Laboratory-Scale High Temperature Electrolysis System

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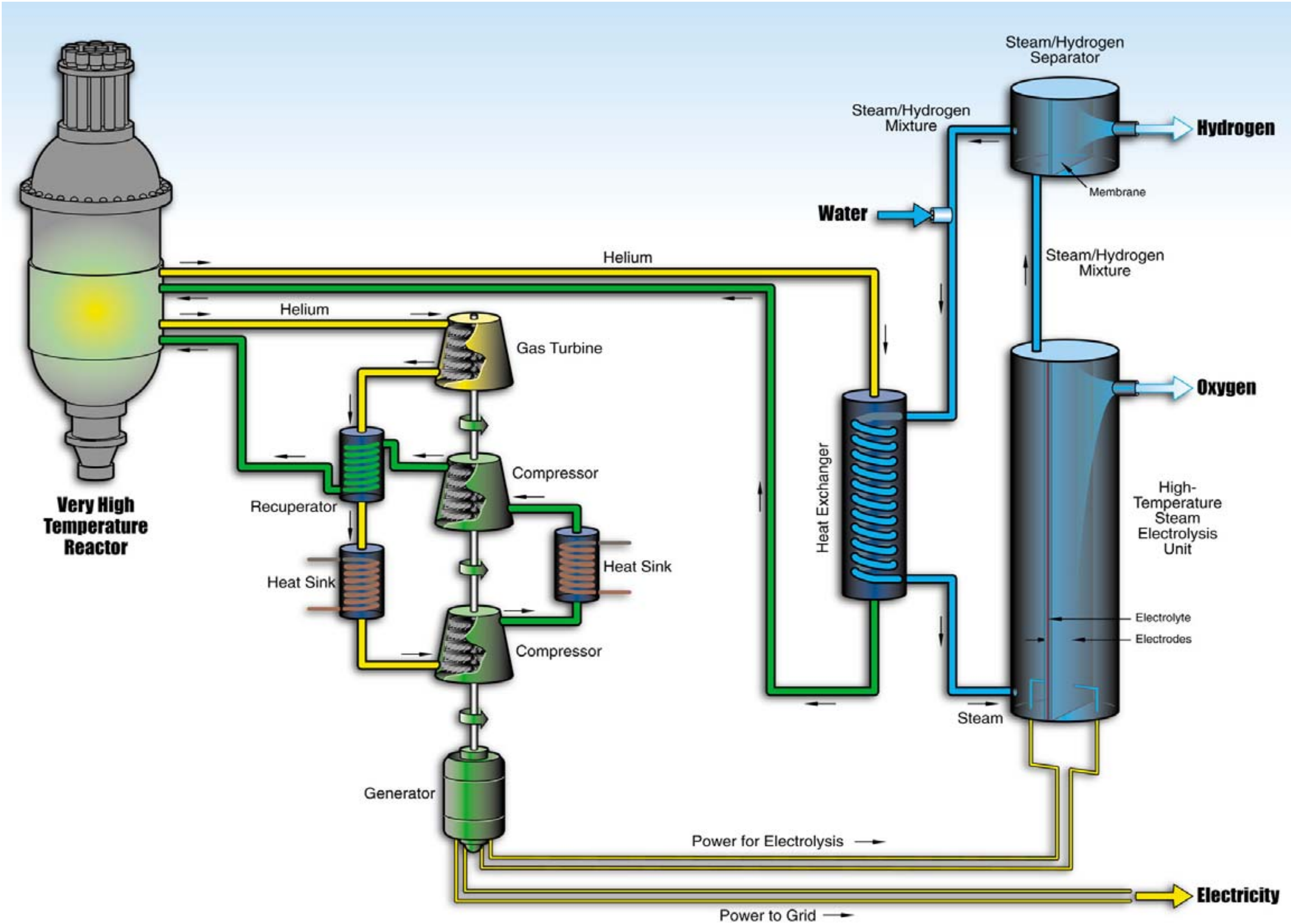
High Temperature Electrolysis Plant



High Temperature Electrolysis Overview

<u>Timeline</u>:
Project start date: Jan 2003, Button cell tests,
Project end date: Engineering Demo, 5 MW, 2015

<u>Partners</u>:
Ceramatec, Inc.
Argonne National Laboratory
Massachusetts Institute of Technology
University of Nevada, Las Vegas

<u>Budget</u>:
Total HTE project funding (all DOE)
- **FY07: $ 3460k**
- **FY08: $ 3559k**
- **FY09: $ 3100k (projected)**

<u>Barriers</u>:
(next slide)

Technical Barriers

Adapted from

3.1.4.2.2 Hydrogen Generation by {Water} Electrolysis [A-K]

G. Capital Cost *- R&D is needed to develop lower cost materials with improved manufacturing capability to lower capital costs while improving the efficiency and durability of the system. Development of larger systems is also needed to improve economies of scale.*

