Laboratory-Scale High Temperature Electrolysis System

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PD22

Idaho National Laboratory

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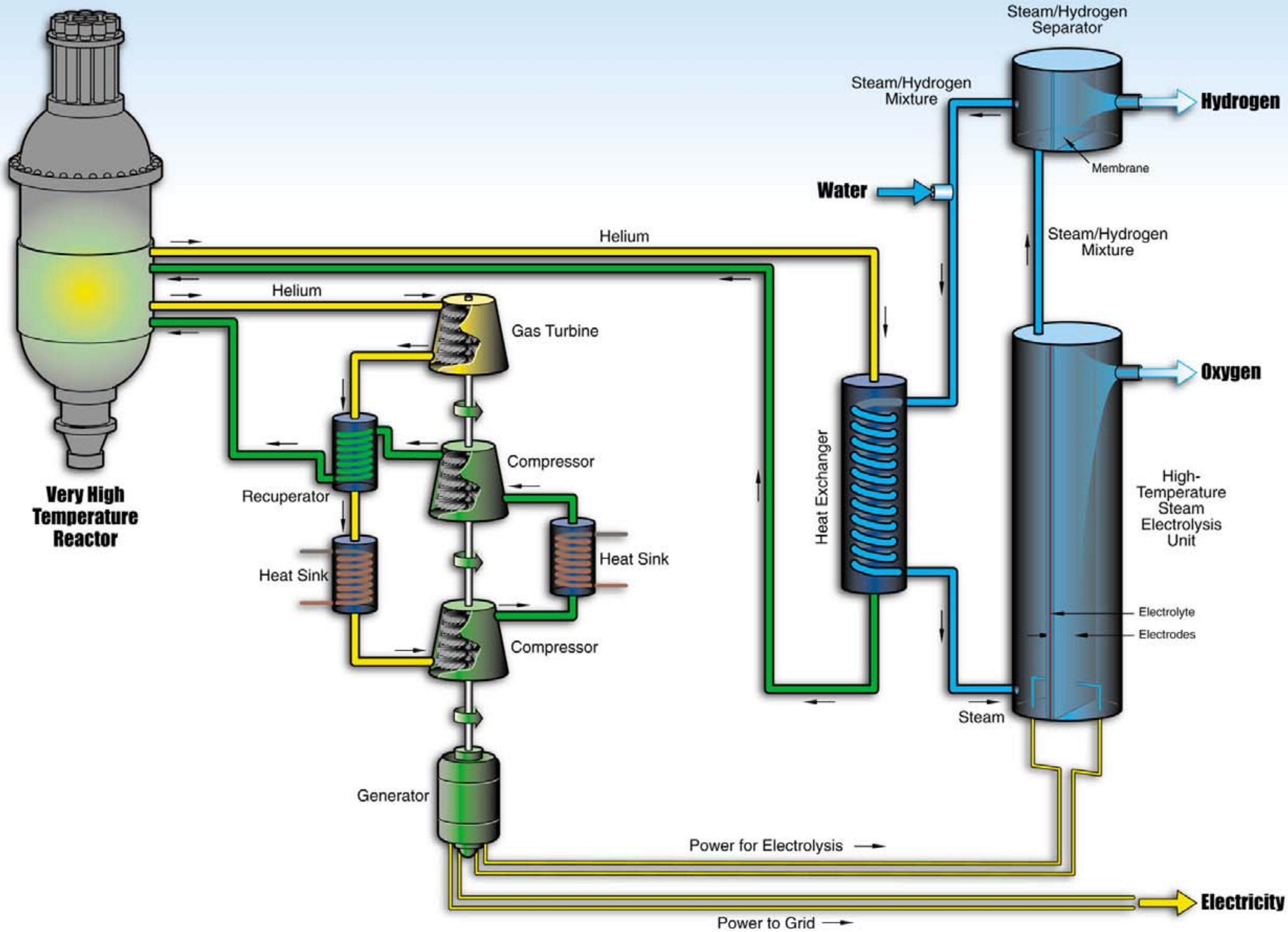
High Temperature Electrolysis Plant



High Temperature Electrolysis Overview

Technical Objectives

- Develop and demonstrate energy-efficient, high temperature solid oxide electrolysis cells (SOECs) and stacks for hydrogen production from steam.
- Demonstrate technology at progressively larger scales
- Perform flowsheet analyses of systems-level HTE processes to support planned scale-up to Integrated Laboratory-scale, Pilot-scale and Engineering Demonstration-scale experiments.
- Develop detailed CFD models of operating SOECs; validate with experiment data
- Investigate alternate cell materials (e.g. alternate electrode and/or interconnect materials) alternate cell configurations (e.g. porous-metal substrates, tubular cells, porous electrodes) and applications of inorganic membranes

Strategy

- Wherever possible, build on previous development of solid oxide fuel cells by DOE-EE, SECA and others.

High Temperature Electrolysis Overview

Timeline:

Project start date: Jan 2003, Button cell tests,
Project end date: Engineering Demo, 1 MW, 2015

Budget

Total project funding (all DOE-NE)

FY05: $ 4695 k

FY06: $ 3460 k

Barriers (next slide)

Partners

Ceramatec, Inc.
Argonne National Laboratory
Oak Ridge National Laboratory
University of Nevada, Las Vegas

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 *– Development is needed for low-cost cell stack optimization considering efficiency, electrochemical compression and durability.*

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

K. Electricity Costs – *High Temperature solid oxide electrolysis can use lower cost energy in the form of steam for water splitting to decrease electricity consumption. Technically viable systems for low-cost manufacturing need to be developed for this technology.*

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

L. Durability – *need to reduce amortized capital costs and allow more thermal cycles in lifetime*

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

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

T. Oxygen Separation (and Handling) Technology – *Especially cooling of enriched oxygen/air mixtures from 850° C and transport to beneficial uses*

Approach (vs Objectives)

- **Develop energy-efficient, high-temperature, solid-oxide electrolysis cells (SOECs) for hydrogen production from steam.**
  - **Optimize energy efficiency, cost and durability**
    - **optimize electrolyte materials (e.g., YSZ, ScSZ, sealants)**
    - **investigate alternate cell configurations (e.g., electrode-supported or tubular)**
- **Develop and test integrated SOEC stacks operating in the electrolysis mode with an aim toward scale-up to a 200 kW Pilot Plant and a 1 MW Engineering Demonstration Facility**
  - **Increase SOEC stack durability and sealing with regard to thermal cycles**
  - **Improve material durability in a hydrogen/oxygen/steam environment**
  - **Perform a progression of electrolysis stack testing activities at increasing scales and complexities**
  - **Develop computational fluid dynamics (CFD) capability for SOEC**
  - **Utilize advanced systems modeling codes (e.g. HYSYS, ASPEN)**
  - **Perform Cost and Safety Analyses**

