Development of Kilowatt-Scale Coal Fuel Cell Technology

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Project ID #
FC070

Overview

Timeline

- Project start date: 6/01/2006
- Project end date: 6/30/2012
- Percent complete: 68%

Barriers

- Barriers addressed
  - Long Term Catalyst durability
  - System Thermal Management

Budget

- Total project funding
  - DOE share: $1,675,800
  - Contractor share: $475,086
- Funding received in FY10: $0
- Funding for FY11: $0

Partners

- The Ohio Coal Development Office (OCDO).
- FirstEnergy Corp.
- Coal fuel cell, Inc.

Objectives / Relevance

- **Overall Objective:** Develop a Kilowatt-scale coal fuel cell technology. The results of this R&D efforts will provide the technological basis for developing Megawatt scale coal fuel cell technology.
- **Relevance:** The development of a coal fuel cell technology constitutes a highly efficient, clean, multi-use technology, which promises to provide low cost electricity, expanding the utilization of domestic coal supplies, and providing a smooth transition from a fossil-fuel economy to a hydrogen-based economy. The anode developed for coal fuel cell exhibit high resistance to sulfur compounds. This novel anode allow the direct use of sulfur-containing hydrogen without complex costly purification steps.
- 2010
  - Evaluate the long term anode and cathode catalyst activity as well as interconnect durability
  - Improve the coal injection and fly ash removal systems.
- 2011
  - Develop the process for fabrication of large scale fuel cell components by tape casting and screen printing.
  - Test the long term durability of fuel cell components

Technical Approach and Plan (I)

Fuel cell: Solid Oxide Fuel Cells (SOFC)

Configuration: Anode supported

Materials: Anode → Ni/YSZ and M-Ni/YSZ cermets*
Electrolyte → YSZ (Yttria Stabilized Zirconia)
Cathode → LSM (Lanthanum Strontium Manganese)

- **Task 1:** Investigate the factors governing the anode catalyst activity for the electrochemical oxidation of carbon in coal.

- **Task 2:** Evaluate the long term anode and cathode catalyst activity as well as interconnect durability.

- **Task 3:** Develop the process for fabrication of large scale fuel cell components.

*: M = reduced metal

Technical Approach and Plan (II)

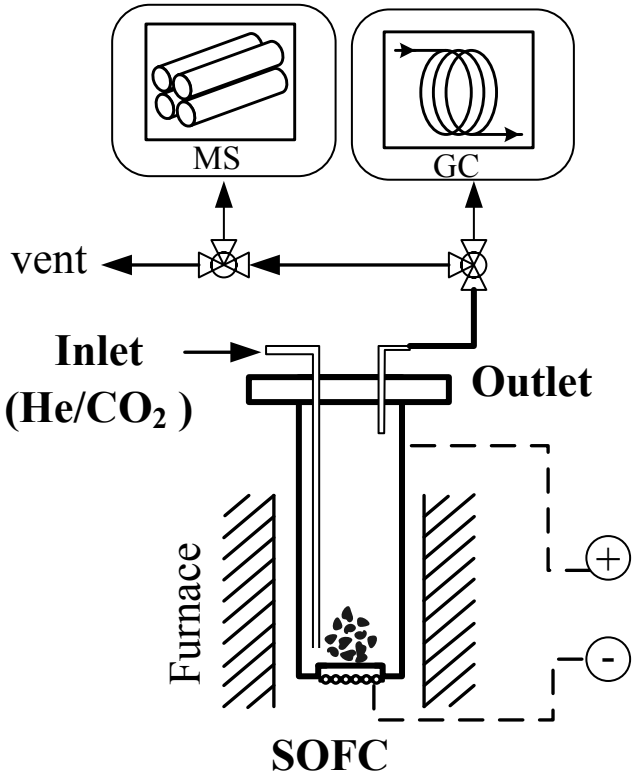
- **Task 4:** Improve the coal injection and fly ash removal systems.
- **Task 5:** Integrate the fuel cell components into the coal fuel cell stack.
- **Task 6:** Develop a computer control system for the coal fuel cell stack.

