Advanced Alkaline Electrolysis

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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

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

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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

	Units	DOE 2012 Target
Cell Efficiency	%	69% (1.8V)
System Cost	$/kg H2	$0.70 ($400/kW)
Electricity Cost	$/kg H2	$2.00
O&M Cost	$/kg H2	$0.60

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Approach

80% complete	Task 1: Define market and requirements • Industrial users survey • Technical and pricing requirements • Nuclear regulatory and environmental impact issues
10% complete	Task 2: Design and build pressurized electrolyzer stack • Develop plastic stack technology • Low cost electrode methods
5% complete	Task 3: Plastics oxidation lifing • Creep resistance • Oxidation
	Task 4: Demonstrate electrolyzer performance and capital costs
	Task 5: System operation testing • O&M cost assessment
	Task 6: Create industrial-scale system conceptual design
	Task 7: Create 1-kg-per-second demonstration system conceptual design

Global Hydrogen Market

	Ammonia Production	Refineries	Metals Fab. & Treatment	Chemical Mfr'g	Food & Personal Care
					
Size:	• $ 17 B	• $ 15.5 B	• >$0.5 B	• $ 1 B	• >$0.5 B
Growth:	• 1.5 % CAGR	• 10 % CAGR	• 5% CAGR	• 1.5% CAGR	• 5% CAGR

← **Captive (90%)** → | ← **Merchant (10%)** →

Ammonia Production

- Flat Demand
- Key Use: Fertilizer
- Captive H2 Production Facilities

Refineries

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

Metals Fab. & Treatment

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

Chemical Mfr'g

- Manufacture of Specialty Chemicals for a Variety of Industries
- Methanol

Food & Personal Care

- Hydrogenating Oils for a range of applications:

Source: HSBC, 2004

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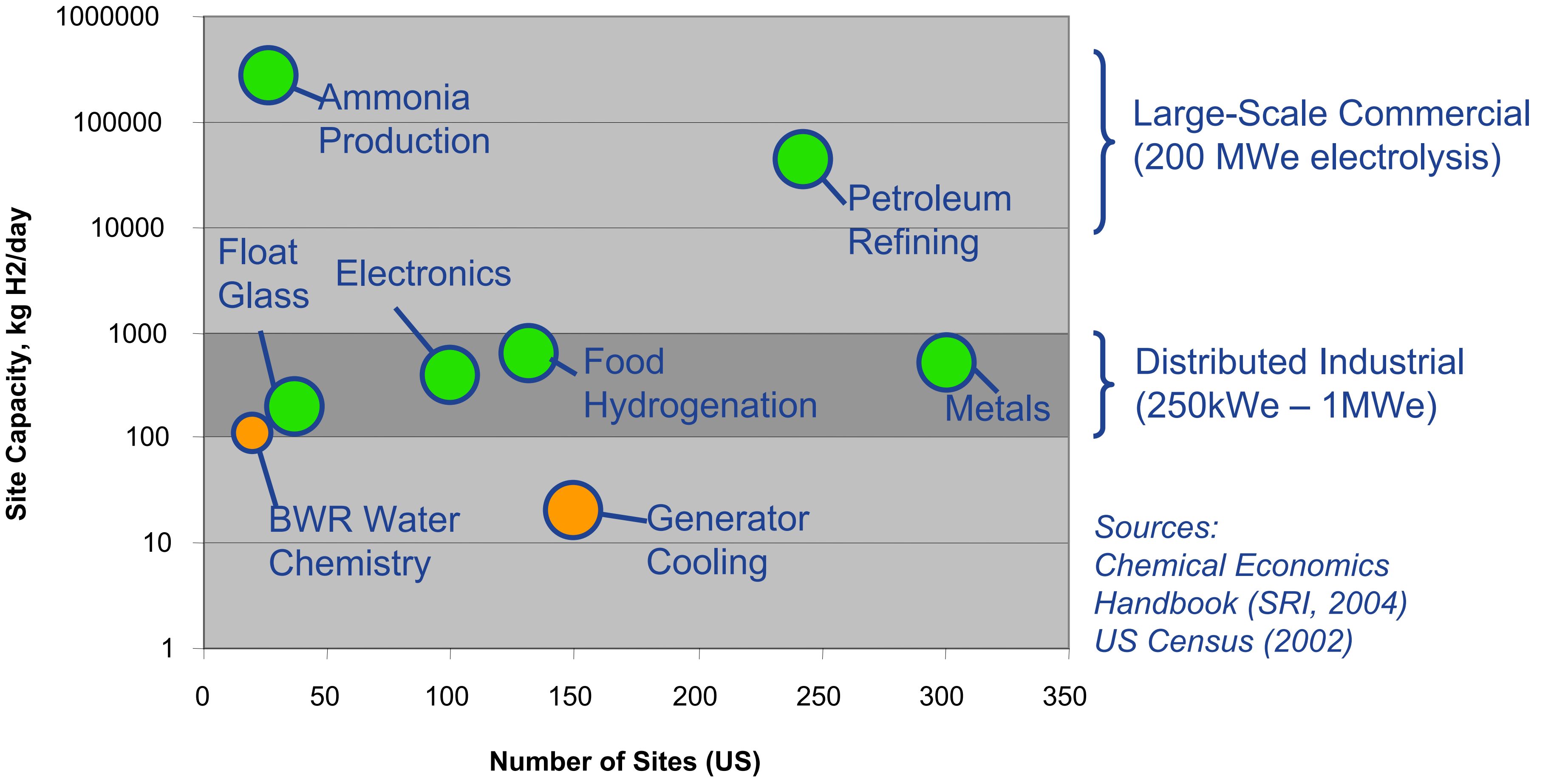
Industrial Hydrogen Market Segments

