

Advanced Alkaline Electrolysis

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Project
#PDP14



imagination at work

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Acknowledgements

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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

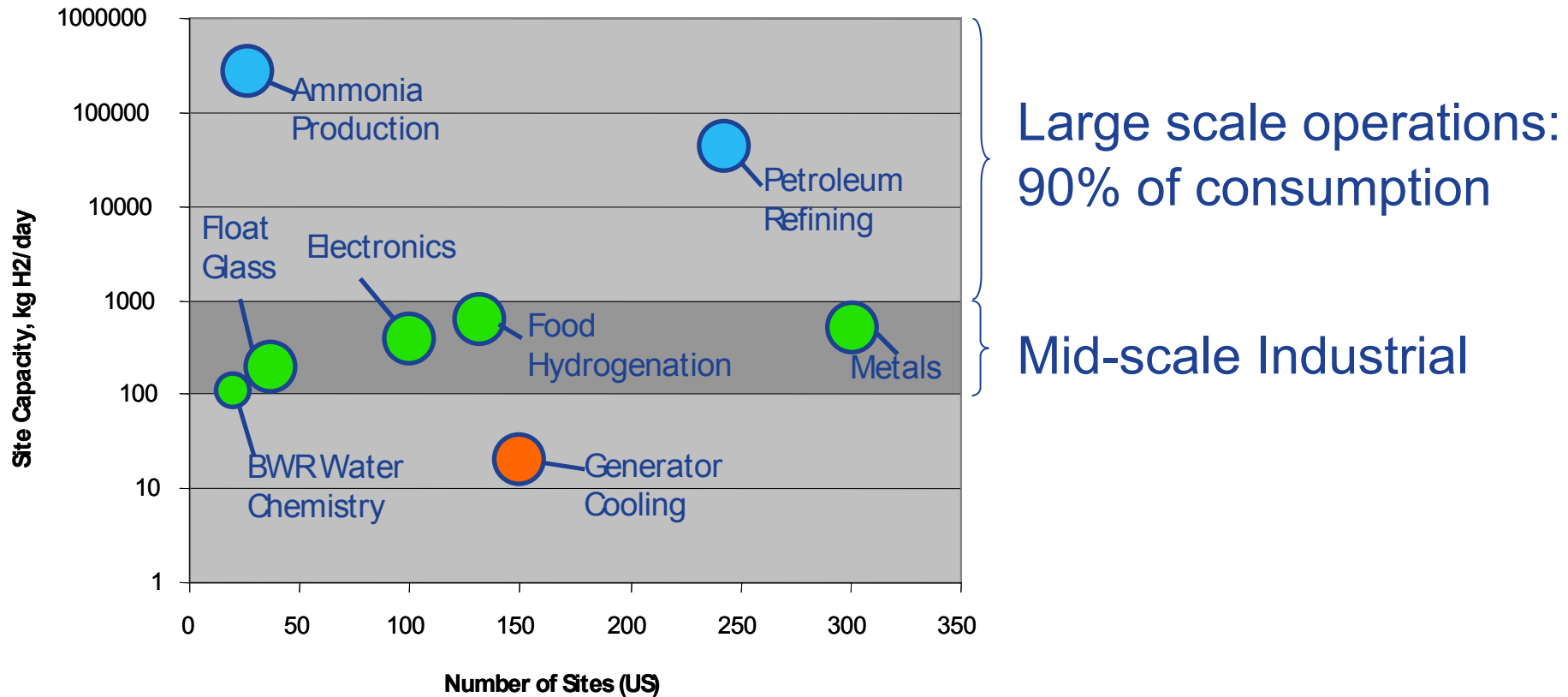
Codes and Safety: Environmental and regulatory impact assessment