H. System Efficiency – *Initial and long-term electrolysis cell and stack performance needs to be improved in order to enable high overall system efficiency with a low capital cost. Cell performance degradation is a particular concern.*

I. Grid Electricity Emissions *– Low-cost, carbon-free electricity sources are needed.*

K. Electricity Costs *– The cost of hydrogen produced by High Temperature solid oxide electrolysis will be affected by the cost of electricity. But the electricity demand is significantly reduced compared to conventional electrolysis. Furthermore, if the HTE system is coupled to an advanced high-temperature reactor, the electricity cost itself will be reduced due to higher power production efficiencies.*

3.1.4.2.3 Separations and Other Cross-Cutting Hydrogen Production [L-U]

L. Durability *– need to reduce long-term performance degradation and allow more thermal cycles in lifetime*

N. Defects *– particularly in the oxygen handling service*

P. Operating Temperature *– trade-off among reaction thermodynamics, materials limitations and use of product hydrogen and oxygen*

T. Oxygen Separation (and Handling) Technology *– materials issues related to pure oxygen or enriched oxygen/air mixtures at 850°C*

FY08 High Temperature Electrolysis Overview

- **FY08 Technical Objectives**
  - Understanding of cell degradation mechanisms (degradation workshop)
  - Long-duration tests of short stacks
    - (delayed due to planning budget reduction)
  - Assessment of alternate interconnect materials and coatings
  - Completion of components for ILS
    - Build second and third modules, new cells for first module
    - Hydrogen/steam re-circulation techniques (side-stream)
    - Heat recuperation
  - Three-module operation of the ILS
    - (Level one milestone, 9/15/08)
  - Conceptual design and optimization of commercial-scale HTE systems

- **FY08 major task areas**
  - Systems Analysis
    - Flowsheet, CFD and economic analysis
    - Implementation and development scenarios
  - Experiments
  - Long-term operation
    - Reduced cell performance degradation rates
  - Post-test analysis and understanding of performance

High Temperature Electrolysis Milestones

Key Milestones (FY-07)

ANL

- Complete assessment of degradation in long-duration test cells, M2, 11/29/06
- Complete analysis of SOEC stack and cell configurations to optimize hydrogen production, M2, 6/15/07
- Demonstrate improved electrode materials for high-temperature steam electrolysis, M2, 6/15/07

INL

- Complete report describing Reactor/HTE models & H2 production efficiencies, M1, 10/27/06
- Complete documentation of ILS safety analyses, M2, 11/30/2006
- Complete ILS fabrication drawings, M2, 12/22/06
- Delivery of Initial Four-stack ILS module, M2, (Ceramatec) 3/21/07
- Complete Corrosion Test Series #1, M2, 4/27/07
- Begin ILS experimental operations, M2, 8/24/07
- Complete Commercial Scale performance predictions, M2, 9/14/07

High Temperature Electrolysis Milestones

Key Milestones (FY-08)

System Definition

ANL ($220k)

- Determine critical causes of stack degradation and work with Ceramatec to mitigate the causes, M2, 9/30/2008

INL ($861k)

- Optimized flowsheet as reference case for HTE comparisons with other methods with complete parameter description for economic analysis and comparison with other cycles, M2, 11/15/2007
- Completed as-built drawings of Initial ILS Configuration, M2, 12/10/2007
- Completed economic analysis for VHTR/HTE using DOE H2A methodology, M3, 1/31/08
- Report on CFD predictions of efficiency, voltages and currents for electrolytic cells in alternate geometric configuration, M2, 8/1/2008

High Temperature Electrolysis Milestones

Key Milestones (FY-08)

Experimental Development

ANL ($127k)

- Demonstrate improved performance of oxygen and steam hydrogen electrodes through the deposition of electrocatalytic materials by the ALD or other infiltration processes, M2, 9/30/2008

INL ($2351k)

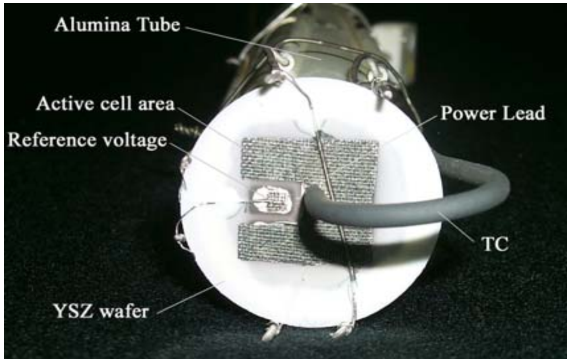
- Characterization of the transient response of the single-module ILS to heatup, changes in power level, and cooldown, M1, 12/14/2007
- Test plan for ILS operations with three modules, M2, 5/15/2008
- Report on O_2 handling and cooling options based on collaboration with AECL, M2, 7/2/2008
- Three module test in the ILS at 15 kW input power, M1, 9/15/2008
- Analysis report on corrosion testing of the second series of BOP materials, M2, 9/30/2008

