Advanced Alkaline Electrolysis

Dana Swalla, Ph.D.
GE Global Research Center
Niskayuna, NY

Project #PDP14

imagination at work

This presentation does not contain any proprietary or confidential information

Acknowledgements

Acknowledgment: This material is based upon work supported by the Department of Energy under Award Number DE-FC-0706-ID14789

Overview

Timeline

Start: 30 September 2006
End: 30 December 2008
70% 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 2007:	$524,841
2008 Funding (to date) :	$283,710

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

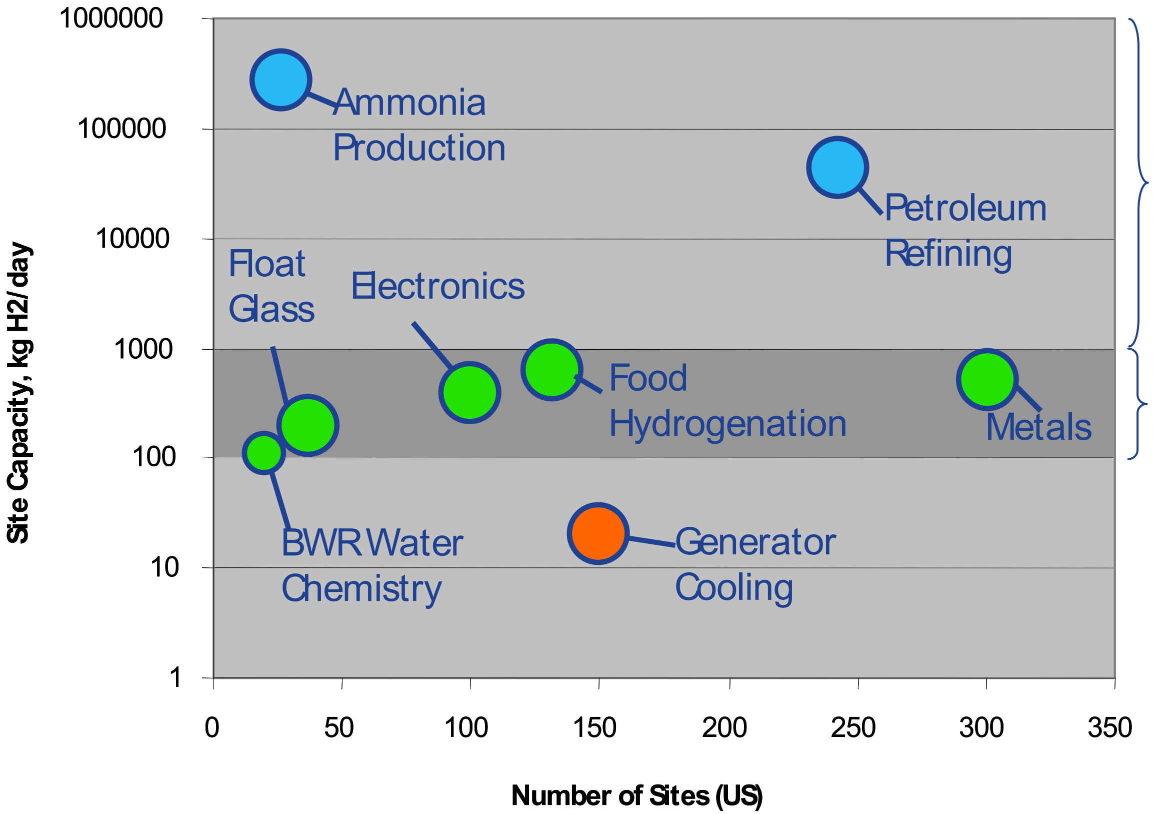
	Units	DOE 2012 Target
Cell Efficiency	%	69% (1.8V)
System Cost	$/kg H2	$0.70 ($400/kW)
Electricity Cost	$/kg H2	$2.00
O&M Cost	$/kg H2	$0.60