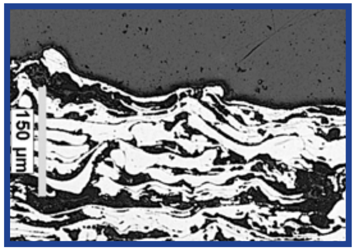


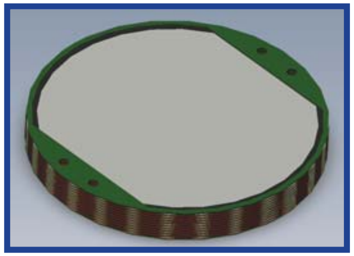
Sources:
Chemical Economics Handbook (SRI, 2004)
US Census (2002)

Industrial market infrastructure can lead fueling infrastructure

GE Technology Capital Costs

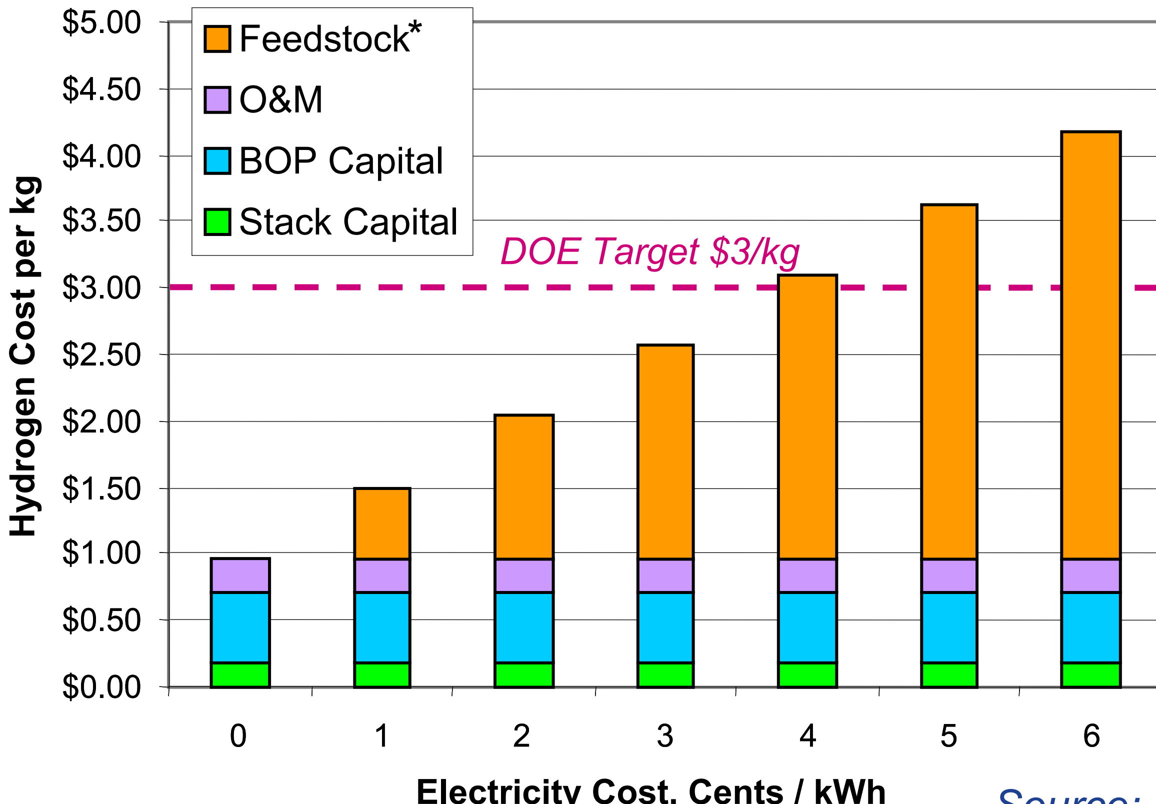
Projected CapEx, 5 kg/hr stack :	Per kg/hr	Per Nm^3/hr
Prototype	$16,000	$1,426
Production	$5,000	$446





At 50 kWh/kg H_2 , production stack cost is **$100/kW**

Projected H2 Cost with GE Electrolyzer: 1000 kg/day, 30 bar pressure



*electricity, water

Source: GE Global Research, NREL H2A Model

Low-cost electricity still key to meeting targets.

