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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Project ID#: PD2

Overview

Timeline

- Project started: 09/30/2004
- Project ends: 11/30/2006
- Percent completed: 25%

Budget

- Total budget funding
  - DOE $1,200k
  - Industry $ 300k
- Funding received in FY04 $150k
- Funding for FY05 $690k

Barriers

Hydrogen generation by water electrolysis

- G – Capital cost
  - Low-cost, durable high-temperature materials development
  - Lower operating temperature

Subcontractors

- 1. University of Missouri-Rolla: Dr. H. Anderson, Dr. X. Zhou
- 2. Aker Industries, Inc.: Dr. G. Benson

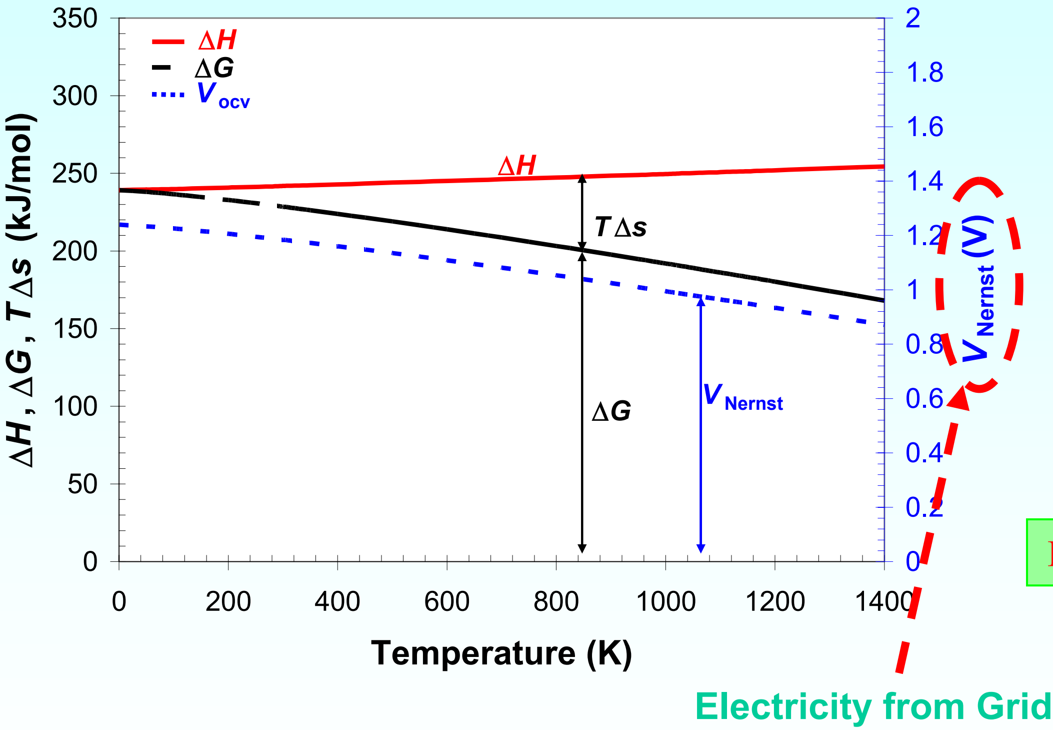
Objective

To develop a composite/hybrid planar 1kW SOFEC-SOFC stack generating both hydrogen and electricity either from distributed natural gas or biogas fuel. The project will focus on material research, stack design & fabrication, and verification.

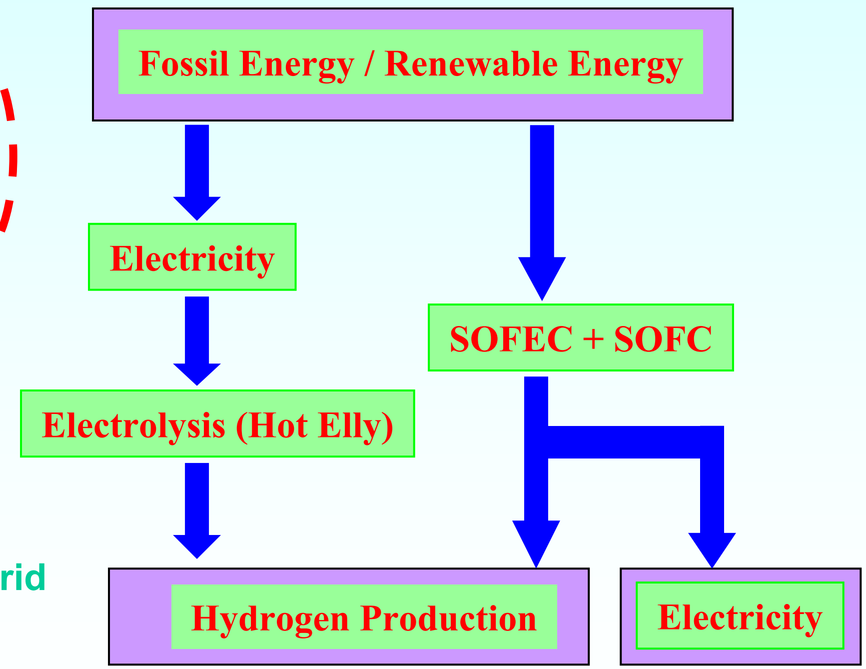
- Anode-supported cell development
  - Anode optimization
  - Electrocatalytically & chemically stable cathode in reducing/oxidizing atmosphere
- Cell/stack design, test, & verification
  - Button cell
  - Short stack proof-of-concept
  - 1 kW stack demonstration

Approach

To replace the external electrical energy needed to electrolyze steam by a chemical energy directly from fuels



