A Reversible Planar Solid Oxide Fuel-Fed Electrolysis Cell and Solid Oxide Fuel Cell for Hydrogen and Electricity Production Operating on Natural Gas/Biogas

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2006 DOE Hydrogen Program Annual Review
May 16, 2006

Project ID#: PDP 33

Overview

Timeline

- Project started: 09/30/2004
- Project ends: 11/30/2006
- Percent completed: 60%

Budget

- Total budget funding
  - DOE $1,200k
  - Contractor $ 300k
- Funding received in FY05
  - $ 567k
- Funding for FY06
  - $ 605k

Barriers

Hydrogen generation by water electrolysis

- G – Capital cost
  - Low-cost, durable high-temperature materials development
  - Lower operating temperature
- H – System efficiency
- J – Renewable integration
- K – Electricity costs

Partners

- Materials & Systems Research, Inc. (MSRI)
- University of Missouri-Rolla (UMR)
- Aker Industries, Inc. (AI)

Objective

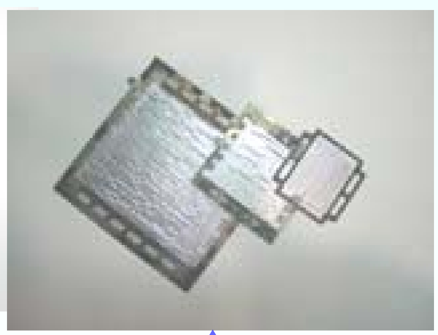
Overall Objective	• To develop a composite/hybrid planar 1kW SOFC-SOFEC stack generating both hydrogen and electricity either from distributed natural gas or biogas fuel. The project focuses on materials research, stack design & fabrication, and verification.
2005	• Anode-supported cell development – Materials selection – Cell design – Cell fabrication – Testing/verification
2006	• SOFC-SOFEC stack development – Stack design – Fabrication – Seals development – Proof-of-concept stack test/verification – Economic analysis

Approach

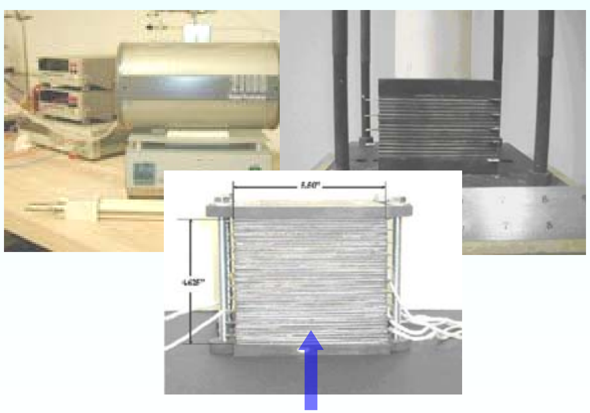
Materials Development	Cell / Stack Design	Experimental Verification
A. Ca materials selection	A. Cell manifolds design	A. Single cell
B. An optimization	B. Interconnect design	B. Seal test
C. Electrolyte optimization	C. Top/end plates design	C. Short stack
D. Catalyst studies	D. Thermal/flow manag.	D. Model verification (T,P)
E. Cell scale up	E. Seals development	E. 1kW stack demo
F. Fabrication Q.A.	F. Economic analysis	
80% complete	**60% complete**	**50% complete**

Success

MSRI, UMR



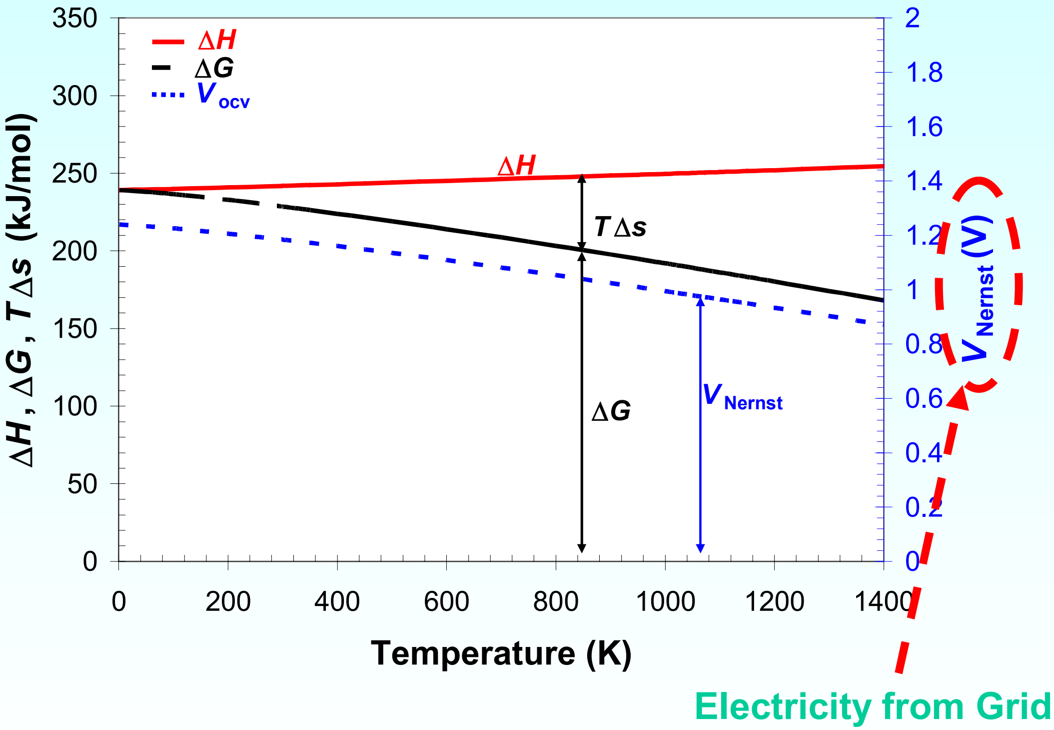
MSRI, AI



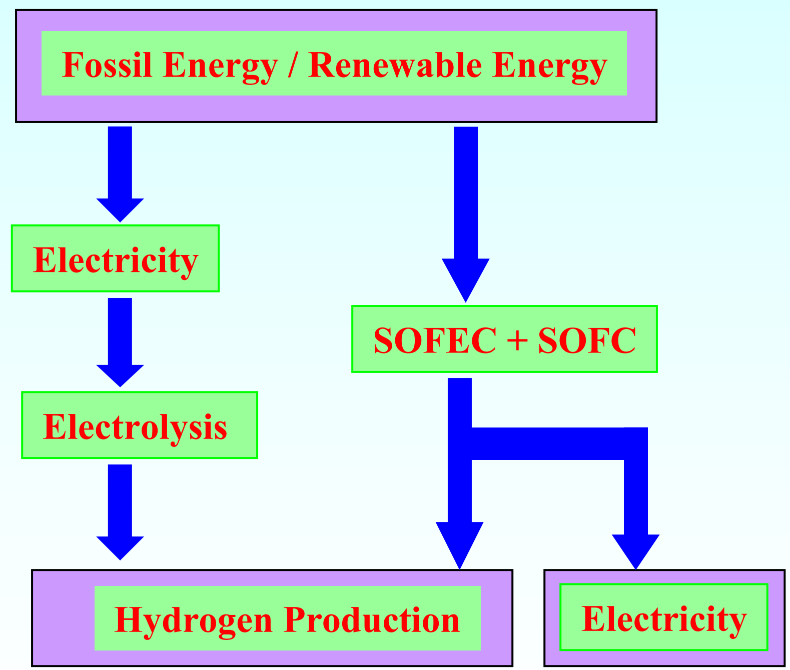
MSRI

Background

A Solid Oxide Fuel-Fed Electrolysis Cell (SOFEC) directly applies the energy of a chemical fuel to replace the external electrical energy required to produce hydrogen from water/steam; decreasing the cost of energy relative to a traditional electrolysis process.



