Advanced Alkaline Electrolysis

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This presentation does not contain any proprietary or confidential information

Project #PDP16
Acknowledgements

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Overview

Timeline
Start: 30 September 2006
End: 30 December 2008
20% complete

Budget
Total Funding: $1,239,479
DOE Share: $973,783
Contractor: $265,696

*Note: funded by both the DOE Nuclear Hydrogen Initiative and DOE HFCIT programs*

Received in 2006: $542,546
2007 Funding (to date): $92,478

Barriers Addressed
G. Capital Cost of Electrolysis Systems
I. Grid Electricity Emissions

Partners
GE Global Research
GE Energy Nuclear
Entergy Nuclear
National Renewable Energy Laboratory
Objectives

Study the feasibility of using alkaline electrolysis technology with current-generation nuclear power for large scale hydrogen production:

*Economic Feasibility*: Market study of existing industrial H2 users

*Technical Feasibility*: Developing pressurized low cost electrolyzer

*Codes and Safety*: Environmental and regulatory impact assessment

<table>
<thead>
<tr>
<th>Units</th>
<th>DOE 2012 Target</th>
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<tbody>
<tr>
<td>Cell Efficiency</td>
<td>%</td>
</tr>
<tr>
<td>System Cost</td>
<td>$/kg H2</td>
</tr>
<tr>
<td>Electricity Cost</td>
<td>$/kg H2</td>
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<tr>
<td>O&amp;M Cost</td>
<td>$/kg H2</td>
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# Approach

<table>
<thead>
<tr>
<th>Percentage Complete</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>80% complete</td>
<td>Task 1: Define market and requirements</td>
</tr>
<tr>
<td></td>
<td>- Industrial users survey</td>
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<tr>
<td></td>
<td>- Technical and pricing requirements</td>
</tr>
<tr>
<td></td>
<td>- Nuclear regulatory and environmental impact issues</td>
</tr>
<tr>
<td>10% complete</td>
<td>Task 2: Design and build pressurized electrolyzer stack</td>
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<tr>
<td></td>
<td>- Develop plastic stack technology</td>
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<tr>
<td></td>
<td>- Low cost electrode methods</td>
</tr>
<tr>
<td>5% complete</td>
<td>Task 3: Plastics oxidation lifing</td>
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<td>- Creep resistance</td>
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<tr>
<td></td>
<td>- Oxidation</td>
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<tr>
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<td>Task 4: Demonstrate electrolyzer performance and capital costs</td>
</tr>
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<td></td>
<td>Task 5: System operation testing</td>
</tr>
<tr>
<td></td>
<td>- O&amp;M cost assessment</td>
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<td></td>
<td>Task 6: Create industrial-scale system conceptual design</td>
</tr>
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<td></td>
<td>Task 7: Create 1-kg-per-second demonstration system conceptual design</td>
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</tbody>
</table>
Global Hydrogen Market

Size: • $17 B
Growth: • 1.5% CAGR

Ammonia Production

Size: • $15.5 B
Growth: • 10% CAGR

Refrineries

Size: • >$0.5 B
Growth: • 5% CAGR

Metals Fab. & Treatment

Size: • $1 B
Growth: • 1.5% CAGR

Chemical Mfr’g

Size: • >$0.5 B
Growth: • 5% CAGR

Food & Personal Care

Flat Demand
Key Use: Fertilizer
Captive H2 Production Facilities

Hydrogen Used to Remove Sulfur
EU & US Regulations Mandating Lower Sulfur Content in Gas, Diesel
Captive H2 Production Facilities

Hydrogen Used for High Heat Processes i.e. Plasma Spray
Batch type process

Hydrogenating Oils for a range of applications:

Manufacture of Specialty Chemicals for a Variety of Industries
Methanol

Source: HSBC, 2004
Industrial market infrastructure can lead fueling infrastructure.
# GE Technology Capital Costs

<table>
<thead>
<tr>
<th>Projected CapEx, 5 kg/hr stack:</th>
<th>Per kg/hr</th>
<th>Per Nm$^3$/hr</th>
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</thead>
<tbody>
<tr>
<td>Prototype</td>
<td>$16,000</td>
<td>$1,426</td>
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<tr>
<td>Production</td>
<td>$5,000</td>
<td>$446</td>
</tr>
</tbody>
</table>

At 50 kWh/kg H$_2$, production stack cost is $100/kW
Projected H2 Cost with GE Electrolyzer: 1000 kg/day, 30 bar pressure

Low-cost electricity still key to meeting targets.