Unique approach

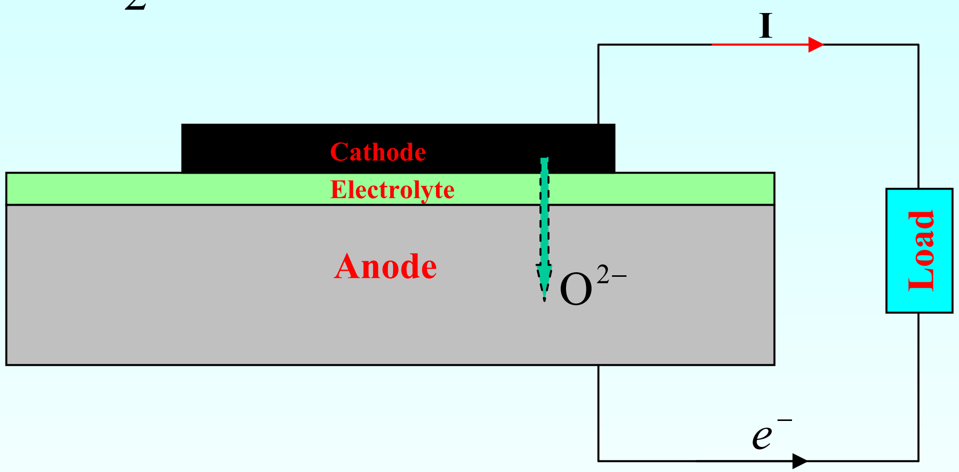


$$H_2O \leftrightarrow H_2 + \frac{1}{2}O_2$$

Approach

Concept of the solid oxide fuel-fed electrolysis cell (SOFEC)*

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



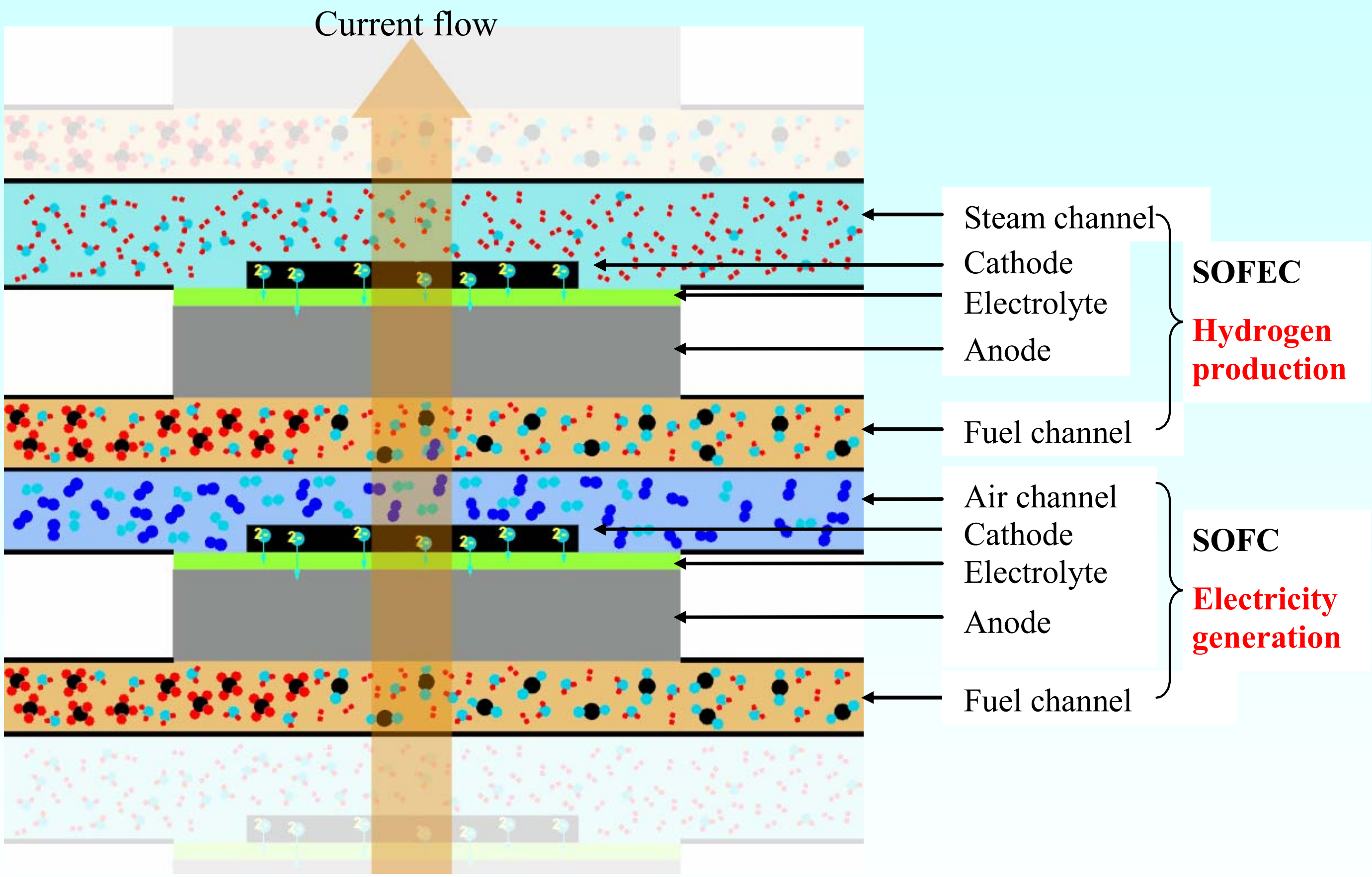
- Cathode: Steam reduction
  pure H_2 evolution
- Anode: Fuel oxidation
  depolarized, chemical energy to replace electrical energy
- Extra electrical energy is needed in order to increase hydrogen production rate

$$2CH_4 + 3H_2O \leftrightarrow CO_2 + CO + 7H_2$$

$$CO + \frac{1}{2}O_2 \leftrightarrow CO_2 \qquad H_2 + \frac{1}{2}O_2 \leftrightarrow H_2O$$

*: H.S. Spacil and C.S. Tedmon, J. Electrochem. Soc., 116, 1618 (1969)
A.Q. Pham, H. Wallman, and R.S. Glass, US Patent No. 6051125 (2000)

Approach



- Fuel, steam, air
- Pure H_2 & e^-
- Same fuel for SOFC & SOFEC
- SOFC provides power to SOFEC
- SOFEC generates H_2
- Better thermal management