Approach

100% complete	Task 1: Define market and requirements • Industrial users survey • Technical and pricing requirements • Nuclear regulatory and environmental impact issues
80% complete	Task 2: Design and build pressurized electrolyzer stack • Develop plastic stack technology • Low cost electrode methods
50% complete	Task 3: Plastics oxidation lifing • Creep resistance • Oxidation
10%	Task 4: Demonstrate electrolyzer performance and capital costs
10% complete	Task 5: System operation testing • O&M cost assessment
50%	Task 6: Create industrial-scale system conceptual design
50% complete	Task 7: Create 1-kg-per-second demonstration system conceptual design

imagination at work

Industrial Hydrogen Markets



Large scale operations: 90% of consumption

Mid-scale Industrial

Global consumption: 42 million tons H_2 per year

imagination at work

An Existing, Growing Market

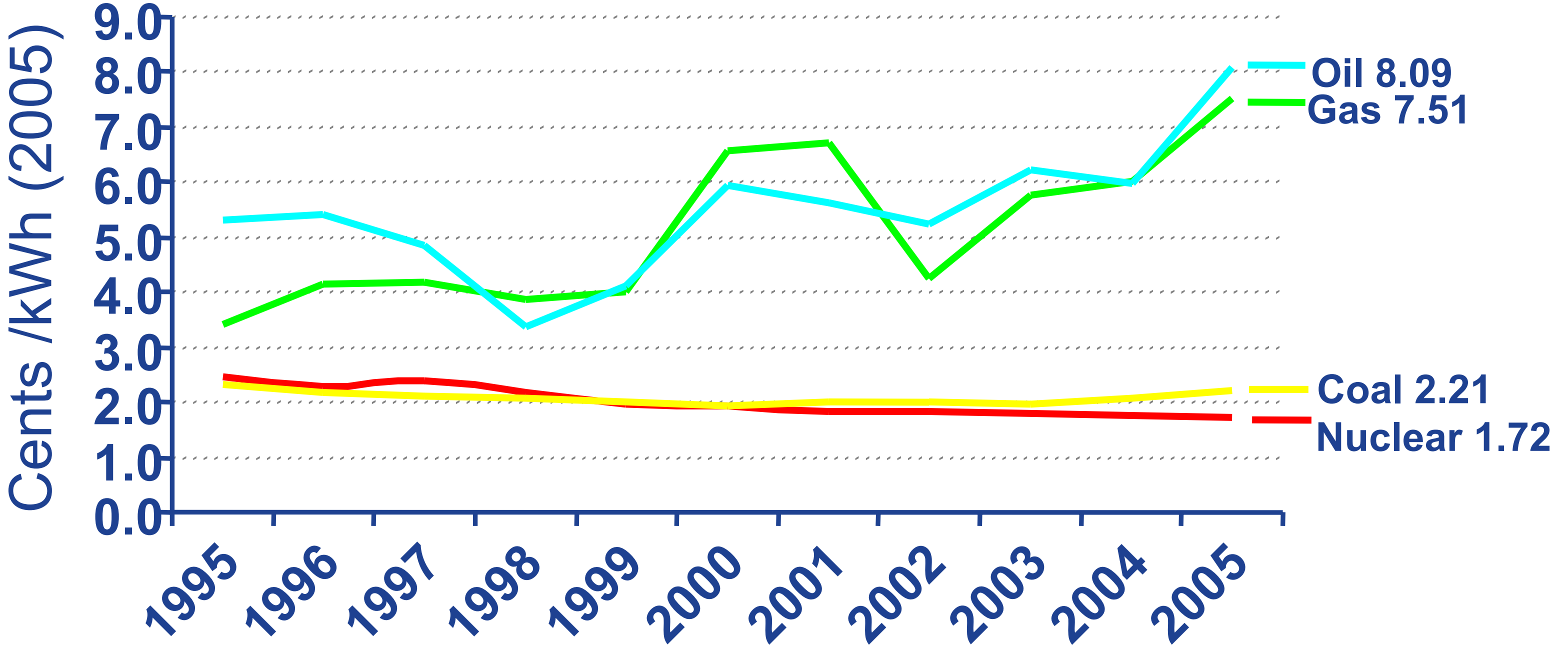
- 4 million tons H_2 / year for mid-range industrial
- Per-site consumption on order of 100-1000 kg per day
- 15% yearly growth
- Currently served by delivered gas or liquid
- Required pressure varies – but much lower than automotive storage scenario
- Costs vary significantly : $4-$15 per kg

Distributed Electrolysis Can Fill Growth Demand, If Cost-Competitive

imagination at work

Electricity Production Costs

existing fleet - US 1995-2005



Source: NEI, 2006

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

imagination at work

Electrolysis Cost of Hydrogen

Basis is the NREL H2A model, modified from the 1500 kgpd case.