HTE FY-07 Task Area Overview

Workpackage	P. I.	FY-07 ($k)	Description/Goal
HTE Systems Definition			
N-IN07EL0101	O'Brien	$690	Engineering analyses needed to define future high temperature electrolysis plant. Design of the Integrated Laboratory Scale experiment.
N-AN07EL0101	Petri	$500	Flowsheet and CFD analyses. Post-test evaluation of stack components. Materials development of higher conductivity electrodes.
HTE Experiments			
N-IN07EL0201	Stoots	$2,020	Operation of the materials testing experiment. Assembly and shakedown of the Integrated Laboratory Scale experiment.
N-OR07EL0201	Bischoff	$50	Analysis and experiments to determine the applicability of inorganic high-temperature membranes for steam/hydrogen separations.
N-AN07EL0201	Petri	$125	Modeling and x-ray/electrochemical characterization of patterned dense thin-film oxygen electrodes on electrolyte substrates produced by atomic layer deposition methods.
N-ID07EL0201	Hechanova	$75	Investigate structure-property-performance relationships for oxygen and hydrogen electrodes and electrolytes, as well as the fabrication of thin-film electrolytes using atomic layer deposition.

Design of Integrated Laboratory Scale Experiment

Test objectives

	Button	Stack		Facility	
	(1.5 W)	Bench (500 W)	Integrated Lab (15 kW)	Pilot (200 kW)	Engineering Demonstration (5 MW)
Electrode / Electrolyte Materials	x				
Electrode/Electrolyte performance	x	x			
Basic cell design	x	x			
Stack design		x			
Stack sealing		x	x		
Stack performance		x	x		
Manifolding		x	x	x	
Electrical configuration			x	x	
Instrumentation development	x	x	x	x	
Heating of feedstock			x	x	x
Product gas heat recuperation			x	x	x
Hydrogen recycle			x	x	x
High-temperature oxygen handling			x	x	x
Stack lifetime			x	x	x
Hydrogen purification				x	x
System startup and control			x	x	x
System maintenance				x	x
High-pressure operation				x	x
Hydrogen storage					x
Demonstration of large-scale hydrogen production					x

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High Temperature Electrolysis Milestones

Key Milestones (FY-07)

- **Complete assessment of degradation in long-duration test cells. M2, ANL, 11/29/06, Completed 11/29/07.**
- **Complete analysis of SOEC stack and cell configurations to optimize hydrogen production, M2, ANL, 6/15/07**
- **Demonstrate improved electrode materials for high-temperature steam electrolysis, M2, ANL 6/15/07**
- **Complete Commercial Scale Performance Predictions, M2, INL 9/14/07**
- **Complete ILS fabrication drawings. M2, INL 12/22/06, completed 12/20/06**
- **Complete documentation of ILS Safety Analyses, M2, INL 11/30/2006, completed 11/30/06**
- **Complete Report Describing Reactor/HTE Models & H2 Production Efficiencies M1, INL 10/27/06 completed 10/26/06**
- **Report on Short Stack and Button Cell Experiments, D2, INL, 9/14/07**
- **Begin ILS Experimental operations, M2, INL 8/24/07**
- **Test Report on Initial Corrosion Test Series, D2, INL 6/25/07**
- **Complete Corrosion Test Series #1, M2, INL 4/27/07**
- **Delivery of Initial Four-stack ILS module, M2, INL (Ceramatec) 3/15/07, Completed 3/21/07**

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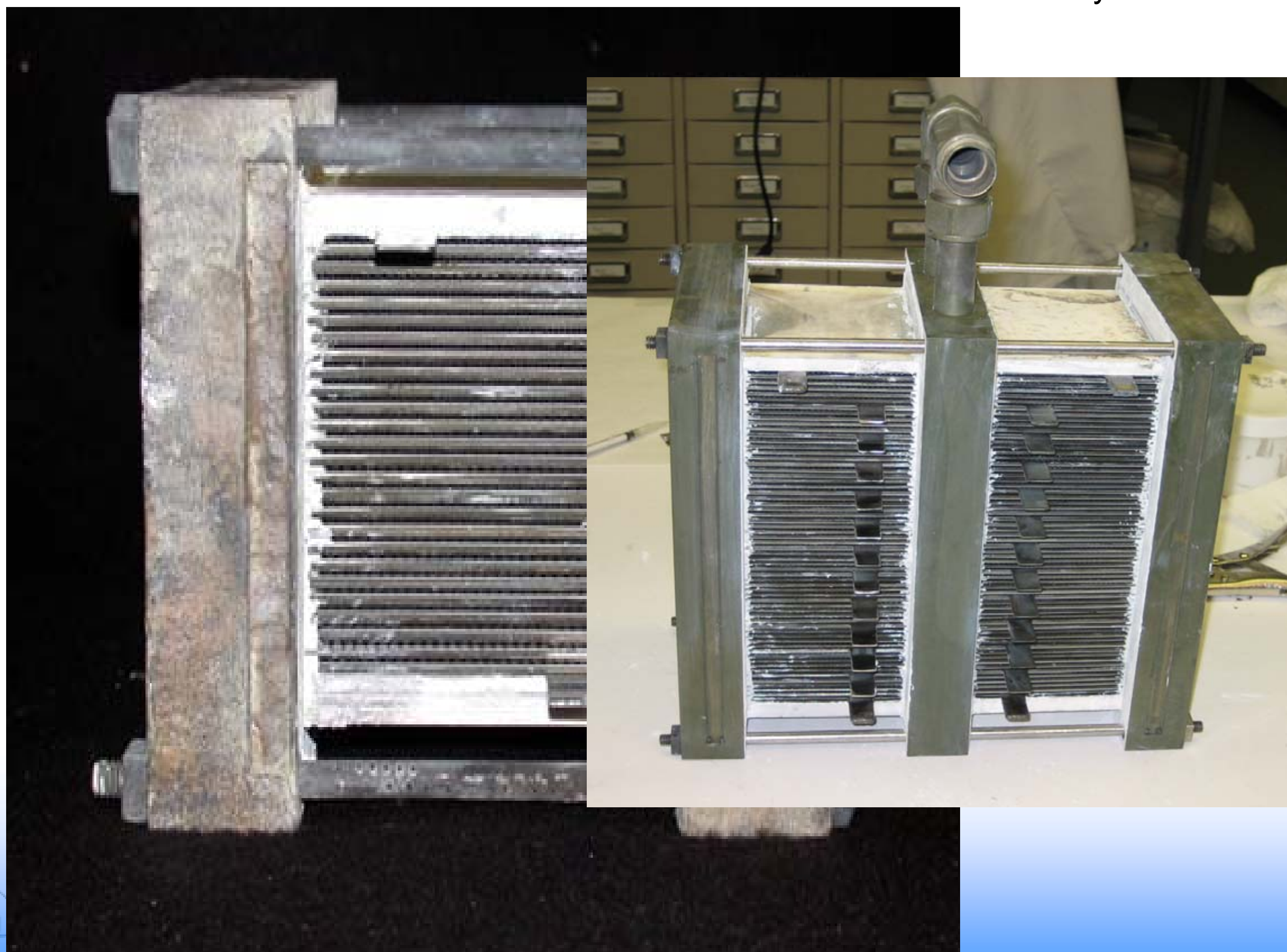
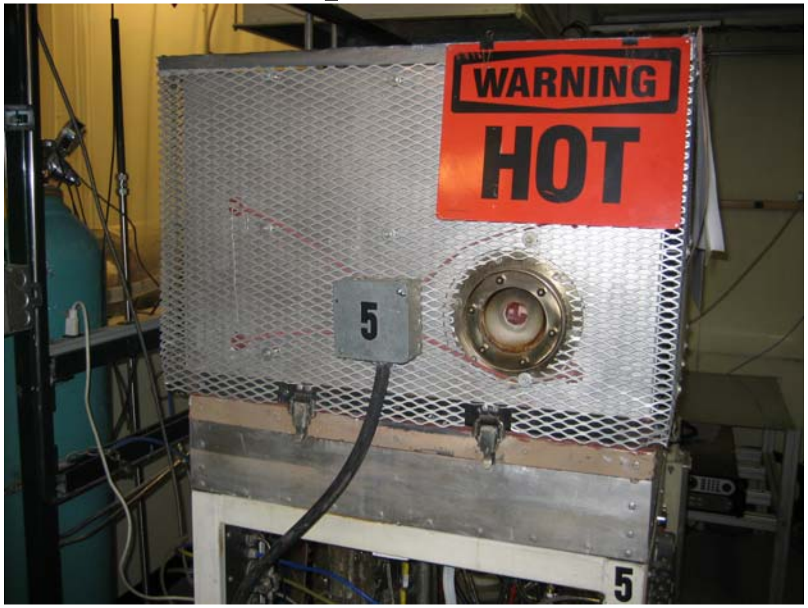
25-cell stack used in 1000-hour test Jan. 4 – Feb. 16, 2006