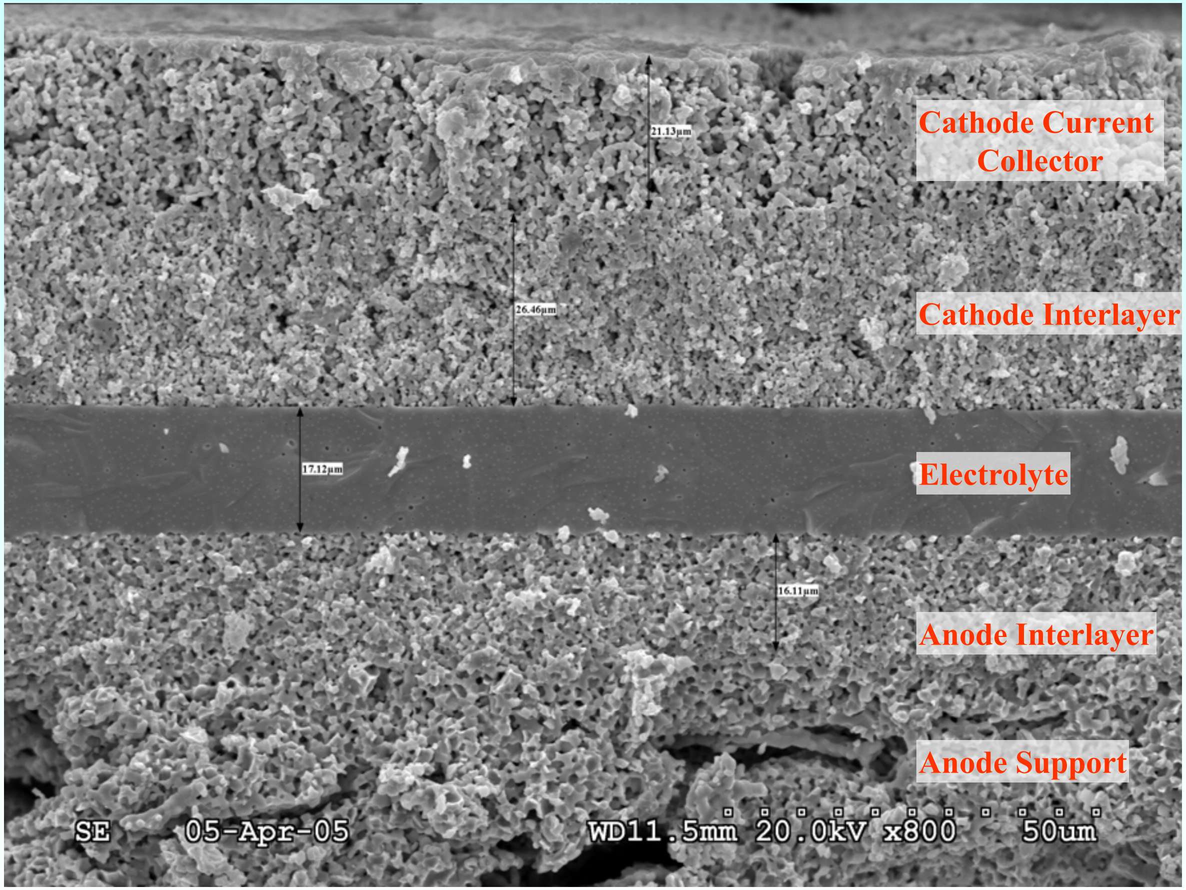
Concept of the composite/hybrid SOFC-SOFEC stack generating both hydrogen and electricity from the natural gas

Technical Accomplishments

Anode-supported cell development – anode w/ electrolyte

- 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 NiO + YSZ anodes
  - Vary pore-former to adjust porosity
  - Improve quality control
  - DIR (100%) capability at 700-850 ^{o}C
- Issues:
  - Trade-off between strength and porosity/thickness
  - Property measurements at high temperatures and in reducing environment

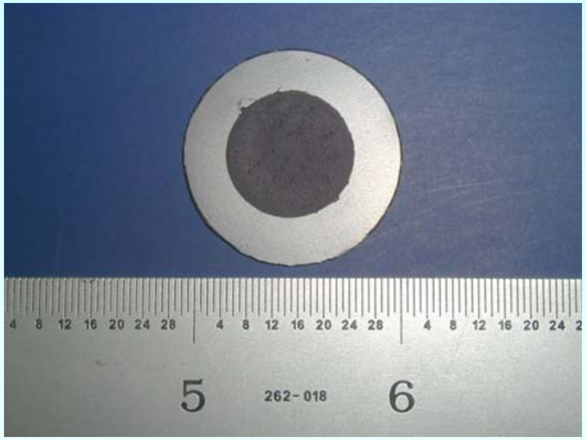
Technical Accomplishments

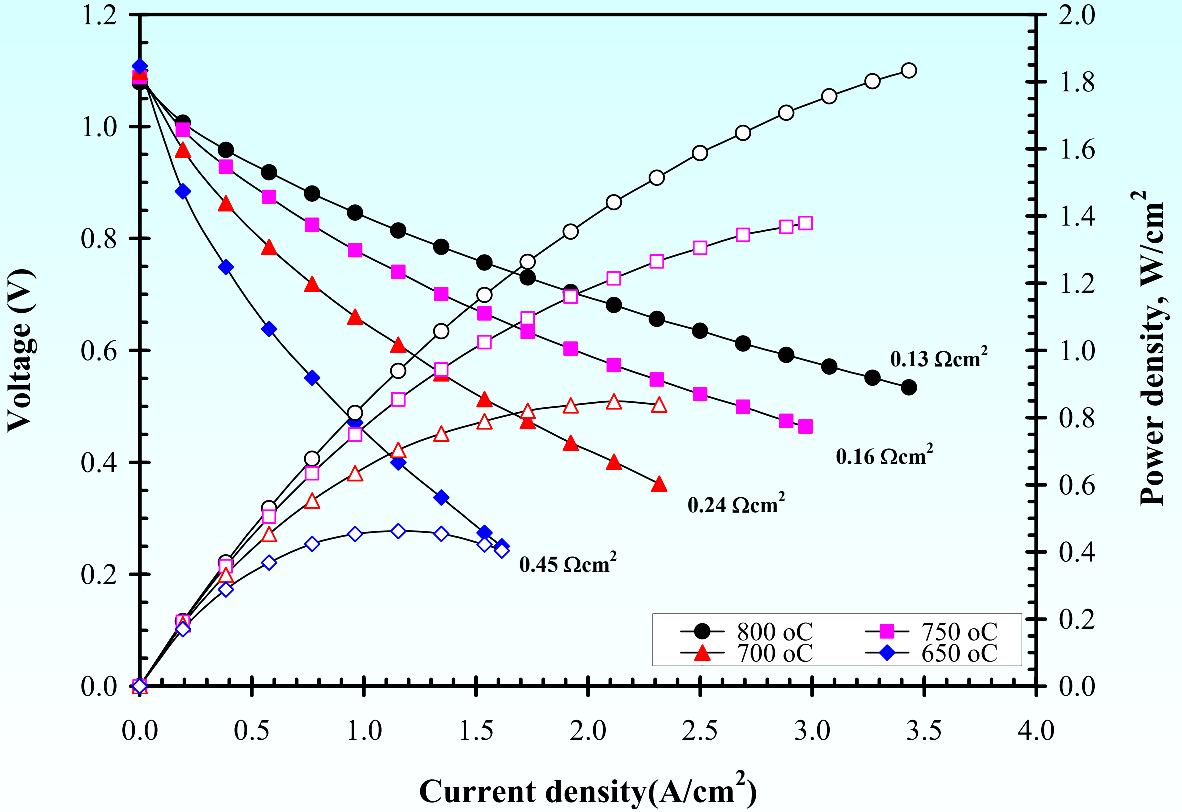


- *Anode* – nickel-zirconia cermet, -- 0.5~0.6 mm thick
- *Electrolyte* – yttria-stabilized zirconia (YSZ), -- 10~20 μm thick
- *Cathode* – conducting ceramic/composite, -- 40~60 μm thick