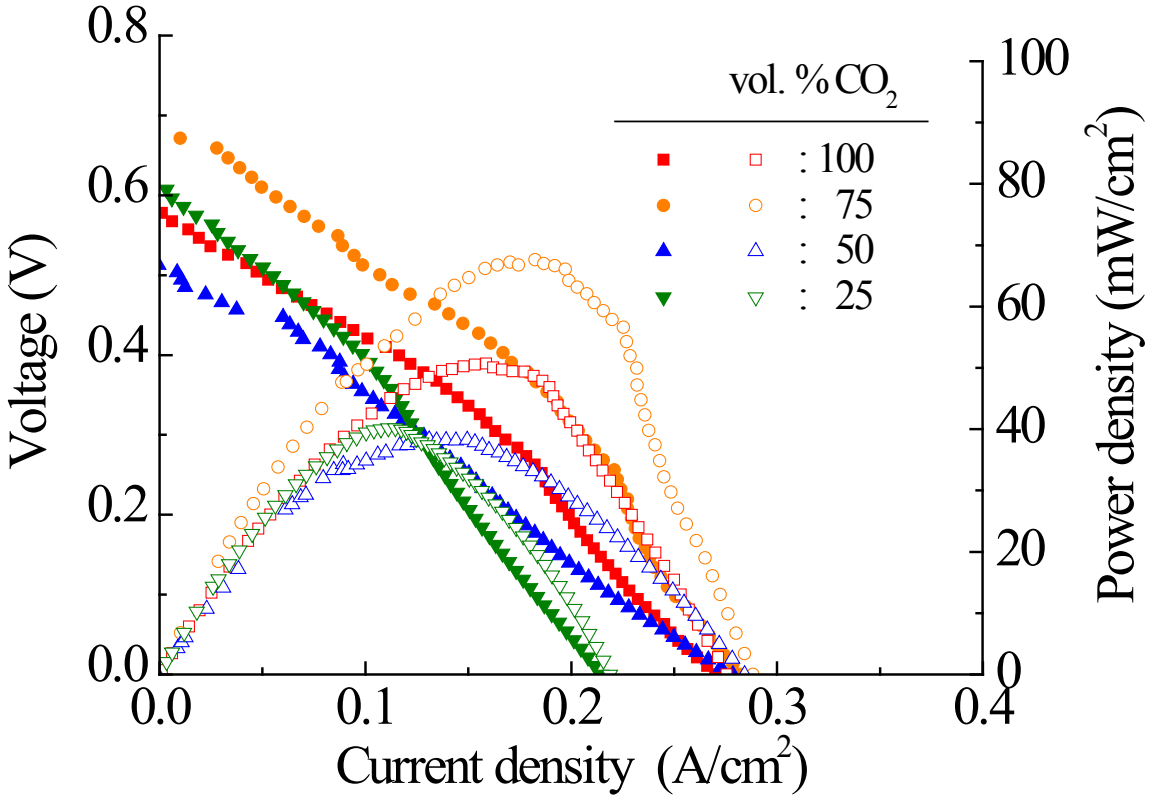
Technical Accomplishments/ Progress/Results

Milestones	Progress	Comments
Factors governing the anode catalyst activity	The Ni-based anode exhibits increased activity for electrochemical oxidation when flowing CO_2 in the inlet stream (25-75 vol.%)	The effect of CO_2 on the anode activity will be further studied for the continuous electrochemical oxidation of carbon fuels.
Develop the process for fabrication of large scale fuel cell components	A process was implemented for fabricating fuel cells with porous anode electrodes.	The effect of porosity on the performance of the carbon fuel cell will be studied.
Testing of sealant materials.	Suitable ceramic and glass-ceramic sealant materials were identified and tested	The long term durability of sealant materials will be investigated.
Evaluate the long term anode and cathode catalyst activity as well as interconnect durability.	The performance of the carbon fuel cell was tested in two different carbon fuels for over 15 hr of continuous operation. Durability of interconnect material was tested for 500 hr in H_2 fuel	The system will be tested for 1 month in carbon fuel.