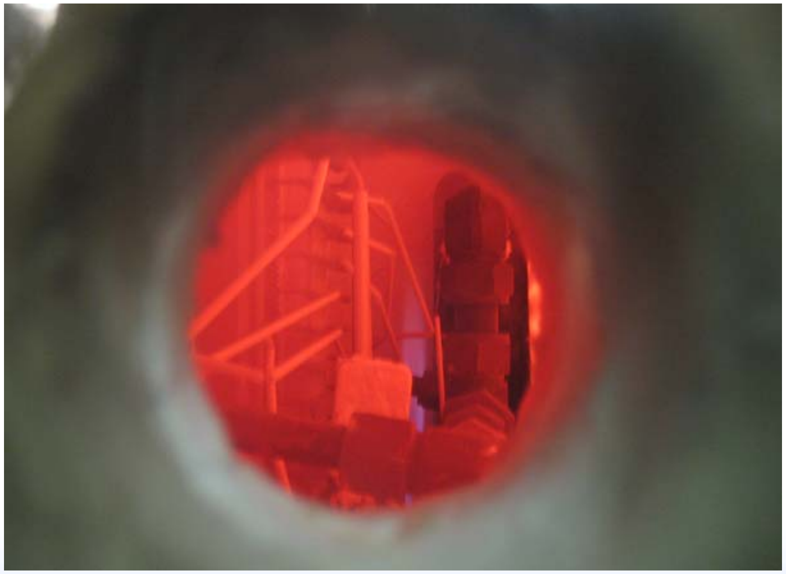
2 x 60-cell stacks tested at Ceramatec, SLC

Initial rate: 1.2 Nm3 H2/hr
final: 0.65 Nm3 H2/hr
2040 hours, ended 9-22-06
>800 hrs in co-electrolysis



Views of Half-Module in Operation





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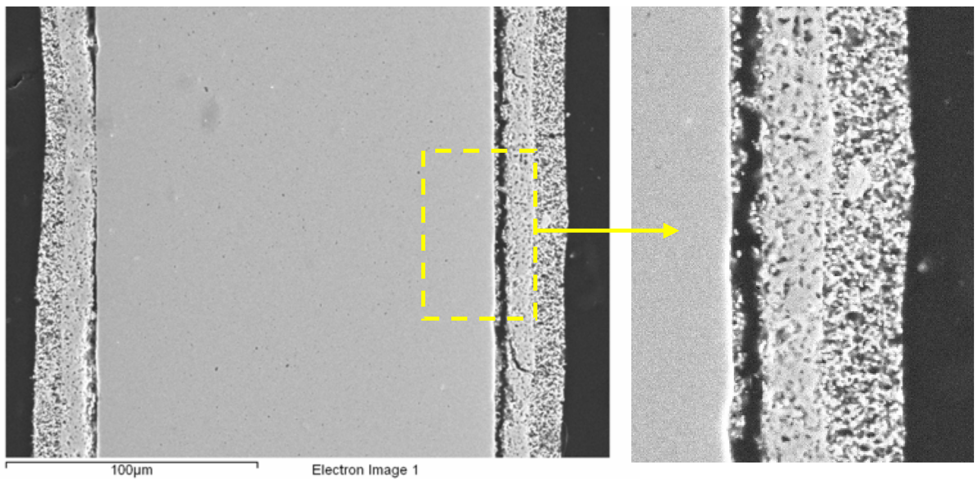
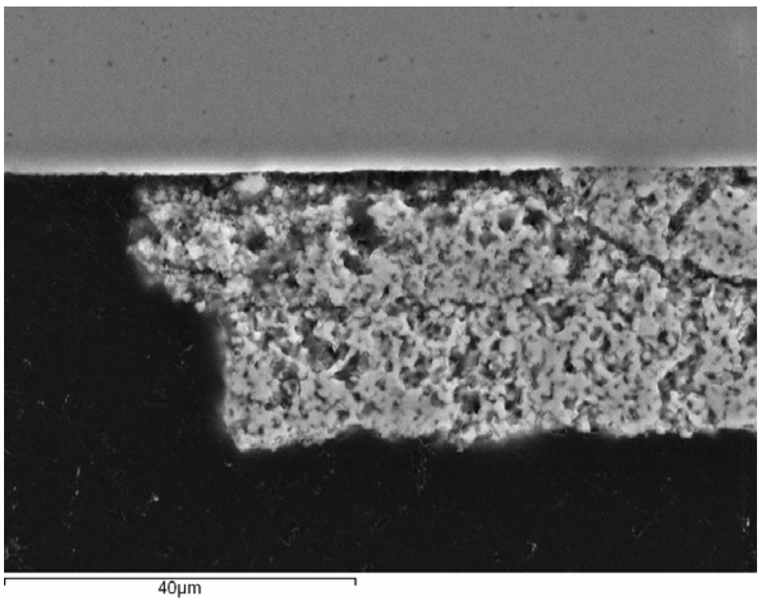
Results of Post-test evaluations (ANL)

