DOE Hydrogen Program

Development of a Novel Efficient Solid-Oxide Hybrid for Co-generation of Hydrogen and Electricity Using Nearby Resources for Local Application

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Project ID#: PDP 14

Overview

Timeline

- Project started: 02/10/2006
- Project ends: 07/31/2008
- Percent completed: 40%

Budget

- Total budget funding
  - DOE $2,480k
  - Contractor $ 620k
- Funding received in FY06
  - $ 452k
- Funding for FY07
  - $ 1,000k

Barriers

Hydrogen generation by water electrolysis

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

Partners

- University of Alaska Fairbanks – anode supports fracture mechanism and modeling residual stresses (S. Bandopadhyay; N. Thangamani)
- University of Missouri-Rolla – cathode & seal materials development (H. Anderson; R. Brow; Y. Sin; and S. Reis)
- University of Utah – interconnects development (A. Virkar)

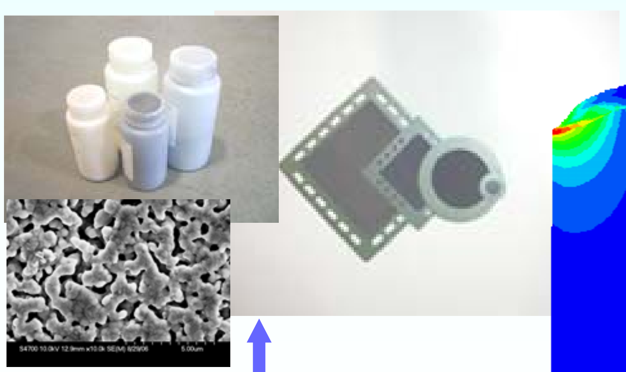
Objective

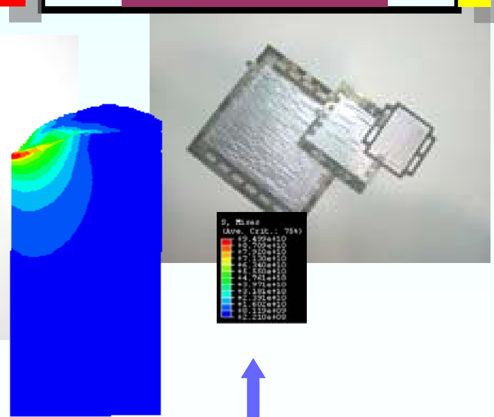
Overall Objective	• To develop a low-cost and highly efficient 5 kW SOFC-SOFEC hybrid co-generating both electricity and hydrogen to achieve the cost target < \$3.00/gge when modeled in a 1000 gge/day hydrogen production. • The project focuses on materials R&D, stack design & fabrication, and system design & verification
2006	• SOFC-SOFEC cell & stack development – Materials development (electrodes & seals) – Stack design & development – Cell fabrication – Proof-of-concept hybrid stack verification
2007	• 5 kW SOFC-SOFEC hybrid system development – Materials development and application (electrodes & seals) – Hybrid system design – BOP components design & development – Fabrication – Hydrogen generation cost analysis

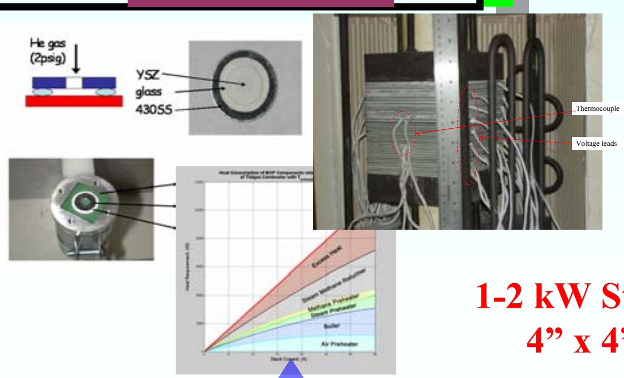
Approach

Materials Development	Cell / Stack /System Design	Experimental Verification
A. Ca materials Dev.	A. Stack design	A. Short stacks in dif. modes
B. An optimization	B. 5kW system design	B. 1 kW hybrid stack
C. Electrolyte optimization	C. BOP design/dev.	C. BOP Manufact.& Eva.
D. Catalyst studies	D. Stresses analyses	D. 5 kW sys. development
E. Seals development	E. Seals application	E. 5kW hybrid system Exp. Evaluation
F. Fabrication Q.A.	F. Economic analysis	
40% complete	**40% complete**	**30% complete**

Success





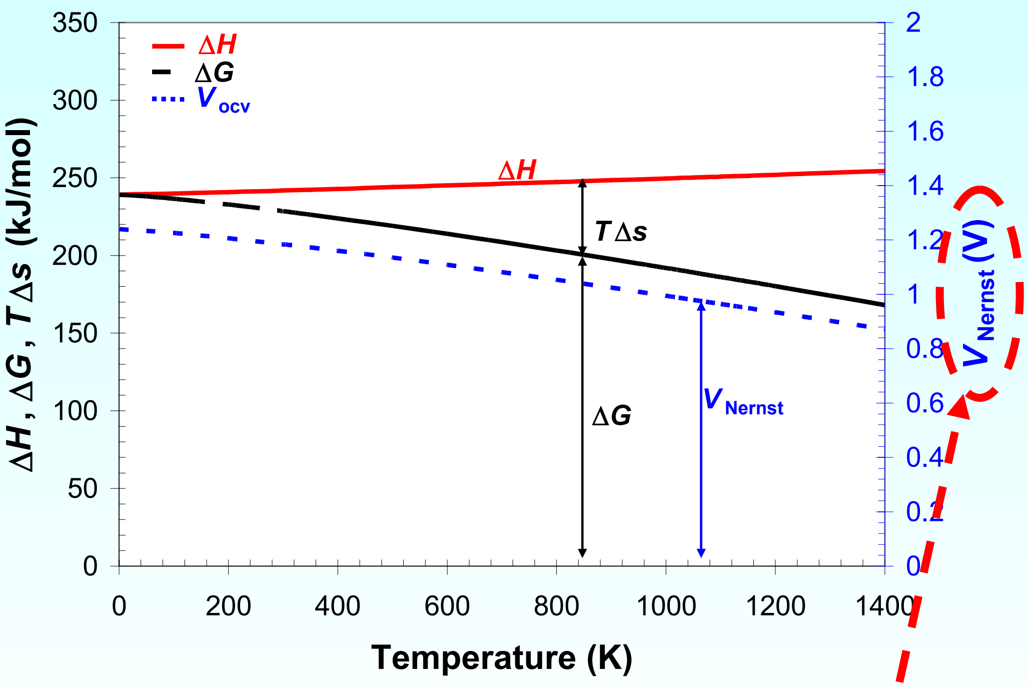


1-2 kW Stack 4” x 4”

MSRI, UMR | **MSRI, UAF, UMR, UU** | **MSRI, UU, UMR**

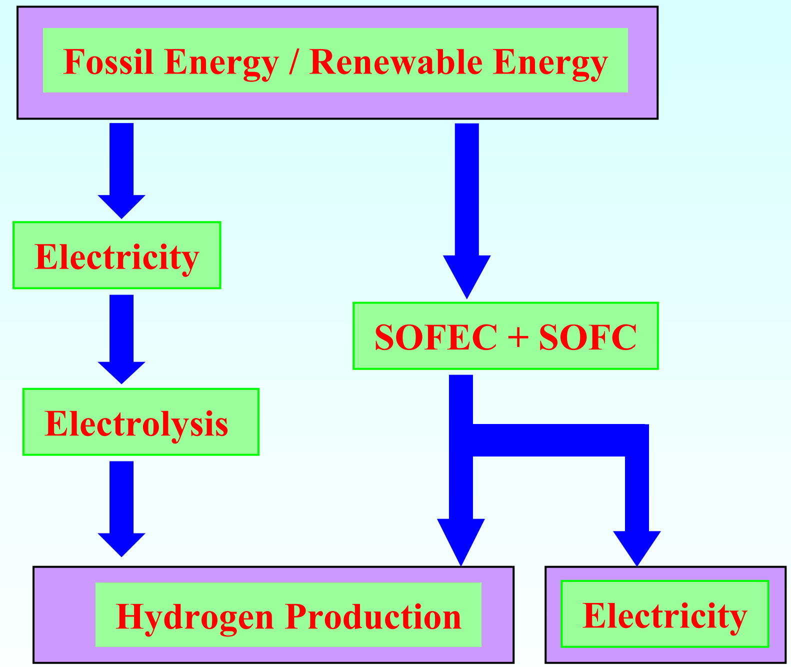
Background

A Solid Oxide Fuel-Assisted 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