Technical Accomplishments

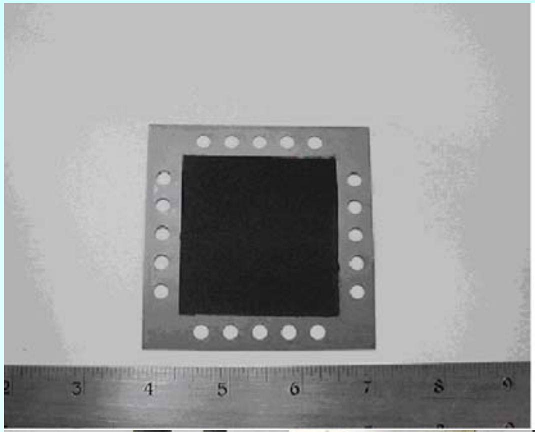
Anode-supported button cell performance operating in SOFC mode

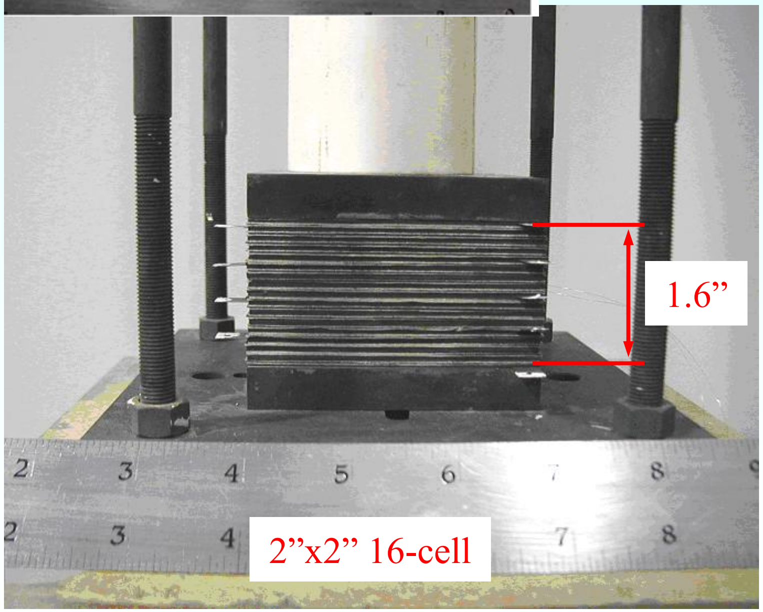


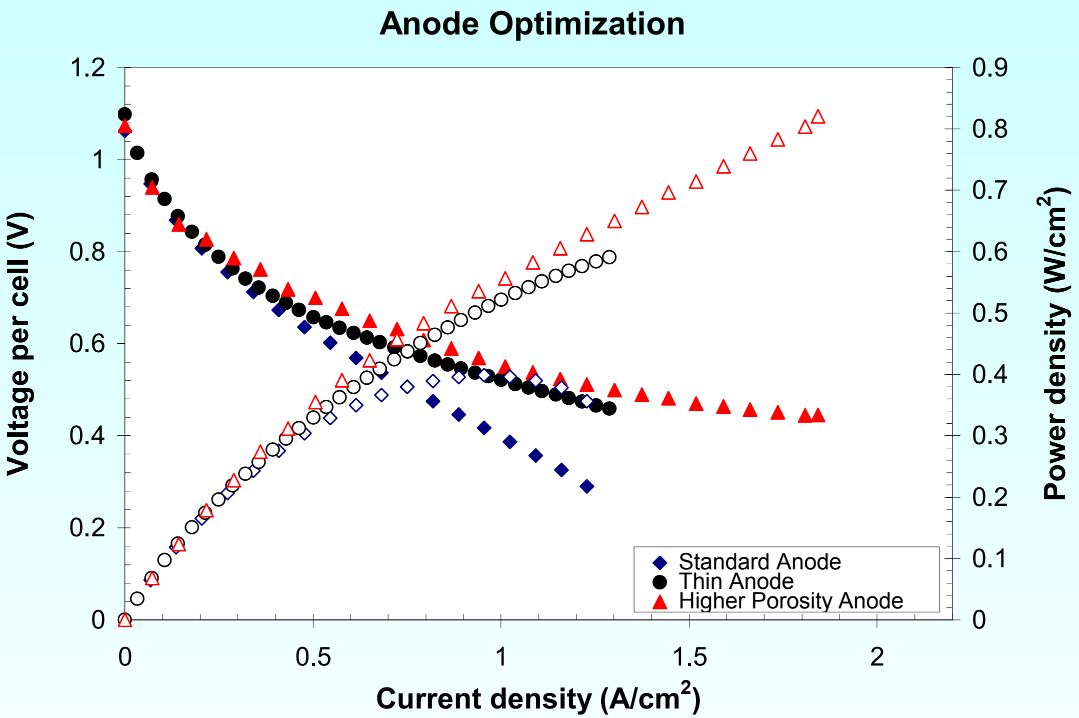


- 1" button cell
- Active area is $2cm^2$
- Tested @ 650 – 800 °C
- Air flow rate @ 550 ml/min
- H_2 flow rate @ 140 ml/min