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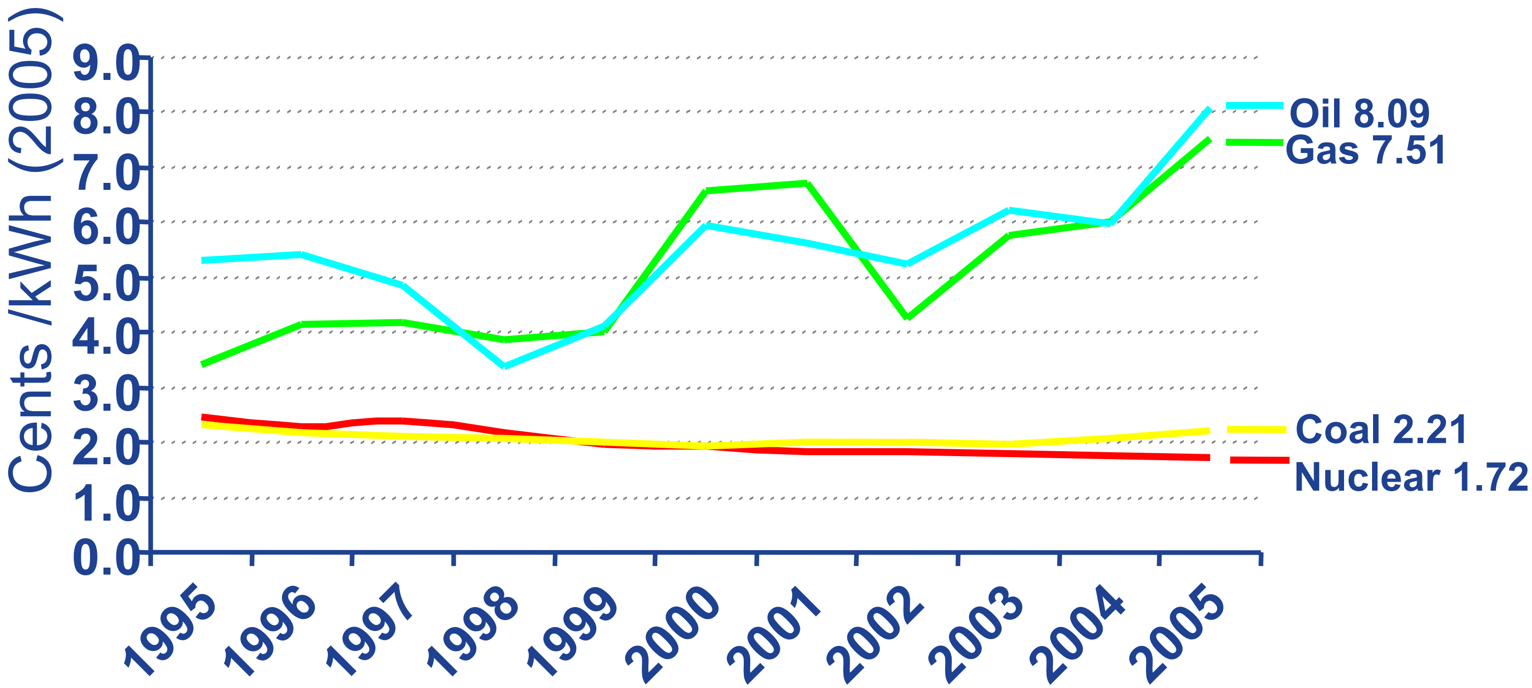
Electricity Production Costs

existing fleet - US 1995-2005



Source: NEI, 2006

Lowest **cost** electricity available from existing nuclear
Electricity market demands set actual **price**

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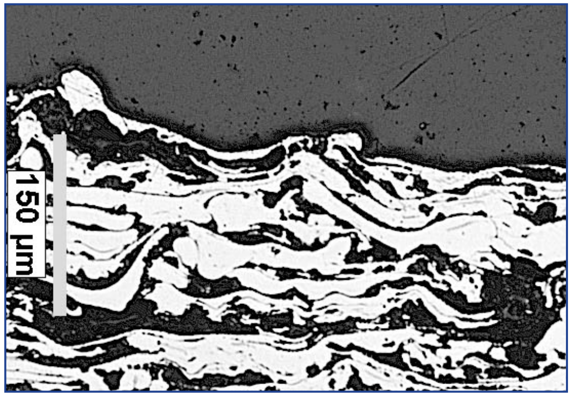
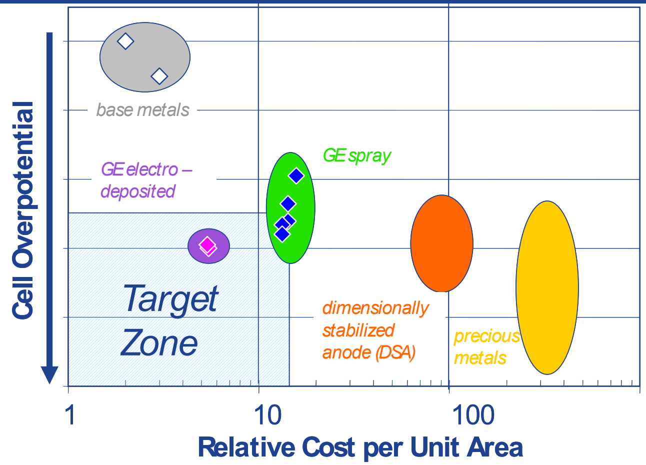
GE Alkaline Electrolysis Technology