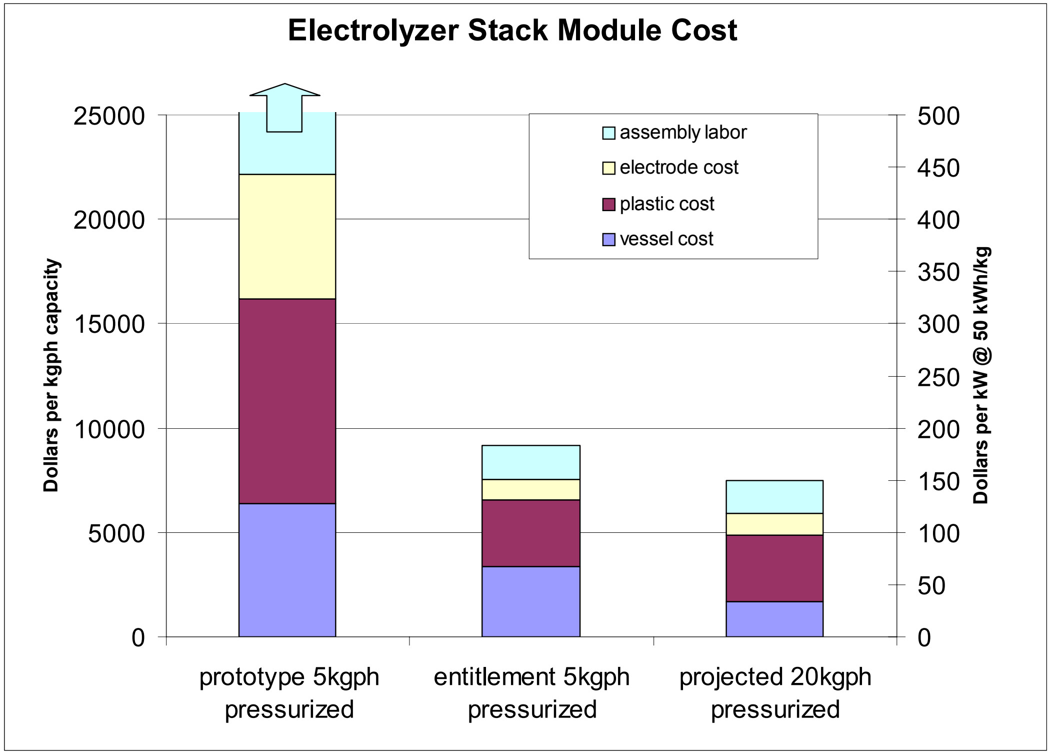
- Industrial point-of-use case:
  No dispensing or distribution costs.

Cost of Electricity, ¢/kWh	Capital Cost, $/kW		
	$4,000	**$800**	**$400**
1.0	$4.79	$1.51	$1.10
2.0	$5.29	$2.01	$1.60
3.0	$5.79	$2.51	$2.10
4.0	$6.30	$3.01	$2.60
5.0	$6.80	$3.52	$3.11
6.0	$7.30	$4.02	$3.61
7.0	$7.80	$4.52	$4.11
8.0	$8.30	$5.02	$4.61

Stack Module Costs

Cost scenarios based on actual cost of demonstration stack, projected assembly and labor costs.

Balance of system costs are additional, and depend on system size.