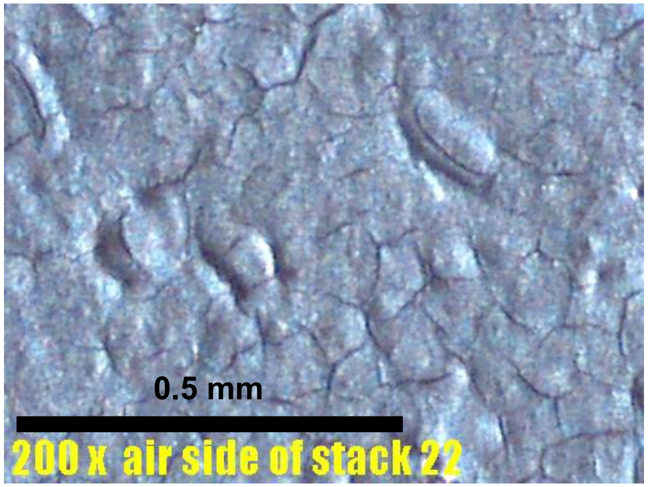


SEM image of CER11, showing delamination at the electrolyte-electrode interface, and over-sintering of the inner layer active electrode. Both the delamination and over-sintering can lead to short-term and long-term performance loss at the electrode.

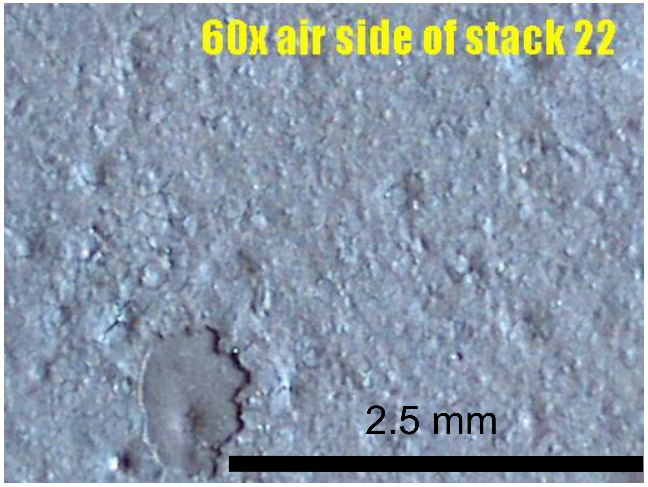


Apparent delamination and cracking of the air electrode near the sealed edge of the 25-cell stack. The gray area at the top of the picture is the zirconia electrolyte.

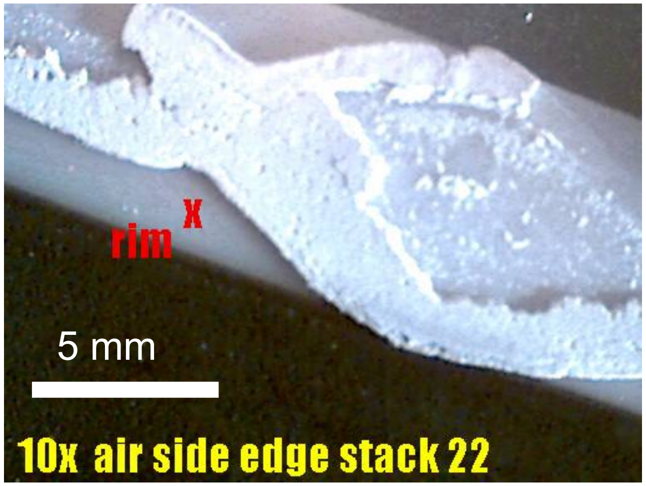
Optical images of air electrode-1 from the 22-cell stack. Regions showing (a) mud-cracking, (b) delamination, and (c) area on rim analyzed by Raman spectroscopy.



(a)