High Surface Electrode



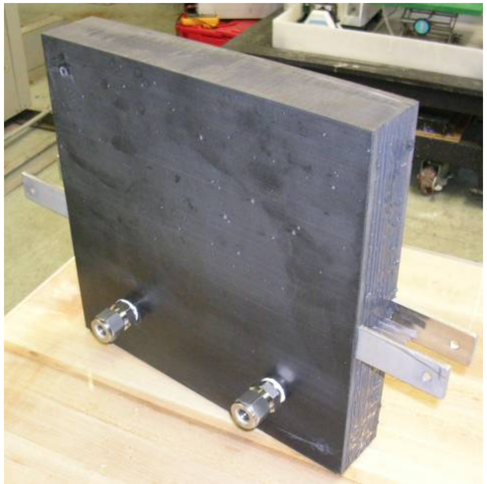


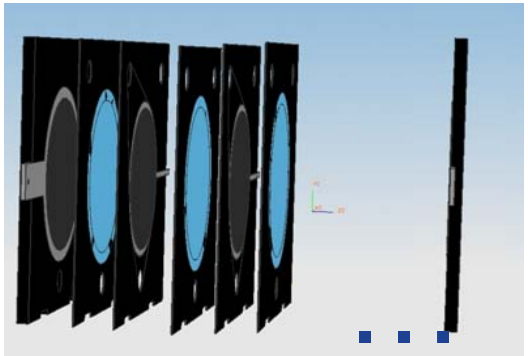
- Wire arc electrode system
- Electrodeposition

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

Plastic Stack

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





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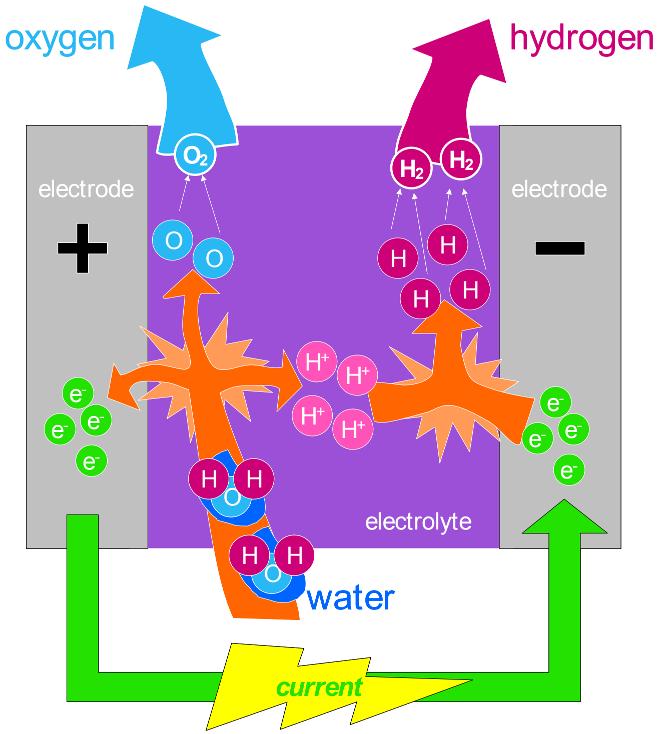
Electrolysis Cell Basics



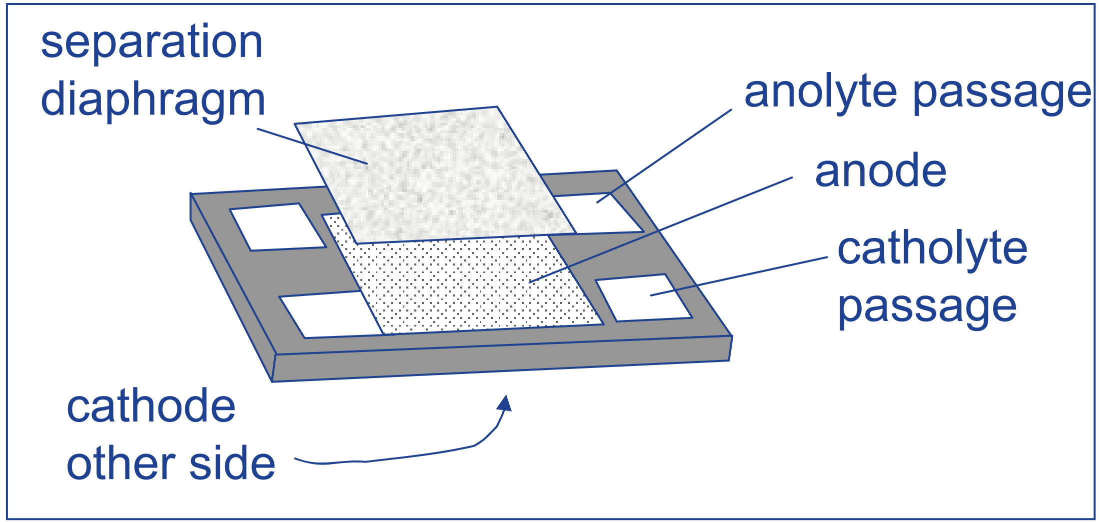
$$2\ H_2O + ELECTRICITY \rightarrow O_2 + 2\ H_2$$

