Idaho National Engineering and Environmental Laboratory

High Temperature Solid Oxide Electrolyzer System

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INEEL

2004 DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review
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This presentation does not contain any proprietary or confidential information

Research Objectives

- *Develop energy-efficient, high-temperature, solid-oxide electrolysis cells (SOECs) for hydrogen production from steam.*
- *Develop and test integrated SOEC stacks operating in the electrolysis mode*
- *Aim toward scale-up to a 500 kW Pilot Plant and a 5 MW Engineering Demonstration Facility*

Budget (EERE)

FY03	*$350k*	*(beginning Jan 03)*
FY04	*$120k*	*(through Jan 04)*
		funding now from DOE-NE

Technical Barriers- high- and ultra-high-temperature thermochemical/electrical processes

3.1.4.2.5 High- and Ultra-High-Temperature Thermochemical Production of Hydrogen[3]

This technology is not mature. Several technical barriers must be overcome. Methods of engineering and manufacturing these systems have not been fully evaluated.

V. High- and Ultra-High-Temperature Thermochemical Technology. High-purity hydrogen production from the proposed water-splitting chemical cycles and direct water-splitting technology has not been proven. Thermochemical technology components and subsystems have not been evaluated.

W. High-Temperature Materials. Very high temperatures are employed in these thermochemical systems. Cost-effective, durable materials are needed that can withstand these high temperatures and the thermal cycling duty cycles that are present in the solar concentrator systems.

[3] DOE's Office of Nuclear Energy has the lead responsibility for hydrogen production utilizing nuclear energy for high temperature (700°-1000° C) thermochemical water splitting chemical cycles. The Office of Hydrogen, Fuel Cells, and Infrastructure Technologies will collaborate with Nuclear Energy the high and ultra-high thermochemical hydrogen production R&D activities.

Technical Barriers (cont)

X. Policy and Public Acceptance. Nuclear restrictions and difficult permitting and licensing procedures severely limit the ability to build nuclear facilities. Permitting and licensing procedures need to be improved, and the public needs to be better educated about the safety issues and potential advantages of nuclear energy systems.

Y. Solar Capital Cost. Solar energy collection is currently expensive and requires large areas of land. Improved, lower-cost solar concentrator/collection technology, including materials, is needed.

Technical Targets

Table 3.1.9. High- and Ultra-High-Temperature Thermochemical Hydrogen Production

Characteristics		Units	2003 Status	2005 Target	2010 Target
High-Temperature Production[1]	Cost at the plant gate	$/kg	NA[2]	10	2
	Energy Efficiency	%	NA[2]	25	40
Ultra-High Temperature Solar Production[3]	Cost at the plant gate	$/kg	12	8	4
	Solar concentrator cost	$/m²	250	130	75
Process efficiency[4]		%	20	40	45

[1] This is based on large scale central production of hydrogen using waste heat from next generation nuclear energy at 700-900°C using a chemical cycle/water splitting process such the sulfur-iodide chemical cycle. It is based on plant gate costs at low pressure (~200 psig). Few and only very rough cost estimates of this technology have been done with one published by General Atomics that projects an ultimate possible cost of as low as $1.00/kg of hydrogen. The targets set for 2005 and 2010 are based on estimates of progress that need to be made to achieve the objective of $1.00/kg by 2015.

[2] Nuclear-based thermochemical cycles are an unproven technology with insufficient information for current estimates.

[3] Based on estimates for a concentrated solar driven thermal methane splitting process. The cost evaluation is documented in "Assessment of Natural Gas Splitting with a Concentrating Solar Reactor for Hydrogen Production"; April 2002, Pamela Spath and Wade Amos; NREL/TP-510-31949. The values in this Table are based on the work done as part of that report and projecting the required technology improvements from what has currently been achieved at NREL on this process and on solar concentrators. These targets serve as guideposts for ultra-high temperature solar concentrated driven hydrogen production technologies such as possible chemical cycle water splitting processes.

[4] Defined as the energy to drive the reaction divided by incident direct sunlight on the concentrators.

Note: These technologies are at the early stage of exploration. The targets below are rough guidelines only. The long-term goal (2015) is for the hydrogen produced from these technologies to be cost competitive with gasoline delivered at the refueling station or stationary power facility.