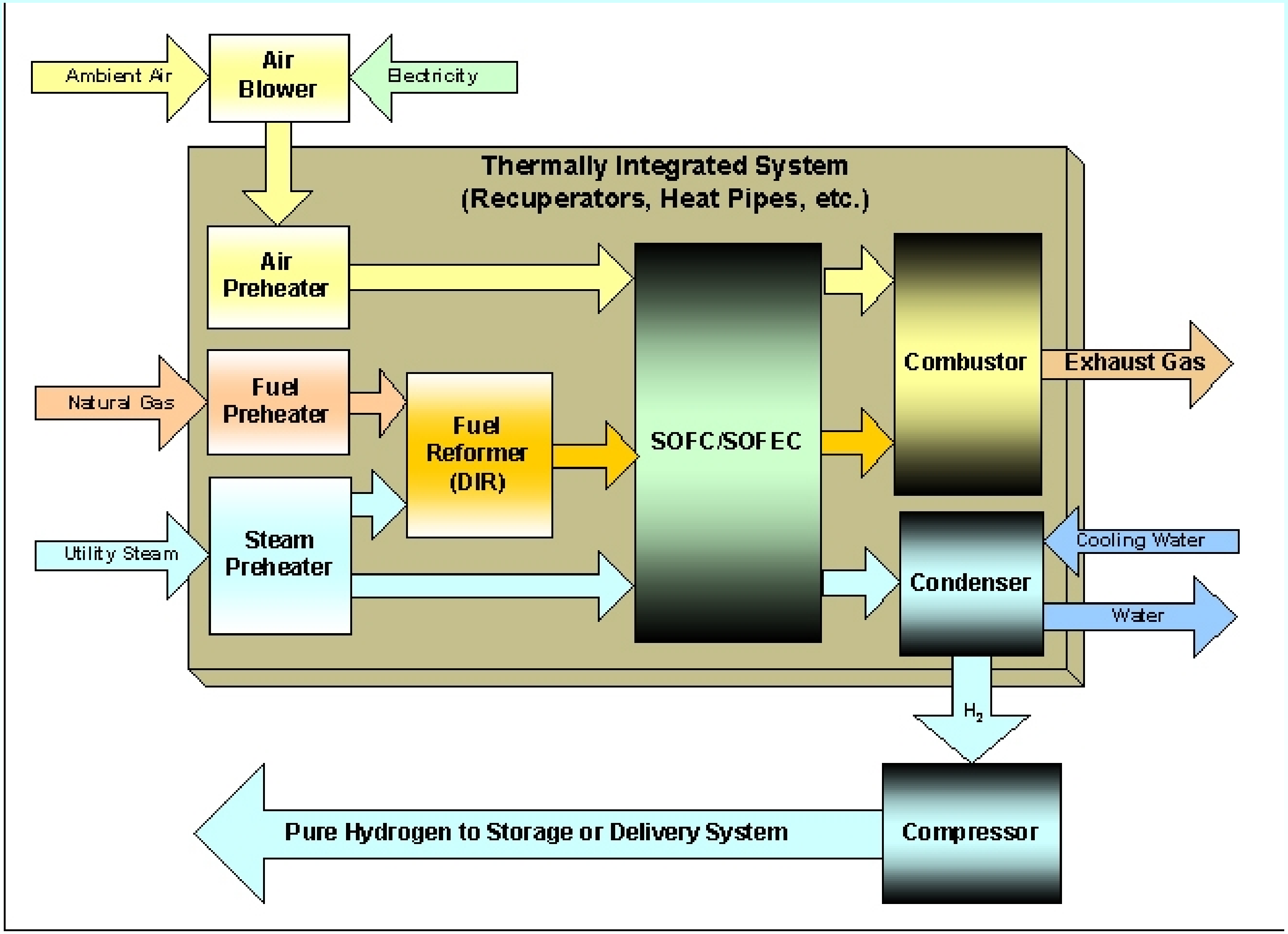
Unique process



Co-generation

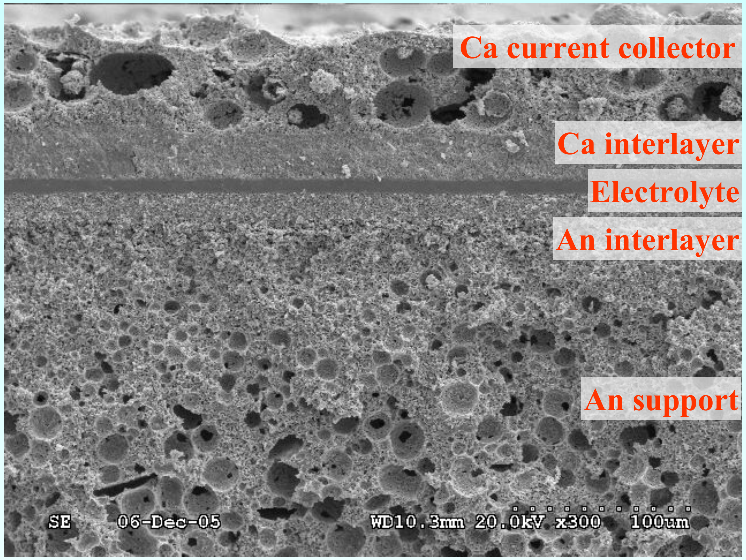
$$H_2O \leftrightarrow H_2 + \frac{1}{2}O_2$$

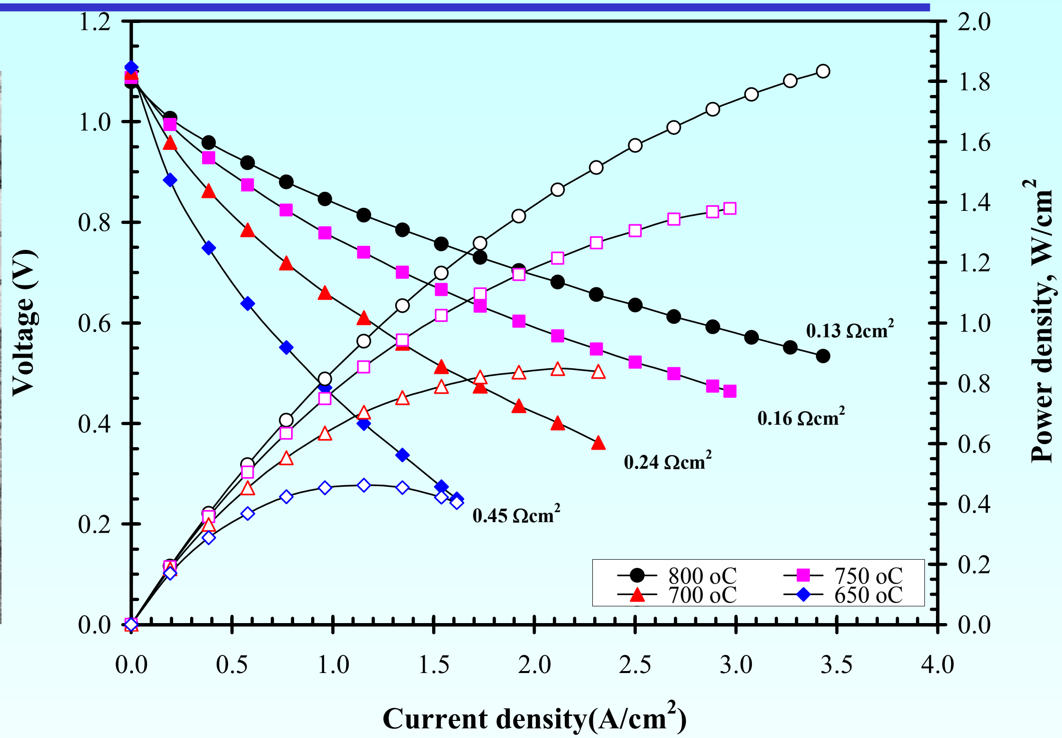
Concept of Hybrid SOFC-SOFEC Integral System



- Pure H_2 & e^- generated from fuel, steam, and air
- SOFECs produce pure hydrogen
- SOFCs generate electricity; increase H_2 production rate
- Thermal integration improves system efficiency