Technical Accomplishments

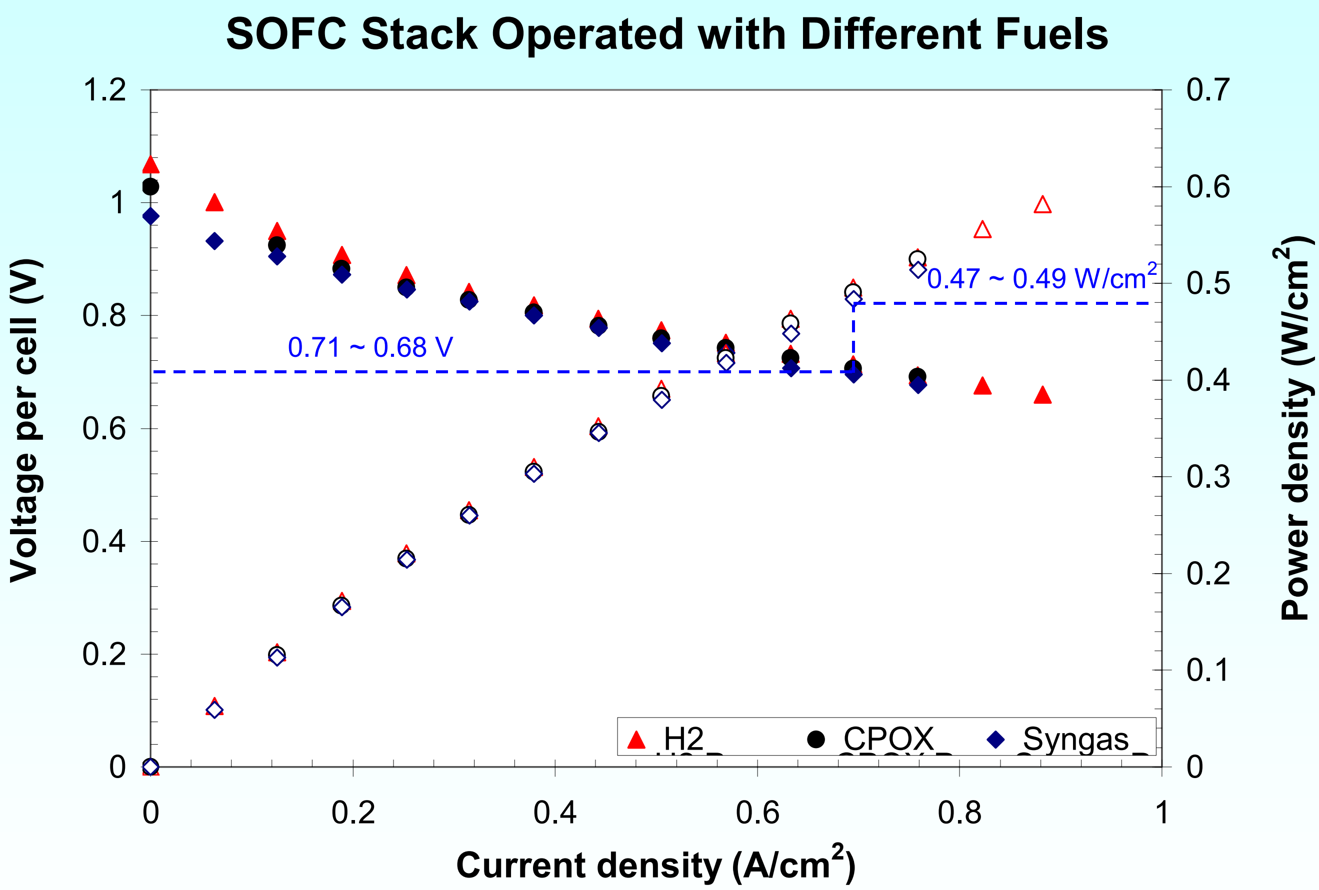






- Scaled up from button cell to 2”x2” cell w/ 32cm^2 active area
- 4-cell SOFC stack
- Tested @ 800 °C, air and hydrogen
- Fuel utilization @ 40%
- Higher porosity and thinner anode decreases concentration polarization at high current densities and high fuel utilizations

Technical Accomplishments

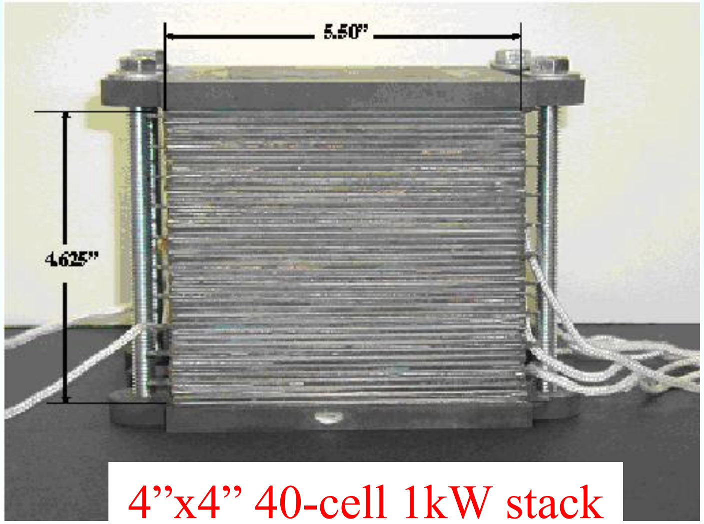


- 2”x2” 5-cell stack
- Advanced anode
- Tested @ 800ºC
- Air and hydrogen
- Fuel utilization @ 60%
- Oxidant utilization @ 50%