HTE Research Goals

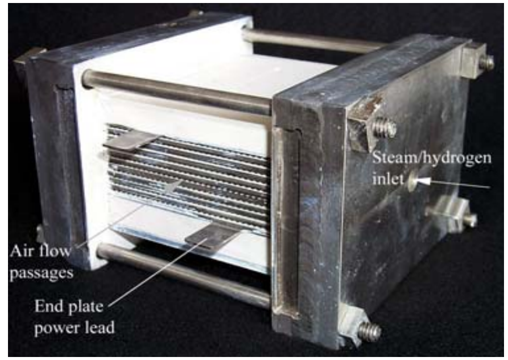
- **Develop efficient solid-oxide electrolysis cells, building on solid-oxide fuel cell research**
- **Decrease cost, increase durability**
- **Determine reasons for long-term cell degradation**
- **Optimize plant designs**
- **Co-electrolyze CO_2 and steam to CO and H_2**
- **Develop designs to apply nuclear heat and H_2 to heavy petroleum and oil sand upgrading**
- **Integrate nuclear energy sources and fossil/biomass carbon sources for hydrocarbon synthesis**

HTE R&D Approach

small-scale experiments and scale-up



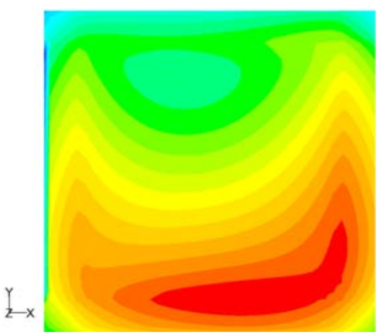
Button cell (2003) 2.5 cm²



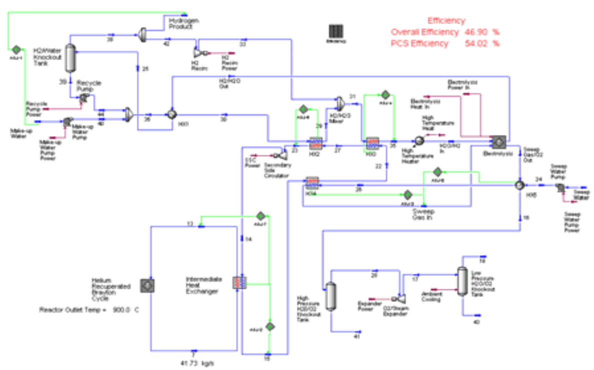
10-cell stack (2004) 640 cm²

240-cell ILS-module (2007) 15,360 cm²

CFD and Flowsheet Analyses



Temperature profile on electrolysis cell



Process Flowsheet for Reactor-driven commercial plant

Integrated Laboratory Scale (operational 8-22-07) 720 cells, 3 modules (2008) 46,080 cm²

Technical Accomplishments

Stack and Cell Performance

- Long-duration test of half-ILS module
- Testing of planar segmented in-series cell design