Electricity from Grid

Unique process



Co-generation

CH_4-assisted SOFEC Reaction

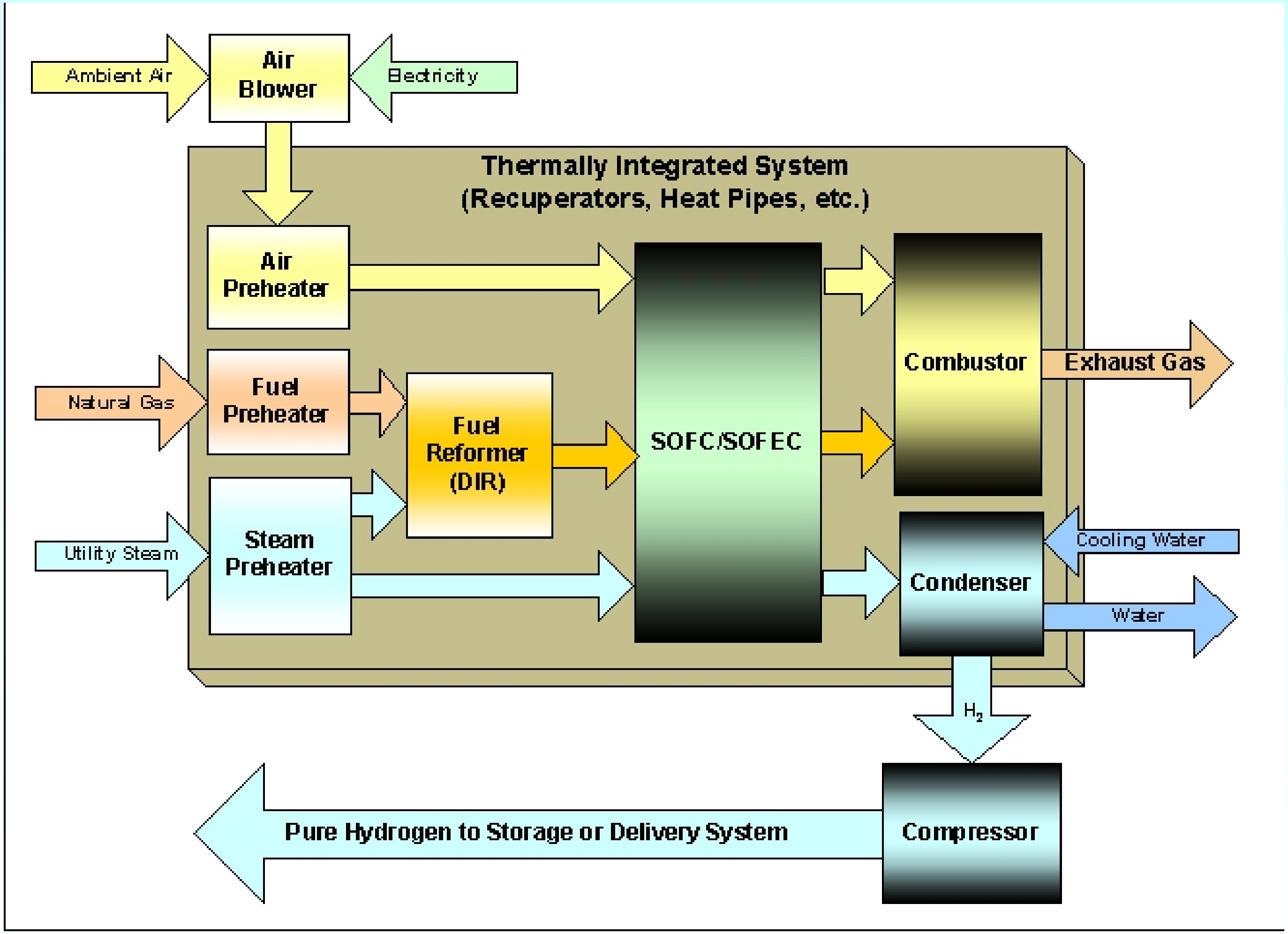
$4H_2O + 8e' \rightarrow 4H_2 + 4O^{2-}$ — Electrochemical Process at cathode

$4O^{2-} + CH_4 \rightarrow CO_2 + 2H_2O + 8e'$ — at anode

$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

Pure H_2 formed. No need for H_2 separation membranes. Lower electricity requirement.

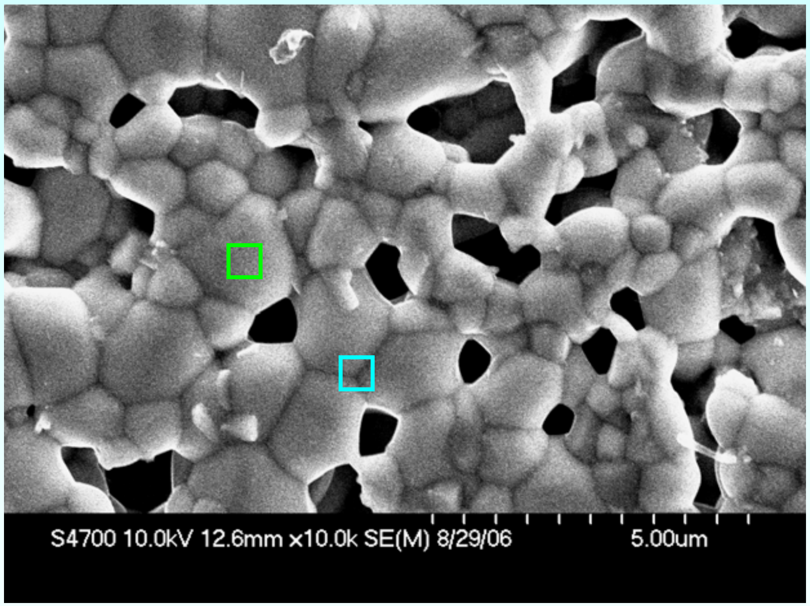
Concept of Hybrid SOFC-SOFEC Integral System



- 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

SOFEC Cathode Materials Development

Chemical analysis of LST/LSCM



Element	Wt %	At %
O K	15.29	49.09
SrL	10.82	6.35
TiK	15.89	17.05
LaL	47.83	17.69
CrK	5.96	5.89
MnK	4.21	3.93
Total	100	100

Element	Wt %	At %
O K	24.16	63.03
SrL	11.06	5.27
TiK	13.68	11.92
LaL	41.97	12.61
CrK	5.35	4.29
MnK	3.8	2.89
Total	100	100