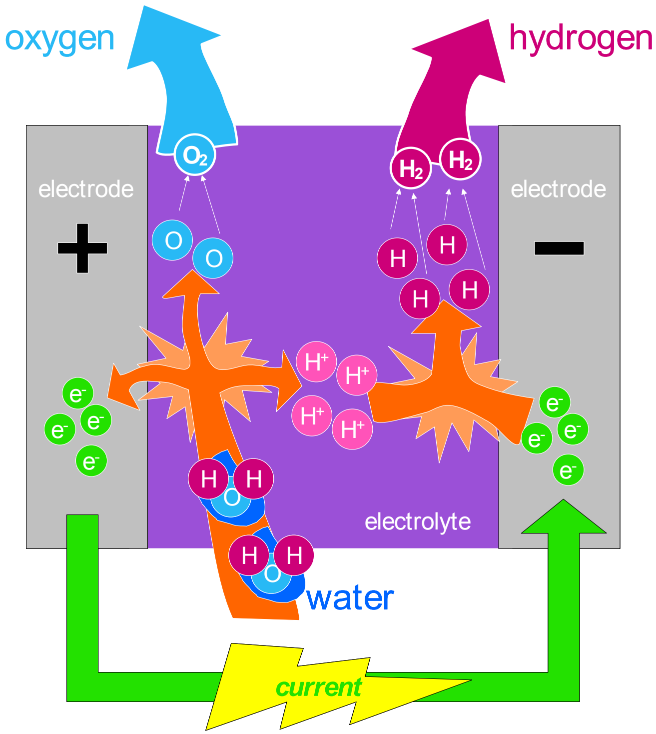


Size	Power*	Module Cost
5 kgph	250 kW	$45,800
20 kgph	1 MW	$150,000

* Assumes 50 kWh/kg H_2

imagination at work

Electrolysis Basics



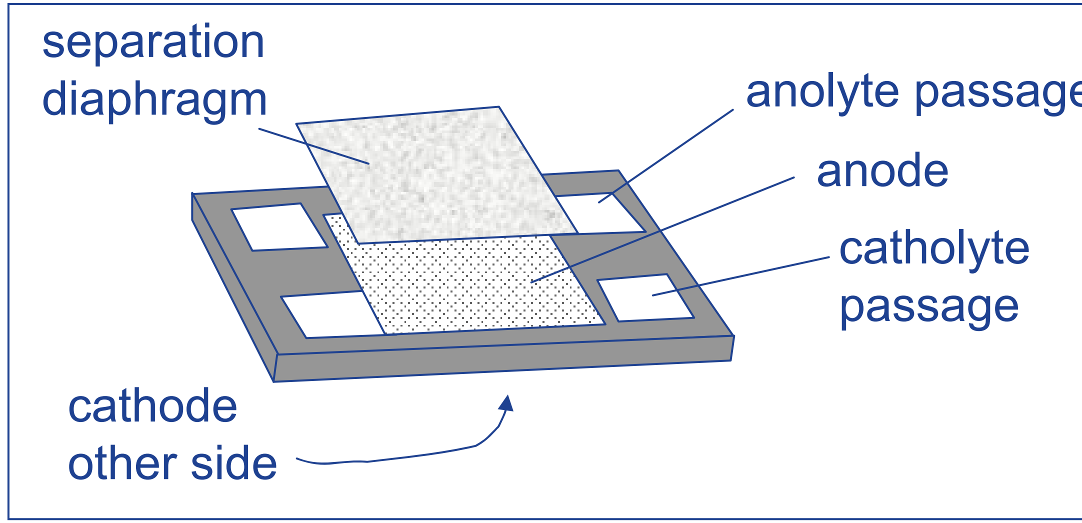
$$2\,H_2O + ELECTRICITY \rightarrow O_2 + 2\,H_2$$

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

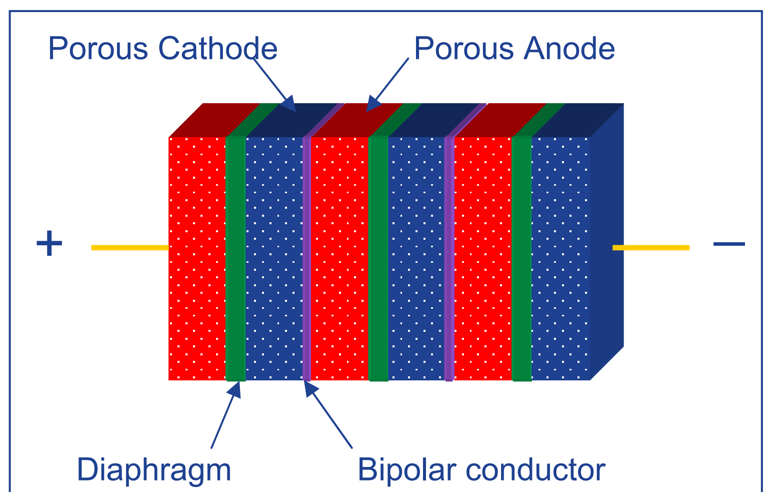
$$2H_2O \;+\; 2e^- \;\rightarrow\; 2OH^- \;+\; H_2$$