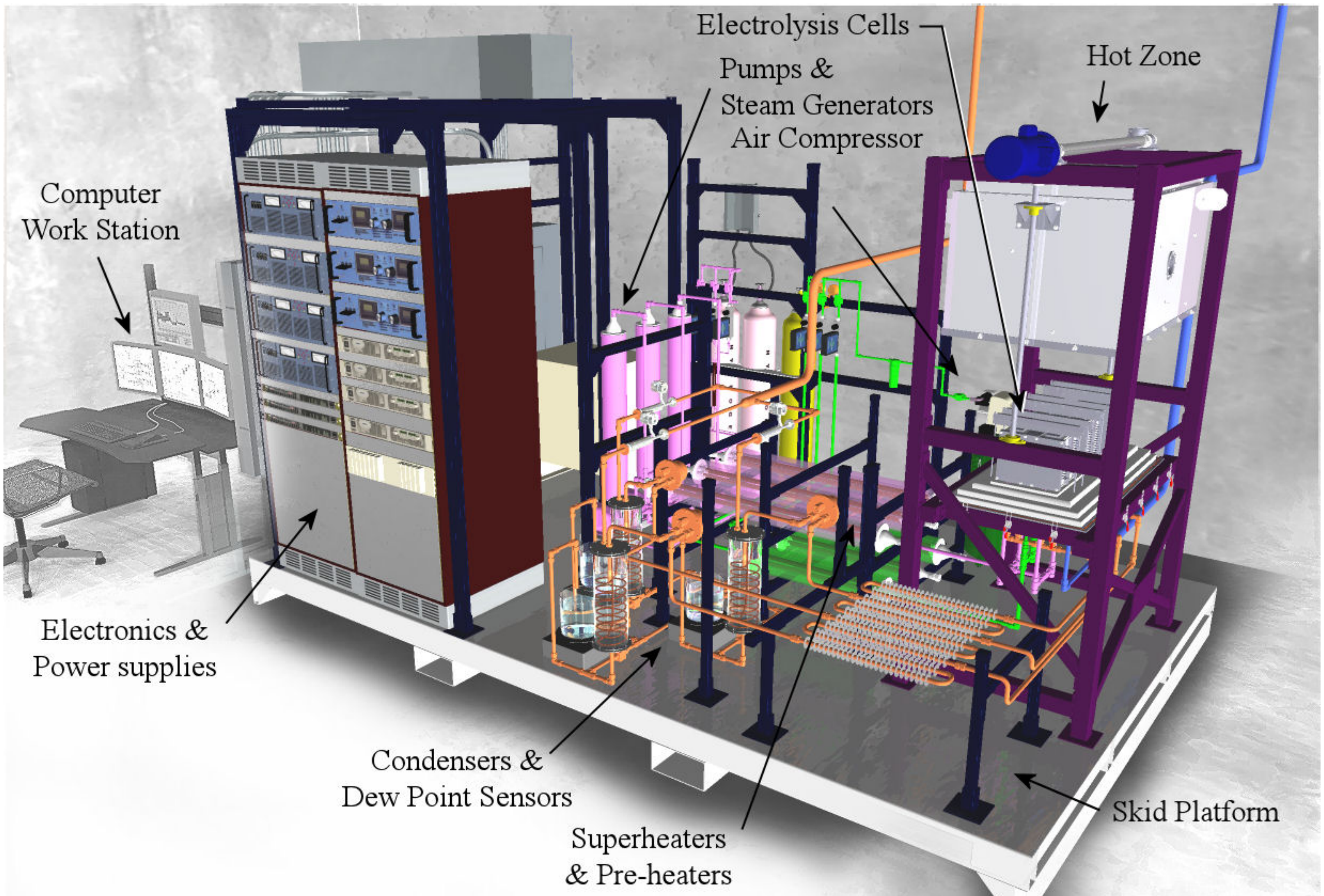
ILS Installation and Operation

- Completed construction of ILS facility
- Performed initial ILS single-module test series (240 cells)

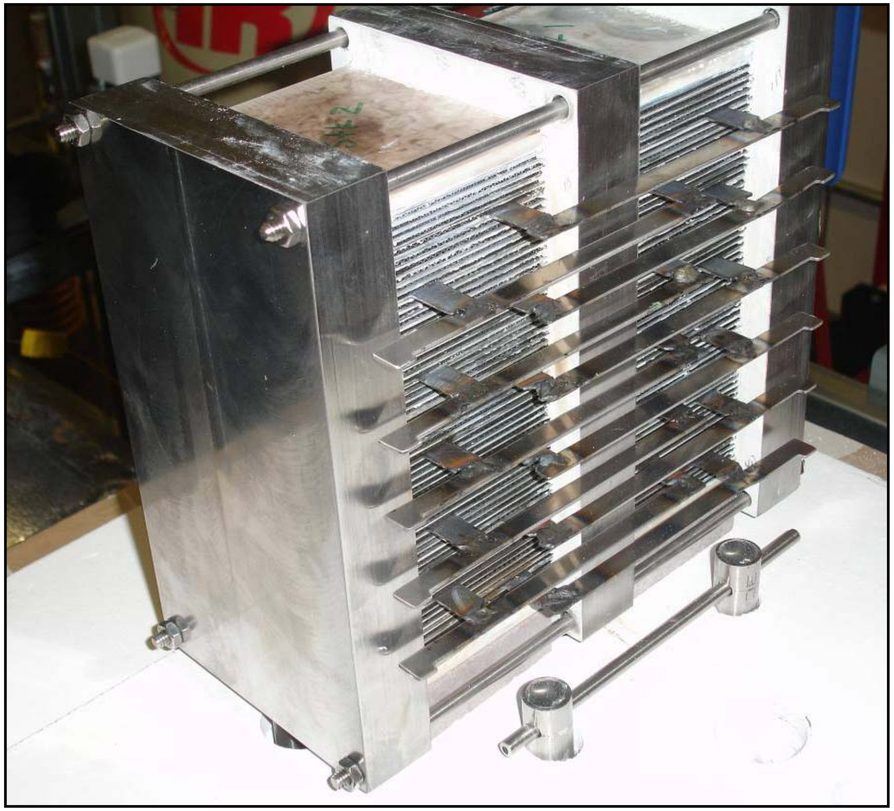
Modeling and Simulation

- Completed analysis of HTE system coupled to three reactor types
- Finalized optimized commercial-scale reference design for HTE coupled to VHTR
- Completed economic analysis for HTE using H2A methodology
- Completed CFD analysis of multiple-cell stack geometry