Anode-supports Optimization

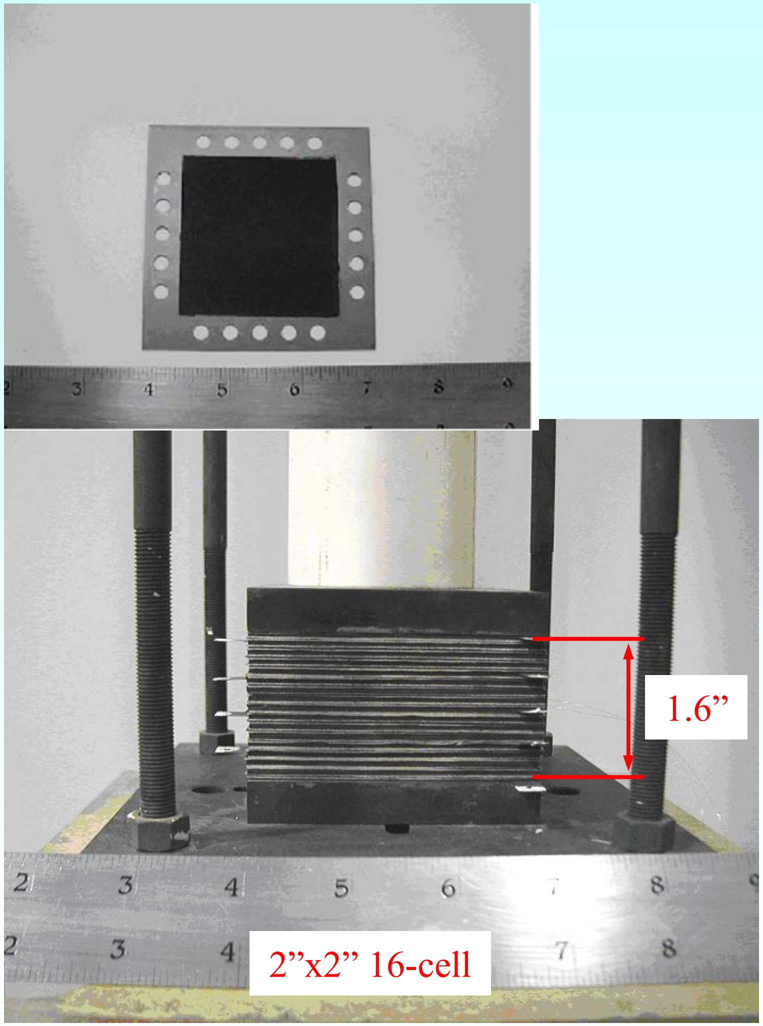


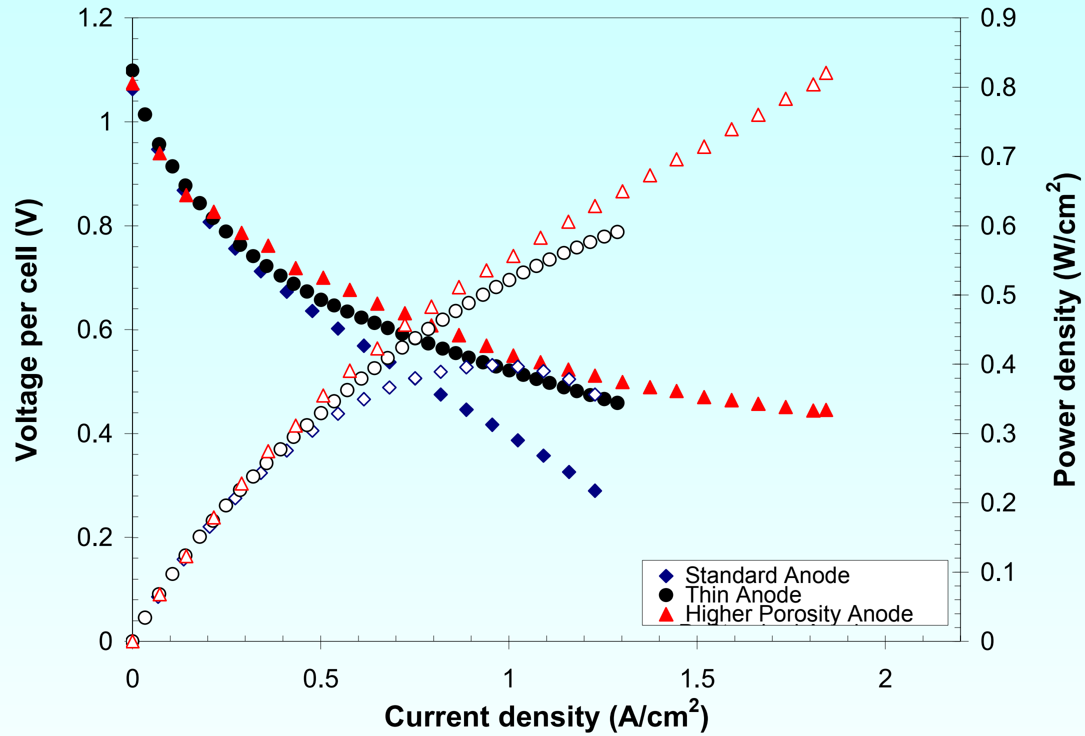


- Objective
  - Increase anode porosity and decrease thickness to minimize concentration polarization
  - Develop anodes with improved mechanical and thermo-mechanical properties
  - Fabricate anode-supported cell with defect-free thin electrolyte layer
- Approach
  - Vary composition and microstructure of anode supports
  - Vary pore-former to adjust porosity
  - Improve quality control

- Cell w/ 2cm^2 active area
- Tested @ 650 – 800 °C
- Air flow rate @ 550 ml/min
- H_2 flow rate @ 140 ml/min

Improved Stack Performance in SOFC Mode

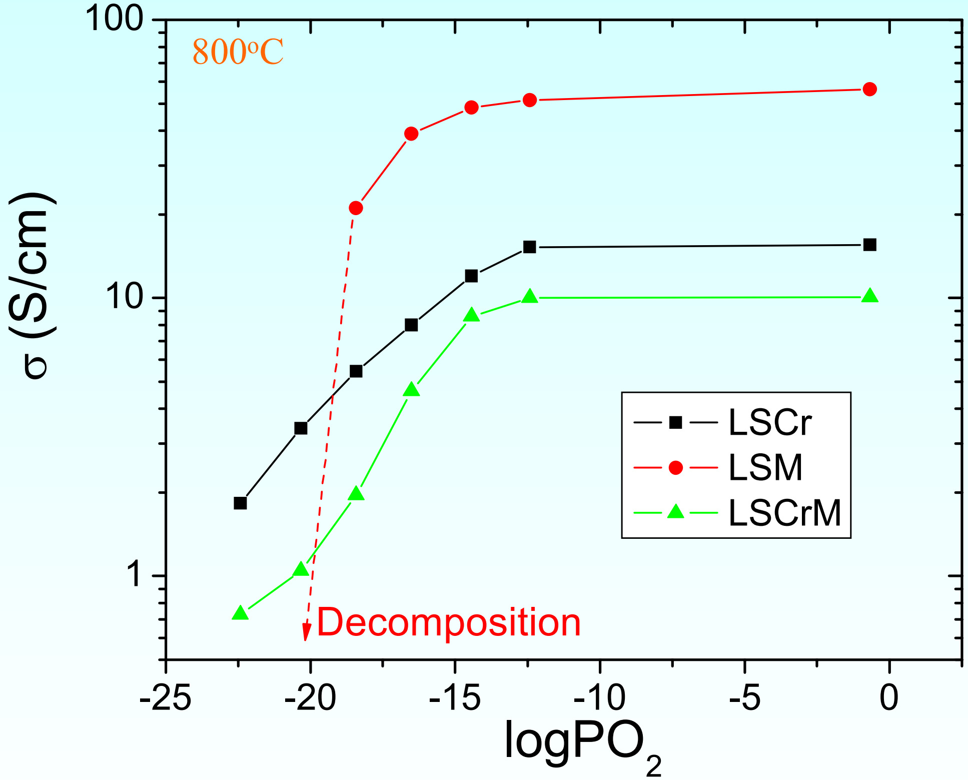




- Scaled up from button cell to 2”x2” cell w/ 30cm² active area
- 4-cell stack tested in SOFC mode
- Tested @ 800 °C, air and hydrogen
- Fuel utilization @ 40%, air utilization @ 40%
- Higher porosity and thinner anode decreases concentration polarization at high current densities and high fuel utilizations