Technical Accomplishment - 1

Effect of CO_2 on the performance of the coal fuel cell



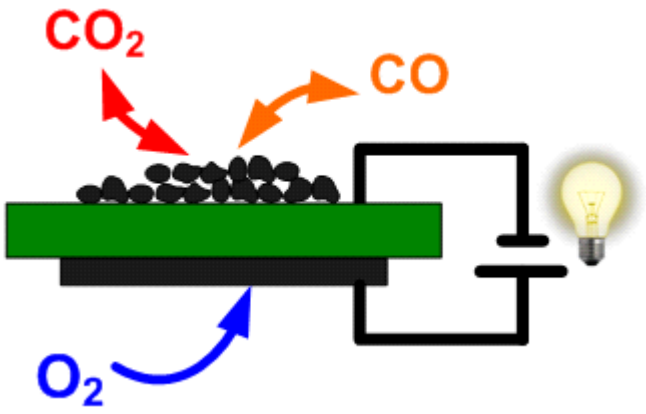


Exp. Conditions: 200 sccm He/CO_2 (25-100 %.vol) at 750°C, 1 atm, 10 g low-ash carbon

- Increasing the inlet concentration of CO_2 from 25 to 75 vol.% results in fuel cell power density improvements of up to 81%
- Testing of the fuel cell in 75 vol.% CO_2 resulted in the highest fuel cell performance (65mW/cm^2).