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

$$2OH^- \;\rightarrow\; H_2O \;+\; 2e^- \;+\; \tfrac{1}{2}\,O_2$$



Bipolar type half-cells

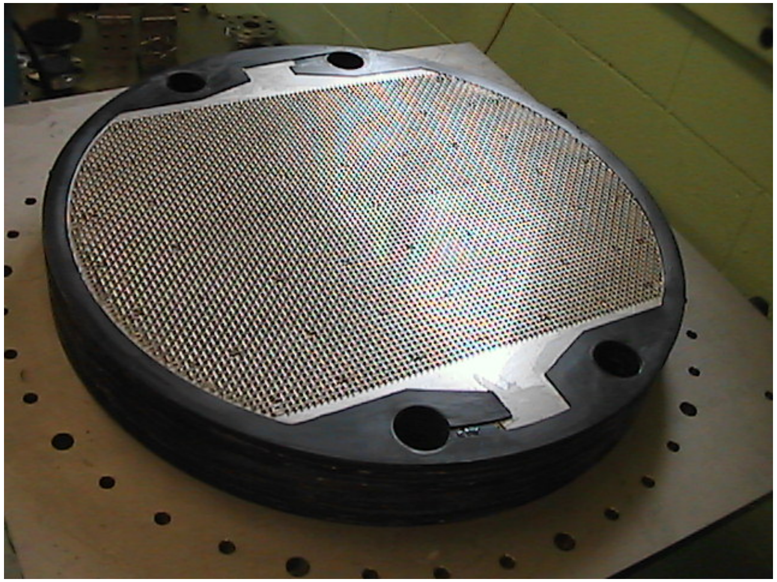


Multicell Bipolar Stack

imagination at work

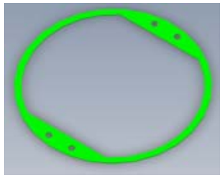
GE Plastic Stack Technology

- Injection-molded sections
- Complex features all molded in the plastic – not machined in the metal
- Sheet metal/mesh electrode
- Single plastic mold for demonstration: 3D / multiple molds in full production



Completed stack assembly

Plastic Stack Construction



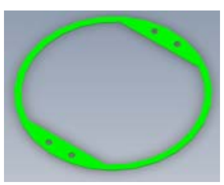
Stack end assembly (machined from molded blanks

Diaphragm cartridge

x9

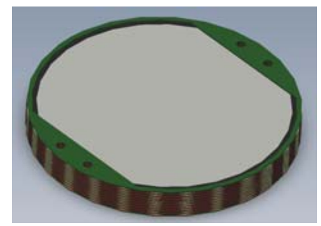
Electrode Assembly

Diaphragm cartridge

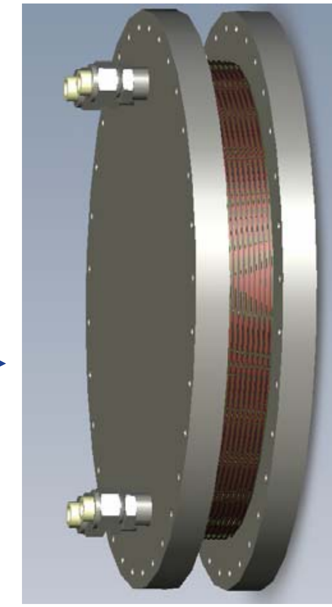


Stack end assembly (machined from molded blanks

Plastic weld



9 cell stack core



10-cell Stack module

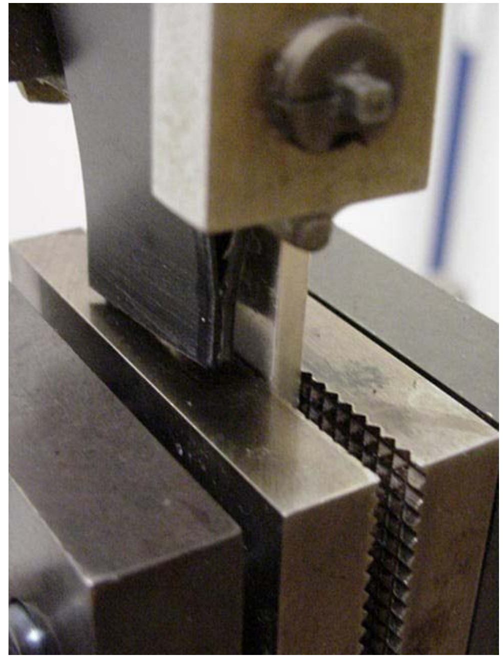
(shell, bolts, current straps not shown)

15 bar pressure stack completed and ready for testing

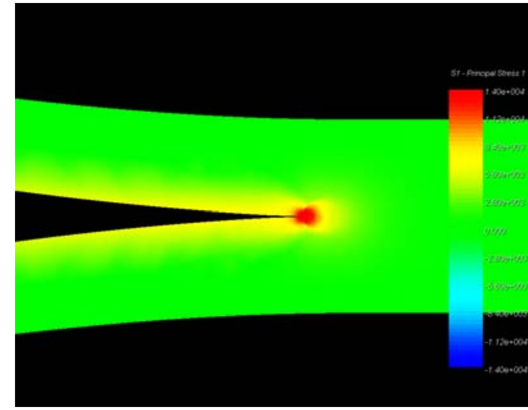
imagination at work

Plastic Joining Method and Testing

- Research on various plastic grades
- Accelerated testing for high pressure oxidant exposure
- Plastics retain high yield strength
- Joint typically as strong as plastic base material