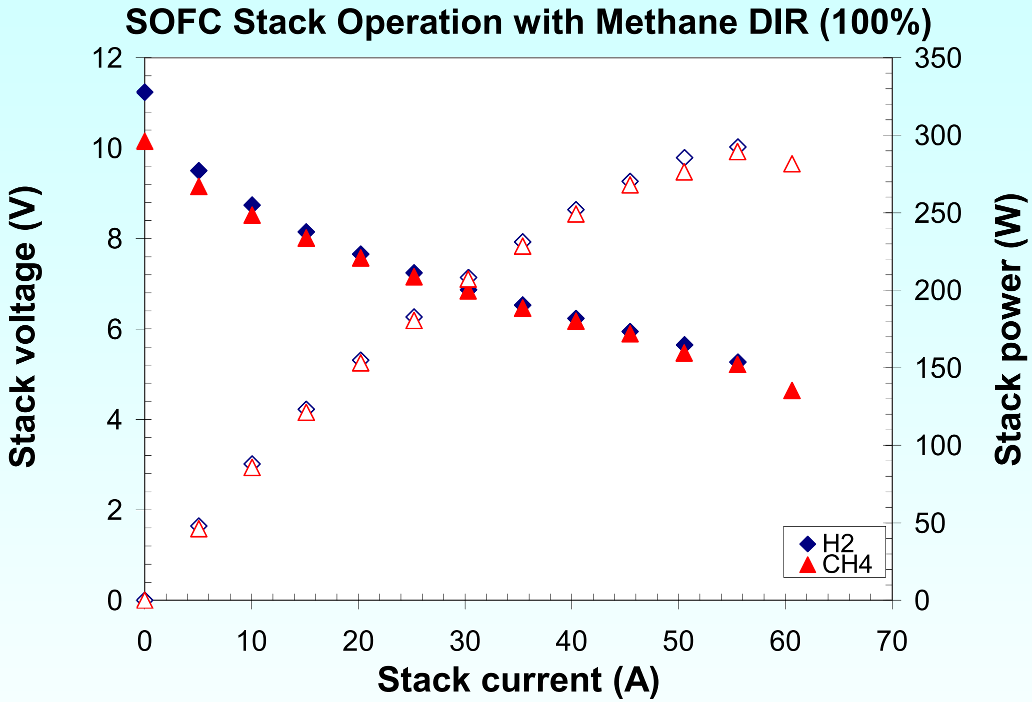
CPOX: 25.7% H_2, 25.6% CO, balance N_2

Syngas: 55.8% H_2, 11.1% CO, 5.9% CO_2, 27.2% H_2O

Technical Accomplishments



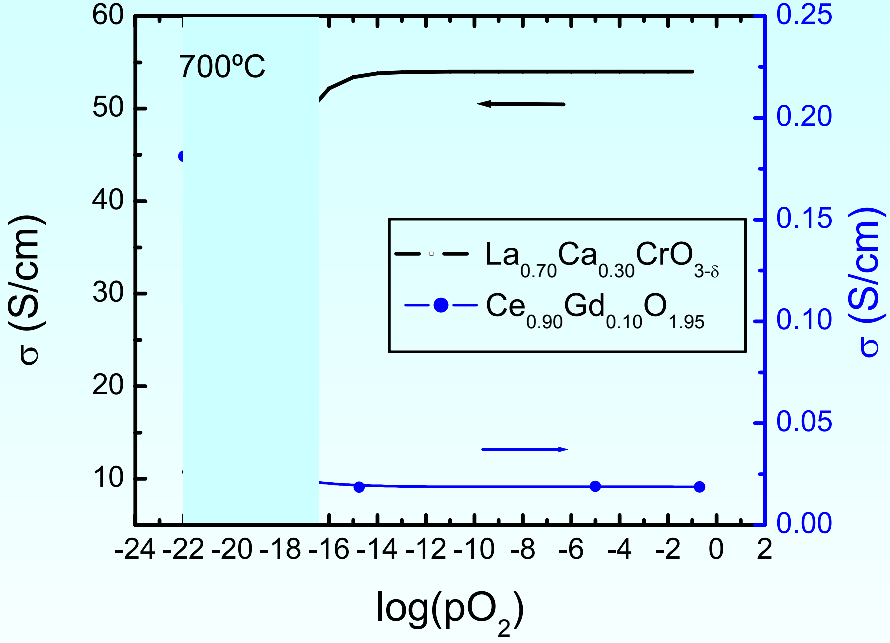
4"x4" 40-cell 1kW stack



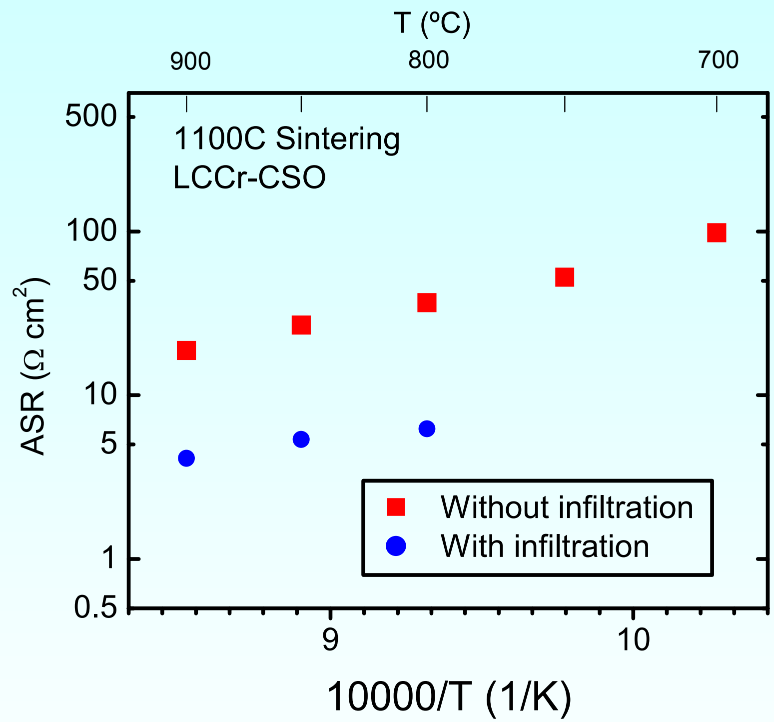
- Scaled up to 4"x4" 10-cell stack w/ 92cm^2 active area
- Tested @ 800^{o}C
- Steam to carbon ratio @ 2:1
- Fuel utilization @ 40%
- Oxidant utilization @ 40%

Technical Accomplishments

Cathode development for SOFEC



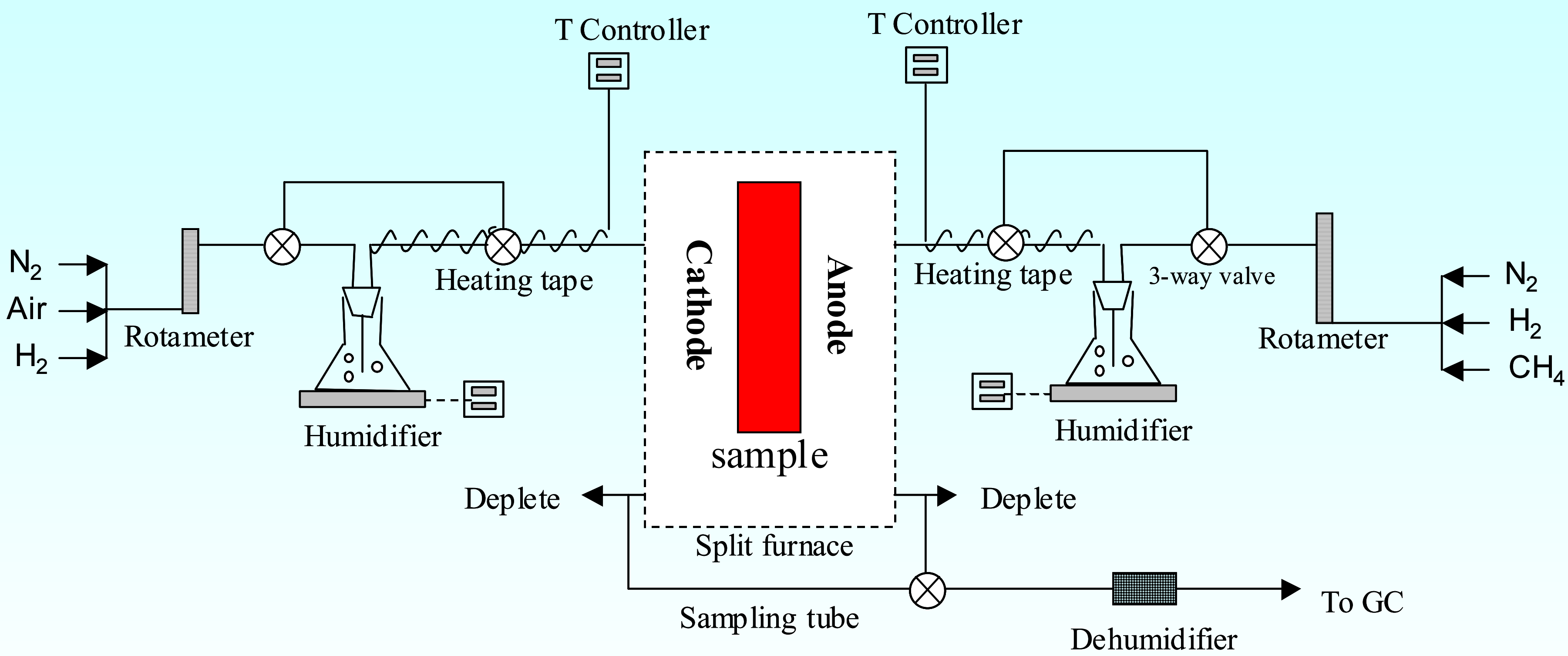
Conductivity as a function of oxygen activity for $(La,Ca)CrO_3$ and $Ce_{0.9}Gd_{0.1}O_{1.95}$.