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

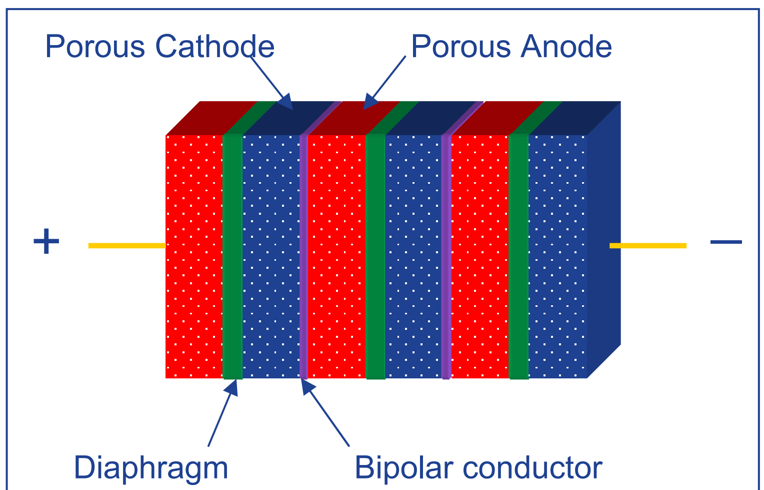
$$2H_2O\ +\ 2e^-\ \rightarrow\ 2OH^-\ +\ H_2$$

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

$$2OH^-\ \rightarrow\ H_2O\ +\ 2e^-\ +\ ½\ O_2$$



Bipolar type half-cells



Multicell Bipolar Stack

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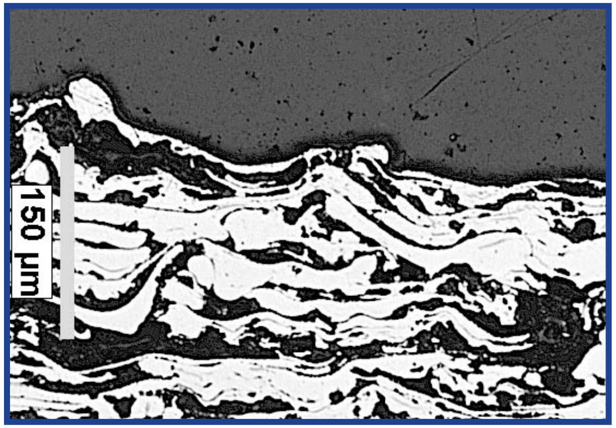
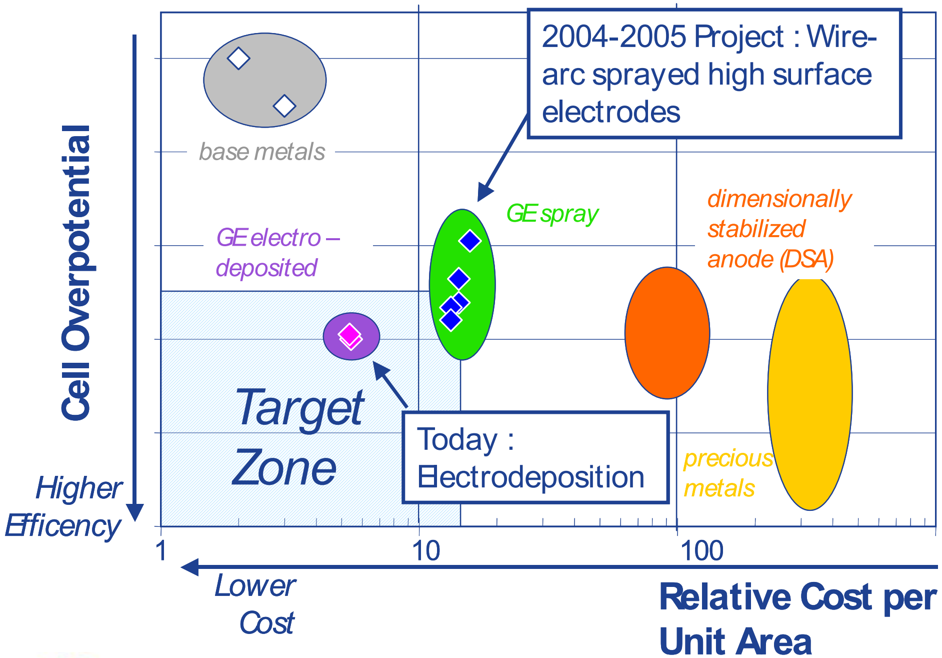
Technical Details - Electrode

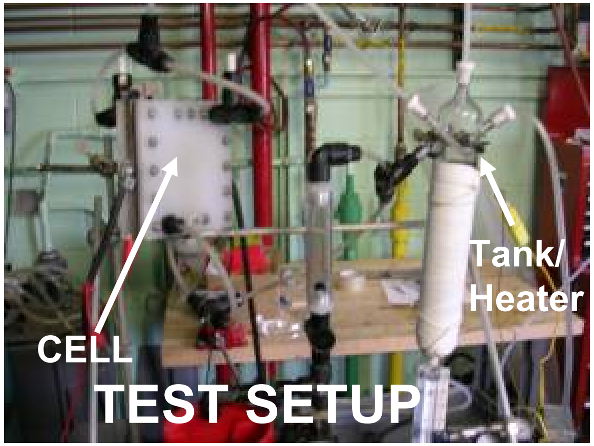
GE electrode technology applies a high effective surface area, nickel-based coating to the base metal bipolar plate for high performance at low cost.