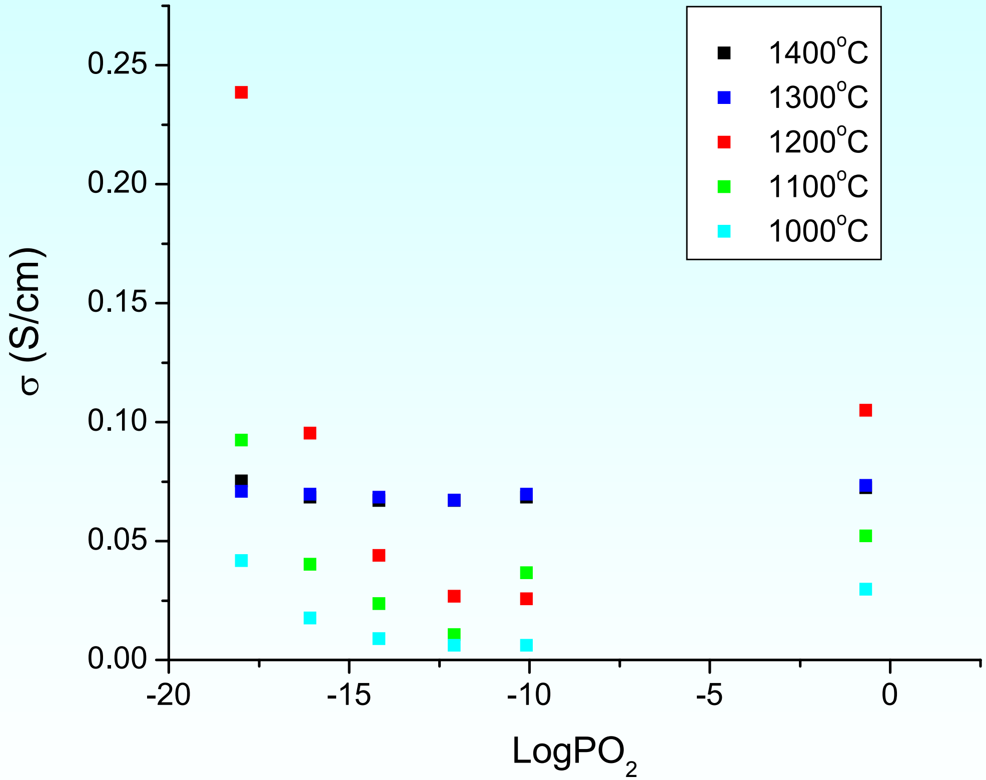
Wt% of $La_{0.8}Sr_{0.2}TiO_{3-\delta}$ and $La_{0.8}Sr_{0.2}Cr_{0.5}Mn_{0.5}O_{3-\delta}$

		La	Sr	Ti	Cr	Mn	O
LST(0.8/0.2/1)	Wt/mol	138.9	87.6	47.9			16
	Wt%	49.5	8	21.2			21.3
LSCM (0.8/0.2/0.5/0.5)	Wt/mol	138.9	87.6		52	55	16
	Wt%	48.3	7.6		11.3	12	20.8

- The LST/LSCM sintered at 1200°C has no significant variation of composition between grain and grain boundary
- The active diffusion process appears to be started between 1100 and 1200°C

SOFEC Cathode Materials Development

Conductivity investigation of LST/LSCM

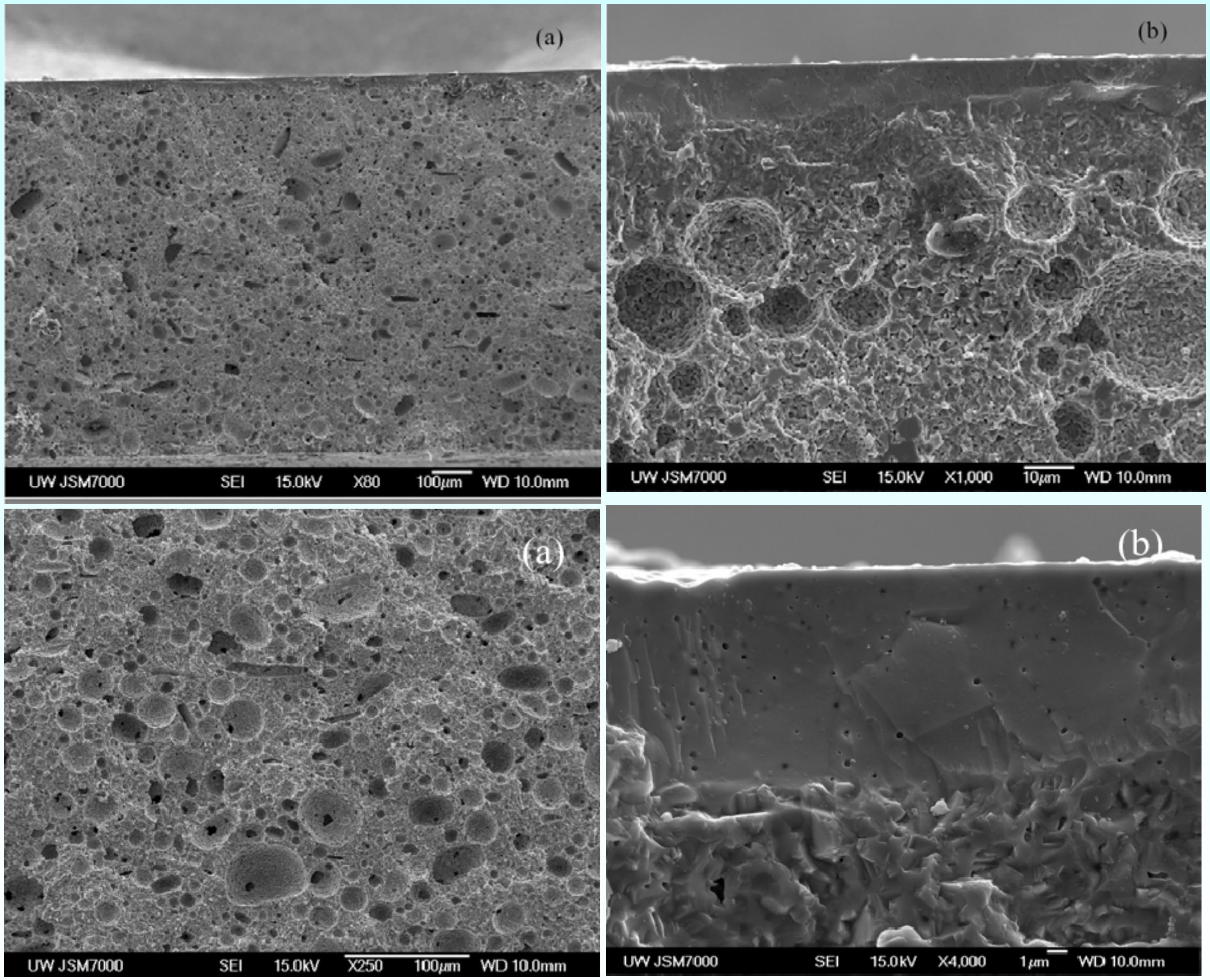


- The higher conductivity at 1200°C is due to
  (1) the higher density
  (2) early stage of inter-diffusion process
  (3) LST and LSCM co-exists without losing their original material properties

- The total conductivity behavior of the LST/LSCM is dominated by the low conductivity of the LST