Plot of ASR as a function of T for the composite electrodes (LCCr – CSO) with and without infiltration.

- 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

Technical Accomplishments

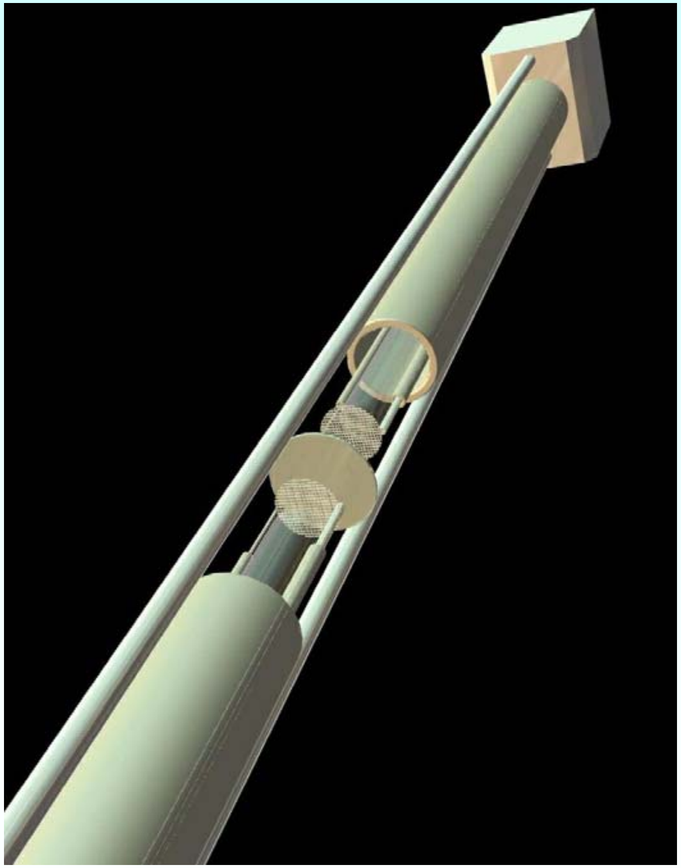


SOFC/SOFEC test rig setup diagram

Capable of operating in both the SOFC and SOFEC modes under various fuel condition

Technical Accomplishments

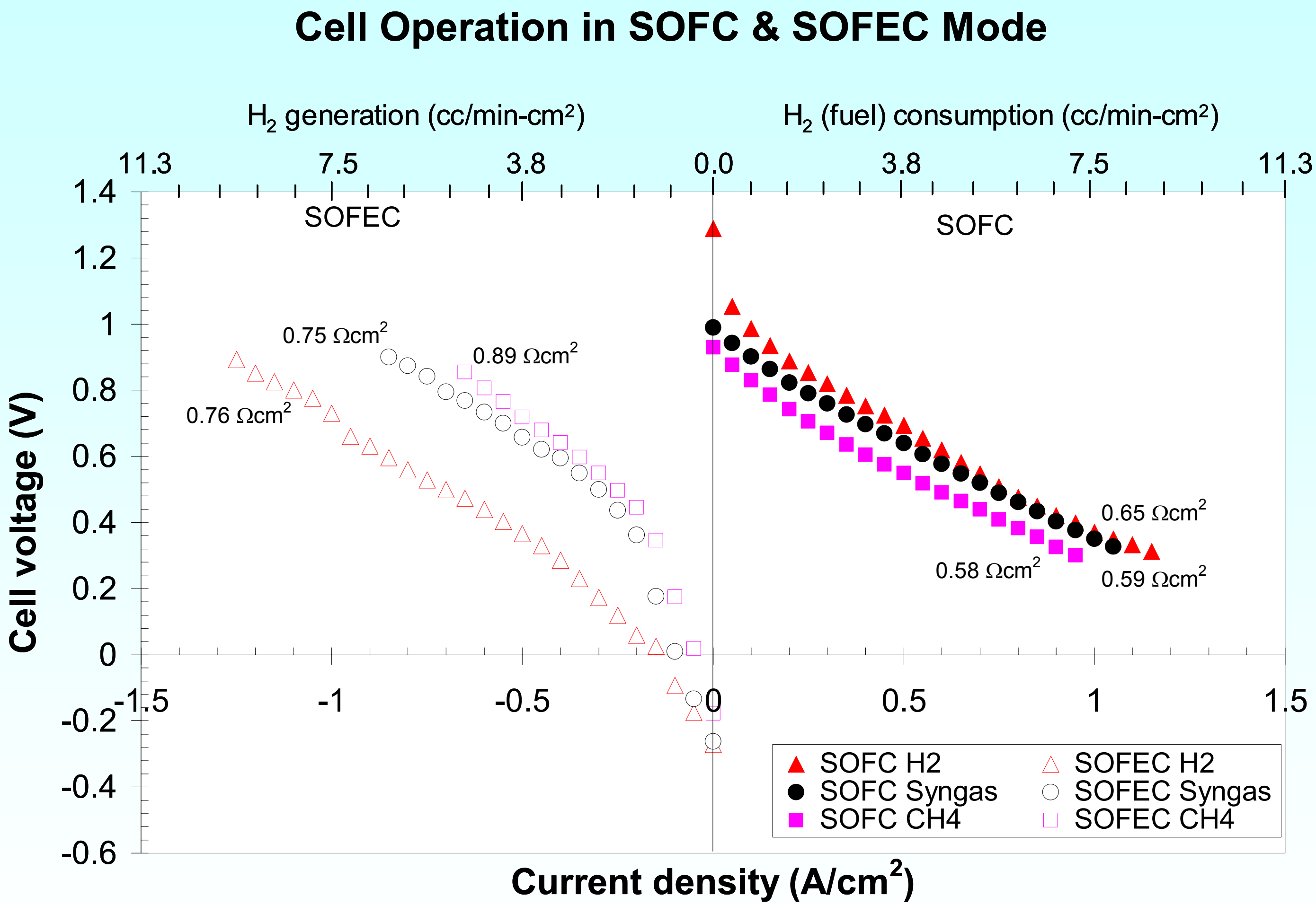
Button cell SOFC/SOFEC test verification