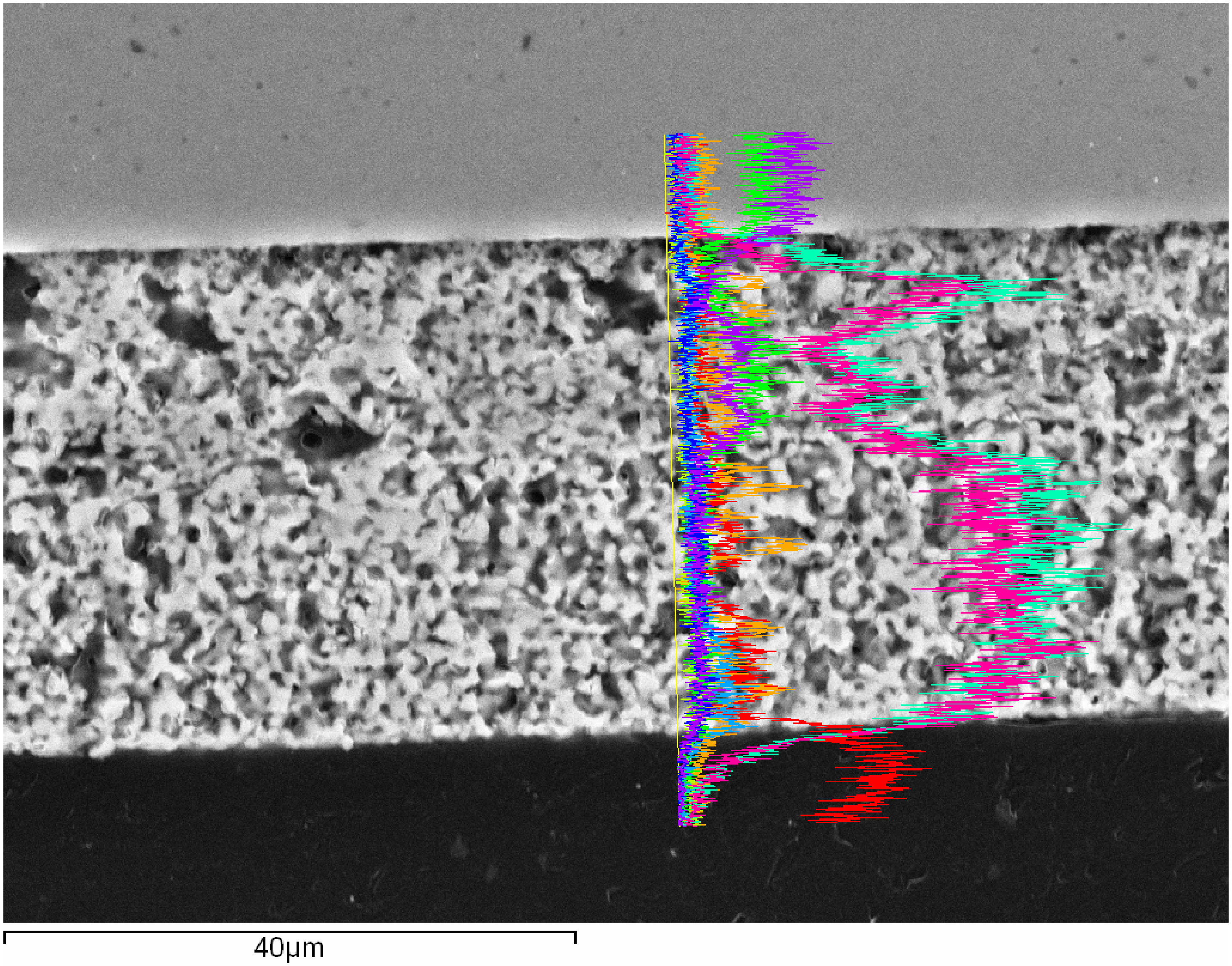


(b)

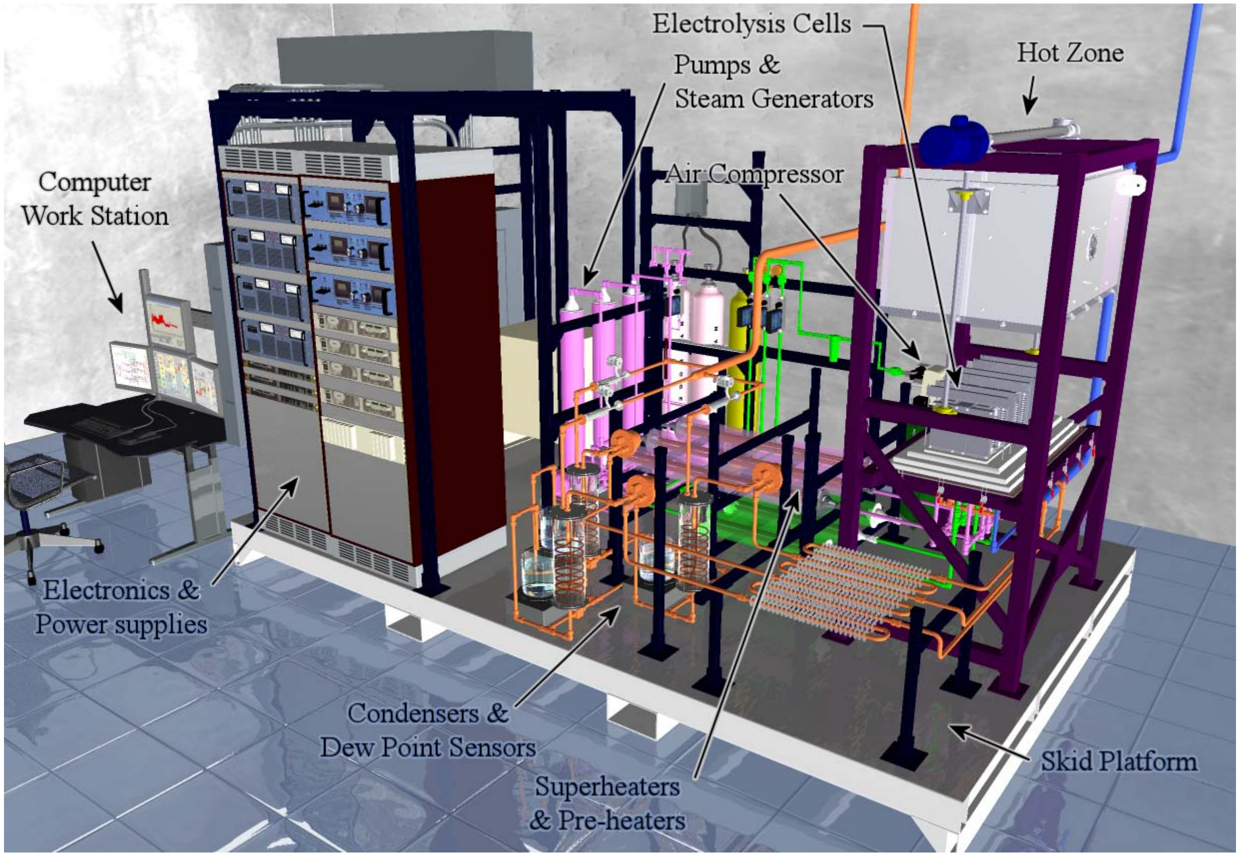


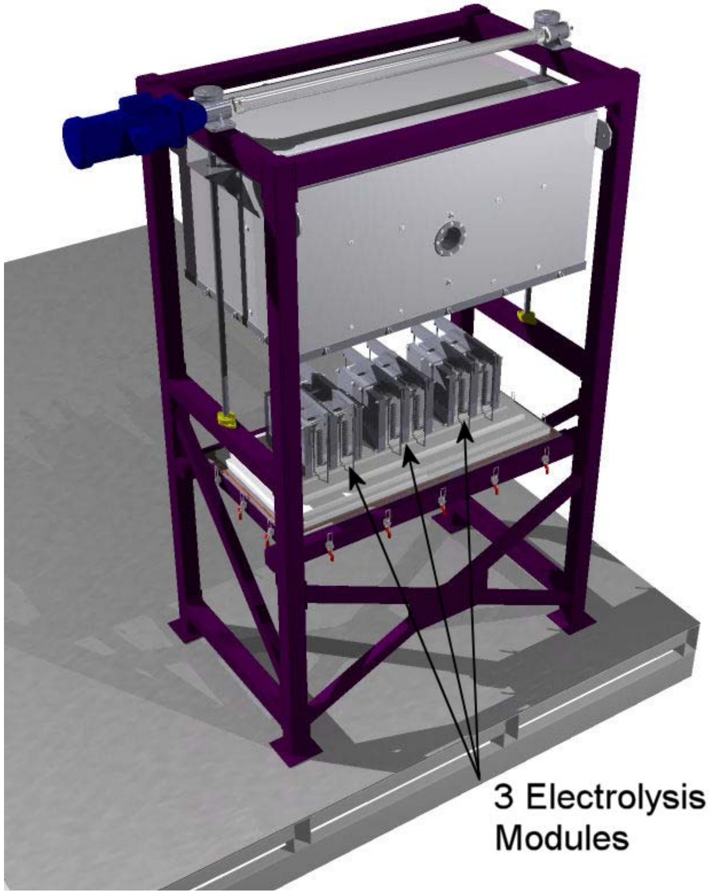
(c)

The air electrode 2 cm away from the sealed edges of the 25-cell stack. The overlaid lines are EDS line scans of the various elements in the electrode.

