

# Adapting Planar Solid Oxide Fuel Cells for Distributed Power Generation

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## Abstract

Solid Oxide Fuel Cells (SOFCs) are an attractive energy conversion technology due to their efficiency and flexibility to handle contaminants, such as CO and CO<sub>2</sub> present in fuels such as syngas derived from coal. However, coal syngas also contains H<sub>2</sub>S and its presence is one of the major obstacles to implementing a coal syngas SOFC. Research completed at Ohio University has shown that the Planar SOFC (PSOFC) may be used to produce electrical energy using gasified Ohio coal that includes the contaminant H<sub>2</sub>S. [1] In this work, two sets of tests for electrolyte supported PSOFCs with sulfur tolerant anodes were completed:

a) Two(2)-cells stack tests with an anode made of nickel - yttria stabilized zirconia (Ni-YSZ), and gadolinium-doped cerium oxide (GDC); the runs were carried out for over 1000 hours, with coal syngas containing H<sub>2</sub>, CO, N<sub>2</sub>, H<sub>2</sub>O and H<sub>2</sub>S; the long-term performance of the cells was assessed by operating under a load of 15 Amps at 850°C and measuring the fuel cell's potential (power) and area specific resistance (ASR). The results show that a power degradation of 20% and an ASR 2.4 Ω-cm<sup>2</sup> after 1000 hours of operation with syngas in the presence of H<sub>2</sub>S was achieved; while a power degradation of 14% and a final ASR of 3.0 Ω-cm<sup>2</sup> after 1000 hours of operation was achieved, for a case with only H<sub>2</sub> and H<sub>2</sub>S.

b) Button-cell size (1" diameter; 2.0-2.7 cm<sup>2</sup>) tests with an anode containing Ni-YSZ and gadolinia doped ceria (GDC) and strontium-doped lanthanum vanadate (LSV); the preliminary runs were carried out for over 6 hours at 800°C operated at 0.7V, with a similar syngas stream containing H<sub>2</sub>S. The preliminary results showed the anode with an additional LSV top layer performs better (ASR of 1.1 Ω-cm<sup>2</sup> and peak power of 0.18 W/cm<sup>2</sup> at 0.4 A/cm<sup>2</sup>) than a traditional anode of Ni-YSZ-GDC (ASR of 2.0 Ω-cm<sup>2</sup> and peak power of 0.1 W/cm<sup>2</sup> at 0.22 A/cm<sup>2</sup>).

## Goals

- Develop more efficient and environmentally friendly methods of producing electricity using coal.
- Develop a distributed power generation source utilizing planar solid oxide fuel cell (PSOFC) technology.

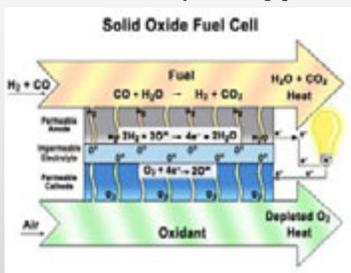
## Objectives

- Determine the carbon deposition resistance of PSOFC anodes.
- Determine the sulfur tolerance of PSOFC anodes.

## Introduction PSOFC Advantages

- H<sub>2</sub> and CO may be used as fuel.
- Operating efficiency of 52% (LHV) for production of power alone, and 80% (LHV) with heat and power [1].
  - Coal fired power generation has an average efficiency of 32-34% (LHV) [2].
- High operating temperature (800°C to 1000°C).
- Low production of environmental pollutants.
  - Little to no production of NO<sub>x</sub>.
  - Sulfur pollutant easily captured (200 to 300 ppm S emitted).
  - Particulate may be cleaned by laminar ESP.
- Produces high quality steam.

## PSOFC Operation[3]



## PSOFC Thermodynamics

- Theoretical open cell voltage (TOCV)
  - Represents the maximum energy available from a fuel cell.

$$E = \frac{RT}{4F} \ln \left( \frac{P_{O_2}(Cathode)}{P_{O_2}(Anode)} \right)$$

For H<sub>2</sub> Fuel:

$$\ln(P_{O_2}(Anode)}) = \frac{2\Delta G}{RT} + 2 \ln \left( \frac{P_{H_2O}}{P_{H_2}} \right)$$

For CO Fuel:

$$\ln(P_{O_2}(Anode)}) = \frac{2\Delta G}{RT} + 2 \ln \left( \frac{P_{CO_2}}{P_{CO}} \right)$$