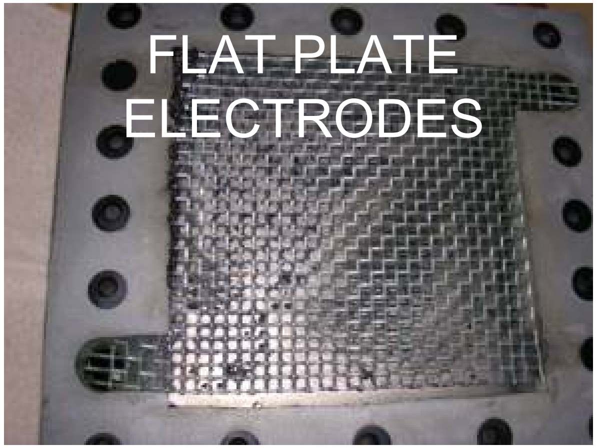


- Achieved target performance with hot spray technique in 2005.
- Researching electrodeposition for additional cost and performance advantage:
  - Thinner bipolar plate
  - Eliminates warping
  - Coats 3D electrode surface

Technical Details – Electrode

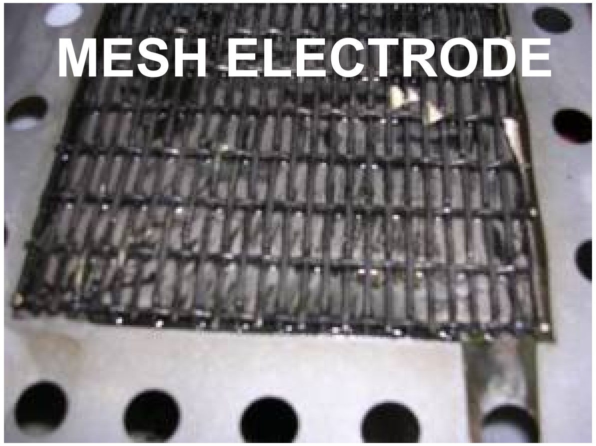


•Single flow cell
•Ambient pressure, 80°C



•Plastic mesh for flow distribution

- Some oxide left – leaching blocked by plastic mesh



•Cathode mesh applied
•Higher coated surface area

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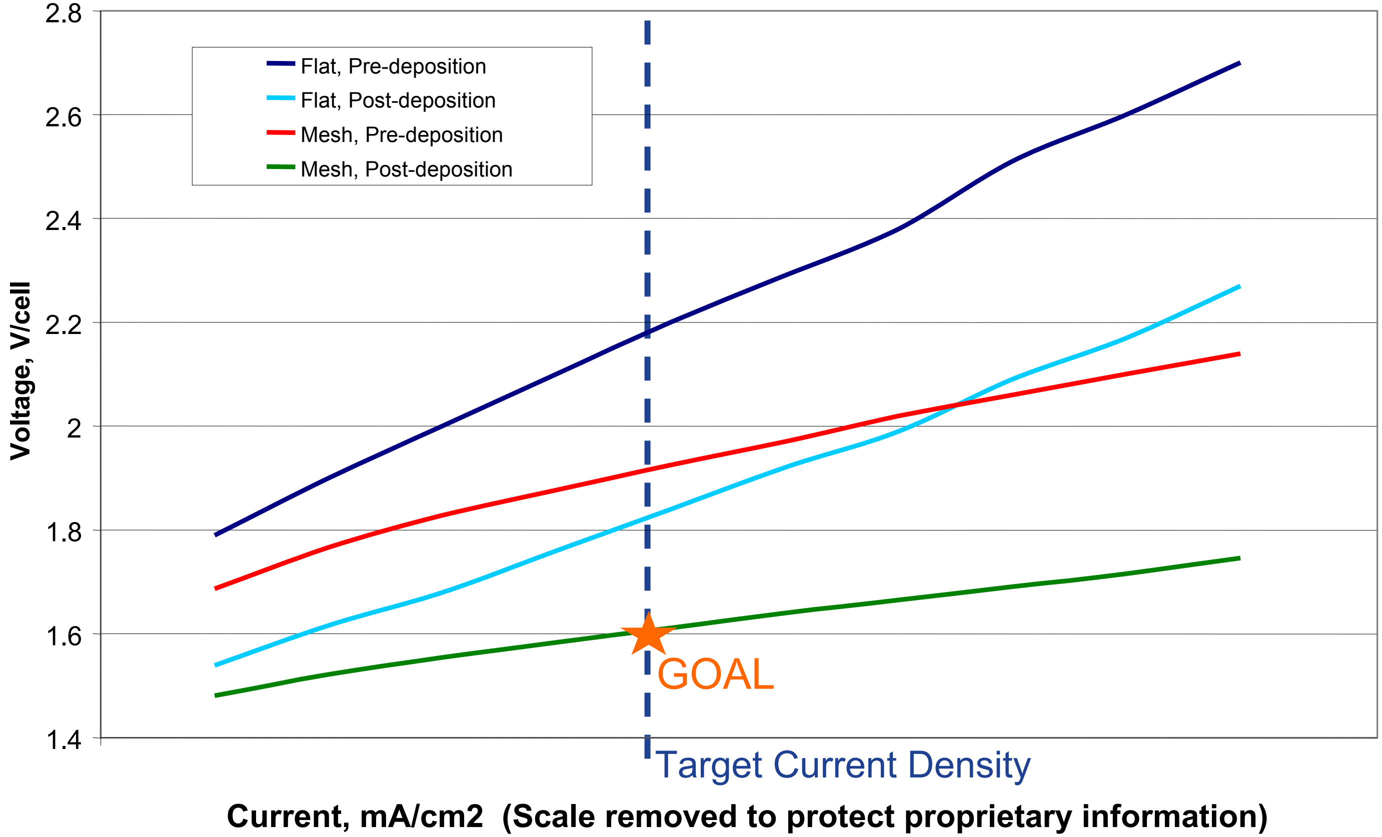
Single Cell Performance



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.