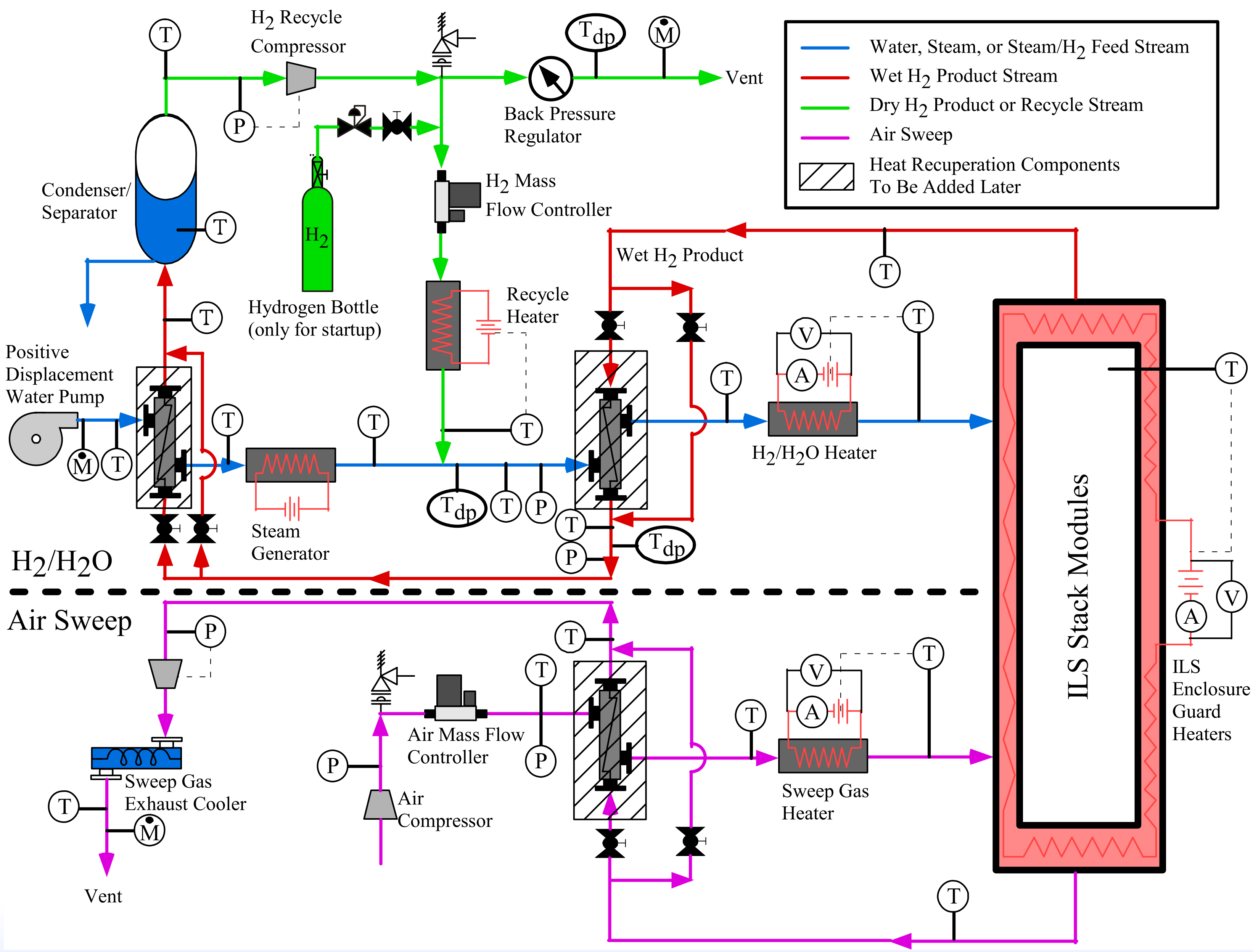


Integrated Laboratory Scale experiment

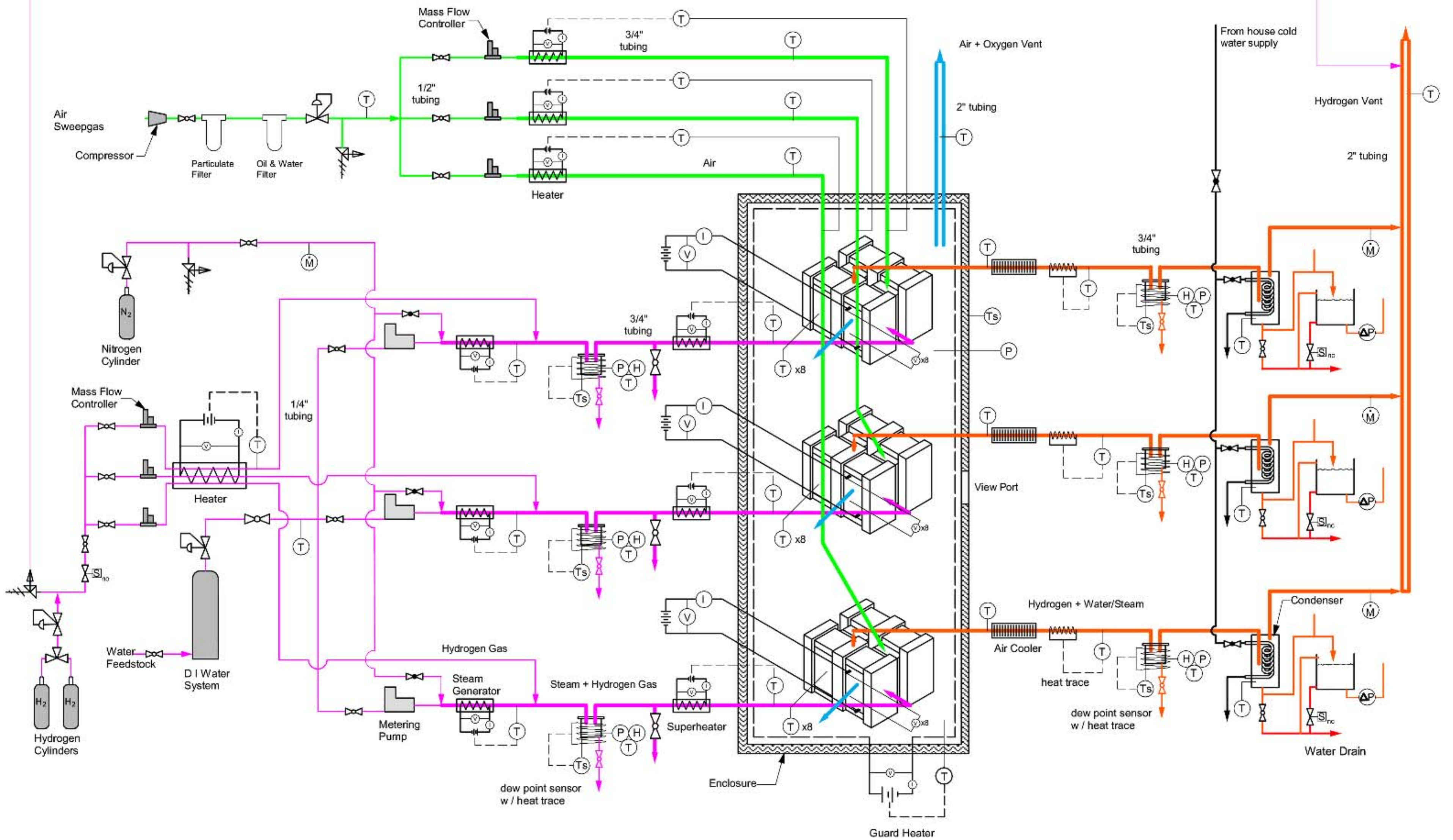