Source: GE Global Research, NREL H2A Model
Electricity Production Costs

existing fleet - US 1995-2005

- Nuclear: 1.72 Cents/kWh (2005)
- Coal: 2.21 Cents/kWh (2005)
- Gas: 7.51 Cents/kWh (2005)
- Oil: 8.09 Cents/kWh (2005)

Source: NEI, 2006

Lowest cost electricity available from existing nuclear.
Electricity market demands set actual price.
GE Alkaline Electrolysis Technology

High Surface Electrode

- Wire arc electrode system
- Electrodeposition

1000x electrode surface: performance at 1/10 traditional electrode cost

Plastic Stack

- One piece stack assembly: minimal part count
- Molded passages, not machined
Electrolysis Cell Basics

Cathode (-):
\[2H_2O + 2e^- \rightarrow 2OH^- + H_2\]

Anode (+):
\[2OH^- \rightarrow H_2O + 2e^- + \frac{1}{2} O_2\]
GE electrode technology applies a high effective surface area, nickel-based coating to the base metal bipolar plate for high performance at low cost.

- Achieved target performance with hot spray technique in 2005.
- Researching electrodeposition for additional cost and performance advantage:
  - Thinner bipolar plate
  - Eliminates warping
  - Coats 3D electrode surface
Technical Details – Electrode

**CELL**

- Single flow cell
- Ambient pressure, 80°C

**FLAT PLATE ELECTRODES**

- Plastic mesh for flow distribution

**FLAT PLATE POST DEPOSITION**

- Some oxide left – leaching blocked by plastic mesh

**MESH ELECTRODE**

- Cathode mesh applied
- Higher coated surface area
Single Cell Performance

Current, mA/cm²  (Scale removed to protect proprietary information)
Electrode Results- First Quarter

- Test results meeting target current density for single cell.
- Additional performance margin needed: large cell and multi-cell stack voltages are typically higher than small single cell.
- Additional mV reductions possible from anode side mesh, method optimization, catalyst additives.
Electrode Assembly

Plastic weld

Diaphragm cartridge

Stack end assembly (machined from molded blanks)

Diaphragm cartridge

Electrode Assembly

Stack end assembly (machined from molded blanks)

9 cell stack core

10-cell Stack module
(shell, bolts, current straps not shown)

15 bar pressure stack under construction for 2007 test
Resistance Wire Welding

- Robust method to join plates for test stack
- Wire path determines weld location
- Allows “blind” welds along passages
- Heat management, inspection method

Test plan to determine process parameters and abate risks:

- wire size, current, voltage
- weld spacing – in-plane and stacking of plates
- weld strength – tensile and crack opening
- clamping strategy
- wire placement and tacking
- weld closure
Welding – Experimental Setups

Coupon

Pressure Test

Full Plate with Manifolds
Plastic Oxidation Lifing

**Risk:** Oxidation reduces strength of plastic over time. Electrolysis produces high-pressure oxygen and other oxidative species such as ozone.

**Approach:** Exposing test samples to oxidant in three experiments:

1) Hot KOH and bubbling air at ambient pressure
2) Ambient pressure electrolysis
3) high pressure $O_2$ in reactor vessels
Oxidation Exposure Testing

Peristaltic Pump

Replenishing H₂O Jug

4L of 30% KOH @ 80° C
DC volts = 2
DC current = 6.0
Fracture Toughness Test

- 3-Point bend notched samples tested at 80C
- No difference between oxygen-only and electrolyzer-exposed samples after 5 days
- Continue sampling at 1 wk intervals

If there is no difference in strength between oxygen-only and electrolysis exposed samples, the high pressure oxygen-only experiment is validated.
2007: Regulatory assessment
Complete industrial market technical requirements
Complete electrolyzer stack technical development
Build and begin testing of 10-cell pressurized stack

2008: Conceptual design of reference plants
Summary

➤ Relevance
Technology for a sustainable hydrogen economy, built on current industrial markets with existing technology.

➤ Approach
Combine GE’s low cost electrolyzer stack technology, Entergy’s experience in nuclear electricity markets, and NREL’s economic modeling expertise to evaluate the feasibility of nuclear electricity and electrolysis for large-scale hydrogen generation.

➤ Technical Accomplishments and Progress
Segmented industrial market and estimated hydrogen costs for developed product. Completed conceptual design for prototype electrolyzer stack.

➤ Technology Transfer and Collaborations
Completing market case and technology development for commercialization. Collaboration between electrolyzer developer and nuclear utility fosters a well-ordered approach to entering the industrial market.