Wedge Breaking Test

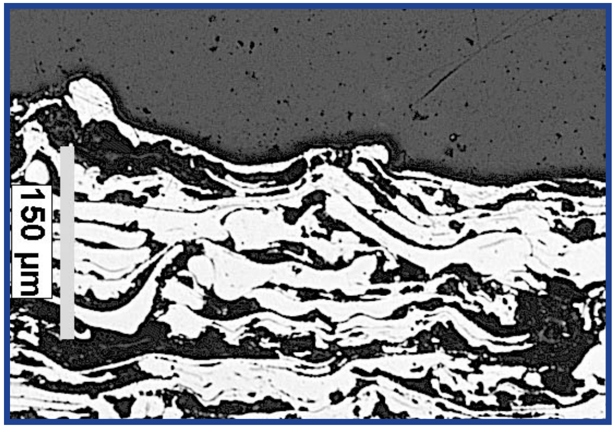


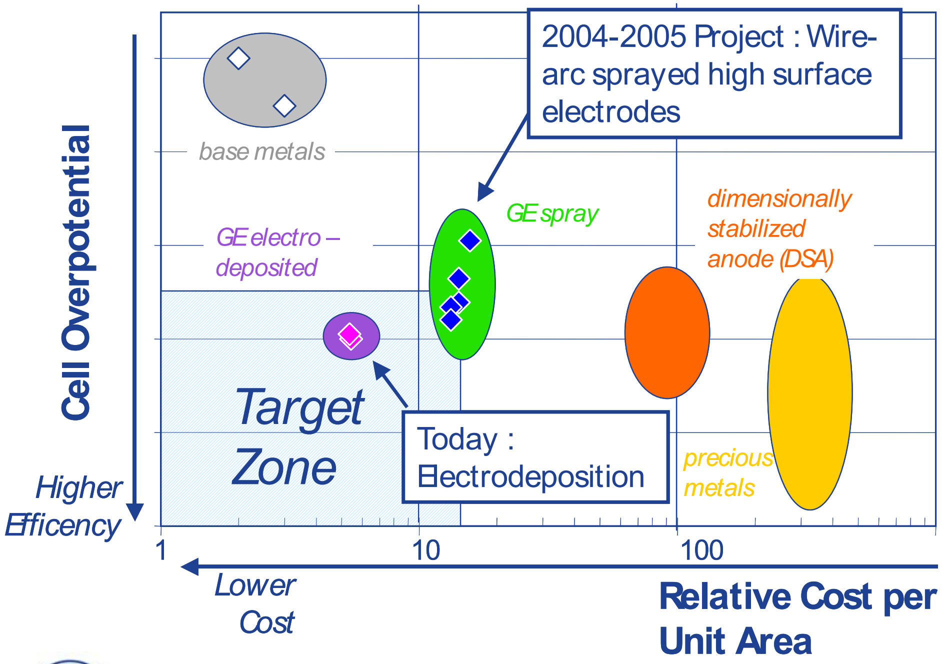
Joint Finite Element

Post Testing

GE Electrode Technology

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



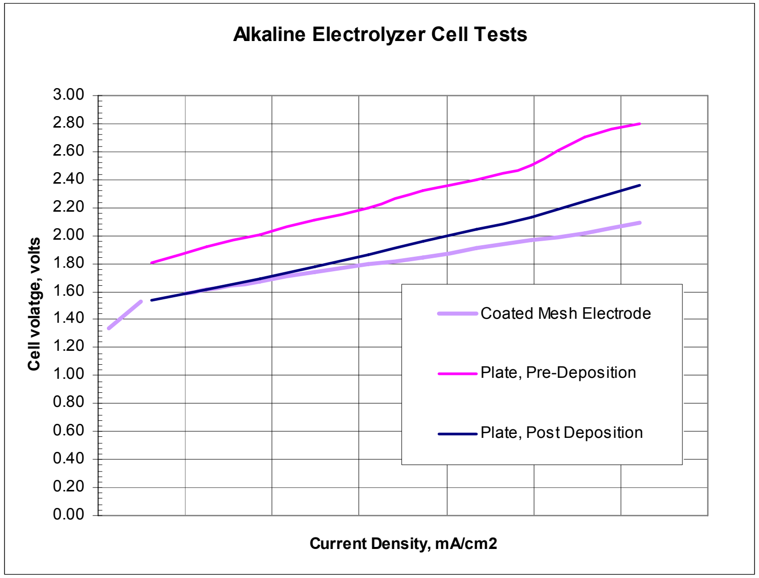


- Achieved target performance with hot spray technique in 2005.
- Demonstrating electrodeposition for additional cost and performance advantage:
  - Thinner bipolar plate
  - Eliminates warping
  - Coats 3D electrode surface