Cathode Materials Selection

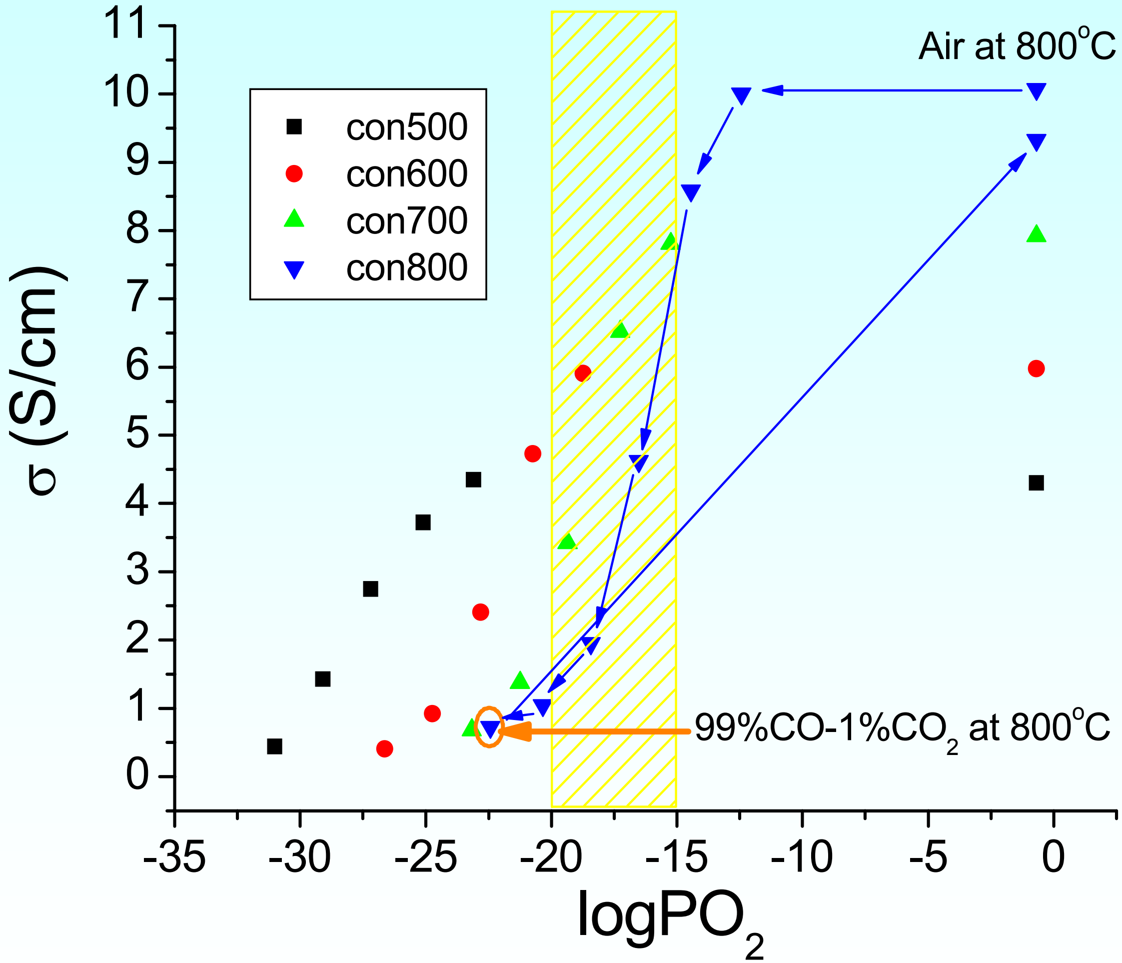
Conductivity of LSCr, LSM, and LSCrM studies



- The electrical conductivity of LSCrM, LSCr and LSM are 10, 15 and 56 S/cm in air
- Due to the porosity, the exact values of the electrical conductivity are imprecise.
- LSCr is the most stable, LSM the least stable and LSCrM in between

- Cathode materials are electrocatalytically and chemically stable in both reducing and oxidizing atmospheres
- Candidates: composite cathode, perovskite cathode (w or w/o infiltrated electro-active material)
- Cathode functional layer optimization

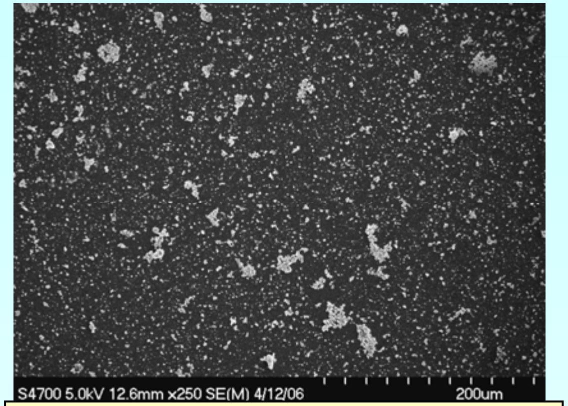
Electrical Conductivity of LSCrM



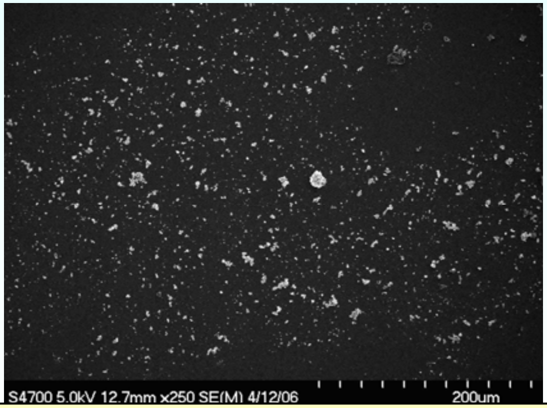
- The electrical conductivity of the LSCrM was reversible when cycled between air and 99%CO-1%CO_2 treatment at 800°C in which oxygen activity was $3.8\text{x}10^{-23}$.

Fabrication of Nano-size Cathode Powder

- To fabricate an efficient electrode and it was found from previous research that this could not be achieved if large particle size powder (about 10 mm) was used.
- To make efficient electrode, low sintering temperatures should be used to produce the smallest grain size possible.
- Therefore, the development of technology to fabricate non-agglomerated, nano-sized powder is required.
- Water based chemical preparation methods were used to prepare LSCrM system.

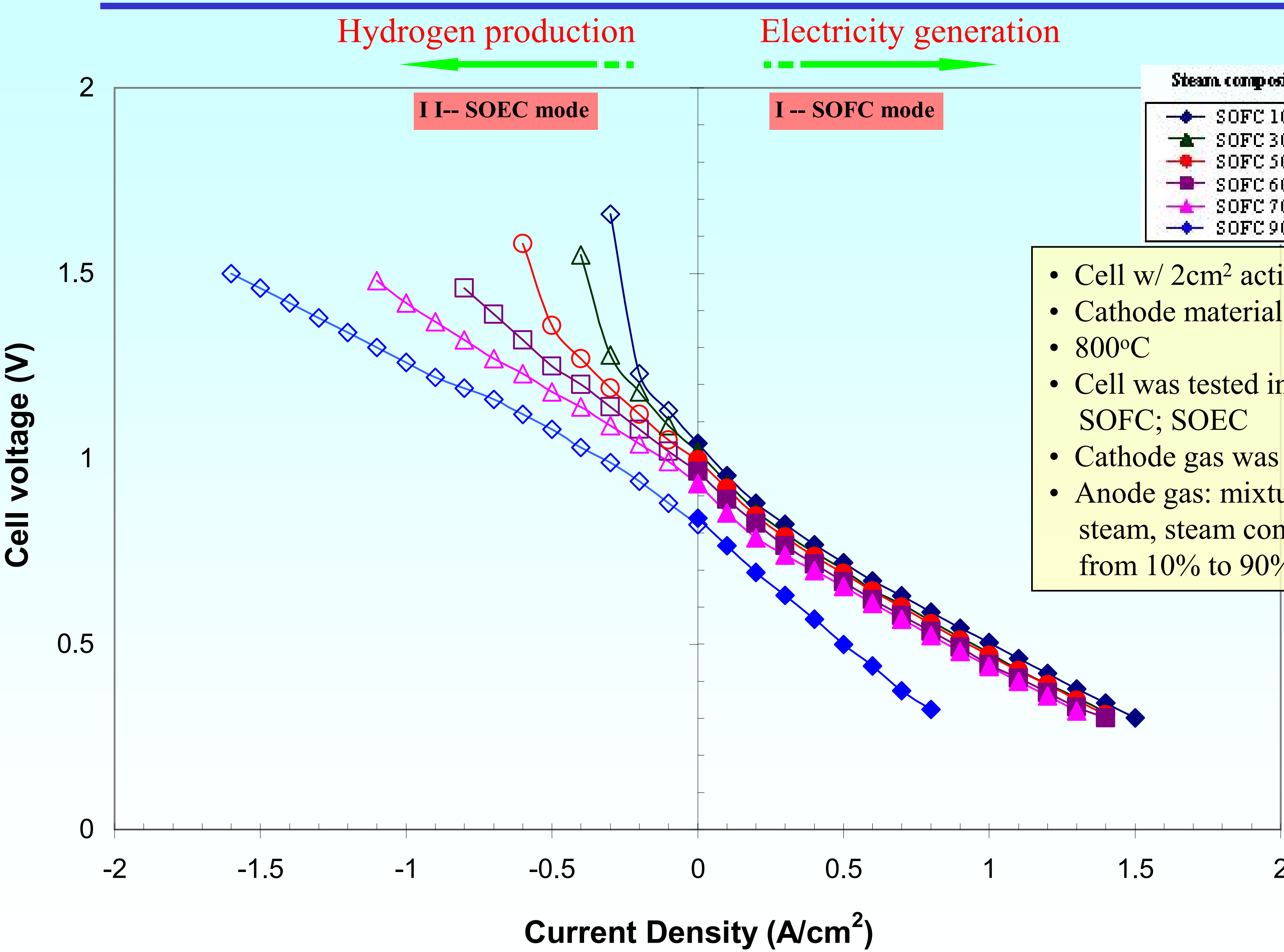


- LSCrM using ethylene glycol
- Agglomerated but well dispersed
- Large particle size ~ 20 mm