Technical Accomplishment - 1

Effect of CO_2 on the performance of the coal fuel cell

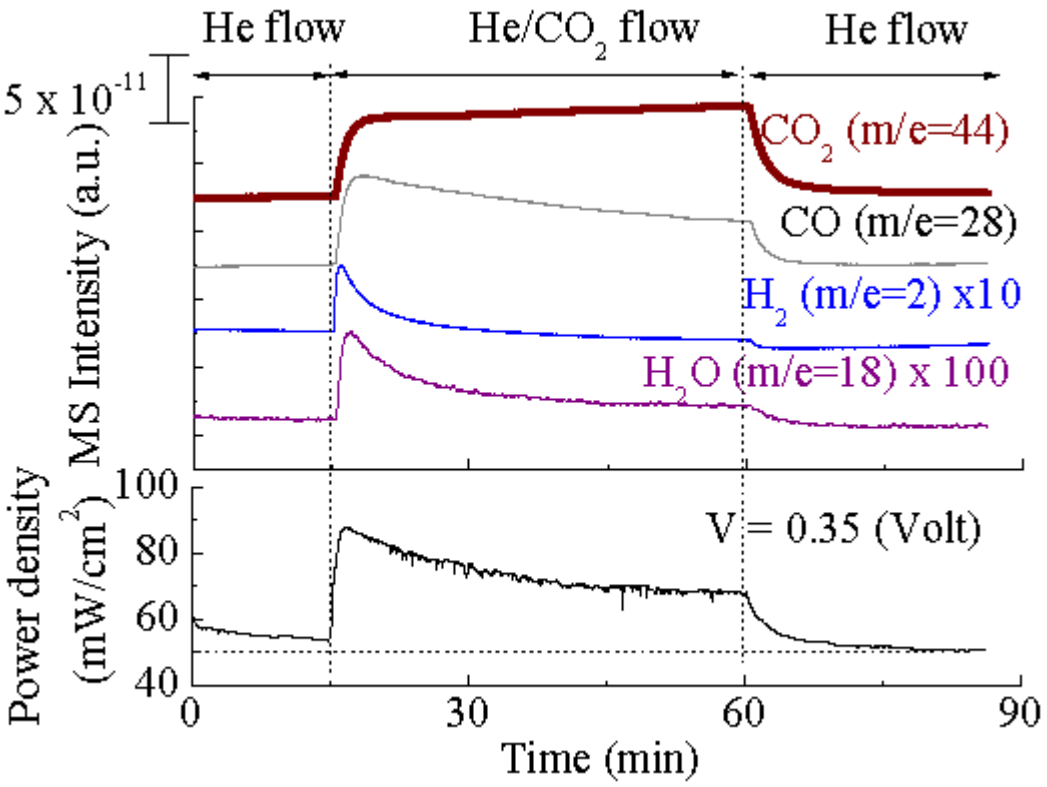


Carbon fuel cell reactions

$$C + O^{-2} \rightarrow CO + 2e^-$$

$$C + 2O^{-2} \rightarrow CO_2 + 4e^-$$

$$C + CO \rightarrow 2CO \text{ (Boudouard rxn)}$$



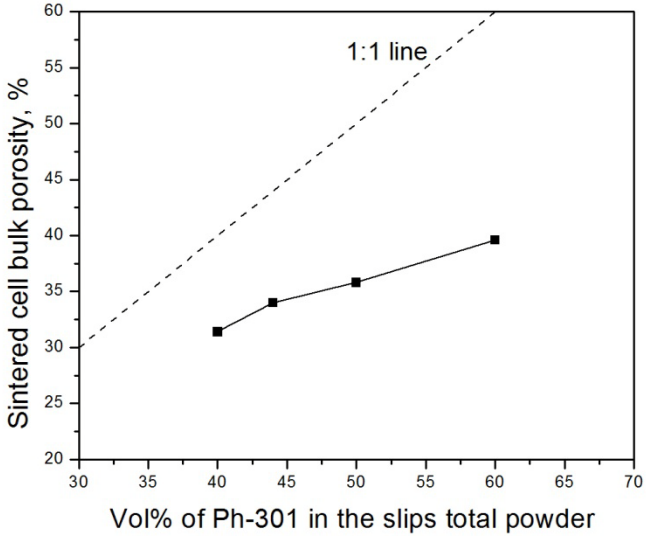
Exp. Conditions: 200 sccm He/CO_2 (75 vol.% CO_2) at 750°C, 1 atm, 10 g low ash carbon

- The rate of CO production from the reaction of CO_2 with carbon was in parallel with power generation.
- CO formed from Boudouard reaction was electrochemically oxidized.
- Hydrogen was produced and replaced from carbon.

Technical Accomplishment - 2

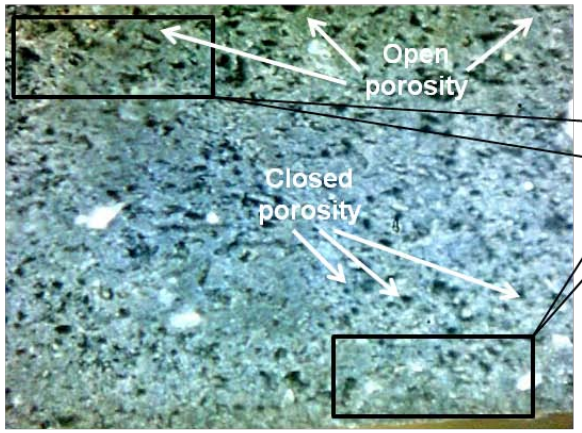
Development of the large scale fuel cell fabrication

Fabrication of fuel cells with porous anode electrodes

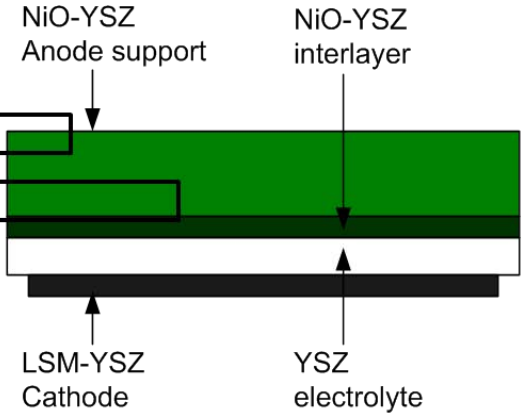


Sintered bulk porosity as a function of Ph-301 amount (Vol %) in the slips total powder.