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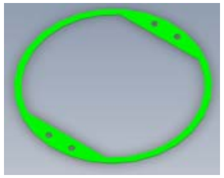
Plastic Stack Construction



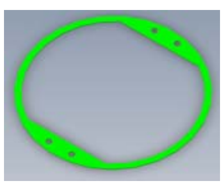
Stack end assembly (machined from molded blanks

Diaphragm cartridge

x9

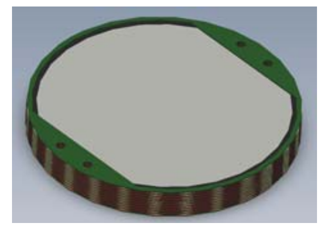
Electrode Assembly

Diaphragm cartridge

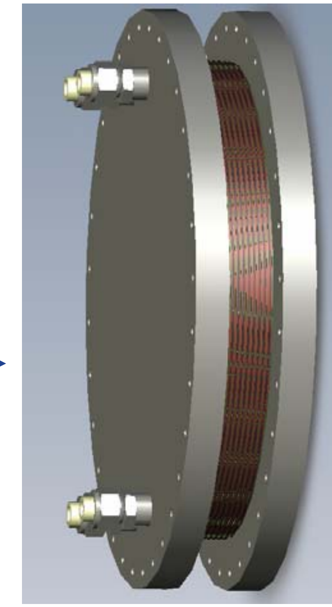


Stack end assembly (machined from molded blanks

Plastic weld



9 cell stack core



10-cell Stack module

(shell, bolts, current straps not shown)

15 bar pressure stack under construction for 2007 test

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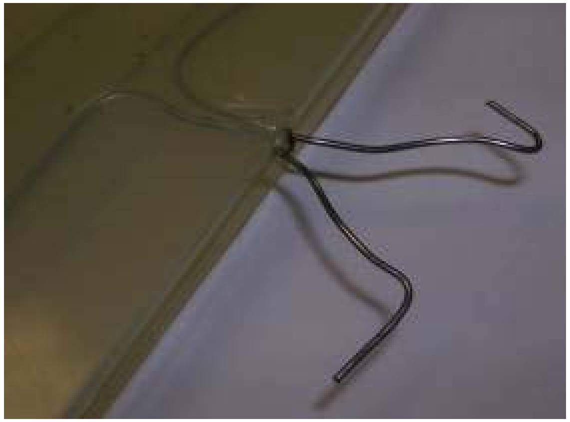
Resistance Wire Welding



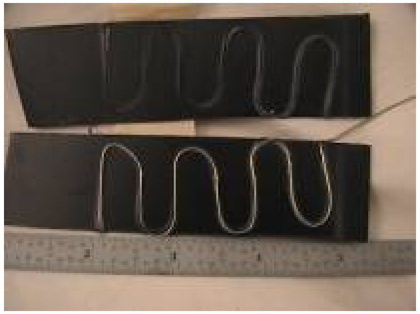
- Robust method to join plates for test stack
- Wire path determines weld location
- Allows “blind” welds along passages
- Heat management, inspection method biggest challenges

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

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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