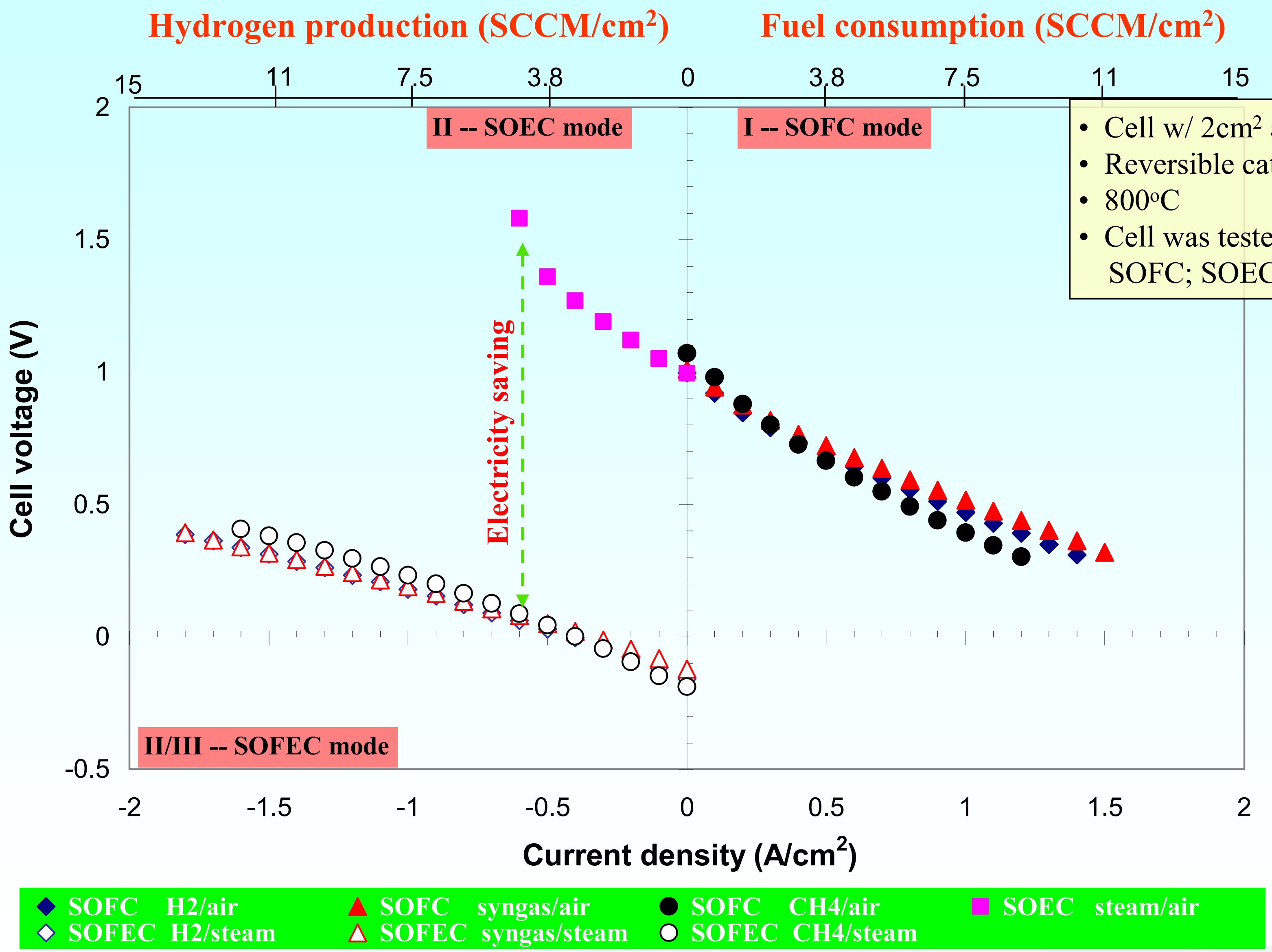
- LSCrM using glycine nitrate method
- After sonication and separation
- Agglomerated particle were sedimented
- Particles are well dispersed

Selected Cathode Evaluation in SOFC/SOEC Modes



- Cell w/ 2cm^2 active area
- Cathode material, LSCrM
- 800^{o}C
- Cell was tested in reversible mode: SOFC; SOEC
- Cathode gas was air
- Anode gas: mixture of H_2 and steam, steam concentration varied from 10% to 90%

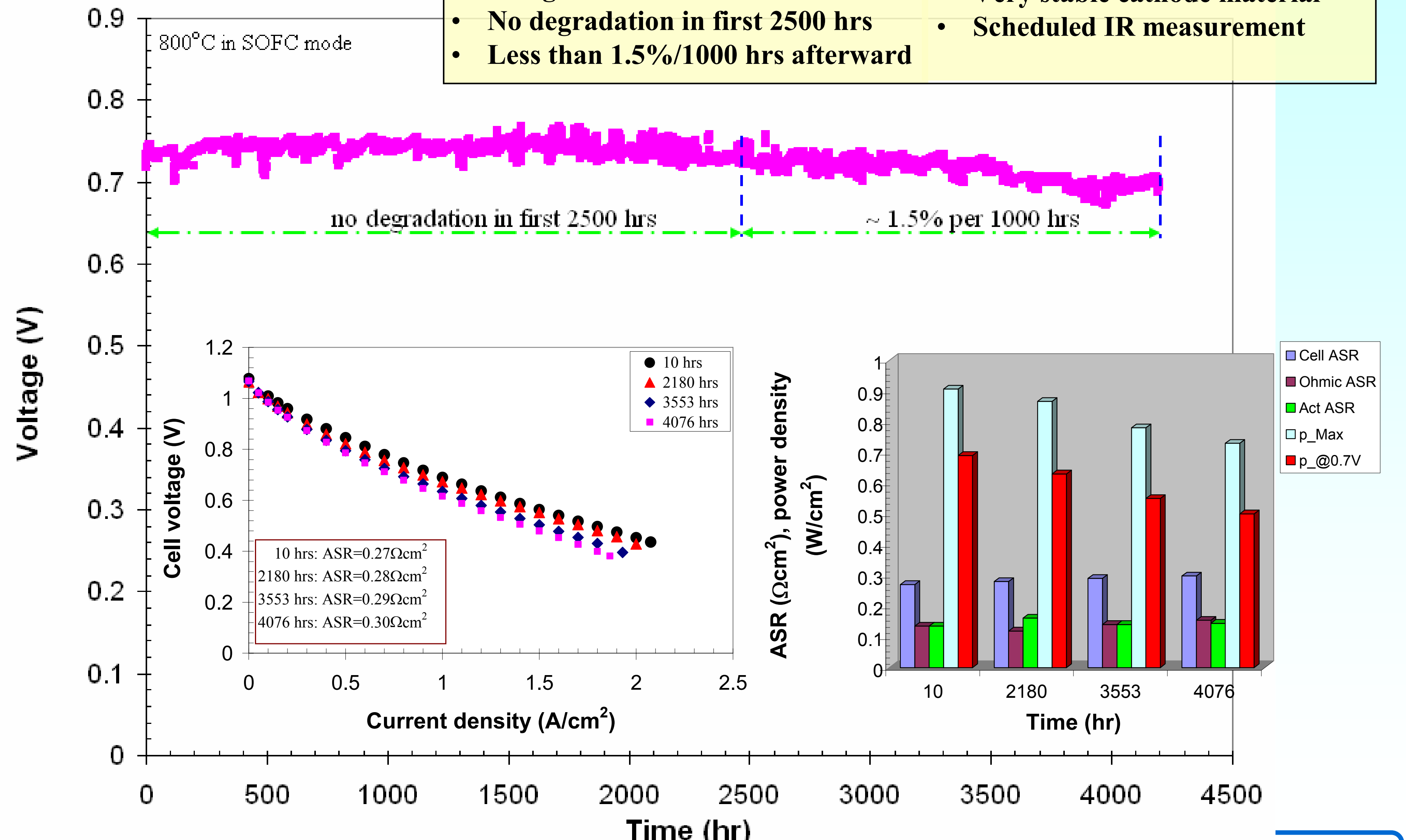
Cathode Performance in SOFC/SOEC/SOFEC Modes