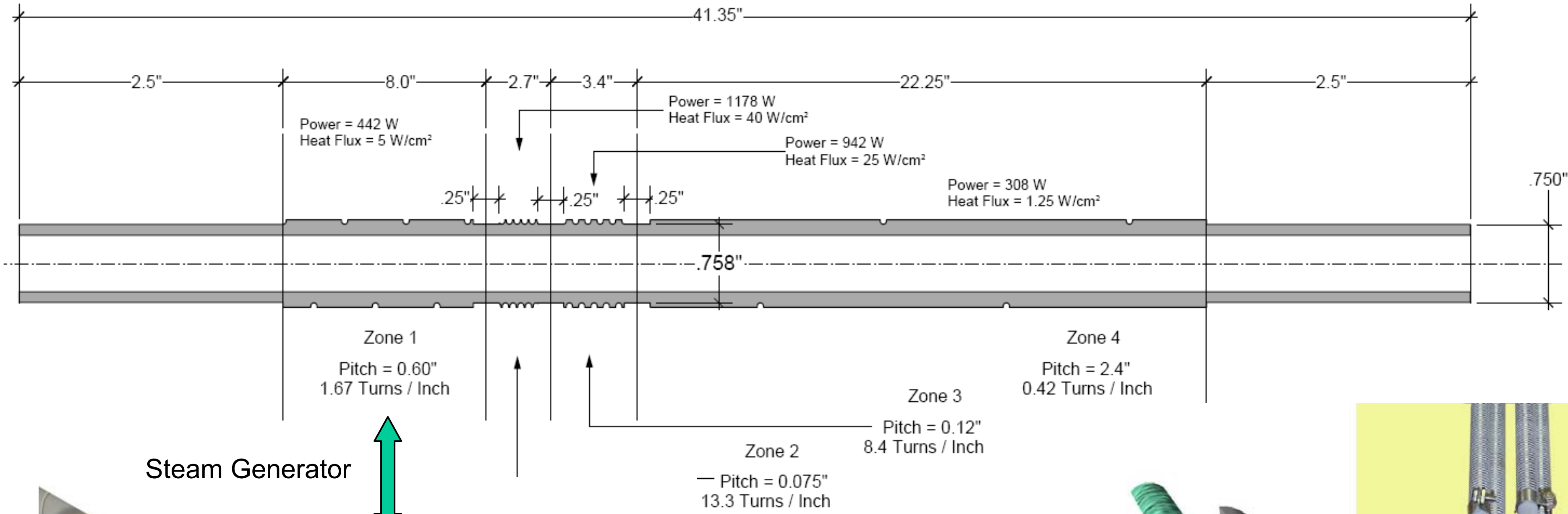
Schematic of Integrated Laboratory-scale system for HTE