Fixture exploded view

Test rig setup

Technical Accomplishments

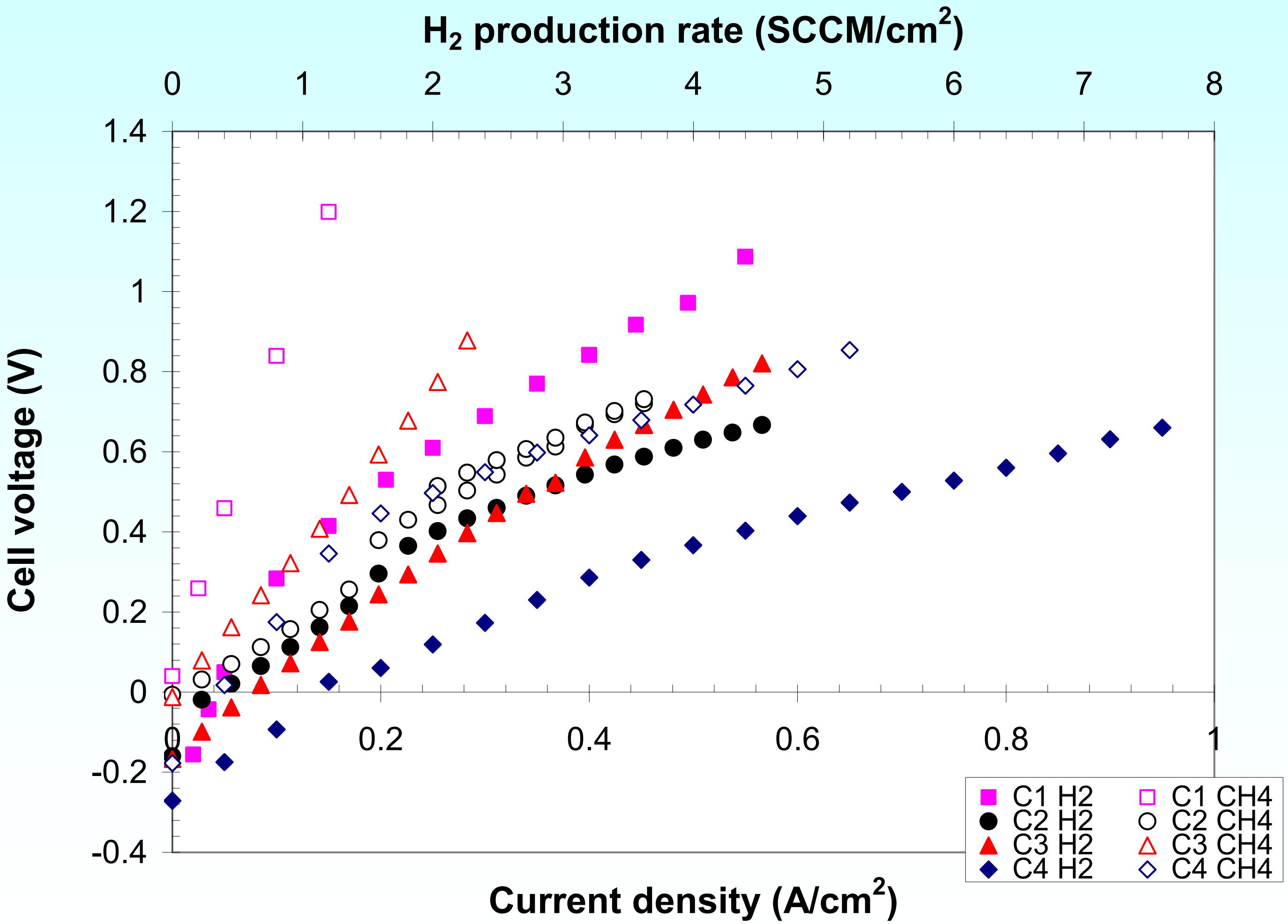


- Button cell
- Anode-supported
- Active area: $2cm^2$
- Tested @ 800^oC

- In the optimized SOFC, MSRI successfully reduced the ASR to less than $0.2\Omega cm^2$
- Efforts will be devoted to develop materials/microstructures so that the ASR is low in both SOFC and SOFEC modes

Technical Accomplishments

Cathode improvement – operation in SOFEC mode



- Button cell
- Anode-supported
- Active area: $2cm^2$
- Tested @ 800^oC

Future Work

- Remainder of FY05
  - Further implementation of quality assurance in cell fabrication
  - Newly developed cathode verification on single cell level
  - Cell improvement (reduce ASR)
  - Single cell reliability testing (long-term, SOFEC/SOFC oscillation)
  - Stack design and machining
  - Short stack testing – proof-of-concept

- FY06
  - BOP cost analysis
  - Stack modeling to optimize fluid flow and thermal management
  - Stack design optimization
  - Long-term and degradation test
  - Thermal cycling test in short stack
  - 1 kW stack testing

Acknowledgement

Department of Energy

- DOE Golden Field Office: David Peterson
- DOE EERE: Matthew Kauffman, Pete Devlin

Hydrogen Safety

- The most significant hydrogen hazard associated with this project is:
  - having a leak from the hydrogen storage tanks or from the testing setup that may cause an explosion.
- Our approach to deal with this hazard is:
  - all of the hydrogen that is on site is stored in qualified pressure vessels and is located in a secluded area away from ignition sources, oxidants and other chemicals. All of the hydrogen pipe lines have been leak tested and are rated for the operating pressures. All testing setups are located under ventilation hoods that are rated at 3000 CFM.