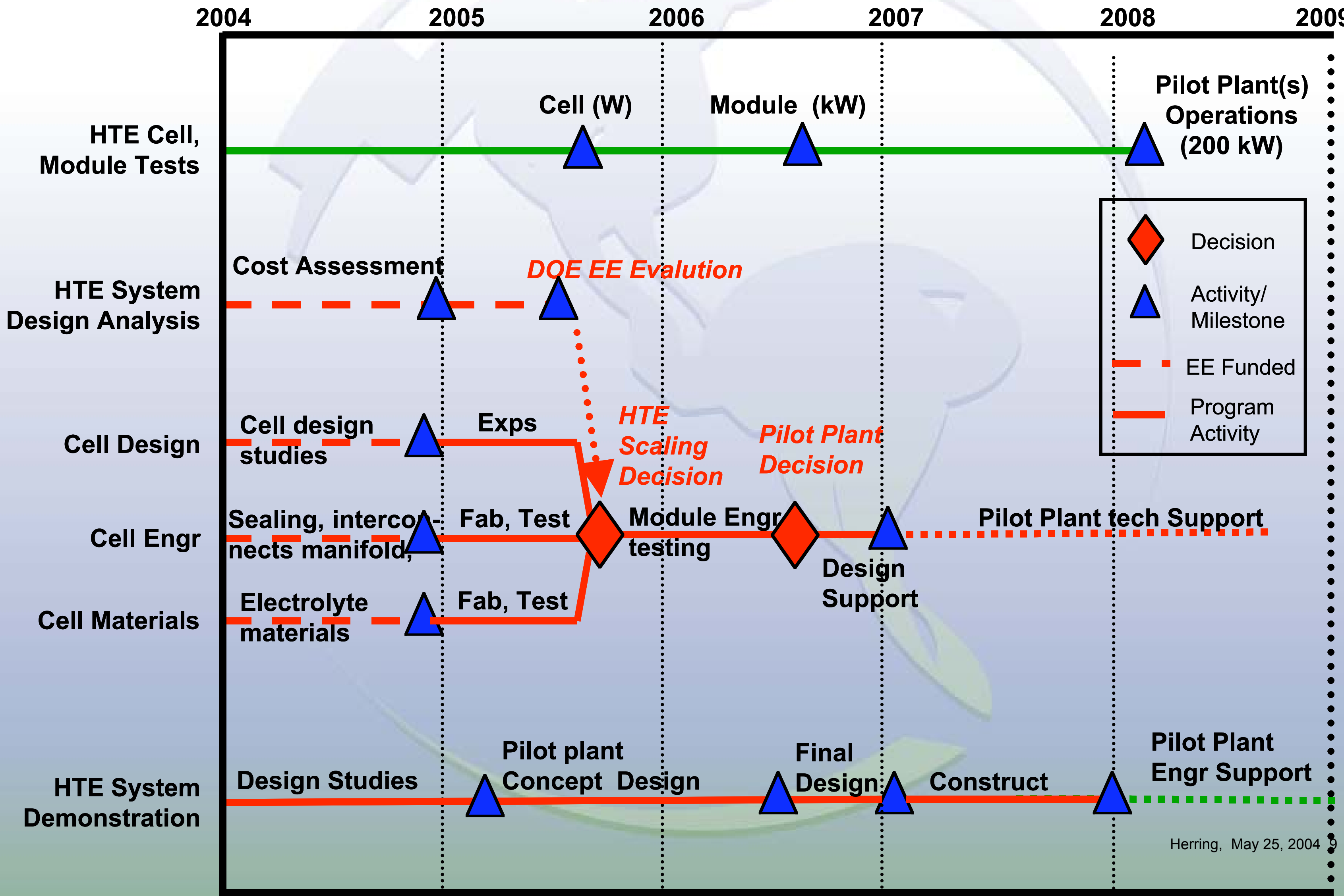
Approach (vs Objectives)

- *Develop energy-efficient, high-temperature, solid-oxide electrolysis cells (SOECs) for hydrogen production from steam.*
  - *reduce ohmic losses to improve energy efficiency*
    - *minimize electrolyte thickness*
    - *utilize high performance electrolyte materials (e.g., ScSZ, LSGM)*
    - *investigate alternate cell configurations (e.g., electrode-supported)*
  - *single-cell performance characterization testing*
- *Develop and test integrated SOEC stacks operating in the electrolysis mode with an aim toward scale-up to a 500 kW Pilot Plant and a 5 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)*
  - *Perform Cost and Safety Analyses*

Project Safety

- *All aspects of our experimental program are carefully reviewed through our Independent Hazard Review (IHR) process.*
- *Potential hazards are identified and mitigated through the application of appropriate Engineering and/or Administrative Controls*