	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

<i>100% complete</i>	Task 1: Define market and requirements <ul style="list-style-type: none">• Industrial users survey• Technical and pricing requirements• Nuclear regulatory and environmental impact issues
<i>80% complete</i>	Task 2: Design and build pressurized electrolyzer stack <ul style="list-style-type: none">• Develop plastic stack technology• Low cost electrode methods
<i>50% complete</i>	Task 3: Plastics oxidation lifing <ul style="list-style-type: none">• Creep resistance• Oxidation
<i>10%</i>	Task 4: Demonstrate electrolyzer performance and capital costs
<i>10% complete</i>	Task 5: System operation testing <ul style="list-style-type: none">• O&M cost assessment
<i>50%</i>	Task 6: Create industrial-scale system conceptual design
<i>50% complete</i>	Task 7: Create 1-kg-per-second demonstration system conceptual design

Industrial Hydrogen Markets



Global consumption: 42 million tons H₂ per year

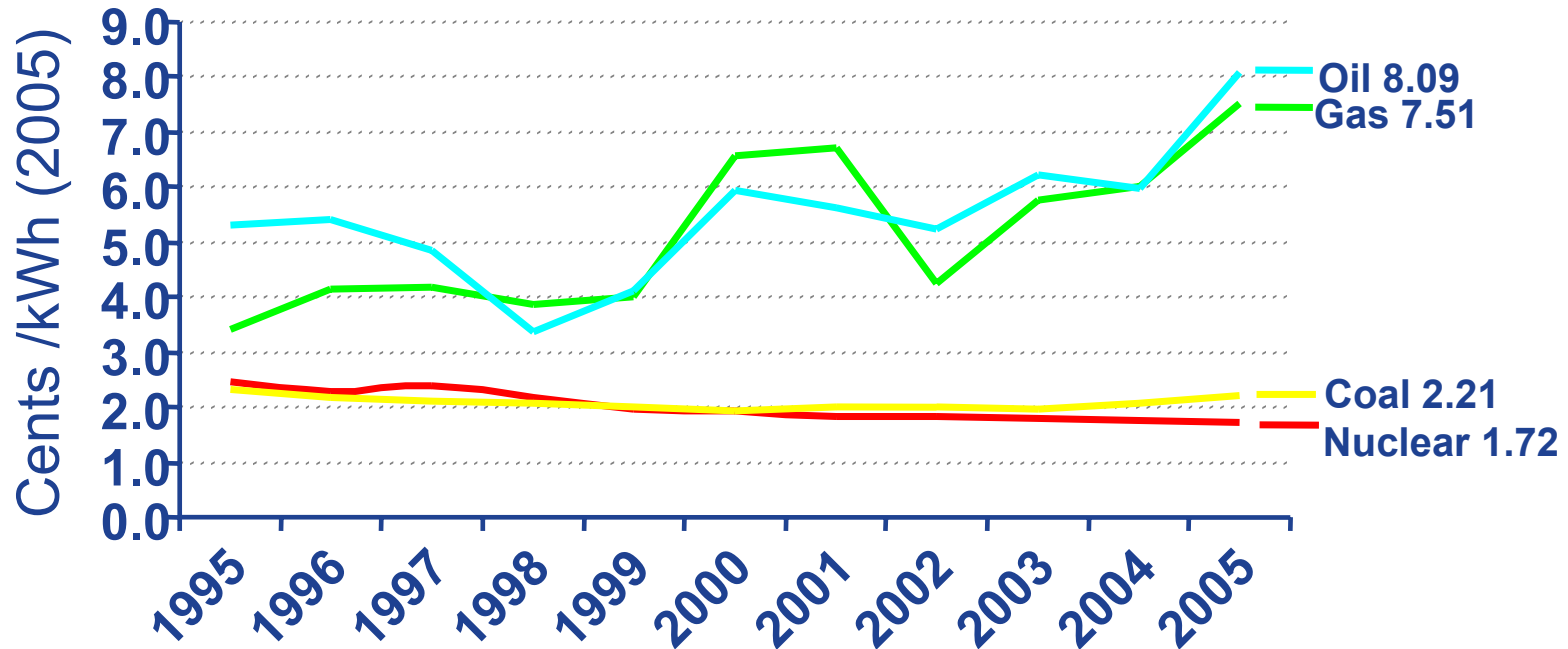
An Existing, Growing Market

- 4 million tons H₂ / 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

Electricity Production Costs

existing fleet - US 1995-2005



Source: NEI, 2006

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

Electrolysis Cost of Hydrogen

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

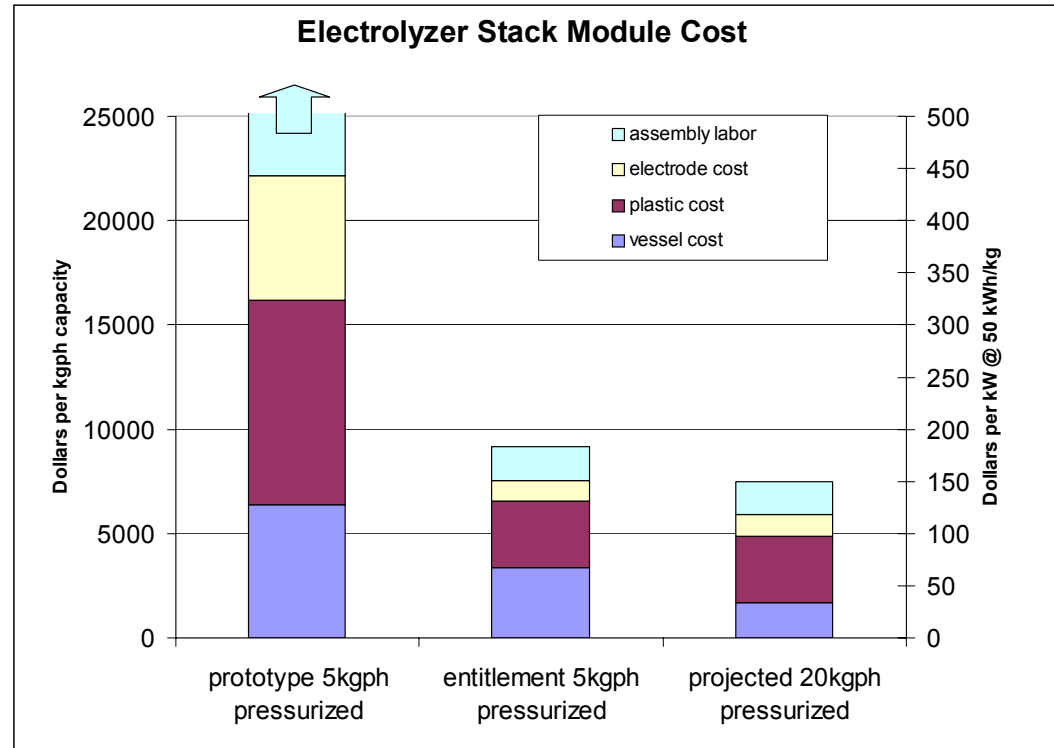
- Industrial point-of-use case:
No dispensing or distribution costs.