- TOCV (H<sub>2</sub>, 850°C) = 1.04 V
- TOCV (CO, 850°C) = 1.08 V

## PSOFC Anode Kinetics

- Oxidation of H<sub>2</sub> & CO take place at the Triple Phase Boundary (TPB).
  - Area where all reactants are present (O<sup>2-</sup>, H<sub>2</sub>/CO, and e<sup>-</sup>).
- Expansion of TPB is advantageous to anode kinetics.
  - Ni/YSZ anodes have a small TPB length.
  - Anodes containing CeO<sub>2</sub> have a larger TPB area.
- Anodes containing LSV can withstand the presence of H<sub>2</sub>S. [2]
  - LSV has the ability to preferentially oxidize H<sub>2</sub>S (low activity for H<sub>2</sub> and CO).
  - No degradation over 48 hrs operation

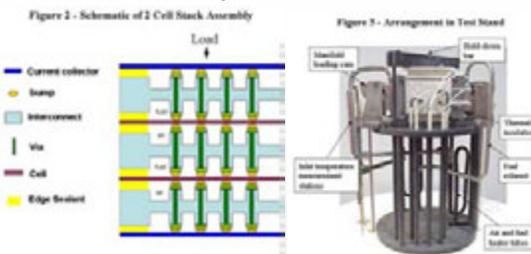
## Anode TPB Examples [4]



## Methodology

- Stack tests:
  - Galvanostatic operation (0.21±0.01Amps/cm<sup>2</sup>) at 850°C utilizing simulated O<sub>2</sub> blown Pittsburgh No.8 coal syn gas.
  - PSOFC Area Specific Resistance (ASR) measured by completing V-I scans; ASR histories plotted and studied.
  - Voltage (power) performance over time monitored and studied.
  - Material analyses on the anodes (before and post tests): scanning electron microscopy (SEM), x-ray diffraction (XRD), and X-Ray Photoelectron Spectroscopy (XPS); to determine if any structural or composition changes had taken place.
- Button-cell tests (preliminary):
  - Potentiostatic operation (0.7V) at 800°C utilizing simulated O<sub>2</sub> blown entrained flow coal syn gas.
  - Area Specific Resistance (ASR) measured by completing V-I scans.

## 2-cell stack schematic & stand and Gas Delivery System



## Experimental Coal Syn Gas Composition

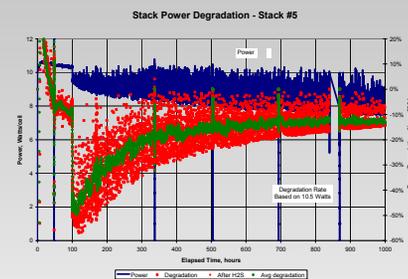
### O<sub>2</sub> Blown Pittsburgh No. 8

Species	Mole %
CO	37.73
CO <sub>2</sub>	15.38
H <sub>2</sub>	24.90
H <sub>2</sub> O	16.21
CH <sub>4</sub>	4.53
H <sub>2</sub> S	0.95
COS	0.02
NH <sub>3</sub>	0.27
HCN	0.02

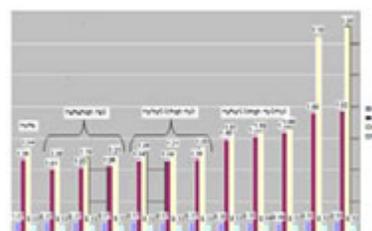
### Typical Simulated Composition

Species	Mole %
CO	33.0±1.0
H <sub>2</sub>	22.0±1.0
N <sub>2</sub>	27.0±1.0
H <sub>2</sub> O	18.0±3.0
H <sub>2</sub> S	240±20 ppm

## Results

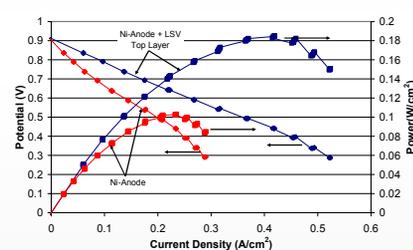


Stack test, Ni-GDC-YSZ (Anode), H<sub>2</sub> and H<sub>2</sub>S (Fuel).



Stack test, Ni-GDC-YSZ (Anode), H<sub>2</sub> and H<sub>2</sub>S (Fuel).

VI Scan after 6hrs w/simulated coal syngas containing 160ppm H<sub>2</sub>S.



Button-cell test, Ni-YSZ-GDC plus LSV-YSZ Top Layer

## Conclusions

- ASR Degradation of 2.4 Ω-cm<sup>2</sup> and 20% degradation per 1000 hrs with coal syn gas in the presence of H<sub>2</sub>S contaminant.
- ASR Degradation of 3.0 Ω-cm<sup>2</sup> and 14.0% degradation per 1000 hrs with H<sub>2</sub> and H<sub>2</sub>S.
- Anodes containing CeO<sub>2</sub> exhibits better sulfur tolerance than any other Ni-YSZ anode composition published in literature.
- Anodes containing LSV on top of Ni-YSZ-GDC show better capability for sulfur tolerance than the Ni-YSZ-GDC anodes alone.