Measured at 900°C

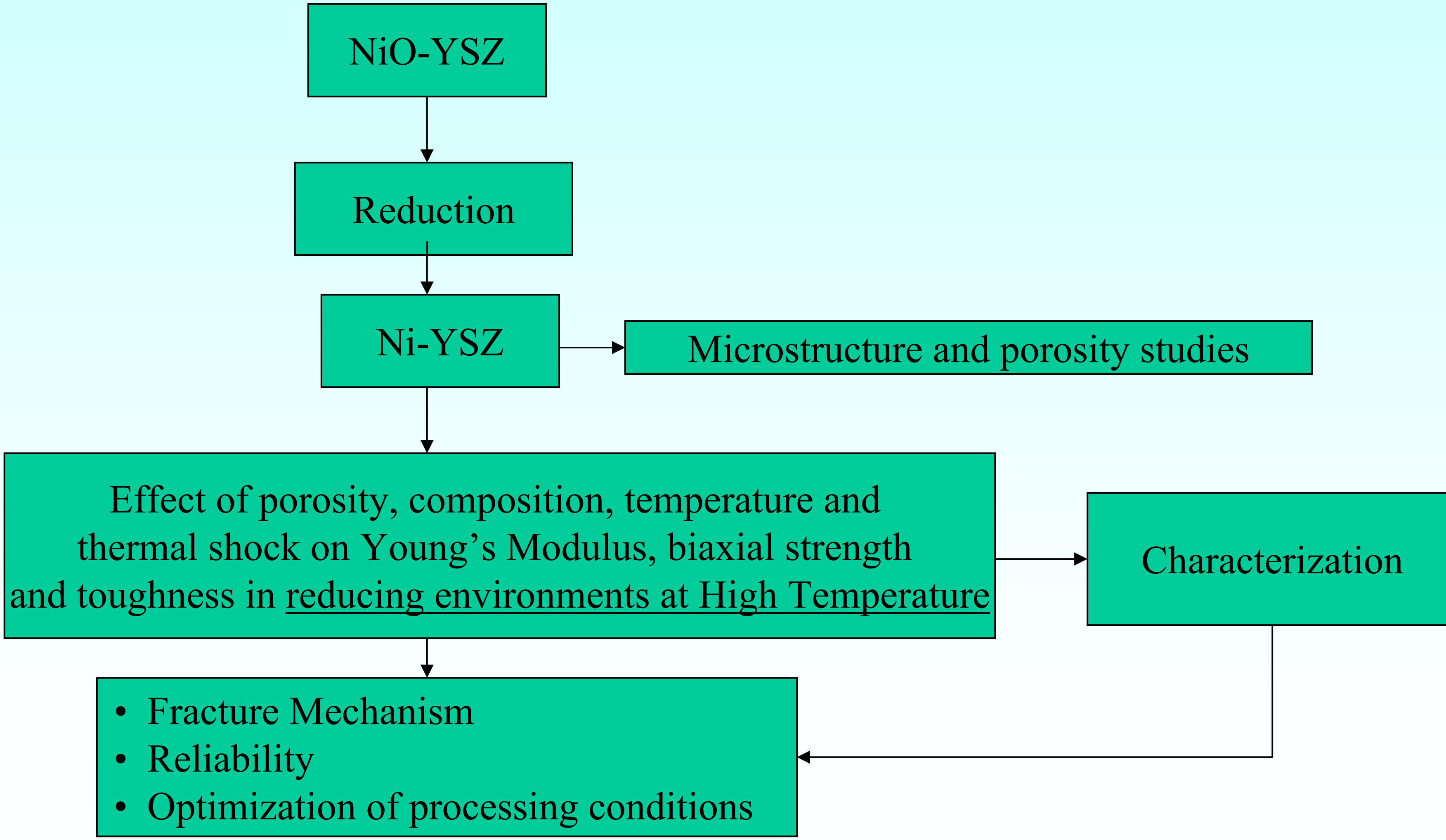
SOFC-SOFEC Anode Substrate Development



- Estimated effects of temperature and load on hardness and fracture toughness of the rectangular and button cells
- Investigated microstructure of the membranes
- Investigated Young's modulus of the membranes at RT
- Studied thermal expansion
- Initiated modeling of the indentation stress distribution
- Designed and fabricated high temperature Equibiaxial flexural strength fixture
- Fabricated an equipment for measuring high temperature modulus using Impulse Excitation technique (IET)

SOFC-SOFEC Anode Substrate Development

Effects of residual/chemical/applied stresses on Mechanical Integrity

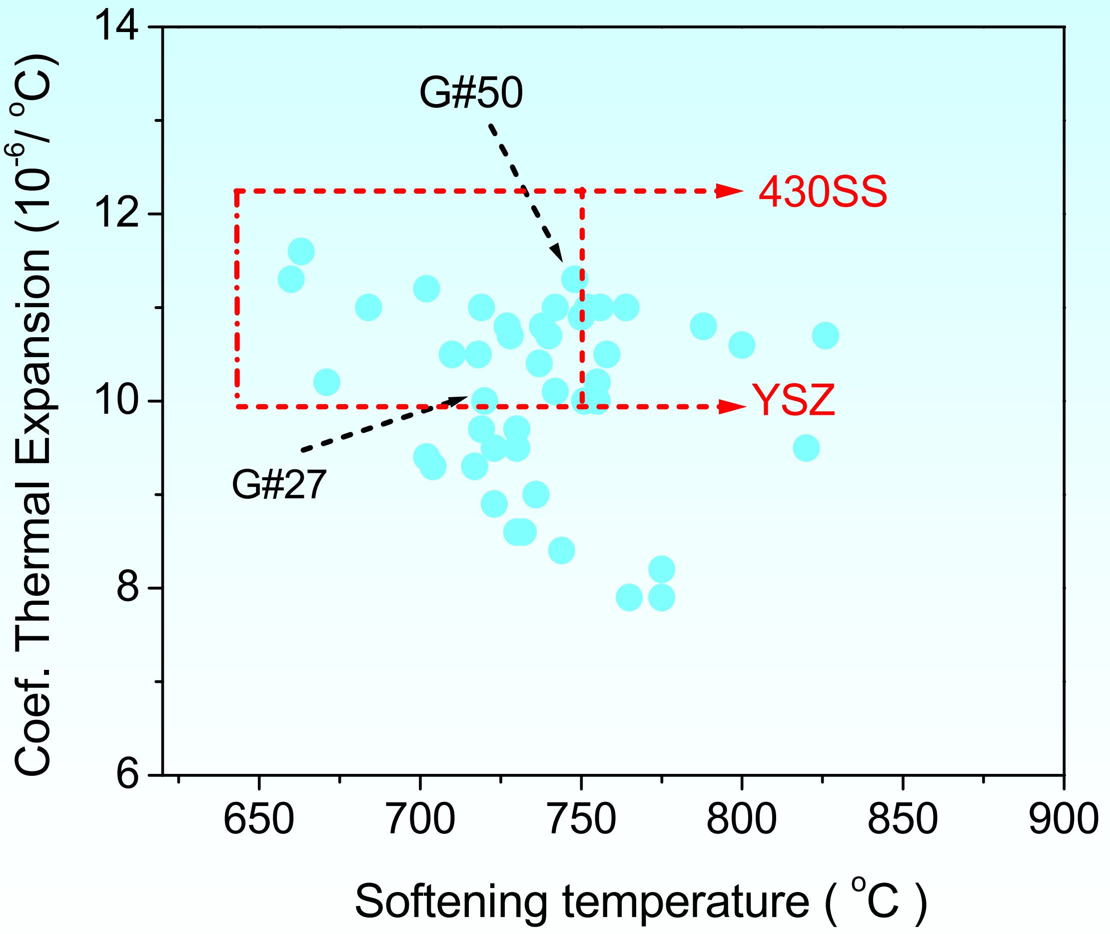


Hermetic Seals Development

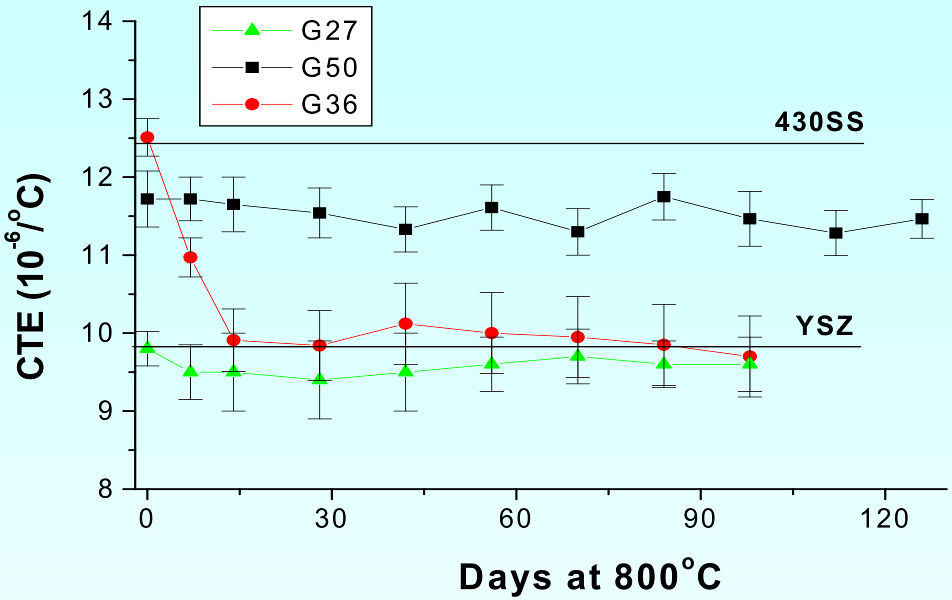
More than 60 'invert' glass compositions have been evaluated