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

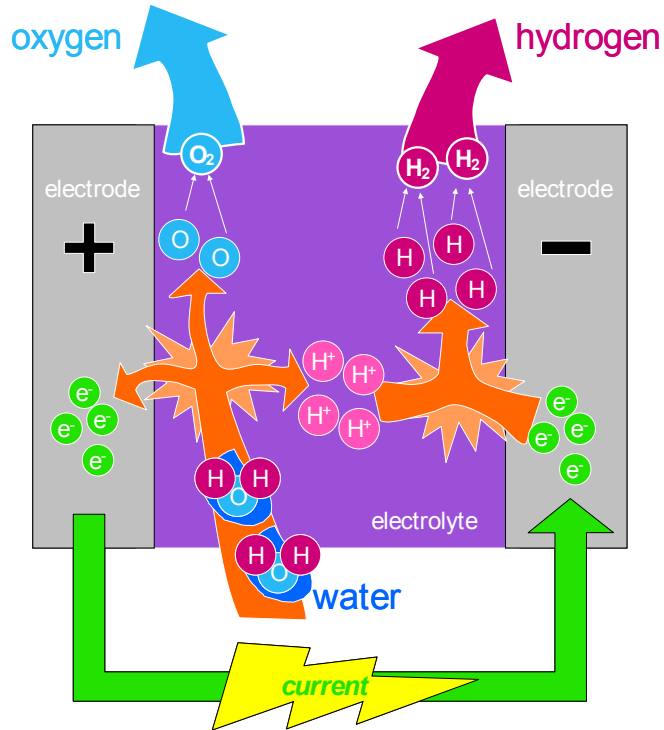
Cost scenarios based on actual cost of demonstration stack, projected assembly and labor costs.

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

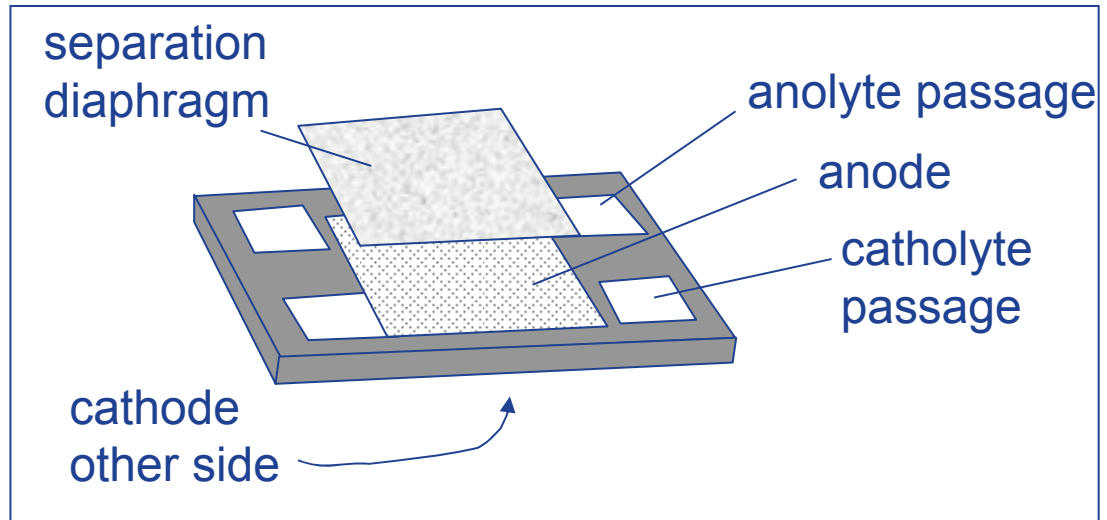
Electrolysis Basics



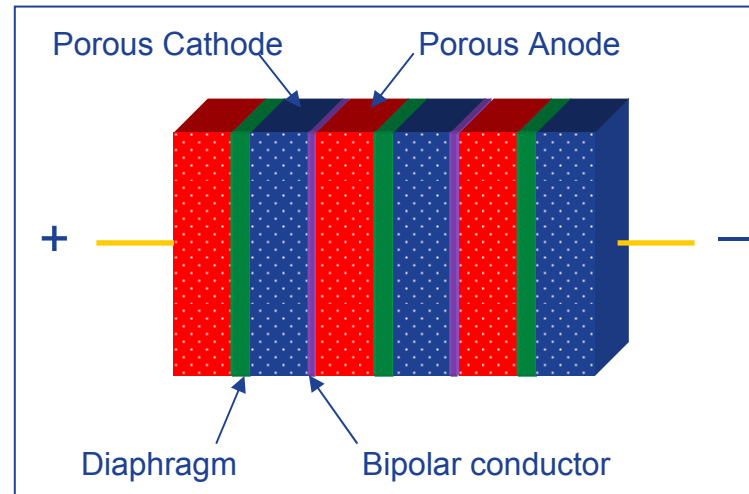
Cathode (-):