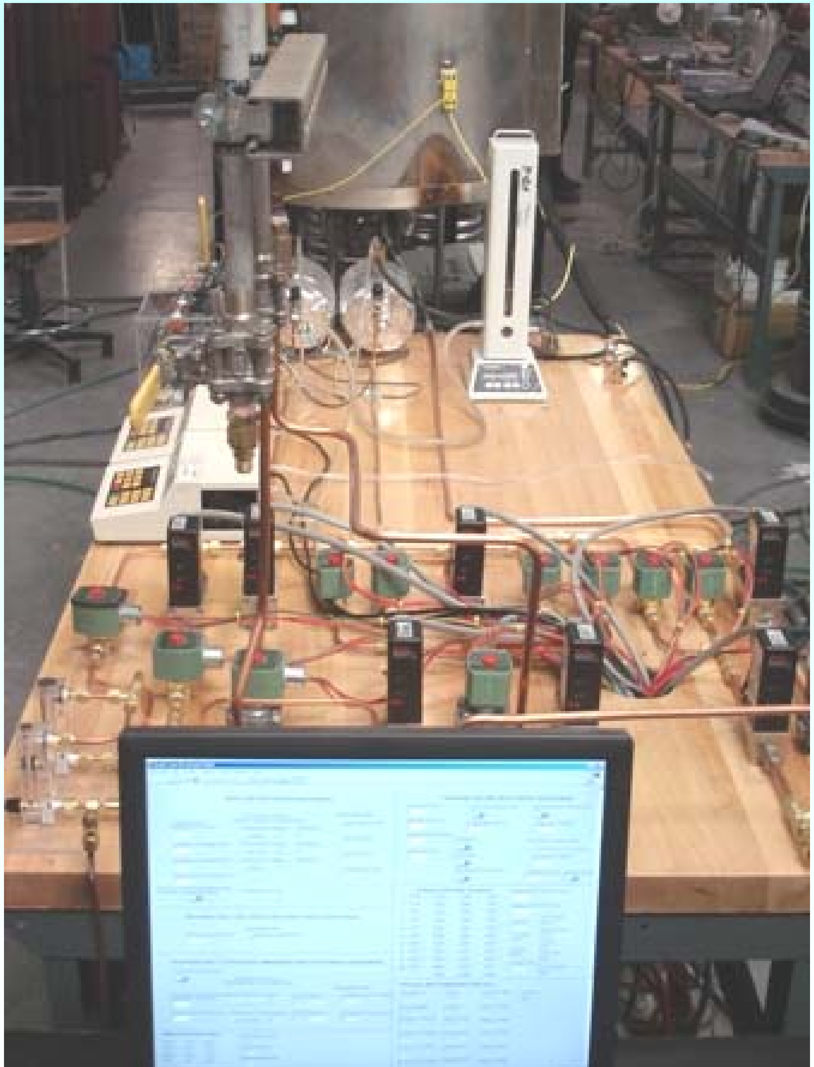
- Cell w/ 2cm² active area
- Reversible cathode, LSCrM
- 800°C
- Cell was tested in three modes: SOFC; SOEC; SOFEC

Long-Term Test Under Constant Load (0.7A/cm²)

- **Being tested more than 4500 hrs**
- **No degradation in first 2500 hrs**
- **Less than 1.5%/1000 hrs afterward**
- **Very stable cathode material**
- **Scheduled IR measurement**

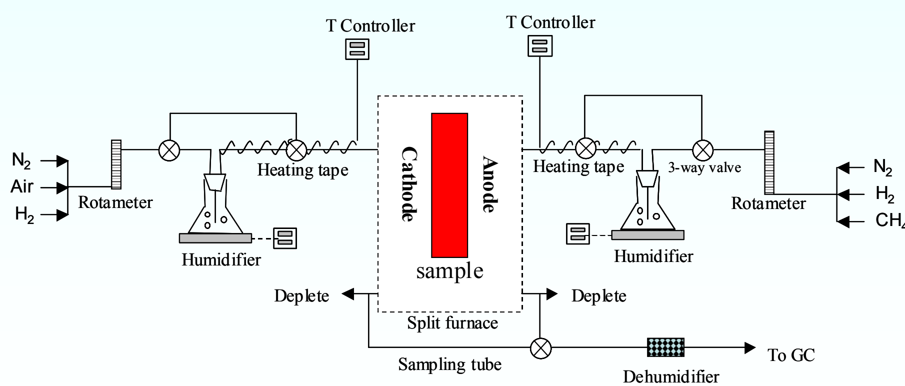


Proof-of-concept Hybrid Stack Testing

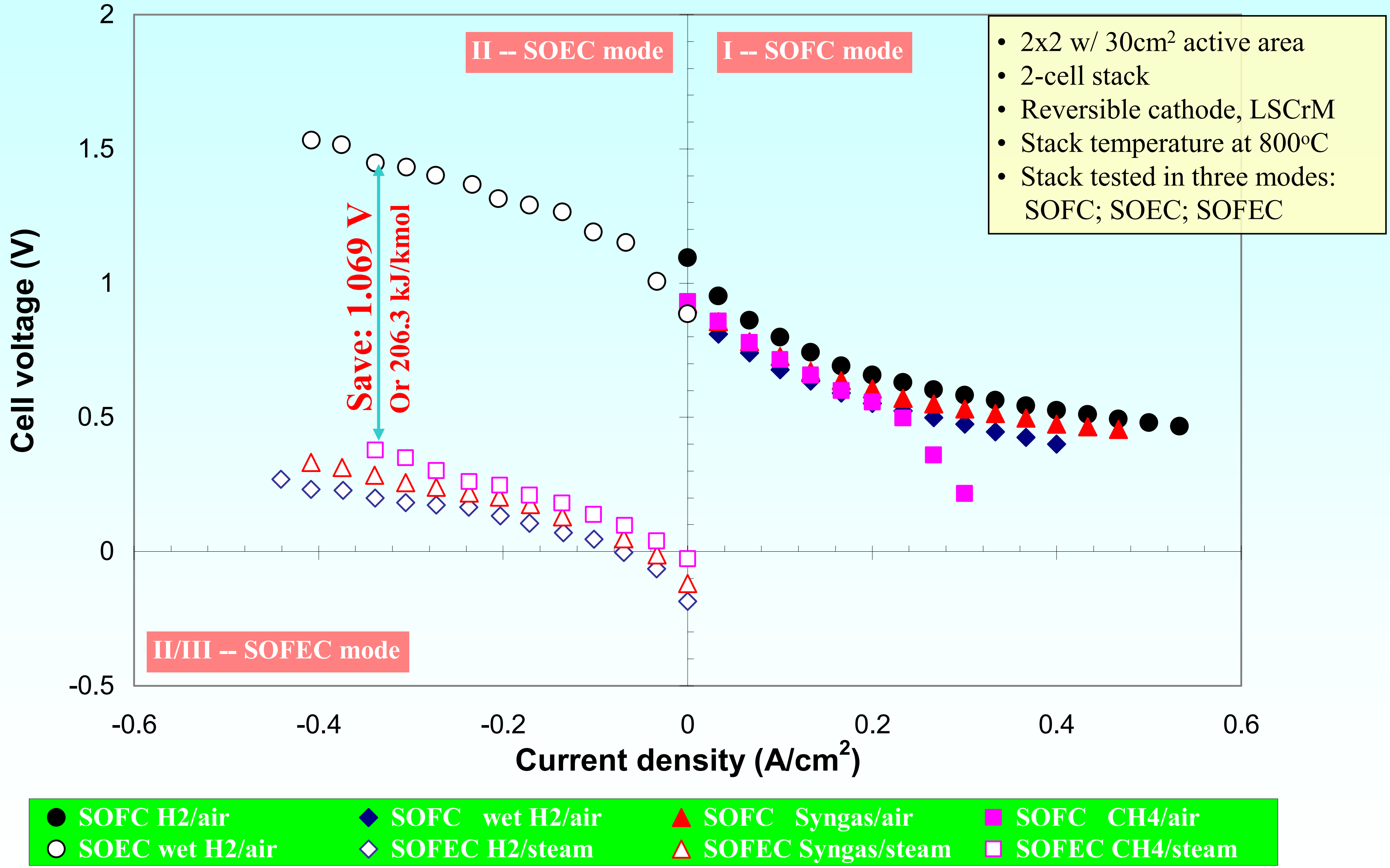


Hybrid stack testing station

- Station capable of operating in three modes: SOFC/SOEC/SOFEC
- Capable of 40+ cell stack
- Capable of hybrid stack
- Automation testing
- Self protection in case of power outage
- Stack IR evaluation
- Gas chromatograph analysis
- Hydrogen production measurement