Project Timeline

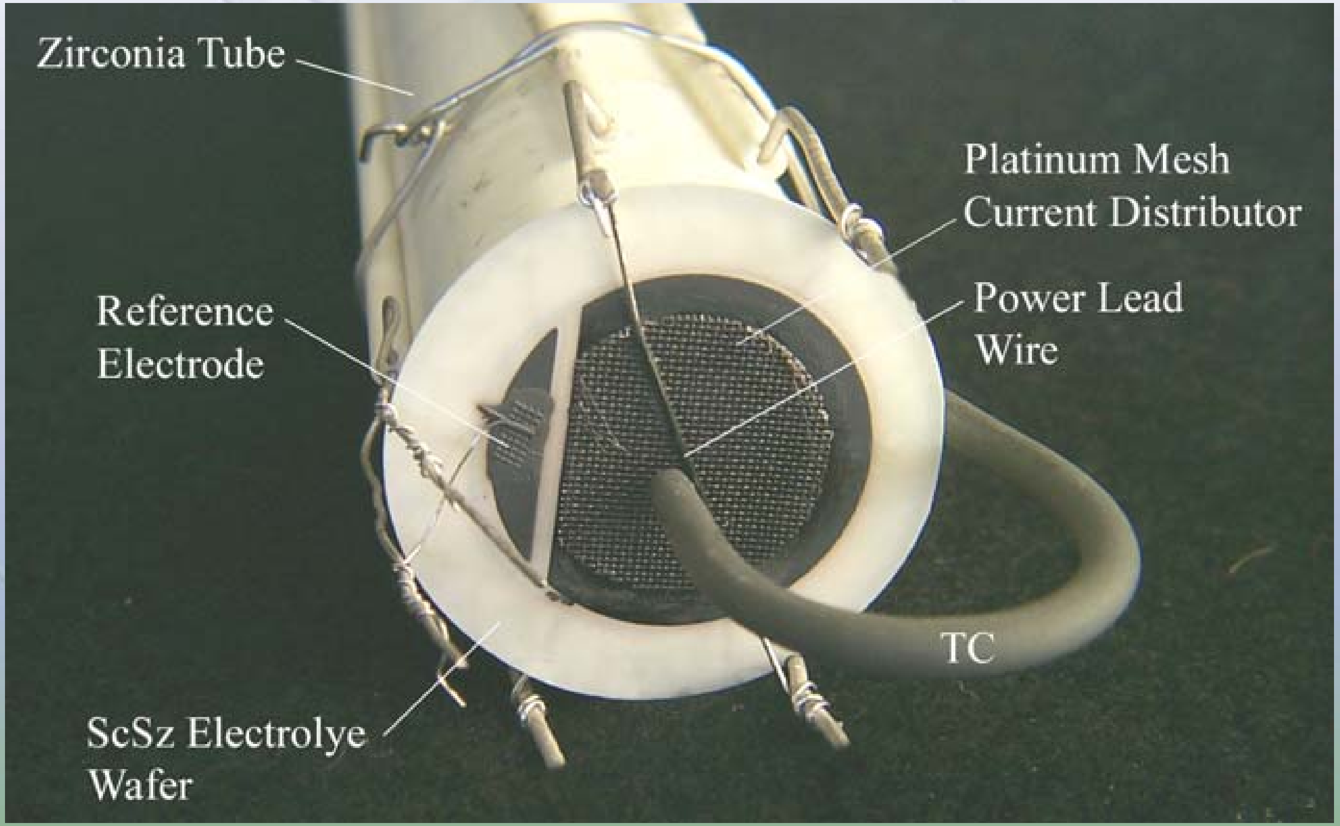


Technical Accomplishments

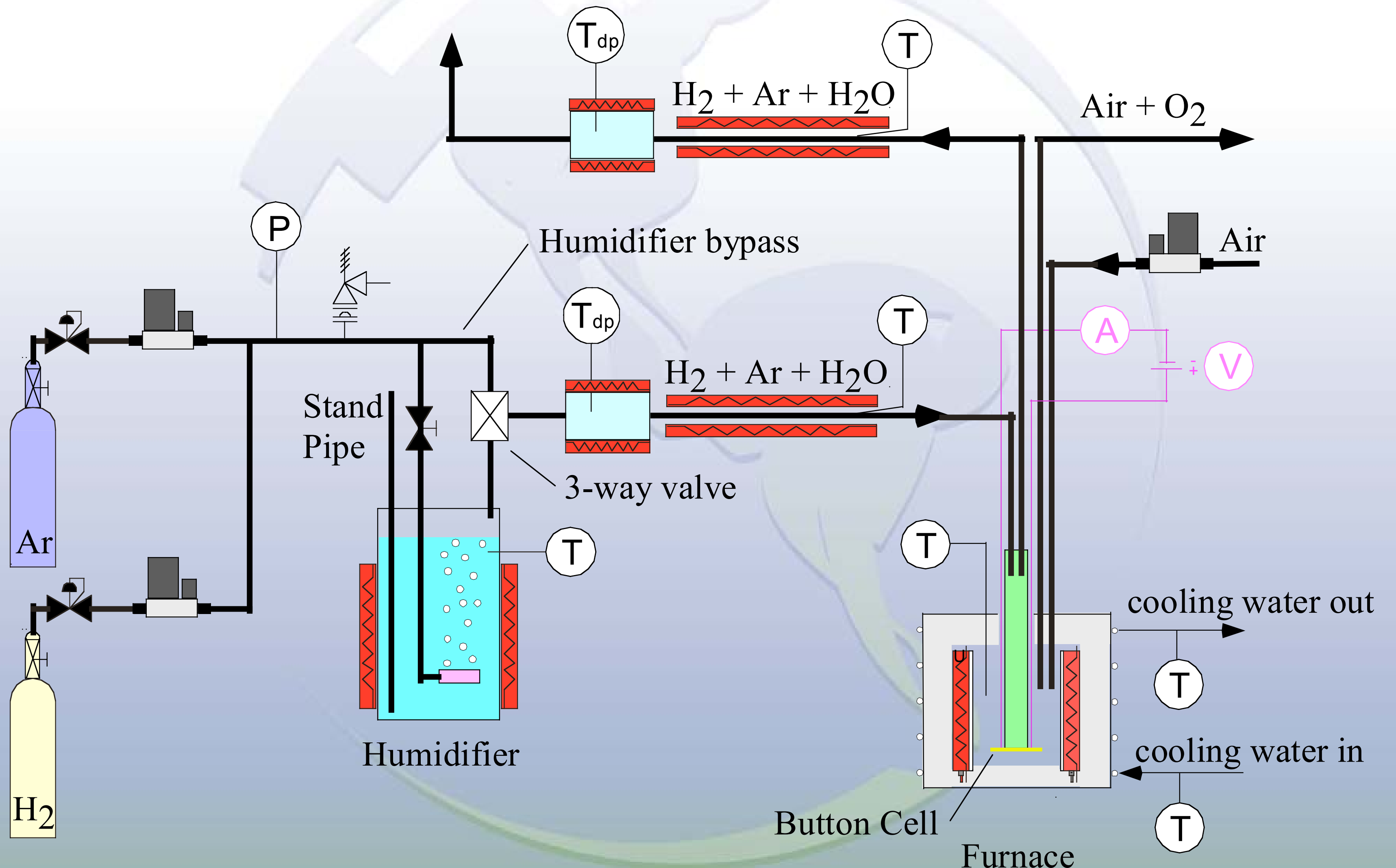
- *Single-cell materials development*
- *Single-cell testing*
- *Stack development*
- *Stack testing*

Button cell for single-cell tests:

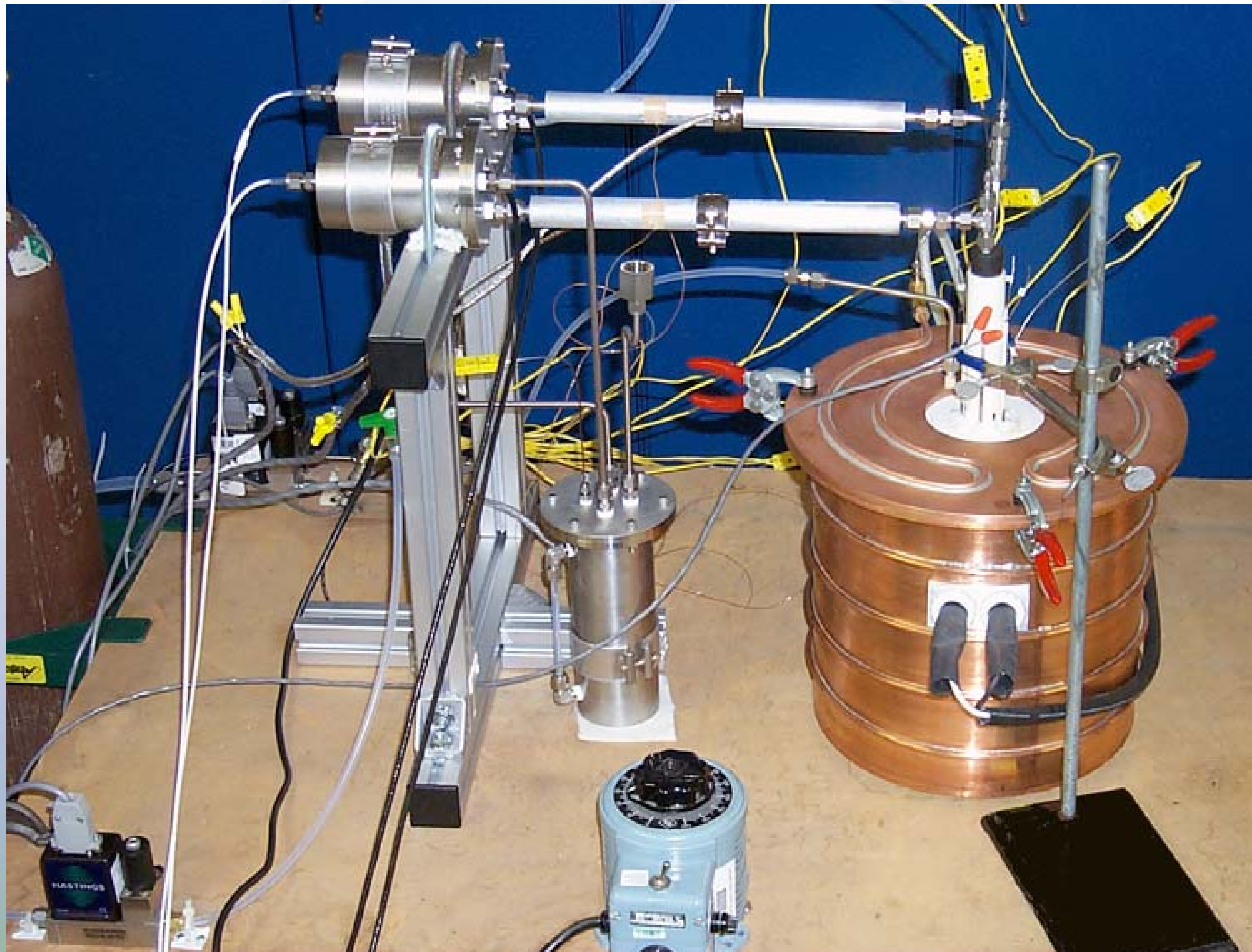
- Steam/hydrogen electrode: Nickel zirconia cermet
- Oxygen electrode: Strontium-doped lanthanum manganite (LSM)
- Electrolyte: YSZ or ScSZ, ~ 100 - 150 μm thickness
- Active cell area: 2.5 cm^2
- Includes an electrically isolated electrode patch for monitoring of reference open-cell voltage



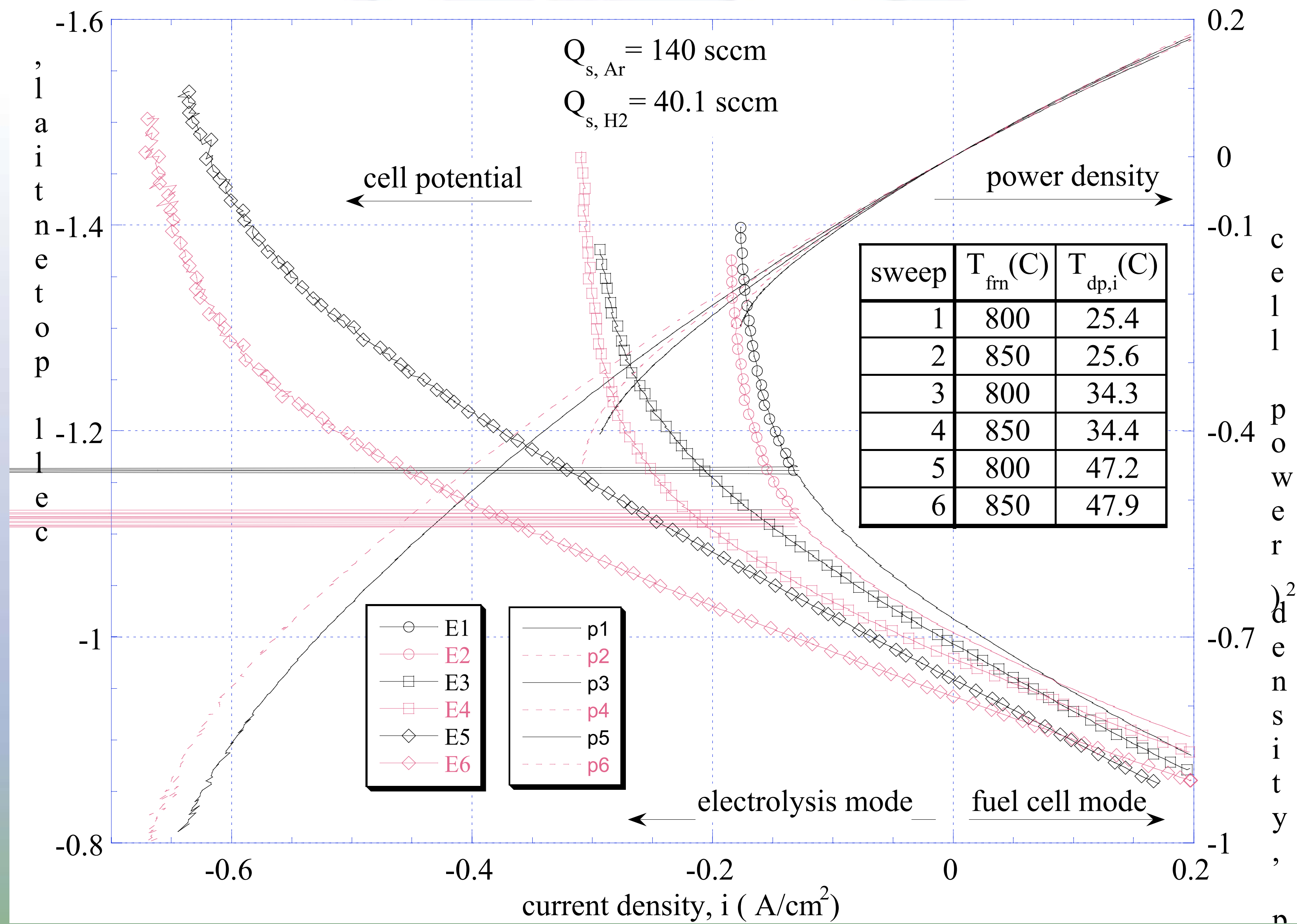
INEEL Single-Cell High-Temperature Steam Electrolysis Experiment