Anode (+):



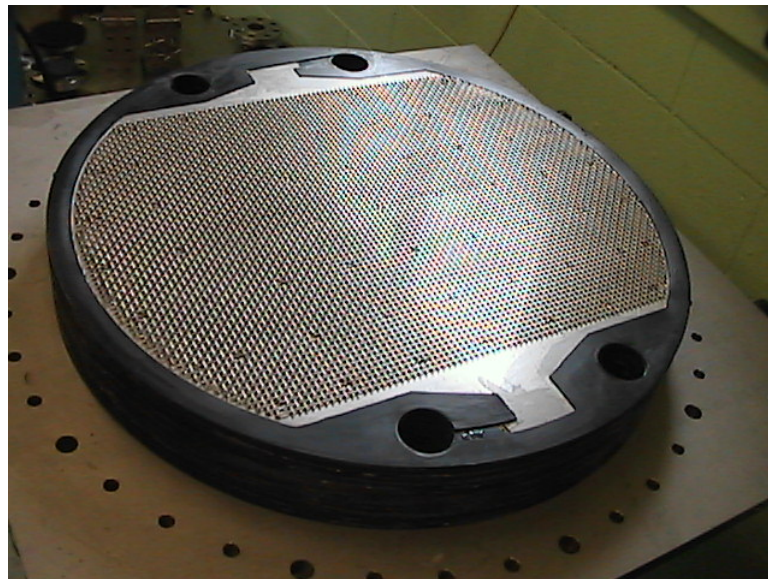
Bipolar type half-cells



Multicell
Bipolar
Stack

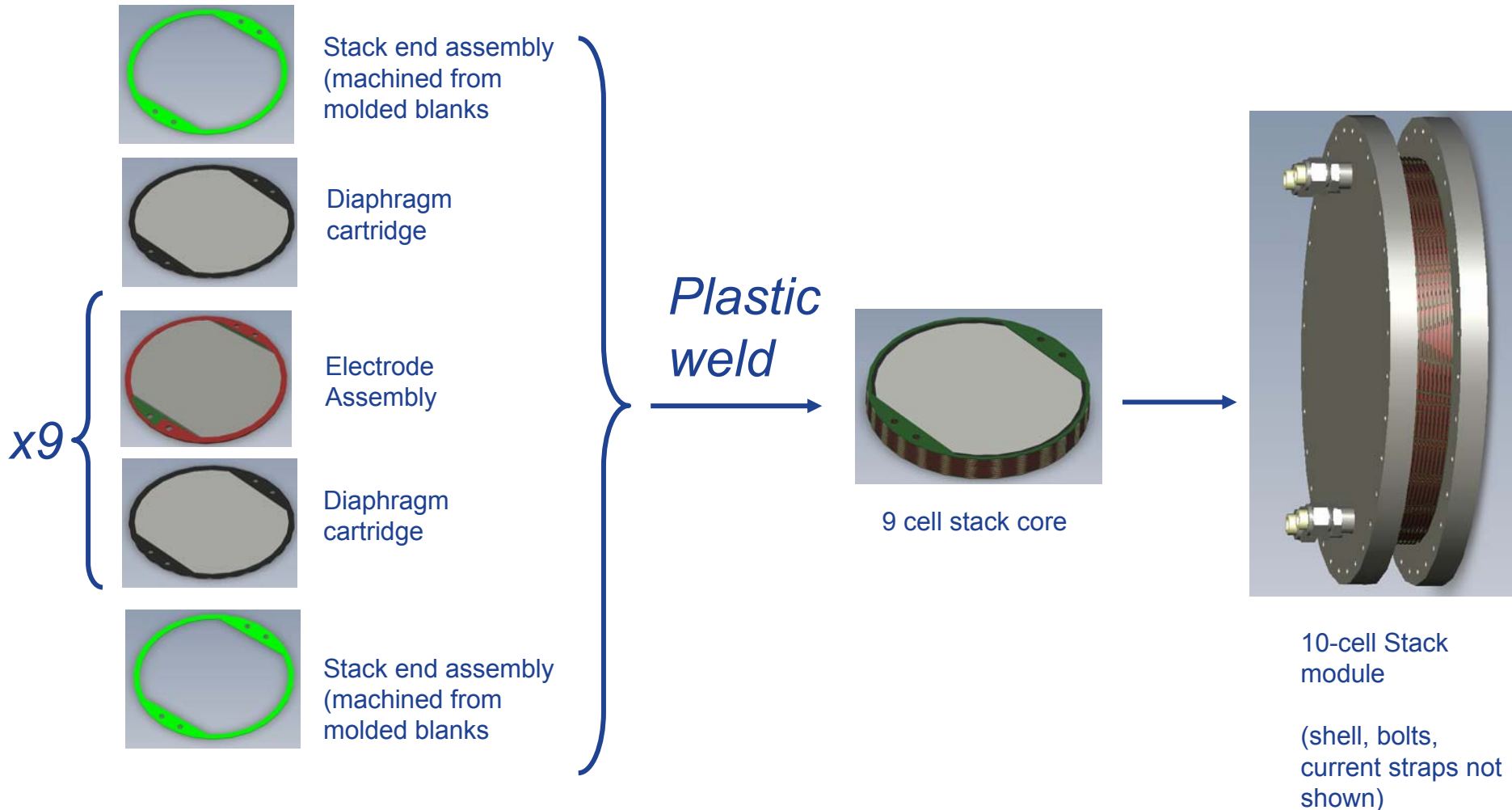
GE Plastic Stack Technology