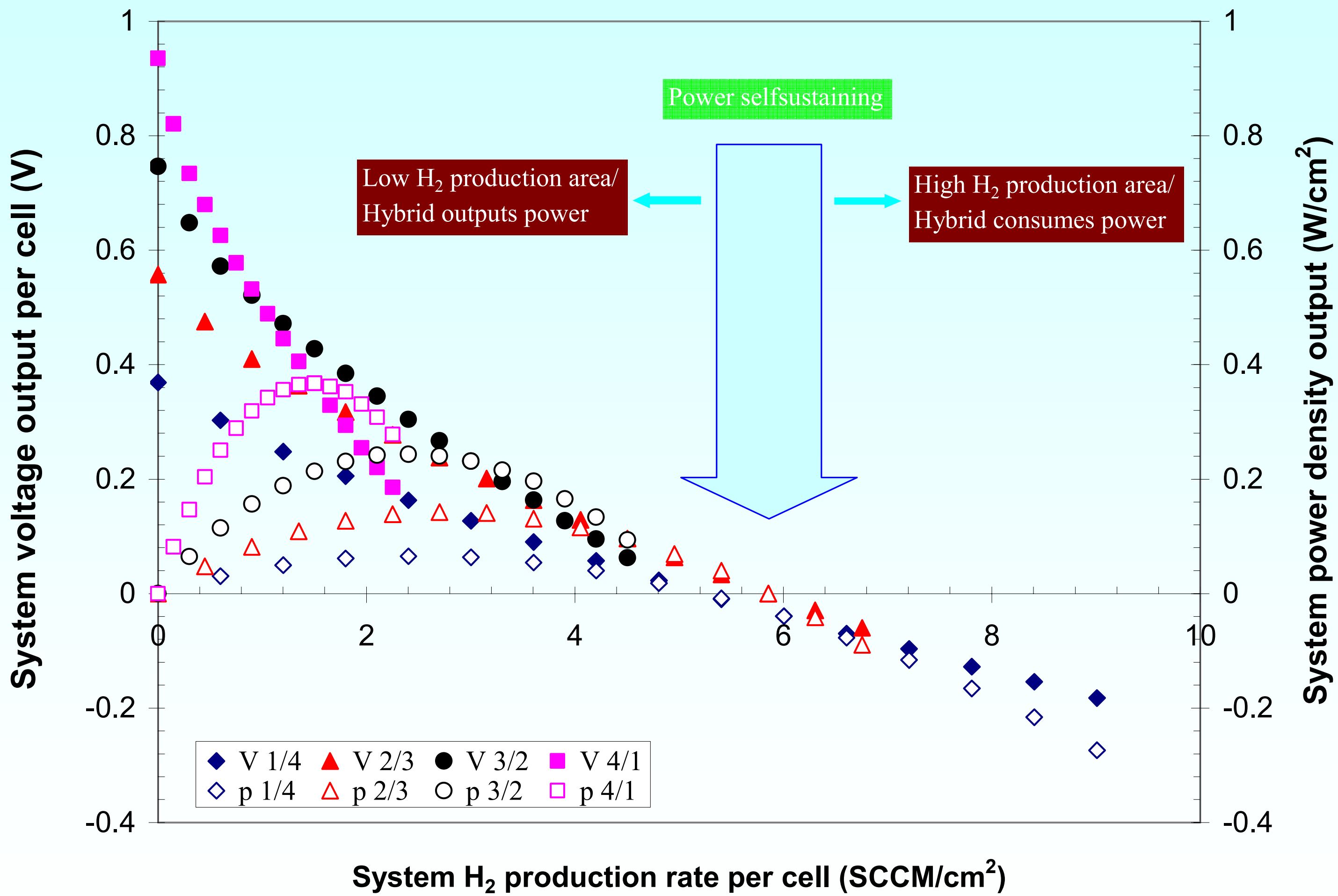


Stack Performance in SOFC/SOEC/SOFEC Modes



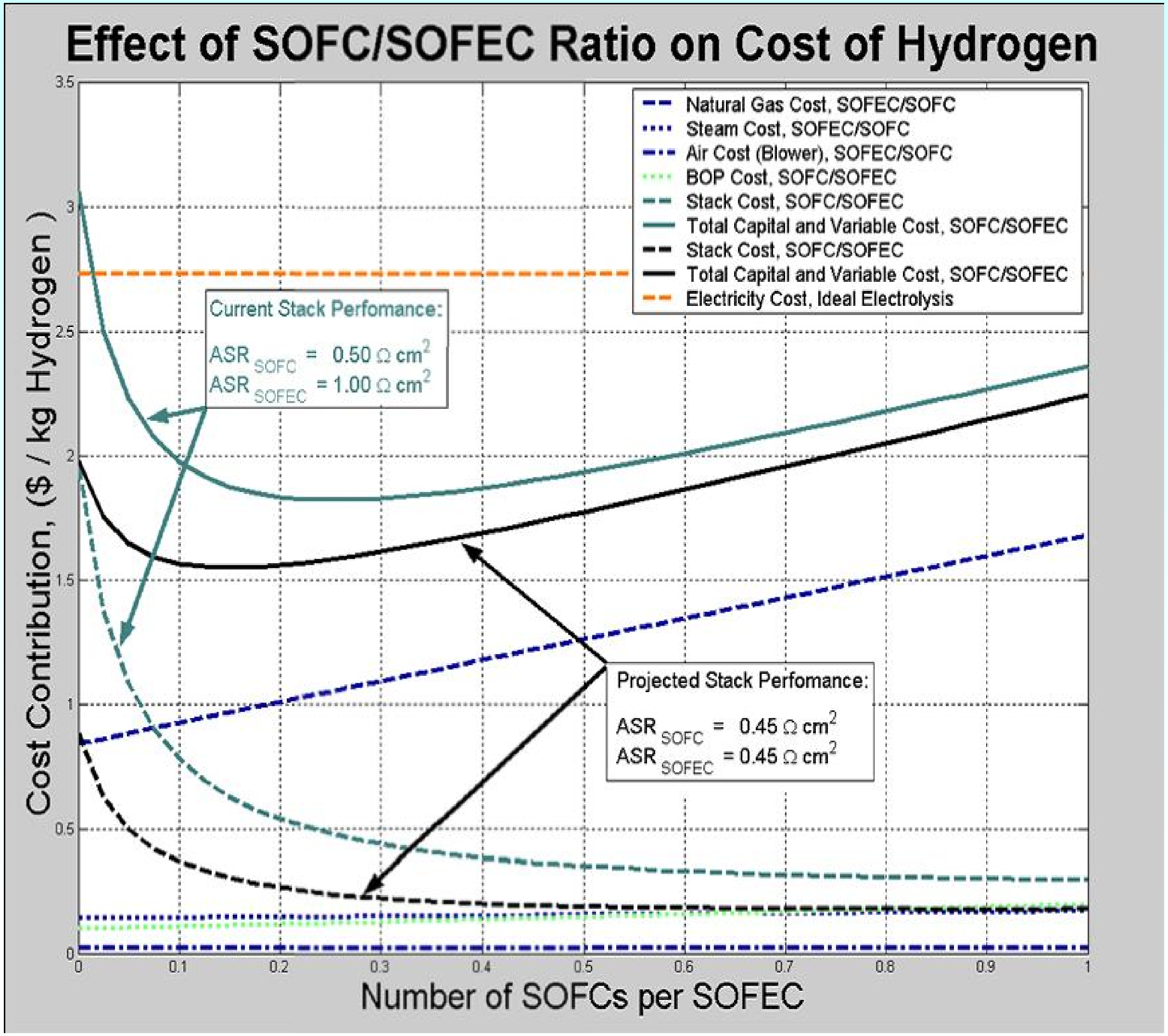
SOFC-SOFEC Hybrid Study

Numbers of SOFCs vs SOFECs Affect on Hybrid Outputs



- Hybrid comprises No. of SOFECs/SOFCs
- Three regions are recognized
- Low hydrogen production region with power output
- Power self-sustaining region for medium H_2 production
- High H_2 production region requiring for external power source

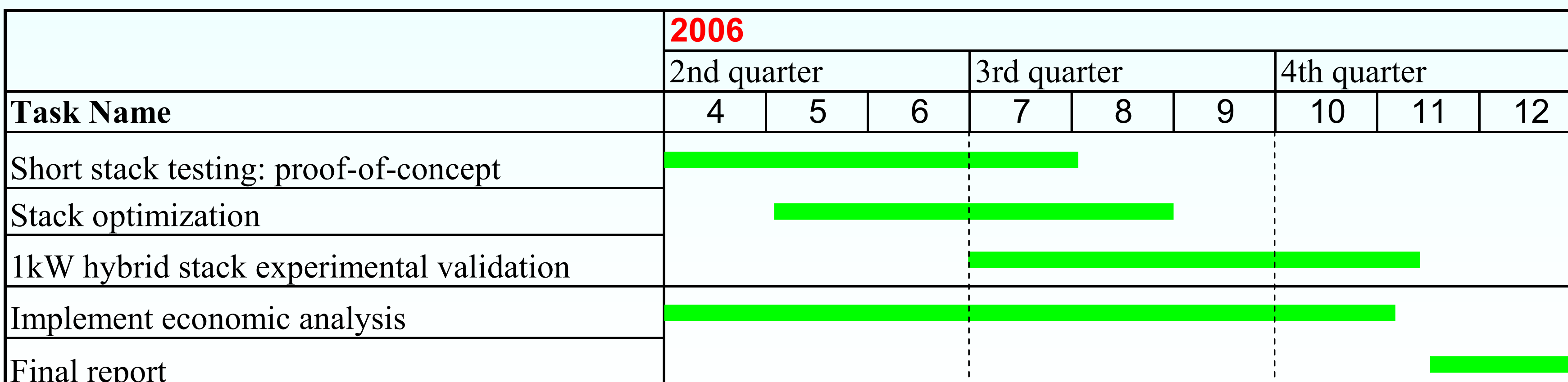
Economic Analysis



- Increased cell ASR increases required cell area and stack cost.
- Ideal SOFC:SOFEC ratio dependent on cell performance.
- Combined feedstock and capital cost less then electricity cost for water electrolysis even with current stack performance levels.