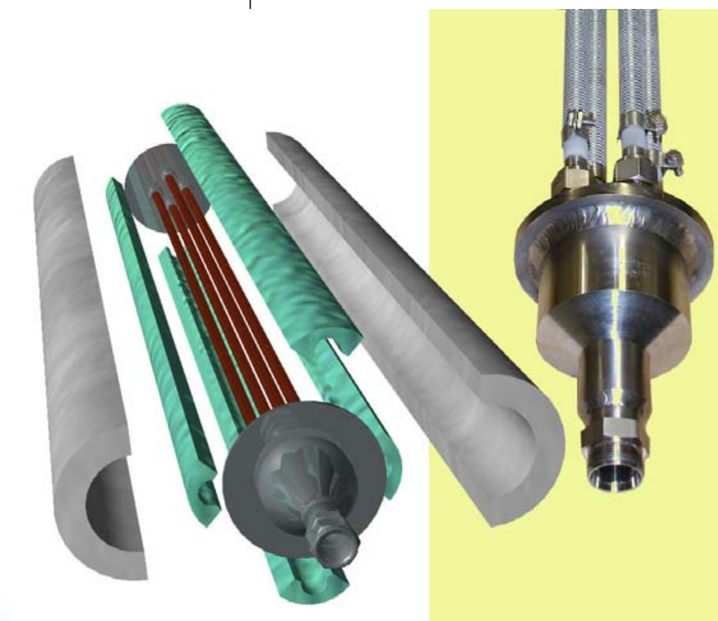
ILS Piping and Instrumentation Diagram



Design of ILS Steam Generators and Superheaters

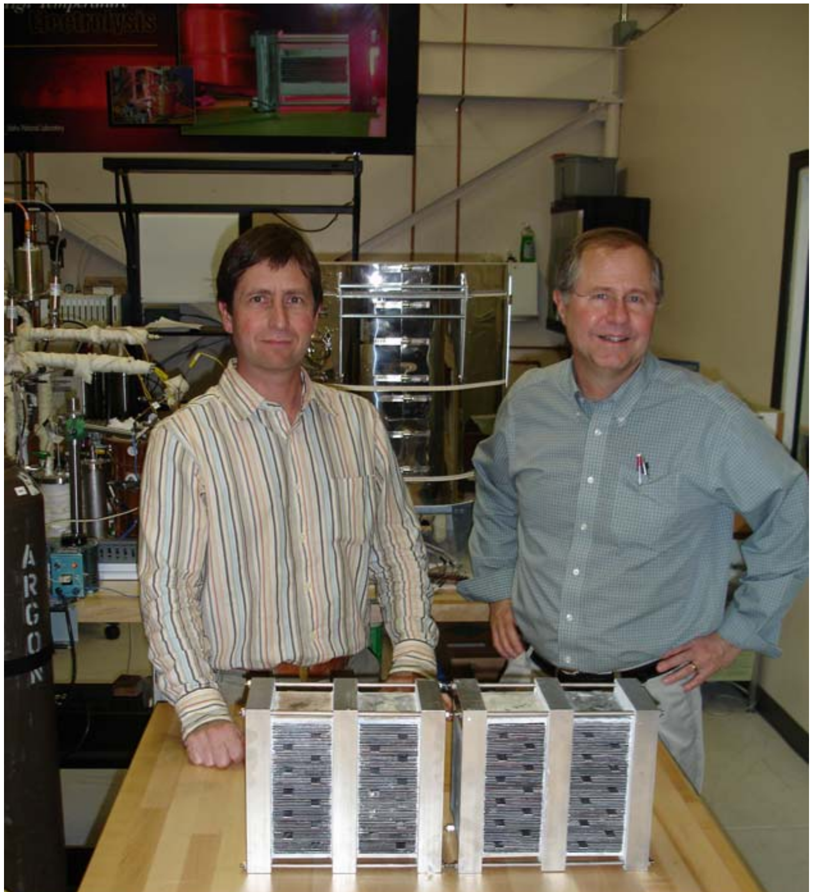


Steam Generator



Superheater

Delivery of Initial ILS module



INL researchers Carl Stoots and James O'Brien accept delivery of first High Temperature Electrolysis Integrated Laboratory Scale module from Ceramatec (March 21, 2007).

Close-up of the four stacks

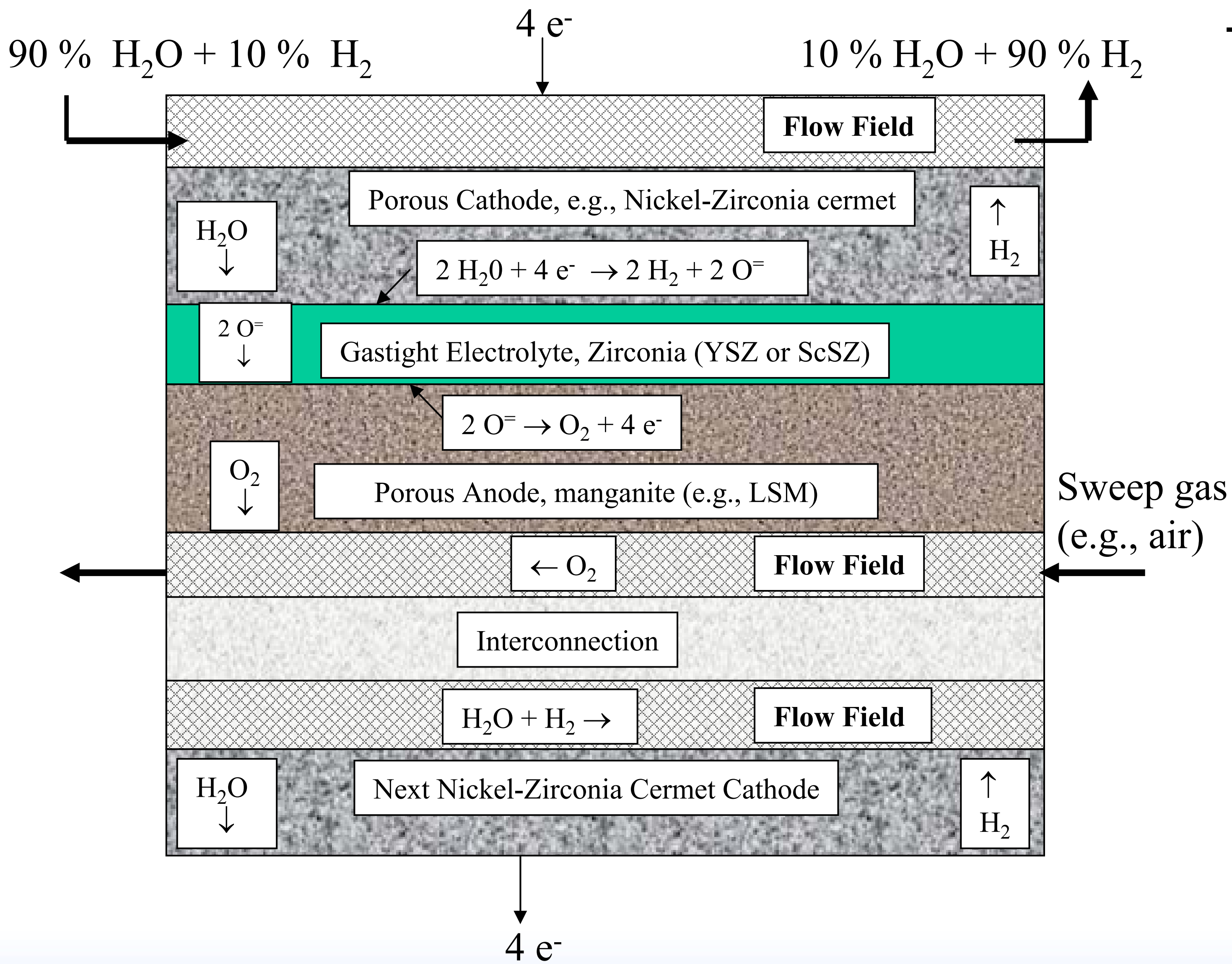
FY-07 HTE Issues / Concerns

- Foci:
  - Demonstration of ILS capability
  - Understanding of degradation mechanisms
  - Economics of manufacture
  - Economics of hydrogen produced
    - Electrolyser design
    - Operating mode
- Develop clear path to commercialization

Next Steps

- *FY08 Priorities*
  - *Long term operation of the ILS and corrosion tests*
  - *Additional components*
  - *Diagnosis of long-term degradation of output*
  - *Larger format cells for better economics*
- *New tasks*
  - *Continued testing of alternate geometries at a small scale*
- *Long term assessment*
  - *Goal: commercial viability in 2014*

Planar Solid-Oxide Electrolysis Stack



Typical Layer thicknesses

Electrolyte-supported	Cathode-supported
30 µm	1.500 mm
100 µm	10 µm
30 µm	50 µm
1 – 2.5 mm	