Experimental Hardware

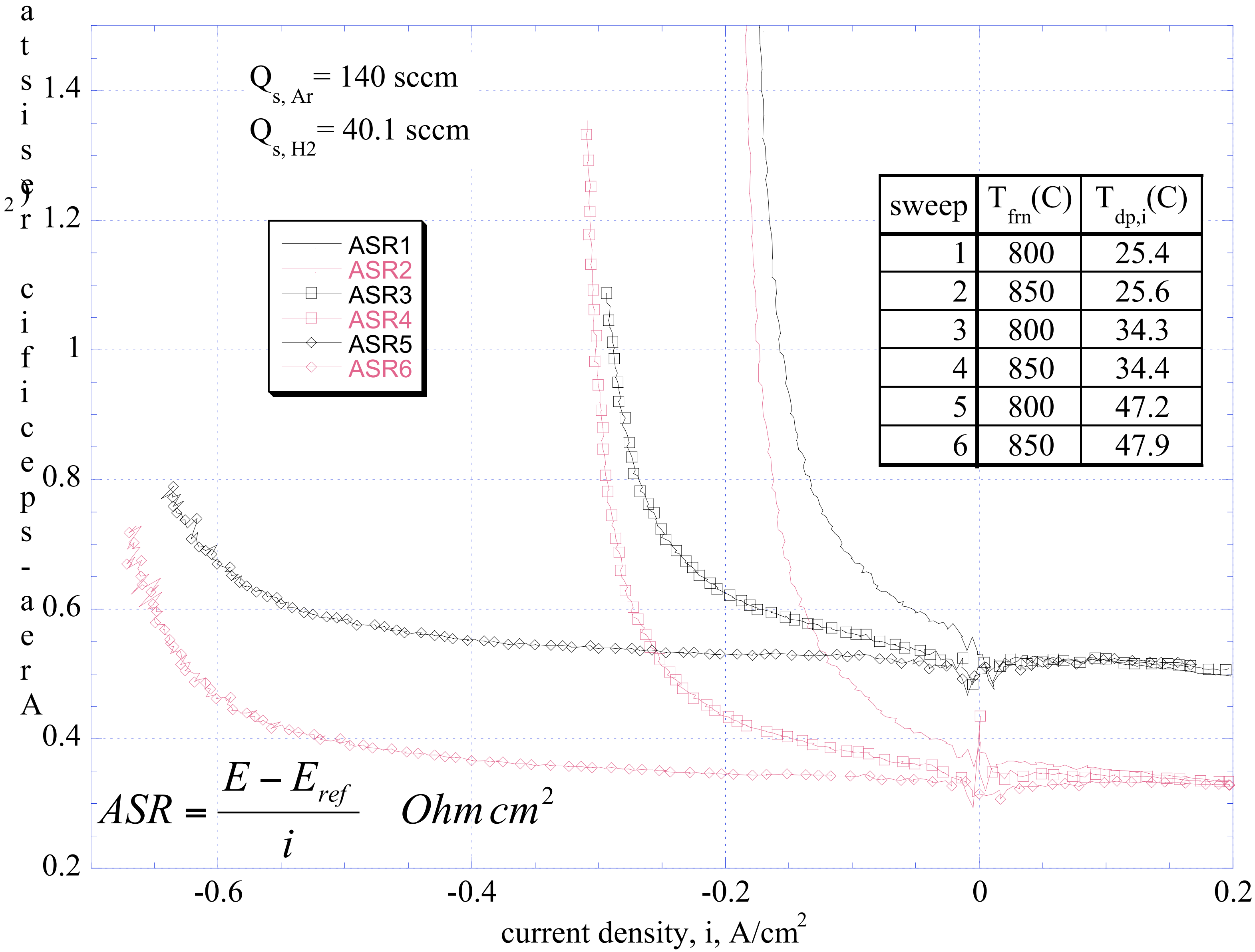


Cell potential and power density as a function of current density.



sweep	T_{frn}(C)	$T_{dp,i}$(C)
1	800	25.4
2	850	25.6
3	800	34.3
4	850	34.4
5	800	47.2
6	850	47.9