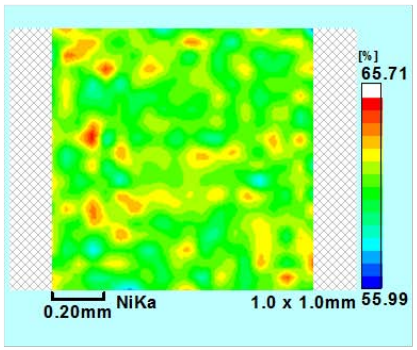
- Addition of pore former resulted in anode electrodes containing open and interconnected pores as well as close pores.
- efforts will be focused on reducing formation of close pores, which decrease the fuel cell performance



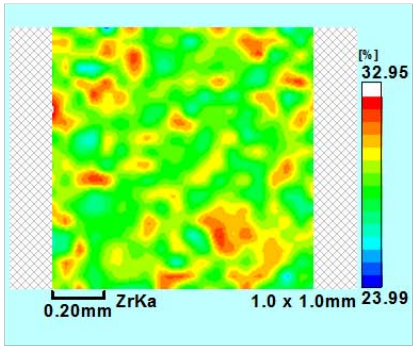
Optical microscope image



Apparent porosity: 38%



Ni map



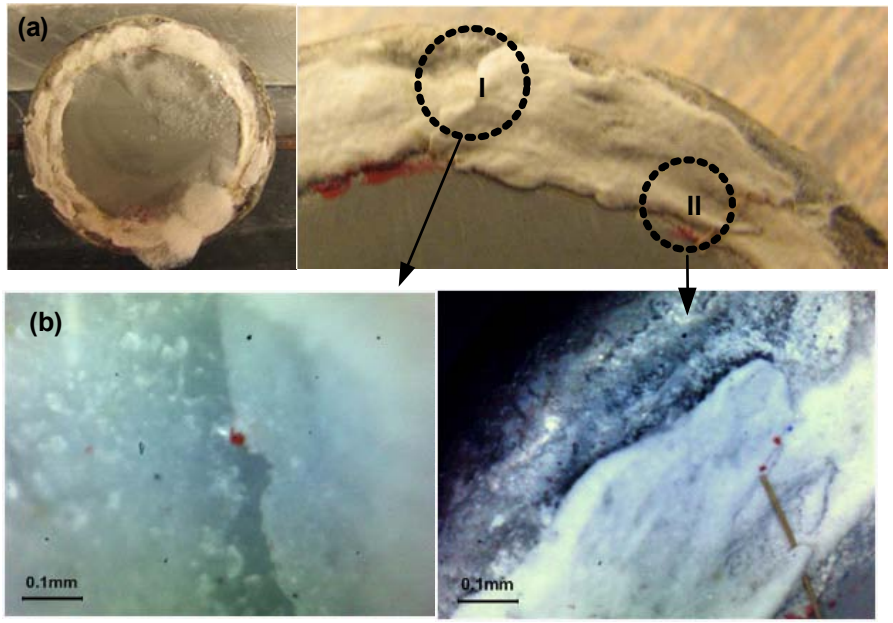
Zr map

Quantitative elemental analysis

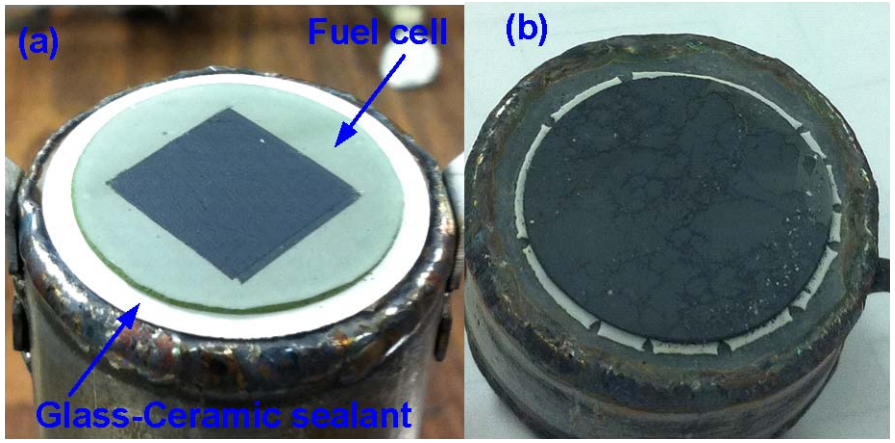
Ni	Zr	Y	Hf	Fe
68%	16.8%	3.65%	0.41%	0.06%

Technical Accomplishment - 3

Testing of sealant materials for coal fuel cell



Ceramic cement sealant after heating and cooling to 800 °C in flowing He (100 sccm), (a) digital images and (b) optical microscope image of leak points.