"Invert" silicate:
Glasses with
SiO_2<45 mole%

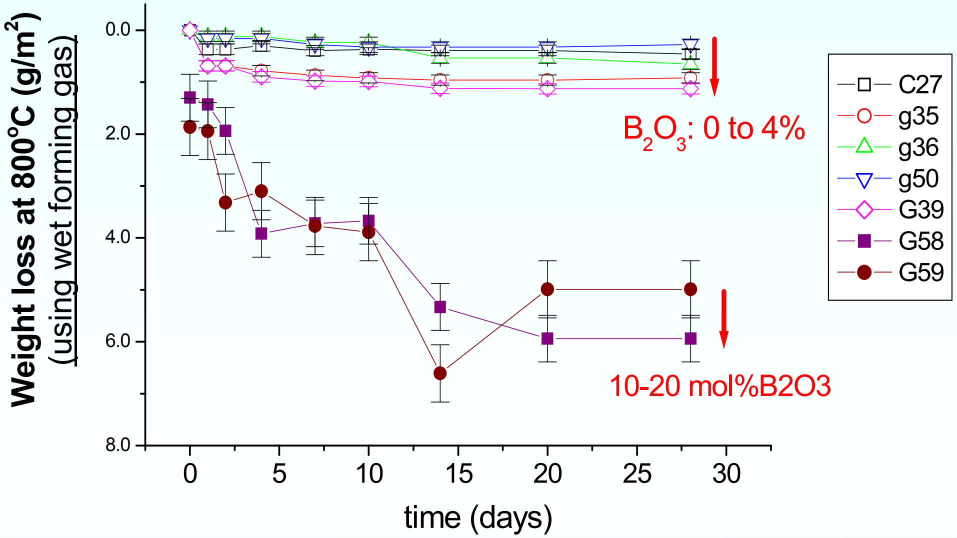
Compositions based on:
Pyrosilicate
and
Orthosilicate