Technical Accomplishments
HTE Integrated Laboratory Scale Facility at INL



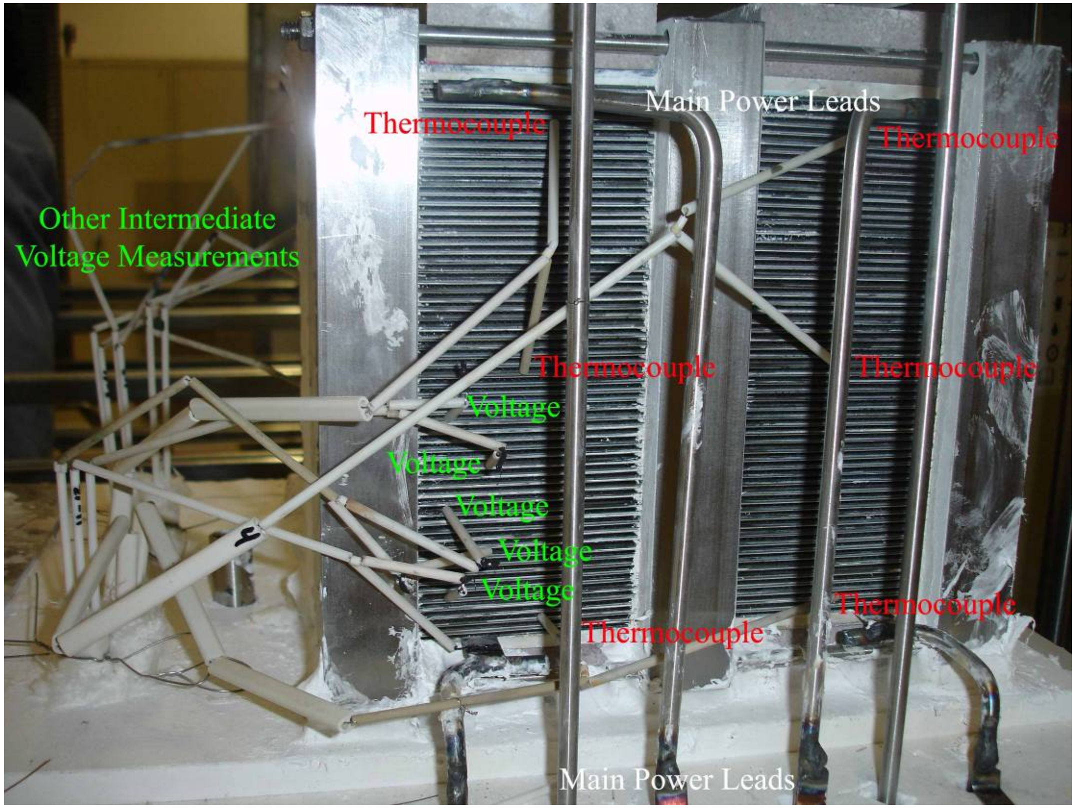
ILS Module Installation

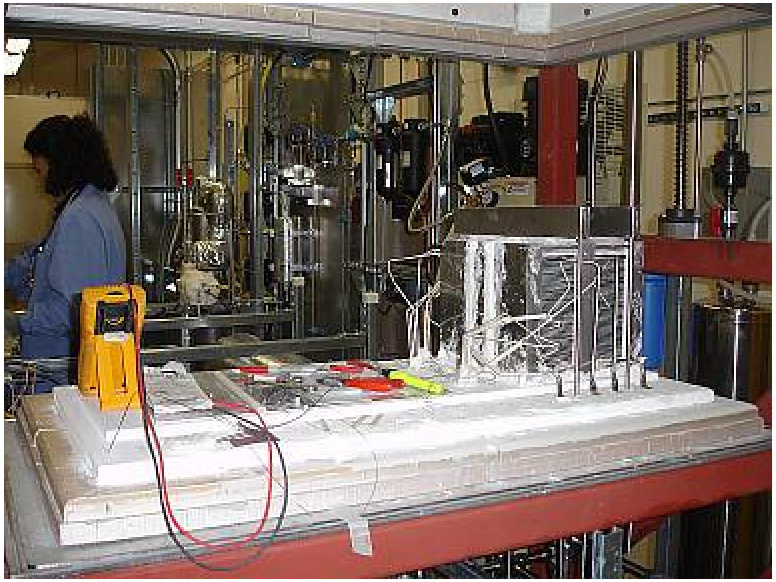


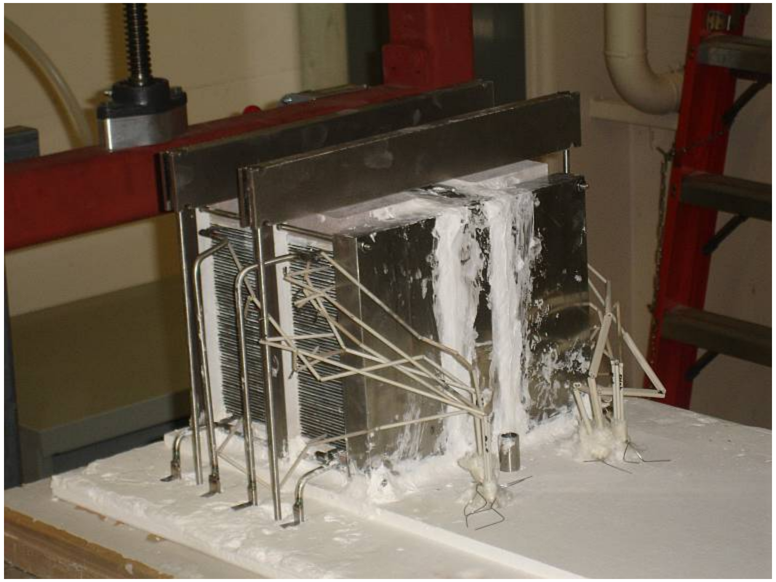
Half module with electrical cross-connections