- 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

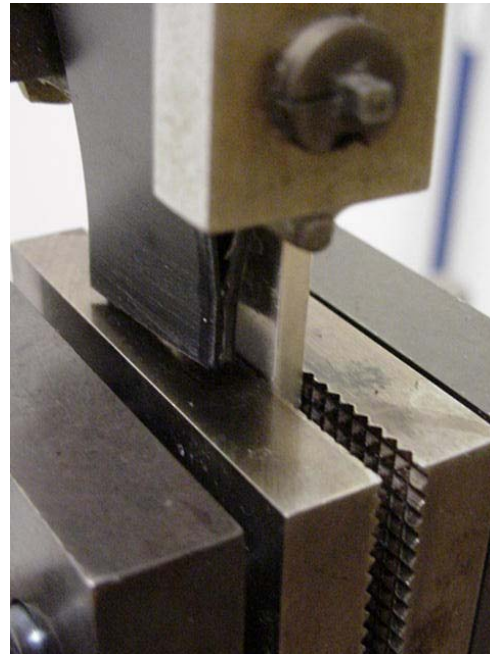
Plastic Stack Construction



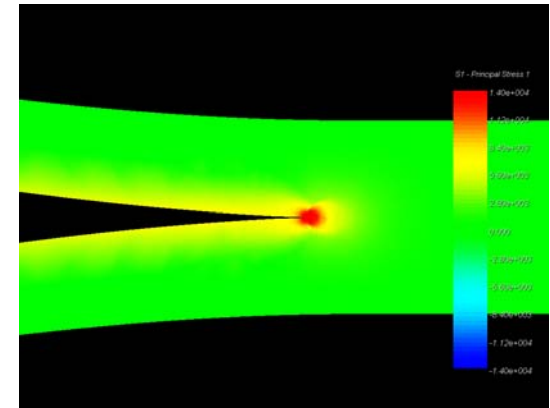
15 bar pressure stack completed and ready for testing

