to 1MW+

H₂-Fueled ICE

Hydrogen Economy Applications Demand Scalable Products

Communications Support
- 10KW electrolyzer
- 1.5M³ Hydrogen storage
- 300 to 3,000 psi compression

(1) Refueling

Small Villages
- 250KW electrolyzer
- 40M³ Hydrogen storage
- 300 to 5,000 psi, or 300 to 10,000 psi compression

(2) Electrical Generation

Power Parks
- (2) 1MW electrolyzers
- 300 to 1,500 psi compression
- 70M³ Hydrogen storage
- (5) 6m x 2m dia. tanks
- 2 x Jenbacher J316 recips

Conceptual Design and Functional Modeling by Dr. Stephen Sanborn, GE
Conceptual Designs

Rendered in 2-D Drawings & 3-D “Virtual Tour”
H2 Power Park Functional Modeling

System Block Model

Wind Energy. Electricity and Fuel Demand Models

TRNSYS15 optimization code

Result: Optimized equipment selection for various scenarios
Additional Work: “1 kgph” System

Capabilities:
- 1 kg H2 / hr production rate
- High pressure operation
- Automated controls
- P, T, massflow, purity measurements
- Upgradeable compression / storage capability

Opportunity for total instrumentation
Study operability & maintenance characteristics
Additional Work: Electrode Lifting

Multiple sample accelerated testing underway

350, 500, and 1000 mA/cm²

Nearing 40k hours with no failures
Future Work

First phase project has ended. Continuation of work with the 1 kgph system has been proposed to DOE and is pending.
<table>
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<th><strong>Relevance:</strong></th>
<th>Provides a technical solution to the electrolysis capital cost problem.</th>
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<tr>
<td><strong>Approach:</strong></td>
<td>Leverage GE expertise in advanced plastics and coating technology to dramatically reduce electrolyzer stack cost.</td>
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<tr>
<td><strong>Progress:</strong></td>
<td>Demonstrated bench-scale proof of concept and scaled up to full size stack. Met efficiency target and projecting to meet 2010 cost target.</td>
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<tr>
<td><strong>Technology Transfer:</strong></td>
<td>Ready to consider demonstration projects.</td>
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<tr>
<td><strong>Proposed Future Research:</strong></td>
<td>System operations and reliability growth to prepare for demonstrations.</td>
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Alkaline Electrolyzer Design Basics

Cathode (-):
$2\text{H}_2\text{O} + 2e^- \rightarrow 2\text{OH}^- + \text{H}_2$

Anode (+):
$2\text{OH}^- \rightarrow \text{H}_2\text{O} + 2e^- + \frac{1}{2}\text{O}_2$

Bipolar type half-cells

Multicell Bipolar Stack
Advanced H2 sensor work by Dr. Michael Carpenter, SUNY Nanotech

Response to Reviewers’ Comments

Rated as #PDP-10 : New York State Hi-Way Initiative

Strengths:
• Highly innovative
• Use of multiple GE technical capabilities
• Integrated GE team with skills and resources to “make this real”

Reviewer’s Comments and Response
• Scope regarding New York’s H2 infrastructure, sensors, etc. not aligned with HFCIT goals
  — 2005 scope focused on electrolysis technology and scaleup.
• “Show path to achieving HFCIT targets… using standard assumptions”
  — H2A model analysis presented to DOE for all GE H2 program work.
• “Current demonstration is too small… 50 kW minimum
  — GE has built and is testing a 50 kW system, and has applied to continue the program with testing at that scale.
Critical Assumptions and Issues

1) Electricity must be available at 5 cents / kWh or lower. This requires off-peak / industrial wholesale electricity at first, and the long term requires a cheap power solution.

2) Electrolyzers can be commercially successful without “waiting for a hydrogen economy”. The right sector of the existing hydrogen market must be targeted, and demonstrations arranged with the needs of this market in mind.

3) A unified set of codes and standards for electrolytic H2 production is necessary so that a standardized packaged product may be deployed anywhere.