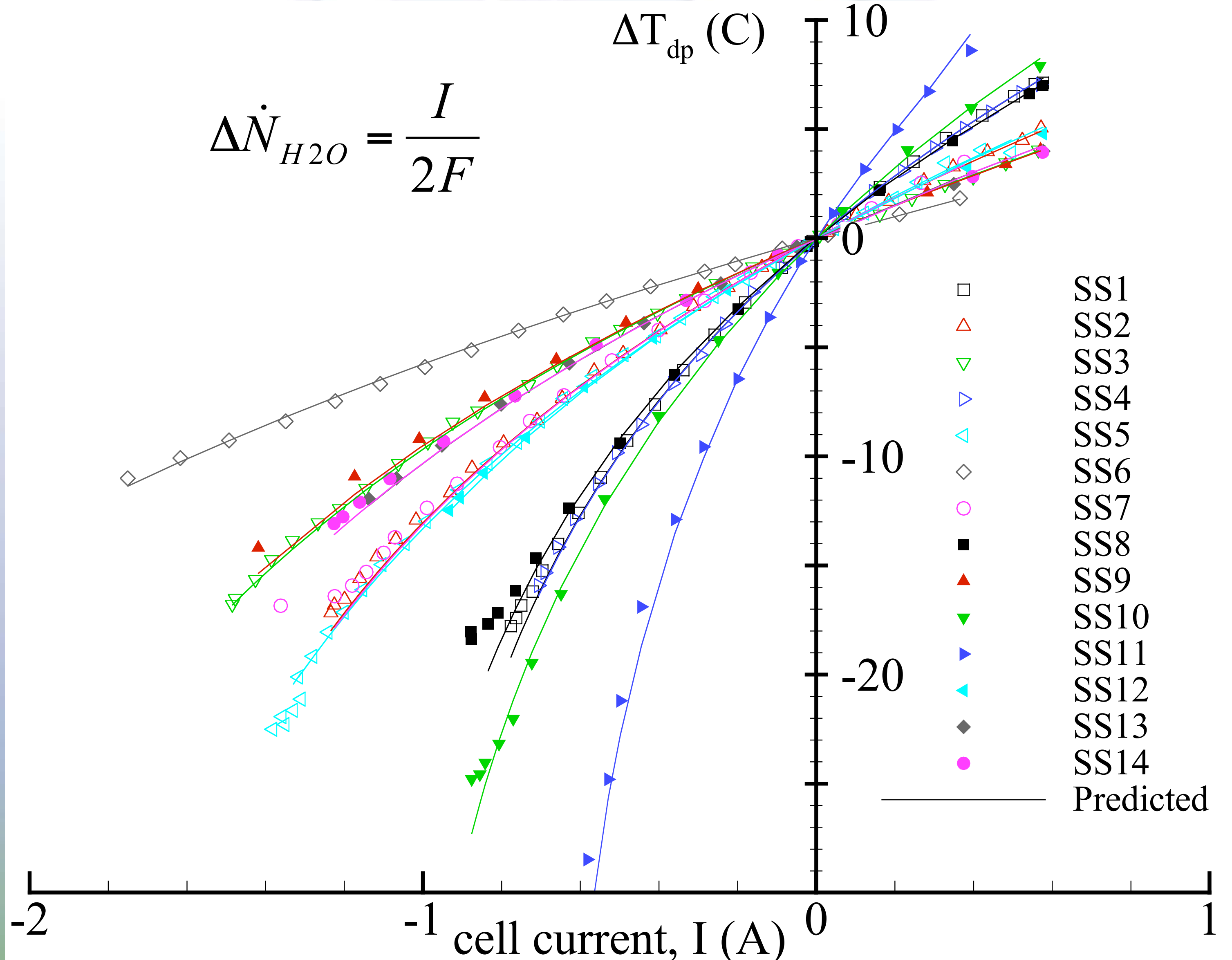
Area-specific resistance dependence on current density and temperature.



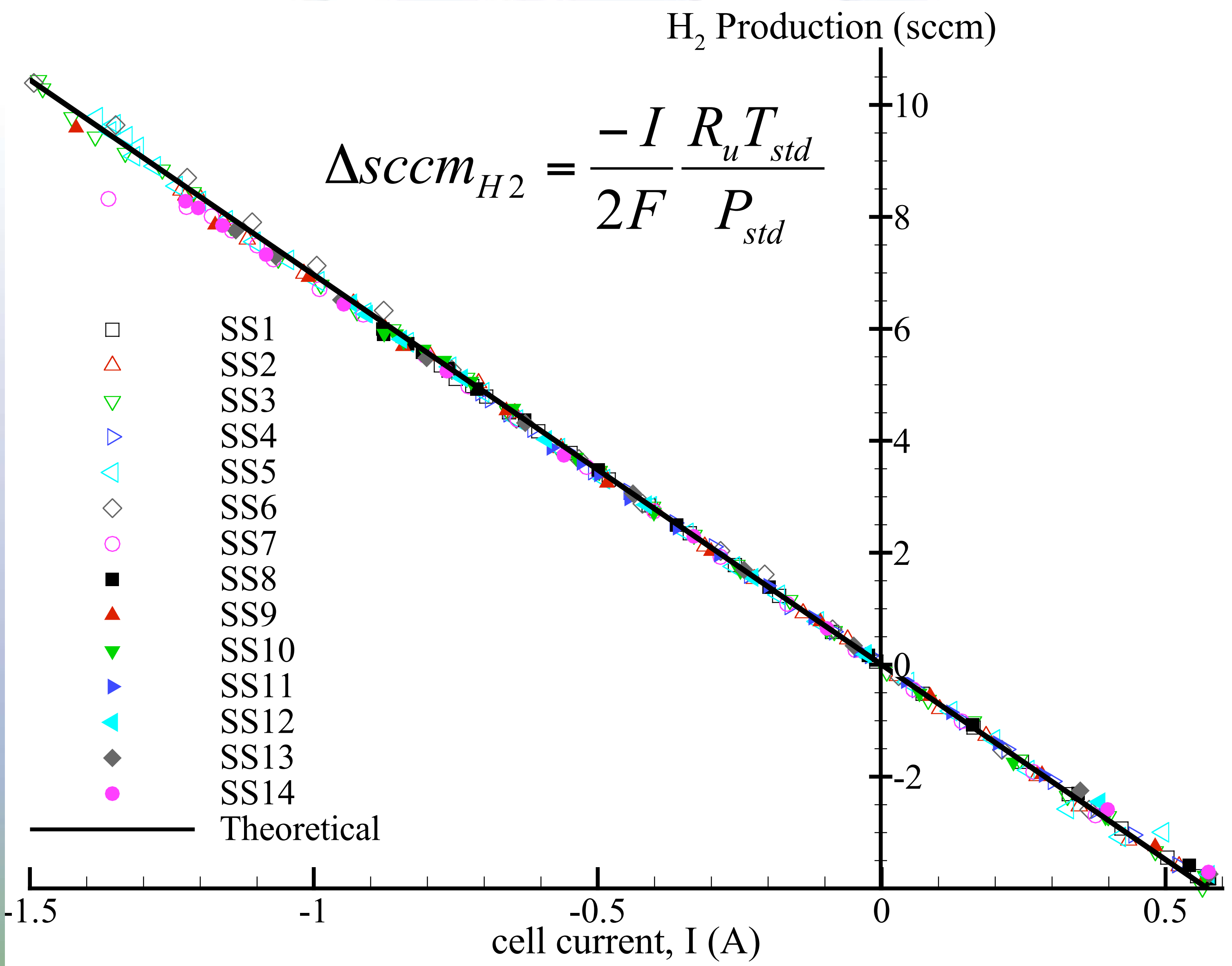
sweep	T_{frn}(C)	$T_{dp,i}$(C)
1	800	25.4
2	850	25.6
3	800	34.3
4	850	34.4
5	800	47.2
6	850	47.9

$$ASR = \frac{E - E_{ref}}{i} \quad Ohm\, cm^2$$

Dewpoint temperature change across cell.