## Acknowledgements

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- Ohio Coal Research Center
  - > Shlyer Switzer/Pat Curran/Micah McCreery/Undergraduate Staff
- SOFCo-EFS

## References

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- Z. Cheng, S. Zha, L. Aguilar, D. Wang, J. Winnick, M. Liu, "A Solid Oxide Fuel Cell Running on H<sub>2</sub>S/CH<sub>4</sub> Fuel Mixtures", Electrochemical Solid-State Letters, 9(1), A31-A33 (2006).
- M. Mogensen, Catalysis by ceria and related materials, 2002, pp. 453-482.

# Technical Barriers and Targets

- DOE Technical Barriers for Distributed Generation
  - Improved CO tolerance
  - Develop CHP fuel cell systems
  - Verify integrated stationary fuel cell systems
  - Mitigate technical barriers to stationary fuel cells
- DOE Technical Targets for 2010
  - 40,000 hours durability
  - \$1000/kWe



# Project Safety

## Hydrogen, Carbon Monoxide and H<sub>2</sub>S Concerns

- FMEA Analysis
- Chemical hygiene training
- H<sub>2</sub>S training
- Gas containment and scrubber system
- Operational SOP's
- PSD's – gas monitors, SKAT packs, room monitors
- Verification gases to test monitors/detectors
- Notification and review with local authorities for the types and quantities of gases used



# Budget

DE-FG36-03GO13059

Ohio

University

## Project Spending and Estimate of Future Spending

Quarter	From	To	Estimated Federal Share of Outlays	Actual Federal Share of Outlays	Estimated Recipient Share of Outlays	Actual Recipient Share of Outlays	Cumulative
1Q05	1/1/2005	3/31/2005		\$200,766		\$121,618	\$1,716,955
2Q05	4/1/2005	6/30/2005	\$201,313	\$662,887*	\$38,434	\$89,457	\$2,469,299
3Q05	7/1/2005	9/30/2005	\$402,626	\$196,420	\$76,867	\$115,456	\$2,781,175
4Q05	10/1/2005	12/31/2005	\$201,313	\$85,813	\$38,434	\$23,345	\$2,89,333
1Q06	1/1/2006	3/31/2006	\$201,313		\$38,434		
2Q06	4/1/2006	6/30/2006	\$201,313		\$38,434		
3Q06	7/1/2006	9/30/2006	\$402,626		\$76,867		
4Q06	10/1/2006	12/31/2006	\$201,313		\$38,434		
1Q07	1/1/2007	3/31/2007	\$201,313		\$38,434		
2Q07	4/1/2007	6/30/2007	\$201,313		\$38,434		
3Q07	7/1/2007	9/30/2007	\$402,626		\$76,867		
<b>Totals</b>				<b>\$3,853,487</b>	<b>\$2,181,539</b>	<b>\$858,555</b>	<b>\$738,794</b>
<b>\$2,890,333</b>							

\* Includes contractor outlays not previously recorded



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# Project Timeline

Start date: Aug 2003; End Date: Aug 2007

- |  |               |
|--|---------------|
| 1. Modeling syngas/SOFC interface          | Aug 03-Dec 04 |
| 2. Fabricate/install syngas system         | Sep 03-May 04 |
| 3. Fabricate/install cell test stands      | Sep 03-May 04 |
| 4. SOFC training for interns               | Apr 04-Jun 04 |
| 5. SOFC material analysis baseline         | May 04-Aug 04 |
| 6. Synthetic syngas testing                | May 04-Dec 05 |
| – 6.1 Baseline syngas                      |               |
| – 6.2 Effect of Hg                         |               |
| – 6.3 Effect of sulfur                     |               |
| – 6.4 Effect of particulate                |               |
| – 6.5 Effect of energy content             |               |
| – 6.6 Effect of O <sub>2</sub> in oxidizer |               |
| 7. Electrostatic separation testing        | Aug 04-Sep 06 |
| 8. H <sub>2</sub> :CO separation or shift  | Aug 05-Aug 07 |
| 9. Integration of fuel cells/gasifier      | Jan 06-Aug 07 |



# Interactions and Collaborations

## Academic and Industrial Partnerships

- SOFCo-EFS (Fuel Cells)
- Case Western Reserve University
- University of Cincinnati
- State of Ohio's Air Quality Development Authority
- BAARD (Power Generation)
- Enercon (Gasification/Steam Reforming)



# Future Work

## Near and Long Term Plans

- Quantify impacts of synthesis gas composition on performance of a commercial planar solid oxide fuel cell system (cell and stack)
  - H<sub>2</sub>S content
  - CO/H<sub>2</sub> ratio and energy content of gas
  - Particulate
  - Metal content
- Demonstrate long term operation of pSOFCs using actual sold fuel-derived synthesis gas
- Integrate CHP into distributed H<sub>2</sub> production



# Future Work

## Near and Long Term Plans