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



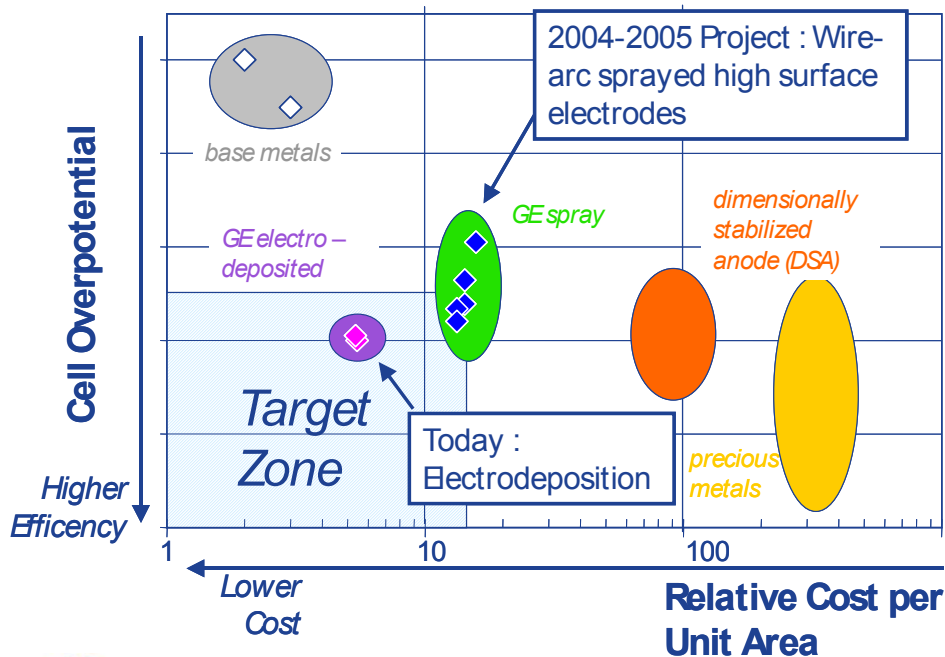
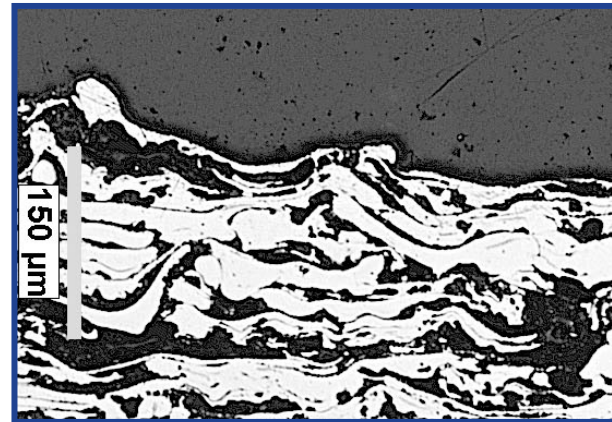
Joint Finite Element



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.

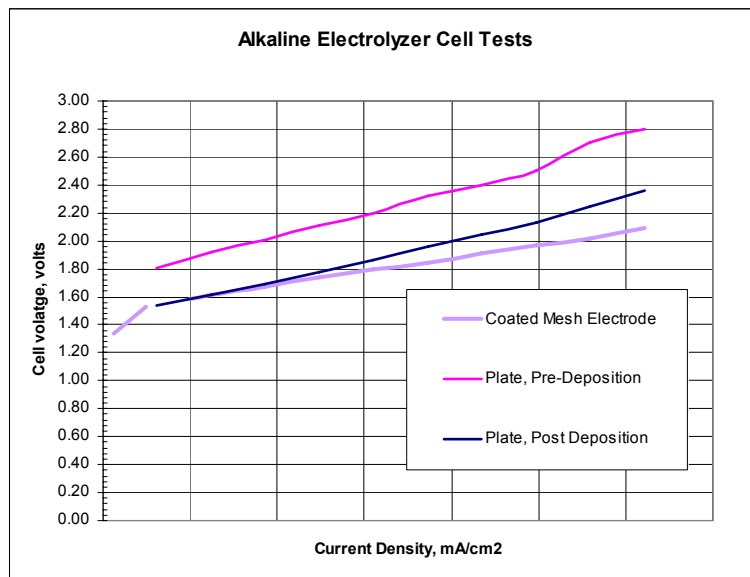


- Achieved target performance with hot spray technique in 2005.
- Demonstrating electrodeposition for additional cost and performance advantage:
 - Thinner bipolar plate
 - Eliminates warping
 - Coats 3D electrode surface