Hydrogen production rates.



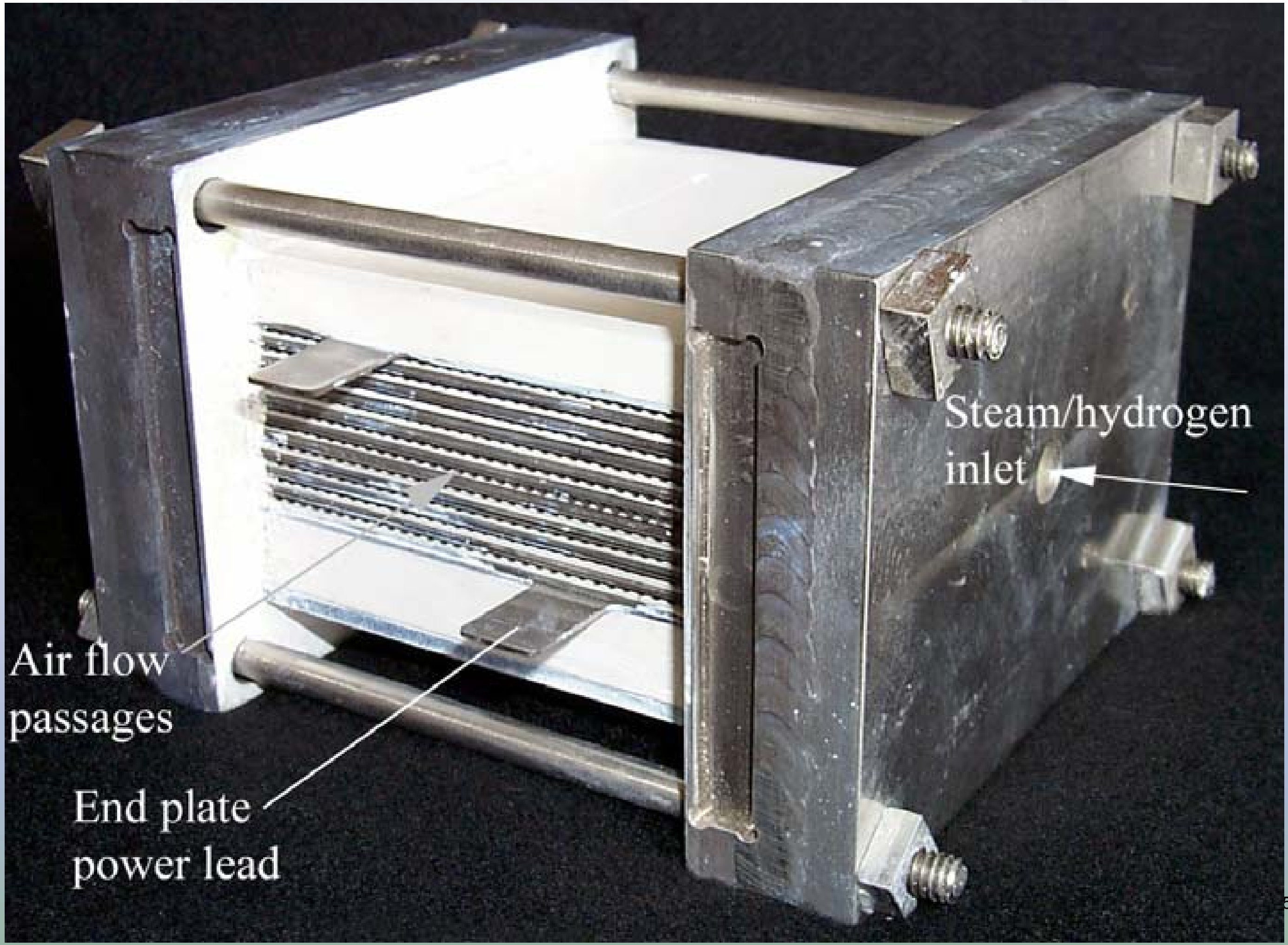
Summary of Single-Cell Test Results:

- Measured open-cell potentials were shown to agree well with theoretical predictions during system heatup and testing.
- Observed values of area-specific resistance ranged from about 0.5 to 1.0, depending on test conditions and the specific cell being tested. Degradation of ASR associated with thermal cycling of the cells was noted.
- The effects of steam starvation on ASR in the electrolysis mode were evident at higher current densities.
- Measured dewpoint-change values obtained during the steady-state tests were shown to agree very closely with predictions based on cell current.