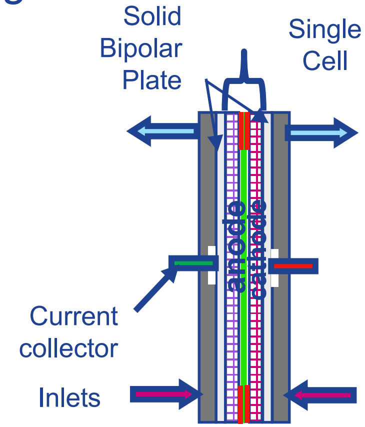
Cell Performance

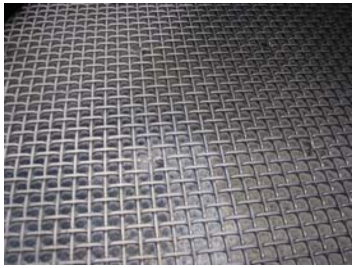
- Wire-arc sprayed electrode tested in 2005-2006
- Electrodeposition successful at small scale: Performance improvement: - 0.2V or better
- Coating uniformity and plating conditions verified using full-size single cell rig
- Electrodeposition of full size, 10-cell demonstration stack completed

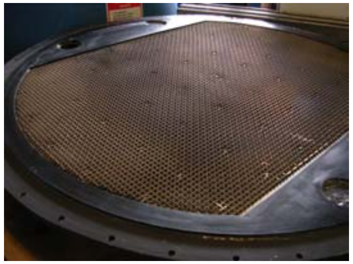
Performance test from bench scale cell



Uniform, stable coating verified on full-size single cell

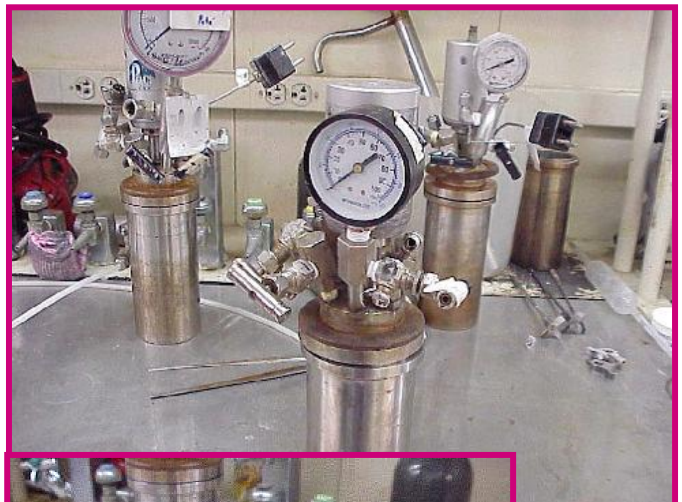






Accelerated material testing

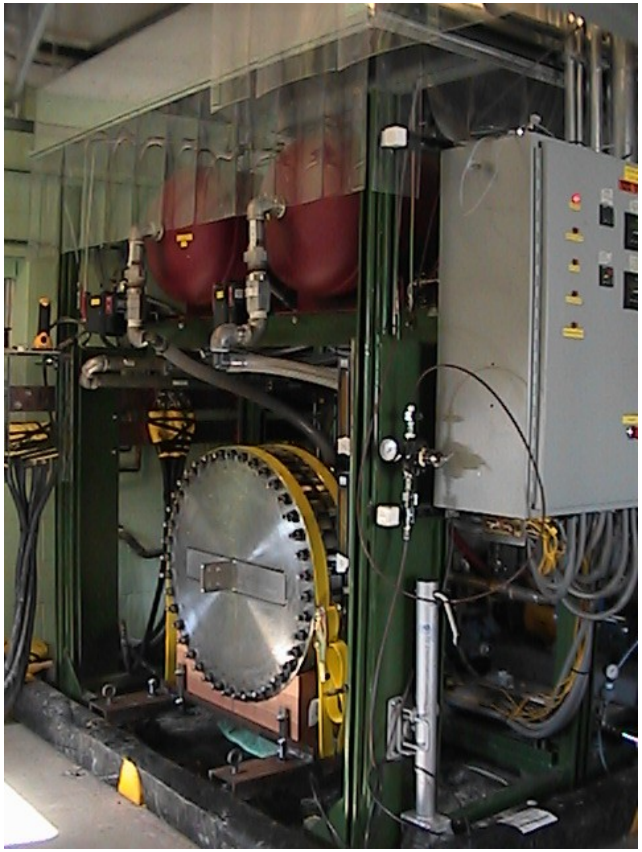
Tensile and bending specimens in O_2 tested to 40-62 equivalent weeks at a design pressure of 15 bar and at 80C