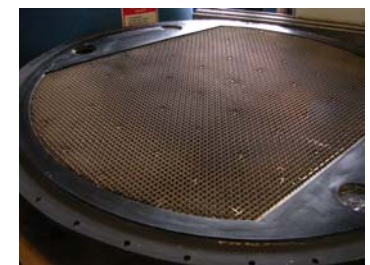
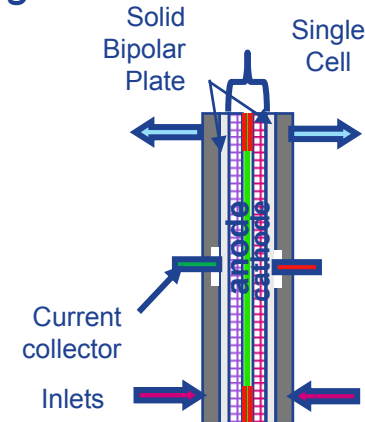
Cell Performance

- 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

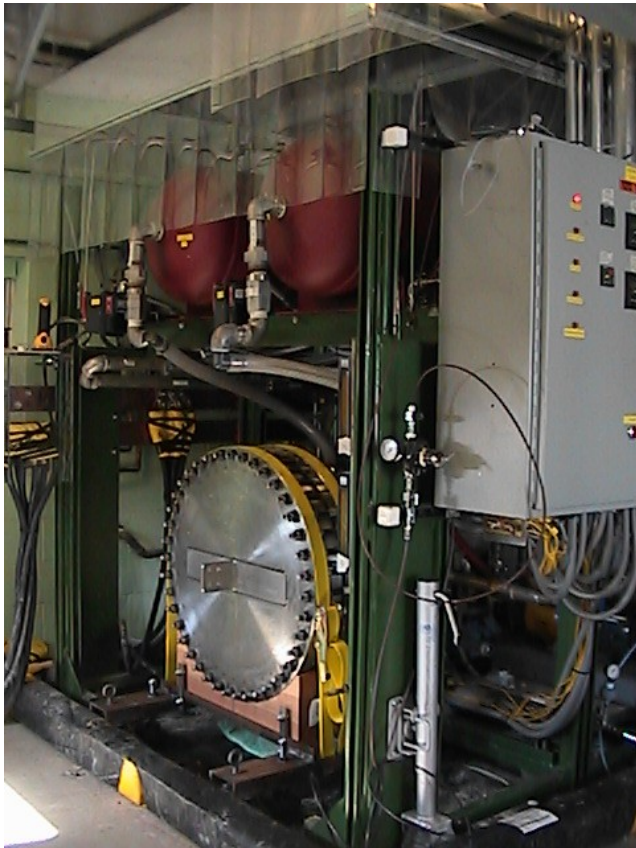
Tensile and bending specimens in O₂ tested to 40-62 equivalent weeks at a design pressure of 15 bar and at 80C



- 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 H₂ / hr production rate
- *Currently being upgraded to 15 bar pressure capability*
- Automated controls
- P, T, massflow, purity measurements

Study operability & maintenance characteristics

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 1/2 the cost of delivered hydrogen.



Pilgrim Nuclear Station – MA

- The electrolytic hydrogen water chemistry (EHWC) system capable of producing 50 SCFM H₂ and 25 SCFM O₂.
- Availability less than 50%.... Attributed to poor facility design and ability to easily maintain.
- System no longer in operation.

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.



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