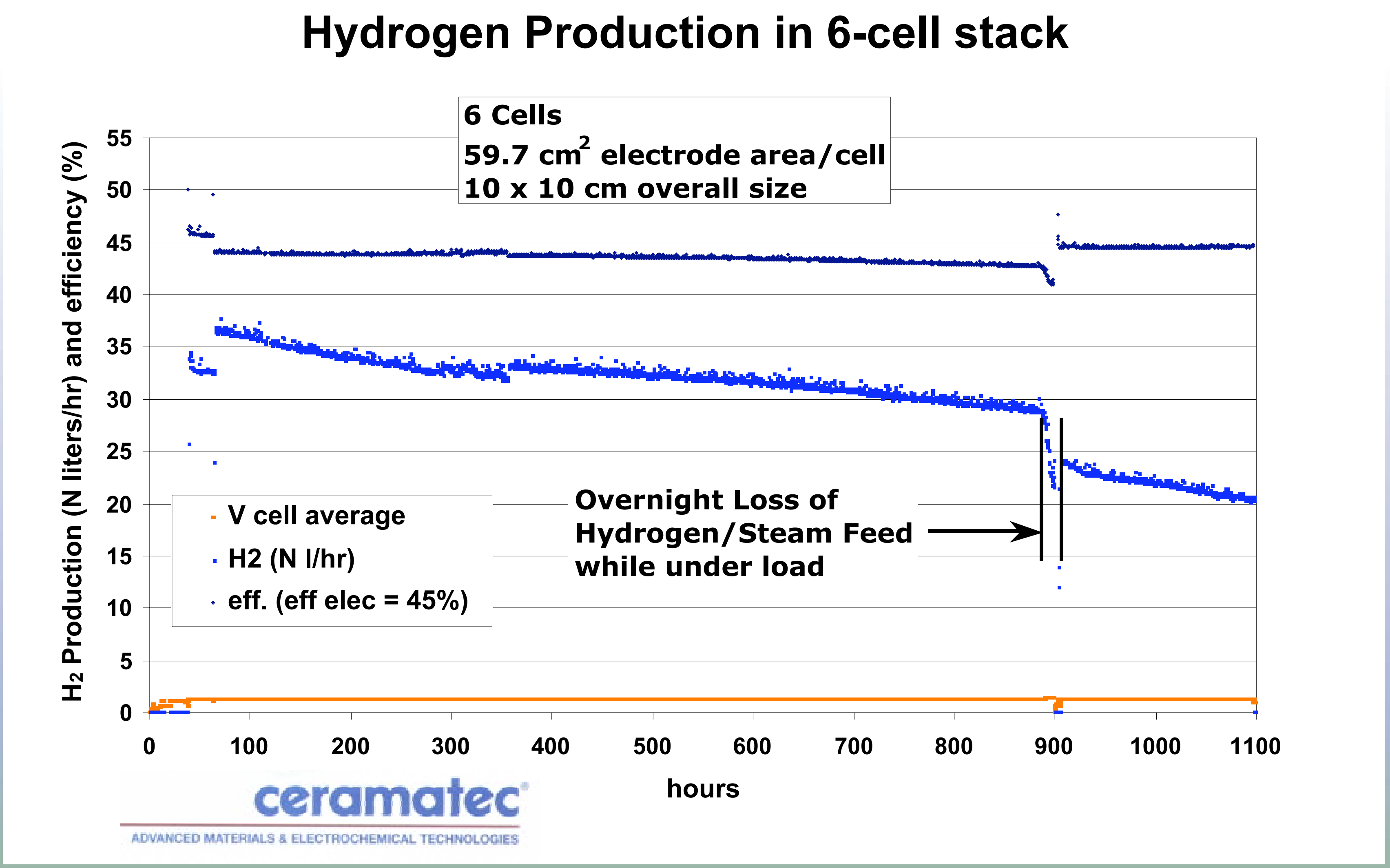
Summary of Single-Cell Test Results (cont)

- Thermal efficiency values based on measured hydrogen production were in agreement with values based on cell operating voltage
- Both efficiencies approach their respective theoretical reversible limits at low current density.
- In general, cell performance was shown to be continuous from the fuel-cell mode to the electrolysis mode of operation.

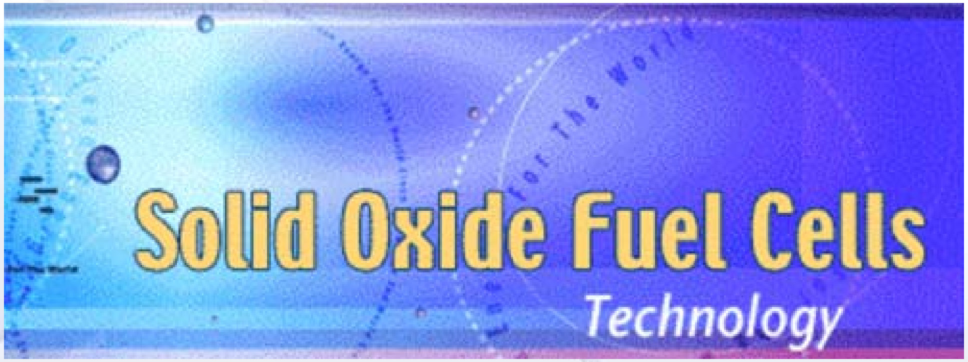
Future Work: Ten-Cell Stack Ready For Testing at INEEL



Ceramatec SOEC Stack test Oct-Nov, 2003



Industrial Collaborator



Ceramatec, Inc.

Salt Lake City, UT

- *25+ years of contract R&D experience developing electrochemical ceramics*

Responsibilities:

- *Fabricate single-cell SOECs and planar cell stacks for testing at INEEL*
- *Collaborate in testing SOECs and stacks for HTE*
- *Develop advanced SOECs for HTE*

Technical Contacts/Collaborations

- *EPRI (Layla Sandell, Scott Penfield, Dan Allen)*
- *Dr. Kyu-Sung Sim (Korea Institute of Energy Research) and Young-Joon Shin (Korea Atomic Energy Research Institute)*
- *INERI with Canada*
- *DOE EE H_2 Review (Philadelphia, May 2004)*

Response to Previous Year Reviewer Comments

Comment

- *"Little progress to date in project."*

Response

- *Project had only been funded three months at time of 2003 Review; significant progress has been made since 2003 review.*

Summary and Conclusions

- *INEEL is implementing the HTE tasks under the DOE NHI*
- *Significant progress has already been made in:*
  - *single-cell materials and testing*
  - *stack development and testing*
  - *Conceptual design of Pilot-Scale Facility*
  - *Scaling analyses for commercial-scale plant*
- *INEEL has generated numerous publications*
- *INEEL HTE activities have begun to attract national and international attention*