Hermetic Seals Development

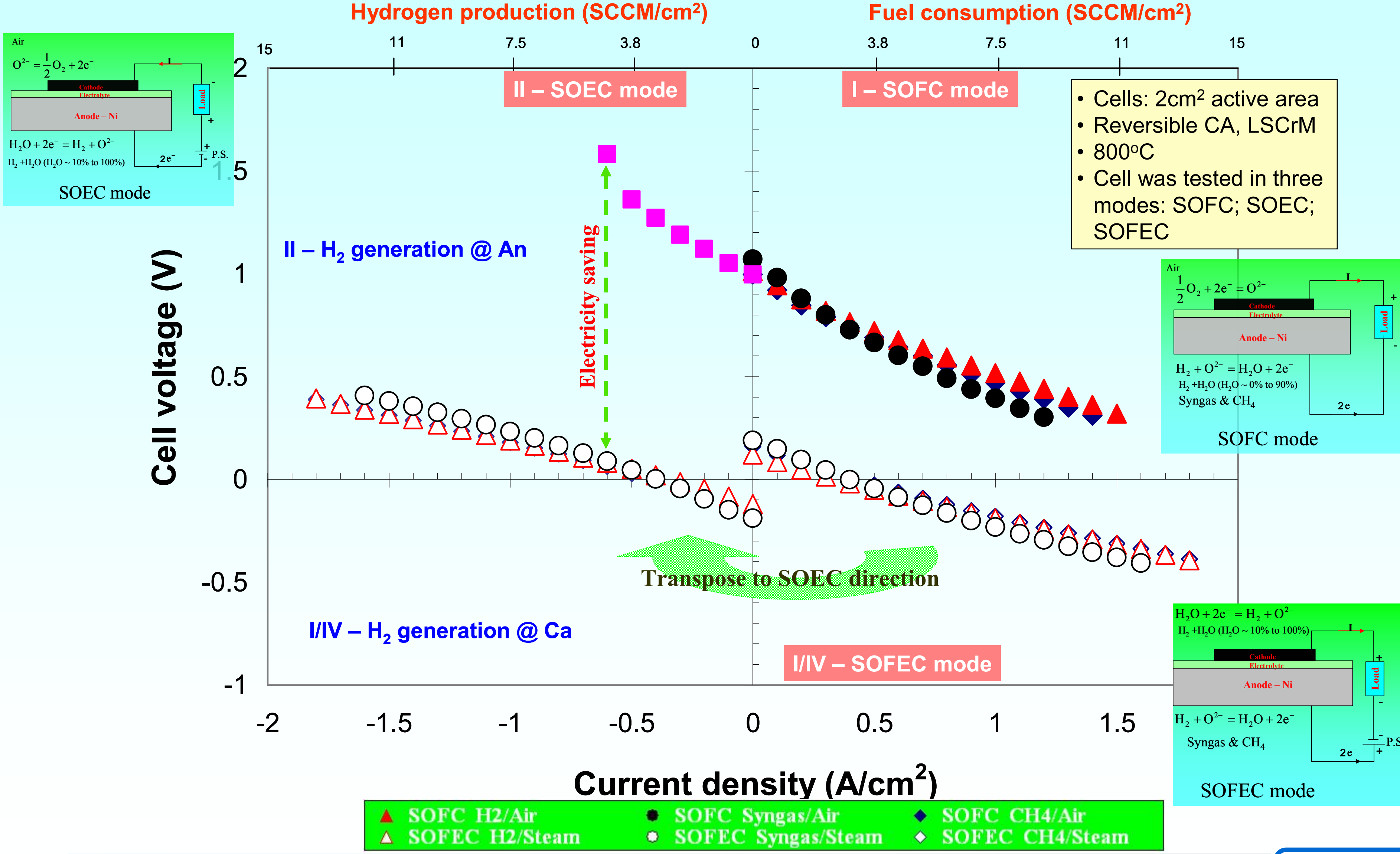


Thermomechanical compatibility is a significant property design target

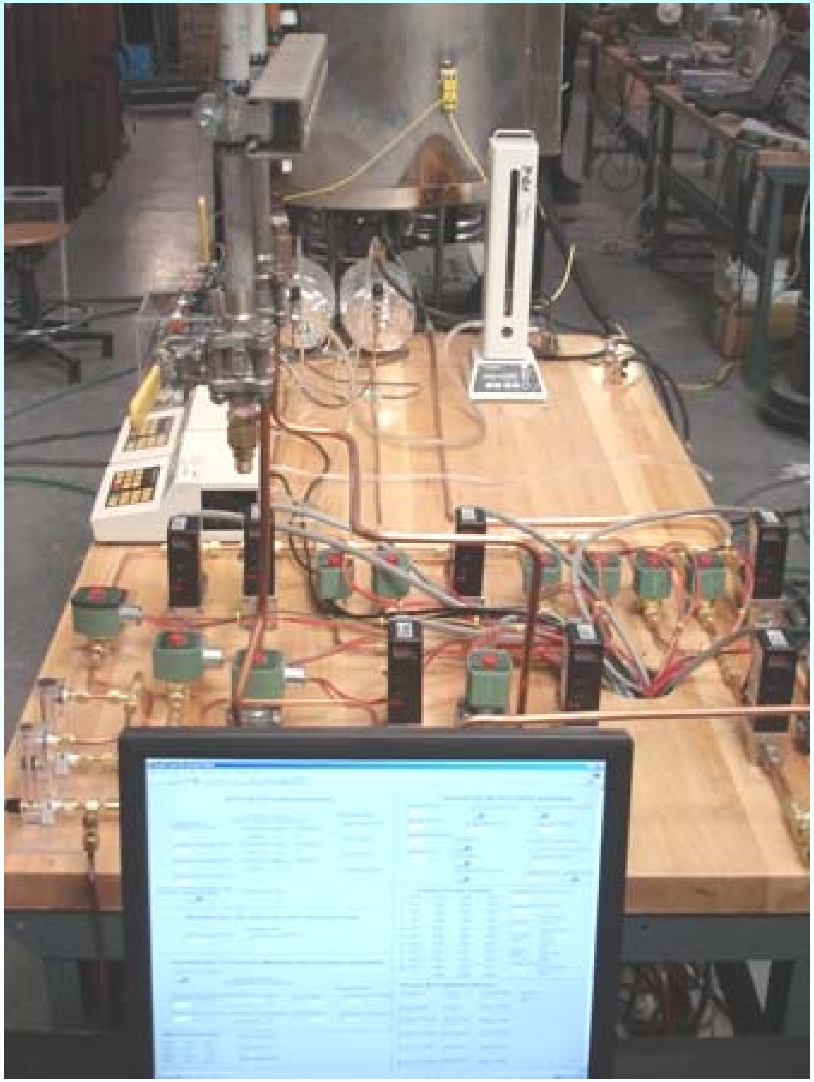


Thermochemical stability depends on glass composition

Cathode Characteristics in SOFC/SOEC/SOFEC Modes

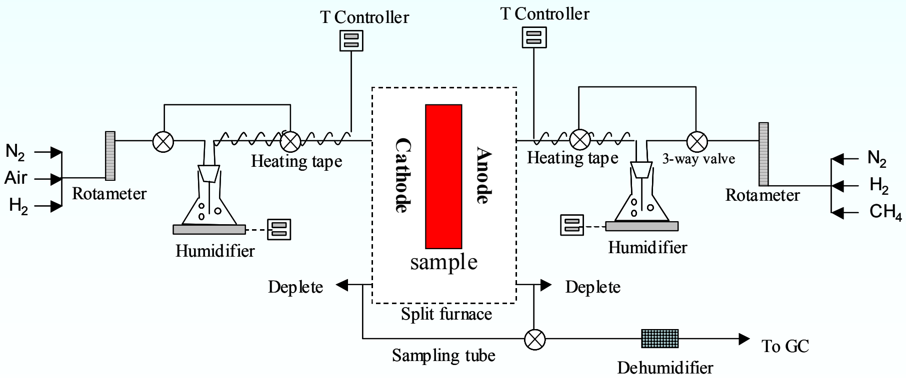


Proof-of-concept Hybrid Stack Testing

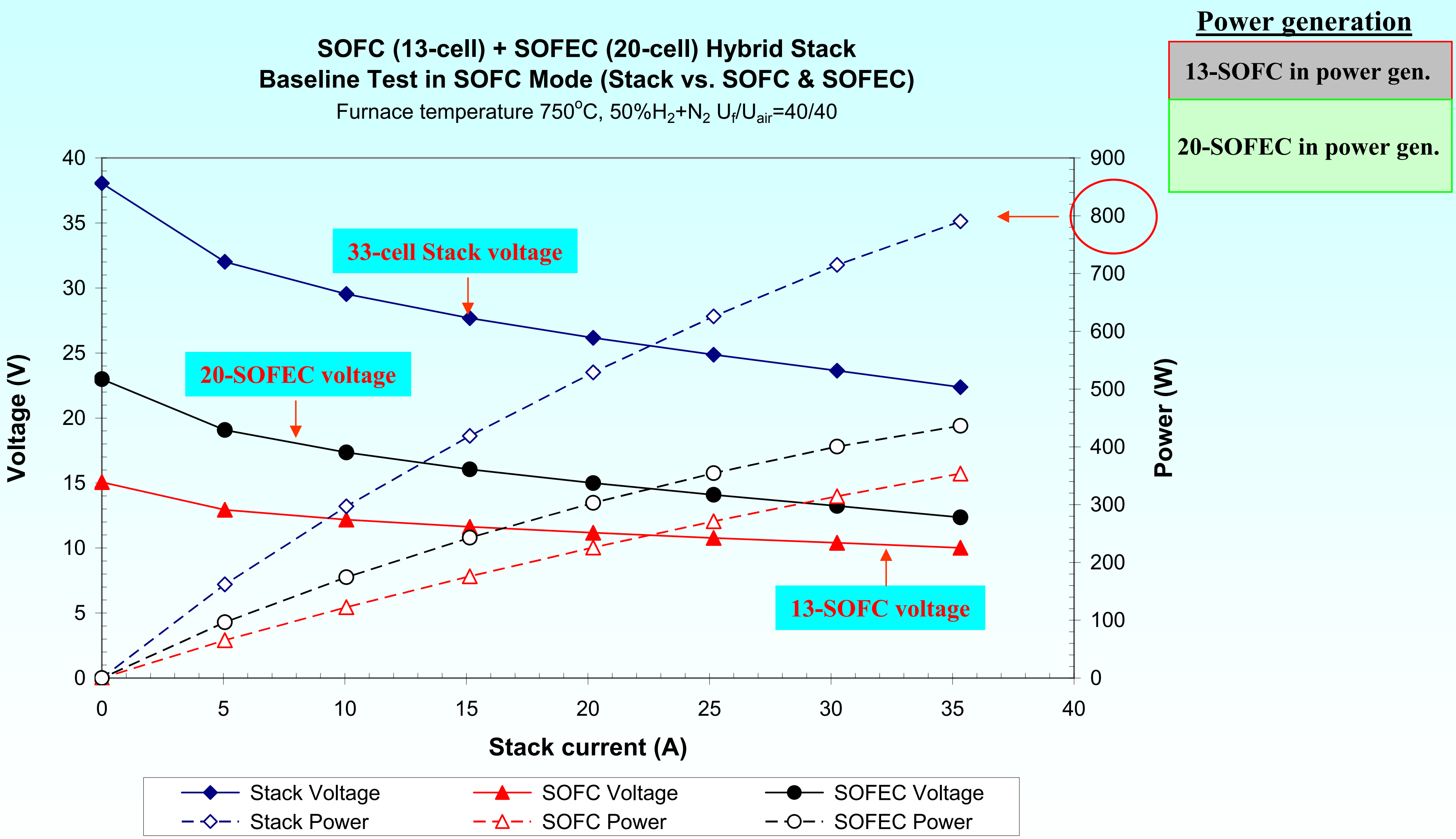


Hybrid stack testing station

- 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