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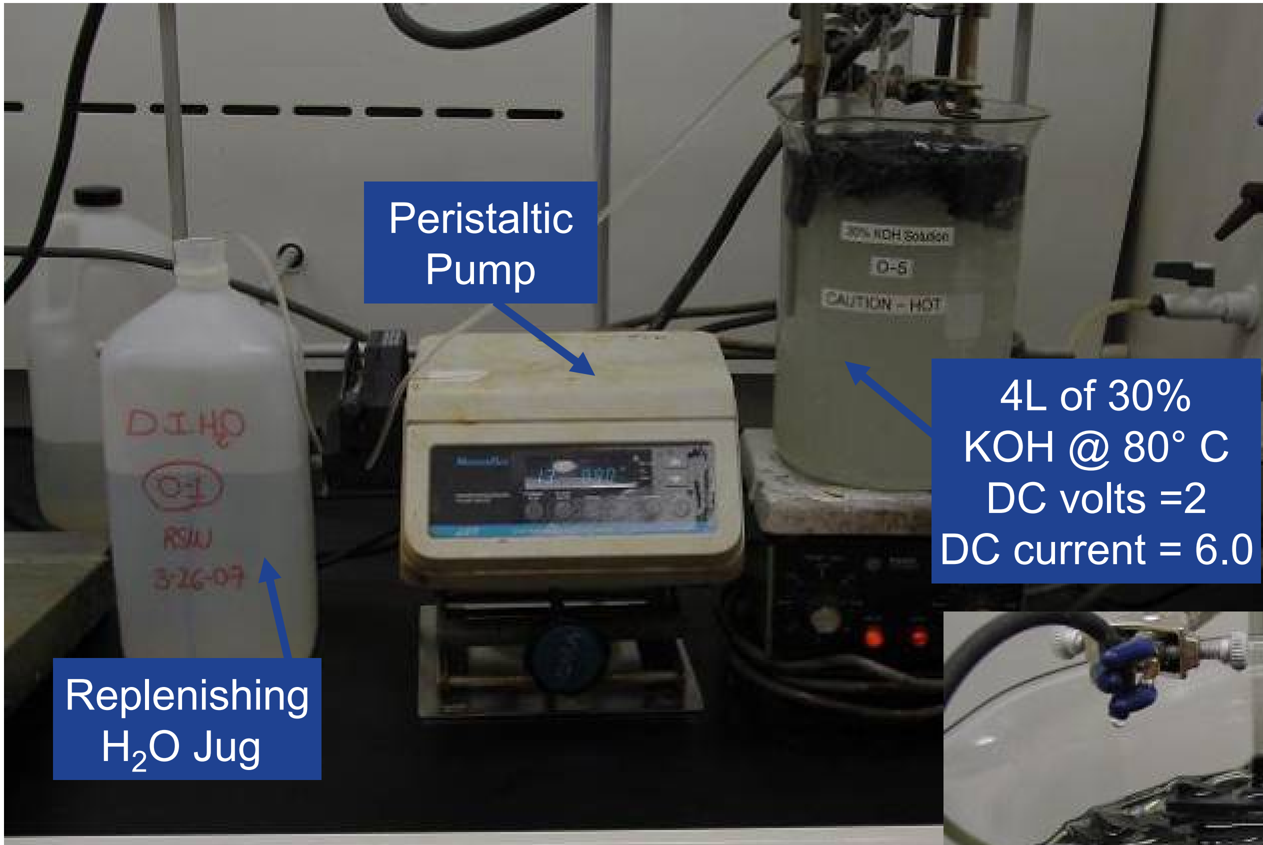
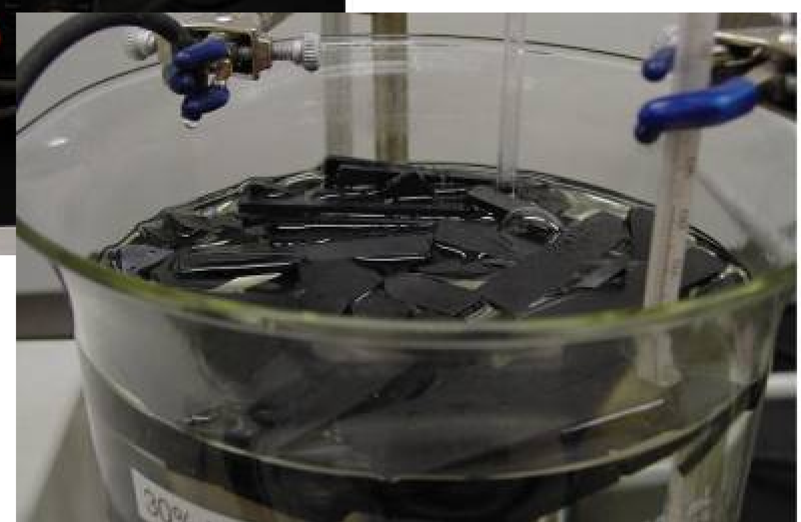
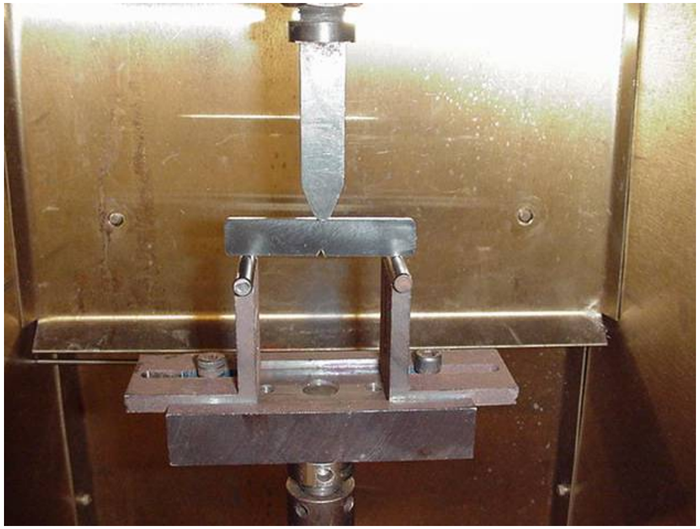
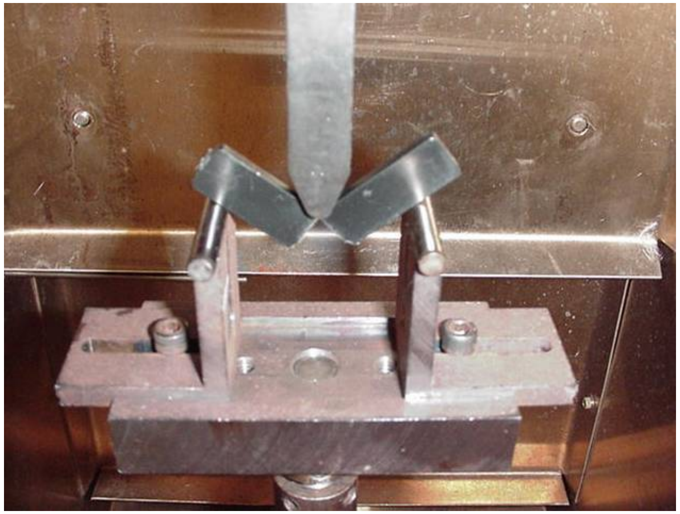
Oxidation Exposure Testing





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.

Future Work

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.

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