Detail of electrical cross-connections between half modules

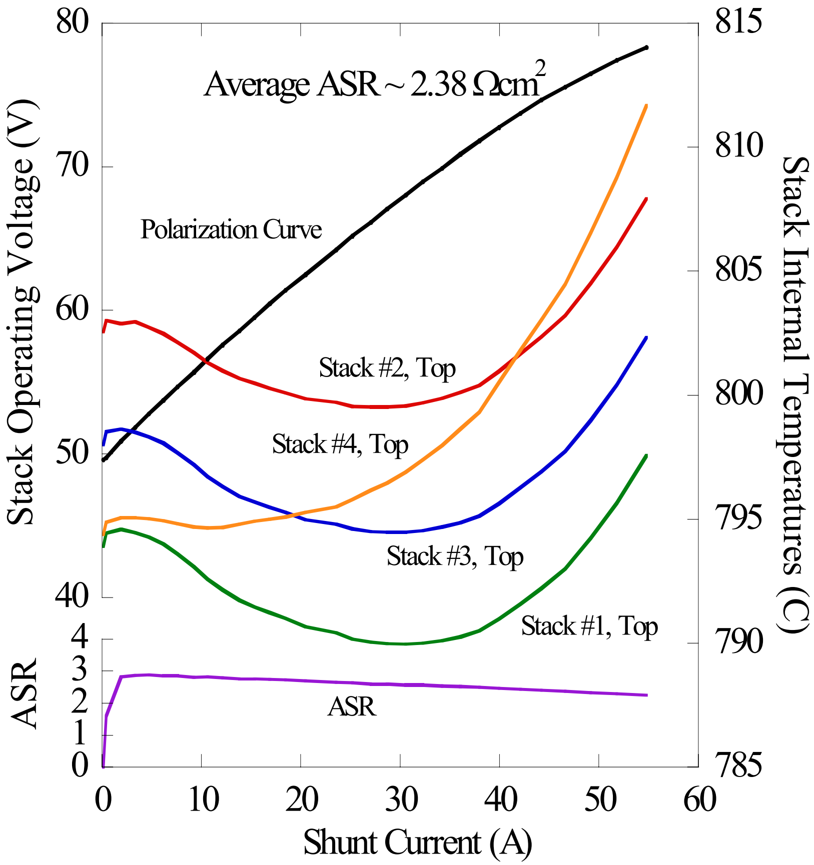
ILS Module Installation

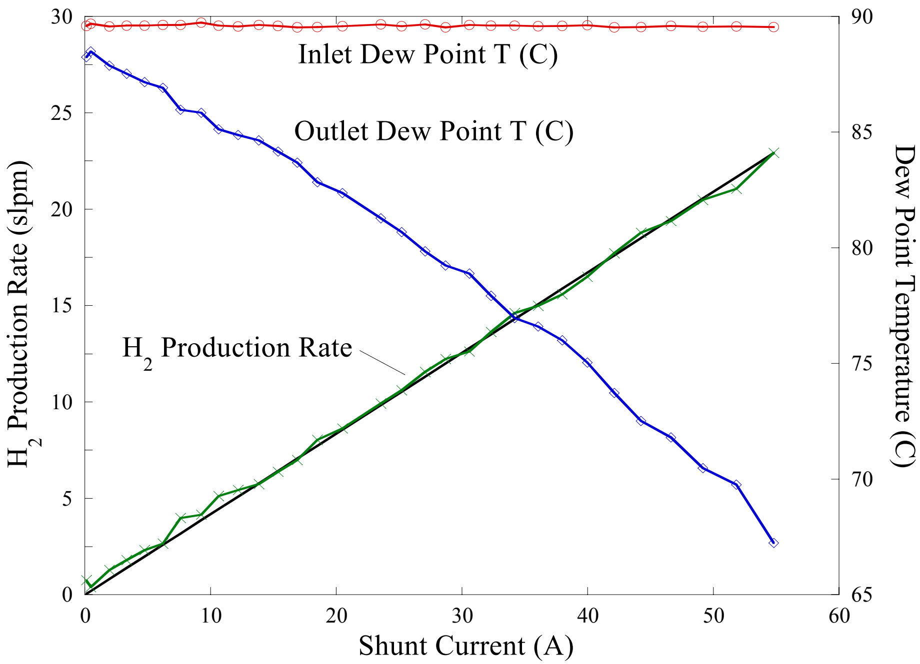




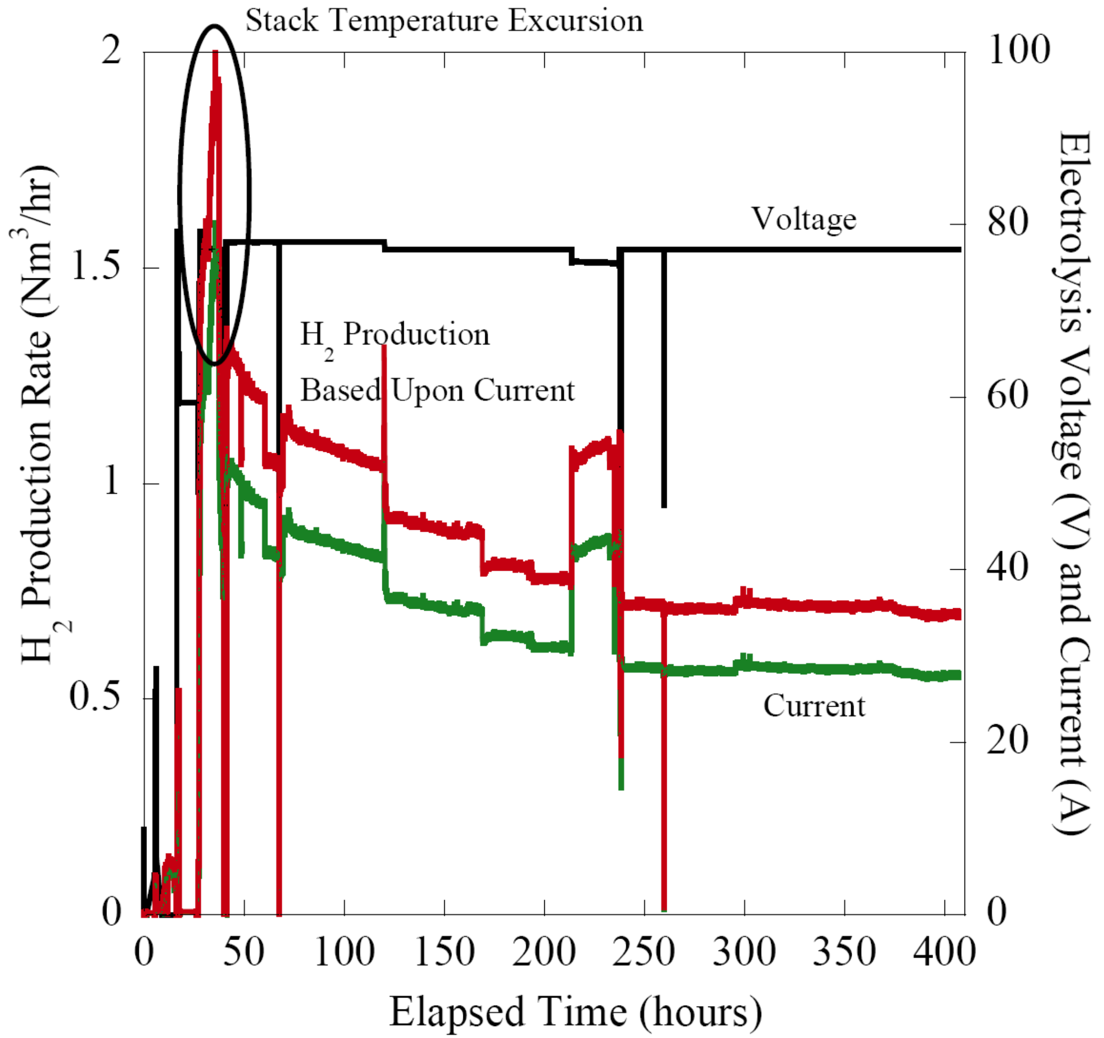


ILS Module Sweep Data



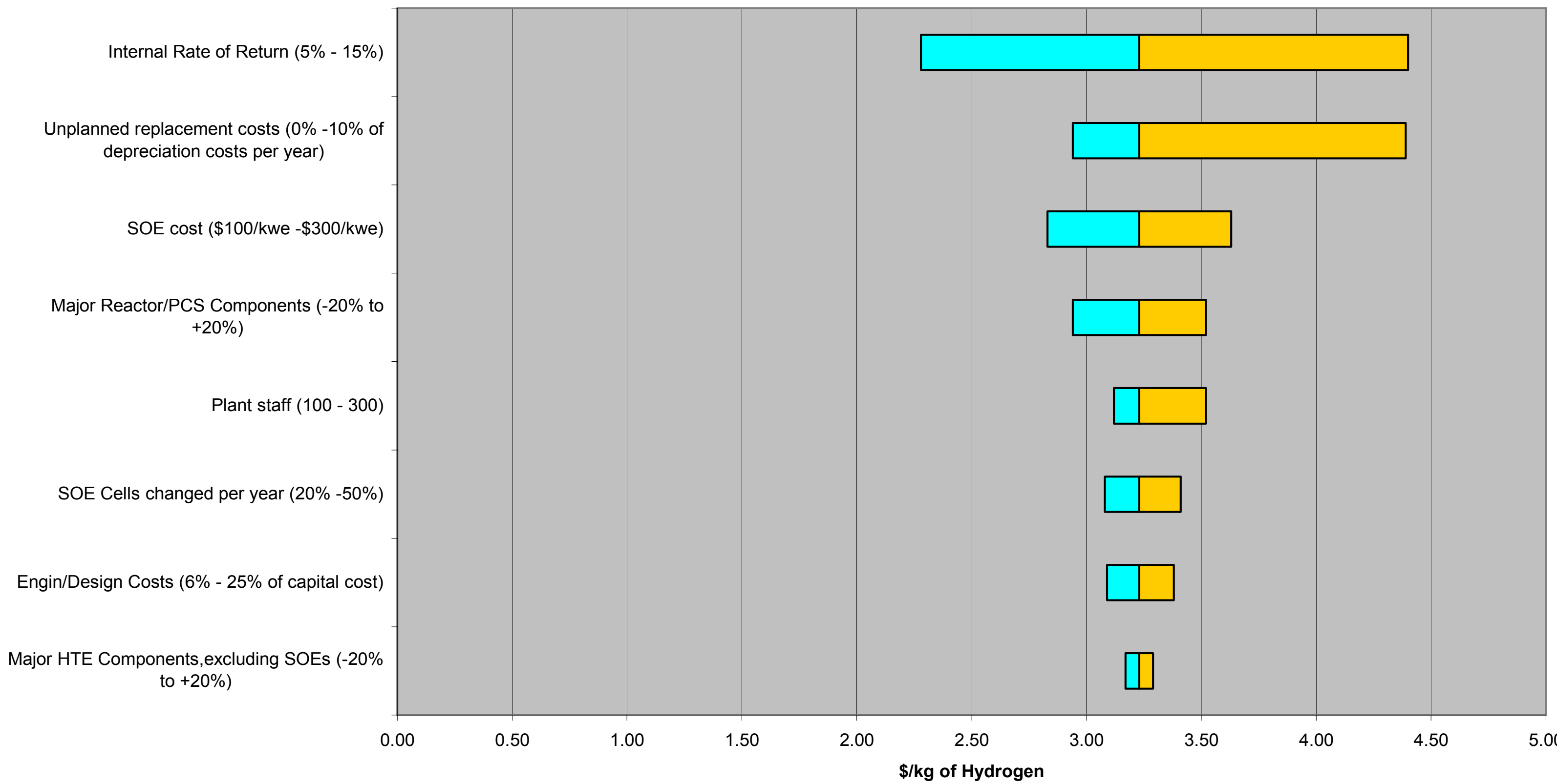


Overall ILS Data



VHTR/HTE Economic Sensitivity Analysis

(For plant gate cost ~$3.23/kg hydrogen and 10% internal rate of return)



Future Work
(FY08 – FY15 HTE Major Milestones)

Time Frame	***Demonstration Level***	***High Temperature Electrolysis Research Targets***
2008	*Single cell to 12 x 60-cell stacks (15kW) Integrated Laboratory Scale Experiment)*	• *Small-scale testing aimed at understanding and minimizing performance degradation* • *Improvements