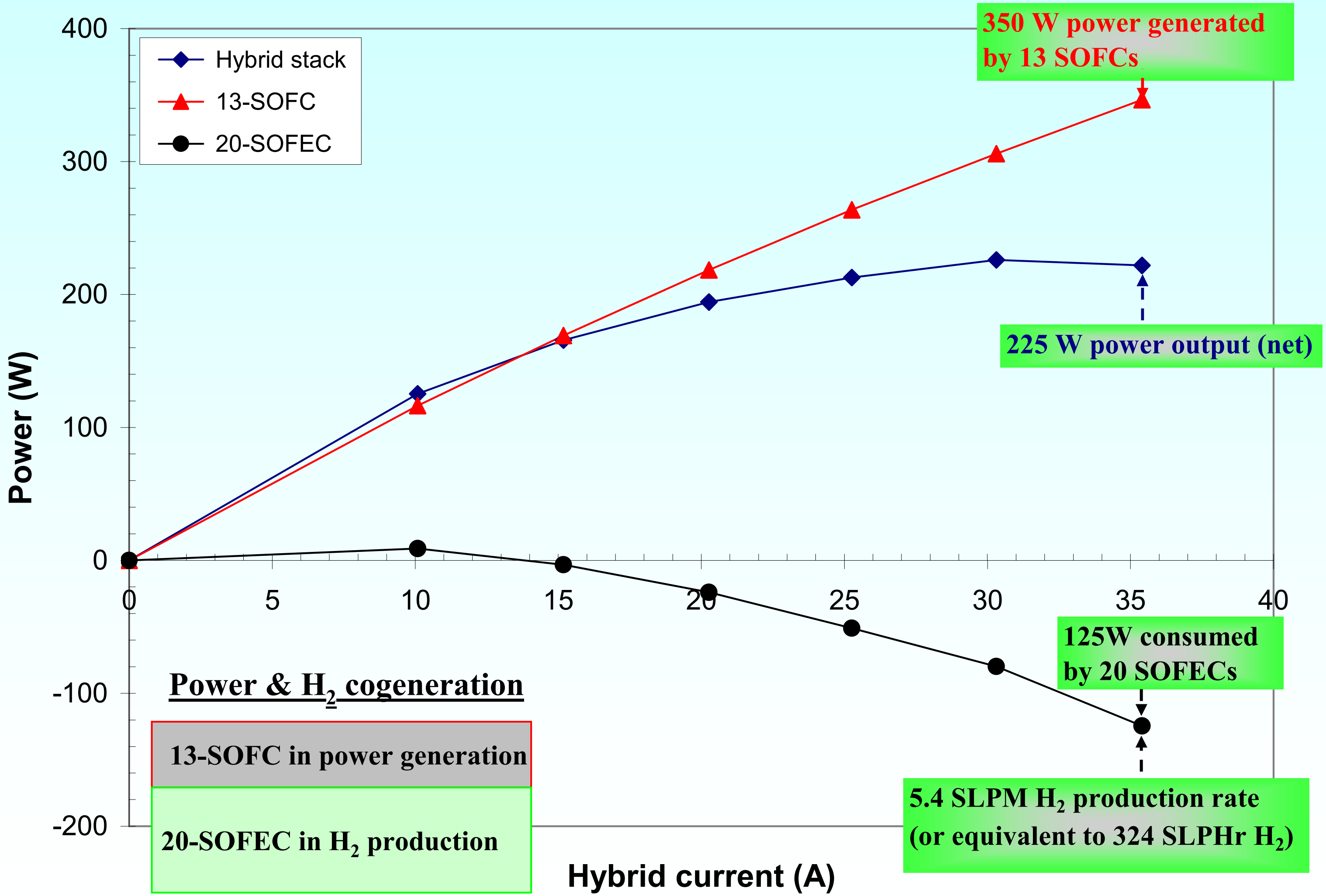


kW Class SOFC-SOFEC Hybrid Stack Power Generation



kW Class SOFC-SOFEC Hybrid Power & H_2 Cogeneration

Power – Current curve: Hybrid vs. 13-SOFC vs. 20-SOFEC



Hybrid stack

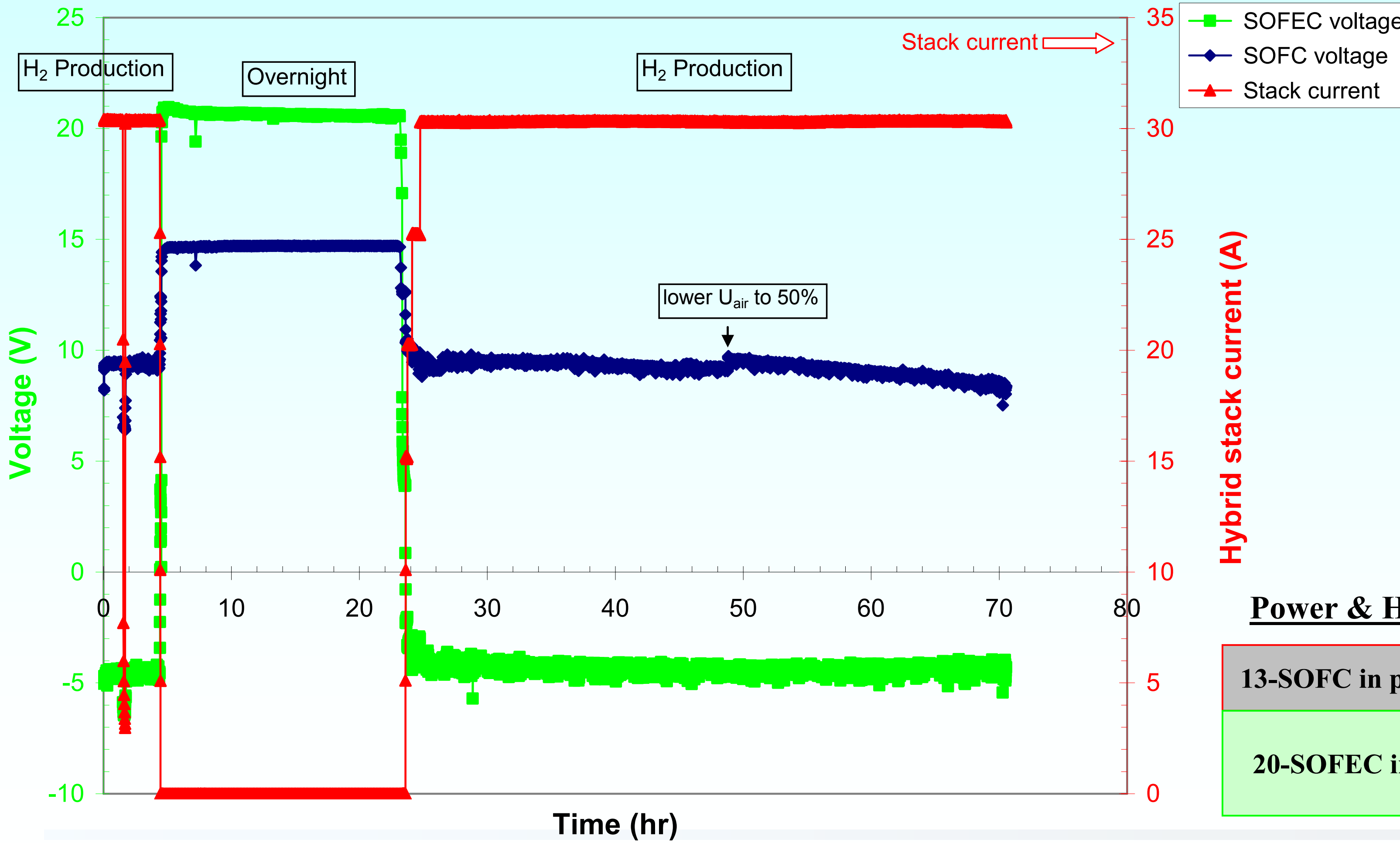
- 13 SOFCs
- 20 SOFECs
- T = 770^{o}C
- Anode: Syngas
- Cathode 1: air
- Cathode 2: steam
- U_f = 40%
- U_{air} = 40%
- U_{steam} = 40%

kW Class SOFC-SOFEC Hybrid Power & H_2 Cogeneration

H_2 Production Rate: 270 standard liters per hour, AND, Net Power Output: 130 Watts