- Polysulfone materials, Udel® and Radel®, retain ductility and yield strength
- Noryl® EN265 and modified Noryl® EN265 maintain yield strength, but limited or no ductility

Udel® and Radel® most likely candidates for long term electrolyzer operation

Additional Work: “1 kgph” System



Capabilities:

- 1 kg H_2 / hr production rate
- *Currently being upgraded to 15 bar pressure capability*
- Automated controls
- P, T, massflow, purity measurements

Study operability & maintenance characteristics

imagination at work

Industrial scale system design

In collaboration with Entergy, the background, performance, and operational history of electrolyzers at Cooper Nuclear Station and Pilgrim Stations used to benchmark system costs and regulatory issues.

Cooper Nuclear Station – Nebraska

- Unipolar design generates 7.5 SCFM or 3,942,000 SCF per year.
- 90% - 97% availability
- *No special regulatory or licensing issues* because hydrogen is generated on demand – no storage.
- Onsite production roughly ½ the cost of delivered hydrogen.

Pilgrim Nuclear Station – MA

- The electrolytic hydrogen water chemistry (EHWC) system capable of producing 50 SCFM H_2 and 25 SCFM O_2.
- Availability less than 50%…. Attributed to poor facility design and ability to easily maintain.
- System no longer in operation.

imagination at work

1 kgps Commercial Scale System

Waterford 3 Generating Station, located in Hahnville, LA is an example of a possible 1 kgps electrolysis plant site

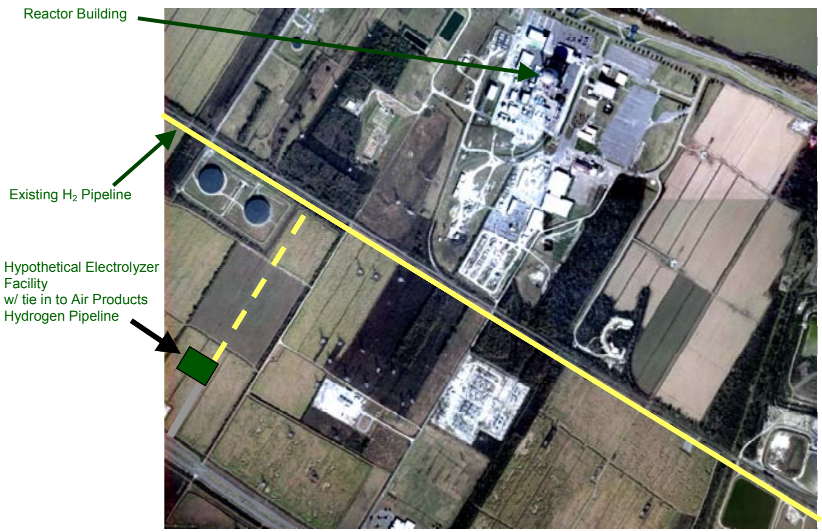
- Energy usage: 50 kWh per kg of hydrogen to produce 1 kgps = 180 MW of electric power.

- Water consumed: 9.2 liters of water/kg of hydrogen produced = 7000 gallons/hr.

- Assume (4) - 200 cell modules powered from the same rectifier in electrical series.
- Each module draws 1500 amps, cell voltage is 1.6 V = 480 kW/module or 1920 kW per power block.

- Each rectifier produces 1500 A at 1280 VDC.

- 90 power blocks required to produce 1 kgps of hydrogen.



imagination at work

Future Work

2008: System testing at ambient and 15 bar pressure

O&M cost assessment

Material lifing studies

Conceptual design of reference plants

Complete regulatory assessment

imagination at work