Future Work

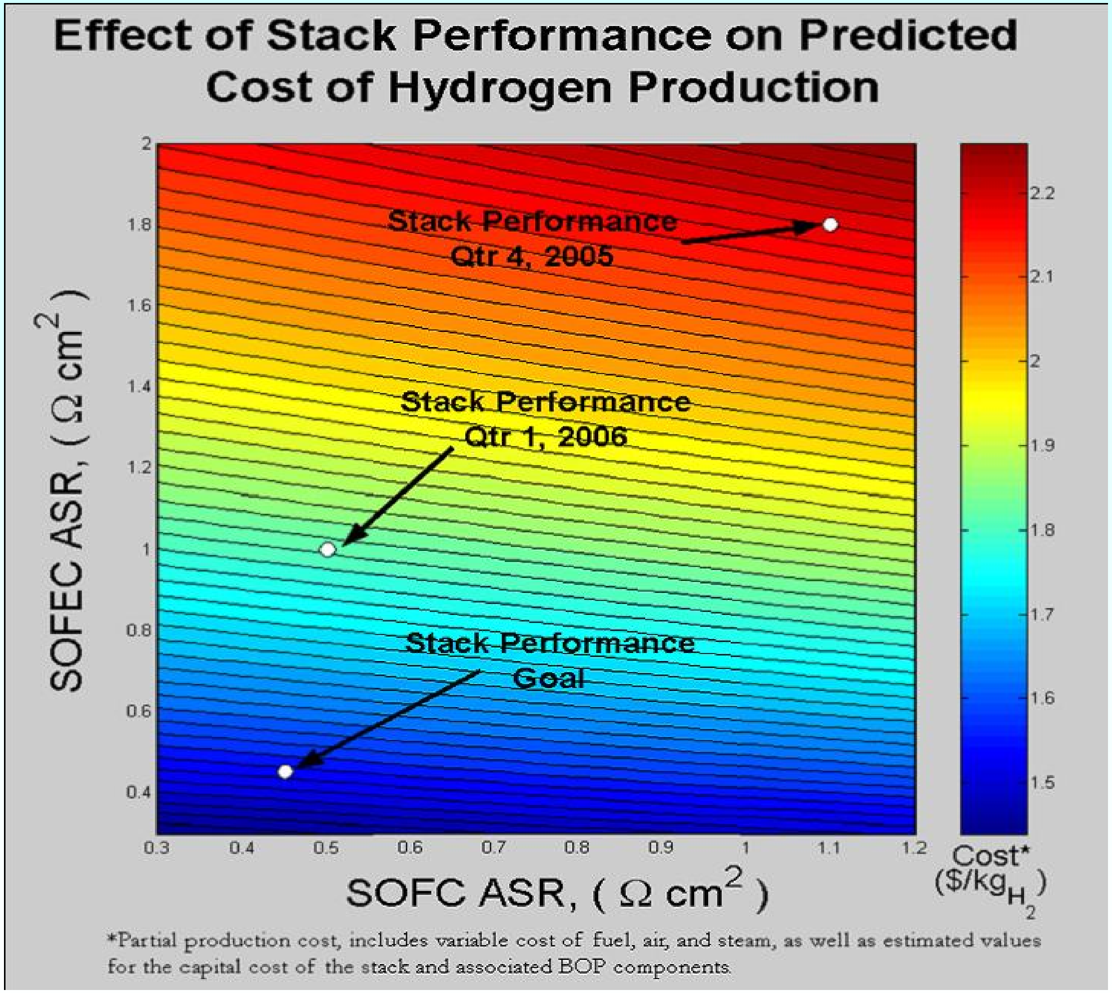
- Remainder of 2006
  - Further implementation of quality assurance in cell/stack fabrication
  - Short stack testing – proof-of-concept
  - Stack optimization
  - Demonstrate hydrogen generation from a hybrid stack worth of 1kW of electricity
  - Implementation of economic analysis



Project Summary

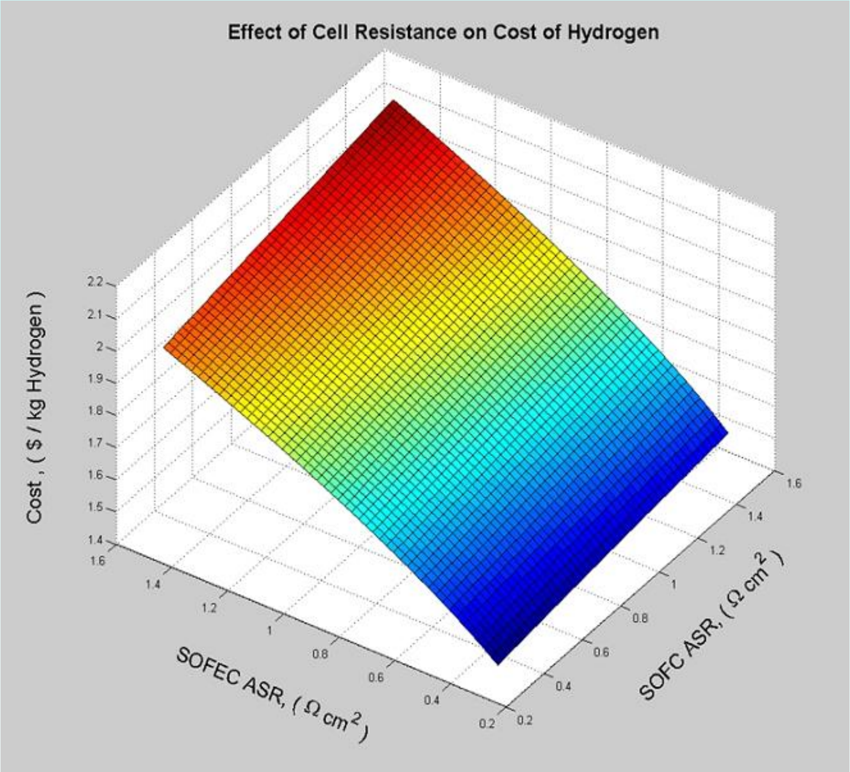
Relevance:	Investigate alternative approaches to produce hydrogen at reduced cost of electricity
Approach:	Develop a SOFC-SOFEC hybrid system to generate hydrogen and electricity directly from fuels
Technologies Accomplishments and Progresses:	Developed/optimized anode-support solid oxide cells; developed/characterized electro-catalytically and chemically stable cathode materials; characterized the selected materials in SOFC/SOEC/SOFEC modes; designed/fabricated hybrid stack
Proposed Future Research:	Proof-of-concept 1kW hybrid stack; implement experimental investigation and economic analysis; optimize the hybrid system for various applications, including hydrogen refueling station.

Responses to Previous Year Reviewers' Comments



- "The project would benefit from defining a target-driven path for achieving cost competitive hydrogen/electricity"
  - Preliminary economic modeling has yielded a method for relating cell performance to predicted hydrogen production cost.
  - A more detailed analysis is in process to include all relevant cost factors.

Responses to Previous Year Reviewers' Comments



- "Integration of the combined functions, power generation and hydrogen production, in a single SO stack has, in similar projects, resulted in poor performance of both functions."
  - SOFEC performance is not compromised by the selected materials set.
  - Performance in SOFC mode is lower than that of non-reversible SOFC materials, but effect on production cost is minimal.
  - Future economic analysis will evaluate the costs and benefits of reversible SOFC cells in a co-production scenario.

- "A process analysis and well-to-electricity/hydrogen analysis is definitely needed. The thermal efficiency of the process needs to be determined."
  - A process analysis was added in the task.
  - Detailed system modeling is underway.
  - Overall production efficiency shall be computed in accordance with the DOE H2A guidelines for forecourt scale hydrogen production.

Publications and Presentations

1. A. V. Virkar and G. Tao, Chemically assisted electrolysis using reversible solid oxide fuel cells, 209th ECS meeting, May 7-12, 2006, Denver, CO

2. Y. Sin, V. Petrovsky, and H. Anderson, Redox stable electrodes for hydrogen producing solid oxide electrolyzer, 209th ECS meeting, May 7-12, 2006, Denver, CO