SOFC (13-cell) + SOFEC (20-cell) Hybrid Stack for a Continuous H_2 Production

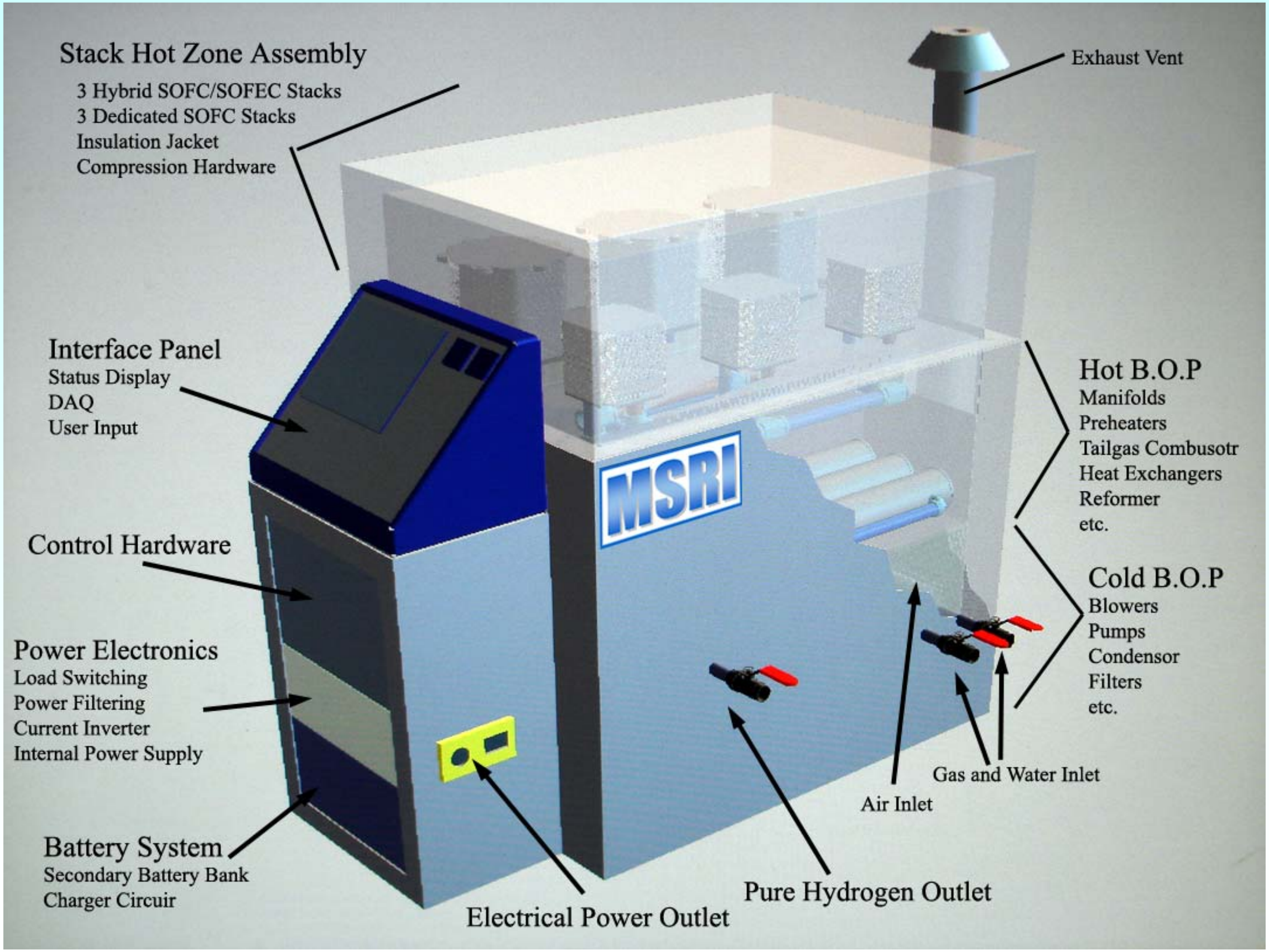
Temperature @ 780°C, AN: Syngas; CA1: air; CA2: H_2O; $U_f/U_{air}/U_{steam}$=50/60/40 --> 50/50/40



Power & H_2 cogeneration

13-SOFC in power generation
20-SOFEC in H_2 production

5 kW Hybrid System Design

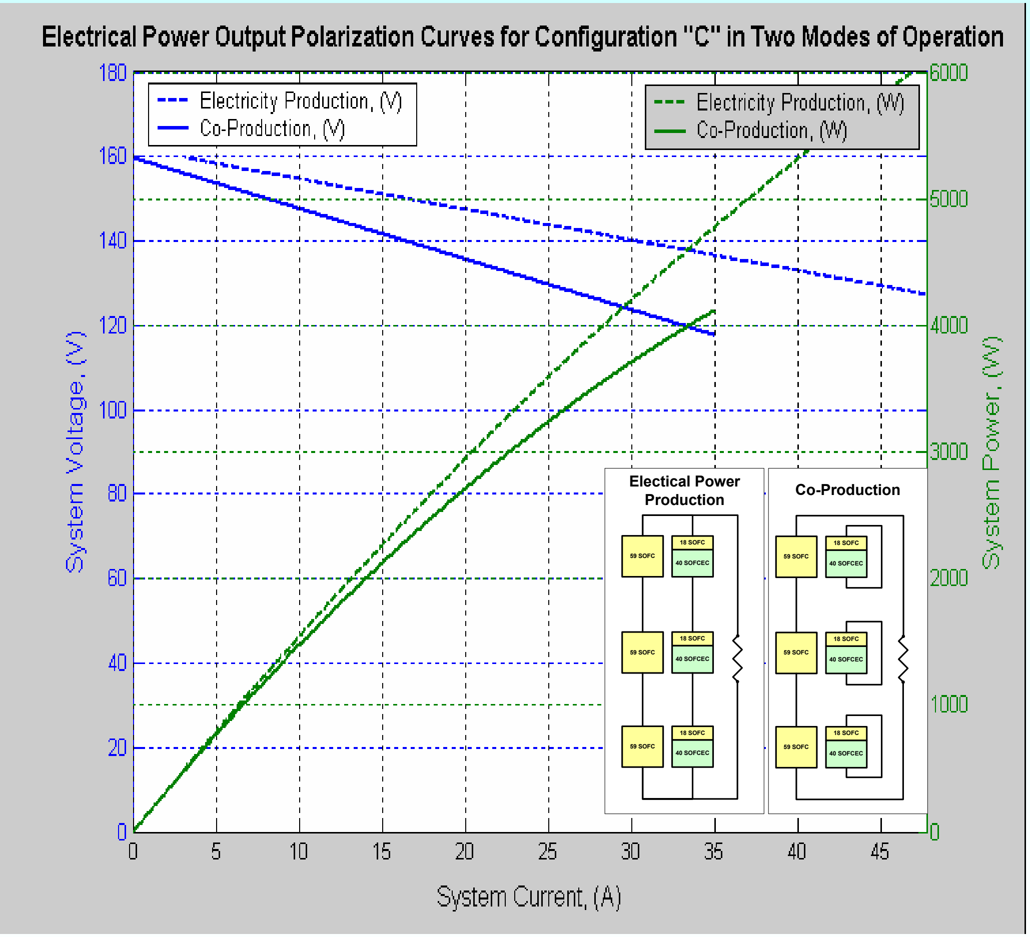


Optimization of System Configuration

2 Modes of Operation:

- Co-generation
  - Hybrid stacks self driven, dedicated SOFC stacks in series
  - Electrical load following independent of hydrogen production rate

- Electrical Power Production
  - Series/parallel configuration of hybrid and dedicated stacks
  - Allows for peak power output with dedicated and hybrid stacks each at optimal current density



Future Work (FY07 – FY08)

- Materials Development
  - Cathode optimization and long-term stability investigation in reducing & oxidizing atmospheres
  - G#50 in-stack implementation, long-term & thermal cycling tests
  - Investigation of fracture mechanism and modeling residual stresses
  - Continuous of investigating effects of residual/chemical/applied stresses on the mechanical integrity of the SOFC-SOFEC
- SOFC-SOFEC Hybrid Stack Optimization
  - Evaluate new interconnect design with enhanced thermal/fluid management
  - Evaluate stack design integrated with heat exchanger
- 5 kW Hybrid System Design and Evaluation
  - BOP components design and fabrication
  - 5 kW hybrid system assembly and evaluation
  - Implementation of hydrogen production cost analysis using H2A model

Project Summary

Relevance:	Investigate an alternative approach to provide low-cost and highly efficient distributed co-production of electricity and hydrogen
Approach:	Develop a 5 kW SOFC-SOFEC hybrid system based on innovative materials development and system design research to co-generate hydrogen and electricity
Technologies Accomplishments and Progresses:	Developed/characterized perovskite-type oxides (p and n-type) cathode materials over a wide range of oxygen activities; studied the influences of combined stresses (residual, chemical, thermal and applied stresses) for understanding and improving SOFC-SOFEC structures in service conditions; developed hermetic seal materials; characterized the selected materials in SOFC/SOEC/SOFEC modes; proof-of-concept kW hybrid stack co-generating hydrogen and electricity; designed a 5 kW hybrid system
Proposed Future Research:	Continue developing electrodes and sealing materials; implement mechanical/thermal analyses of anode supports; optimize the 5 kW hybrid system; fabricate and evaluate BOP components; implement system experimental investigation and cost analyses