in stack edge sealing and interconnect technologies for extended operation* • *Complete an integrated laboratory-scale module experiment at a nominal 15 kW power level by September 2008*
2012	*Pilot scale module (50 kW)*	• *Complete a pilot scale module experiment to demonstrate efficient thermal management, manifold design and sealing.*
2013	*Multi module 200 kW*	• *Successful operation of a multi module, pilot scale experiment at 200 kW*
2015	*Multi module 5 MW*	• *Construct an engineering scale demonstration of a 5 MW section to confirm performance and cost estimates for a commercial HTE system.*

Project Summary

Experimental:

- Significant progress has been made in improving cell and stack performance and in scale-up to the 15 kW Integrated Laboratory Scale Operation (9/08); this experience will enable further scale-up to the Pilot (200 kW) and Engineering Scale (5 MW) Demonstration facilities.

Modeling and Simulation:

- Have gained significant insights into the operation of proposed large-scale HTE systems via system modeling
  - Optimized commercial-scale reference design for VHTR/HTE (600 MWt reactor, ~2.4 kg/s hydrogen produced, ~47% production efficiency)
  - Completed economic analysis for HTE using H2A methodology (plant gate cost ~$3.23/kg hydrogen, assuming 10% internal rate of return)
- Completed several CFD analyses of multiple-cell stacks and alternate geometries, providing insight into flow distributions and thermal behavior