Glass-Ceramic sealant (a) prior to and (b) after heating to 800 C in flowing He (100 sccm).

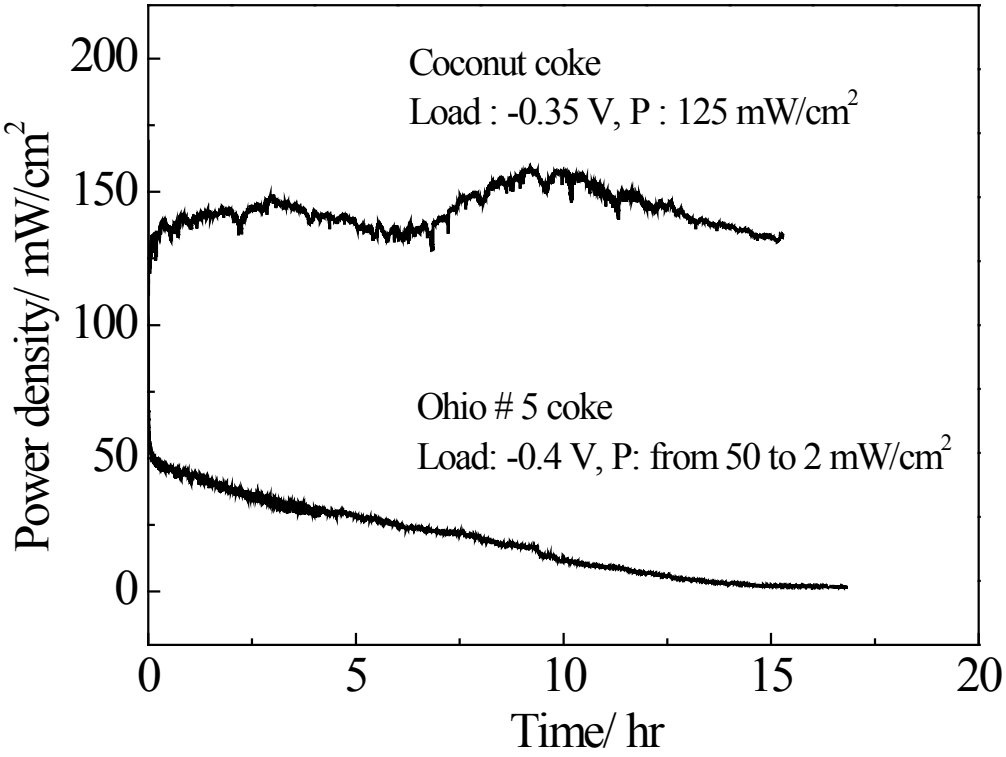
- Use of ceramic cement sealants provided gas tight fuel cell housing with leakages as low as 1.6% (0.17 sccm/cm), which is 35% lower rate than well established compression seals[1]

	Ceramic cement sealant I		Glass-Ceramic Sealant		Ceramic cement sealant II	
Inlet (sscm)	Outlet (sscm)	Leak (%)	Outlet (sscm)	Leak (%)	Outlet (sscm)	Leak (%)
45.80	34.2	25.3	-	-	45.05	1.6
93.17	78.33	15.9	-	-	90.9	3.3
140.85	124.48	11.6	114	19%	133.3	5.3

[1]:Chou, Y.-S.; Stevenson, J. W.,. J. Power Sources 2003, 124, (2), 473-478.

Technical Accomplishment - 4

Power generation with Ohio#5 coke and coconut coke



- The higher power density at 750 °C produced from coconut coke was attributed to high reactivity of carbon, which contained higher alkali metals.

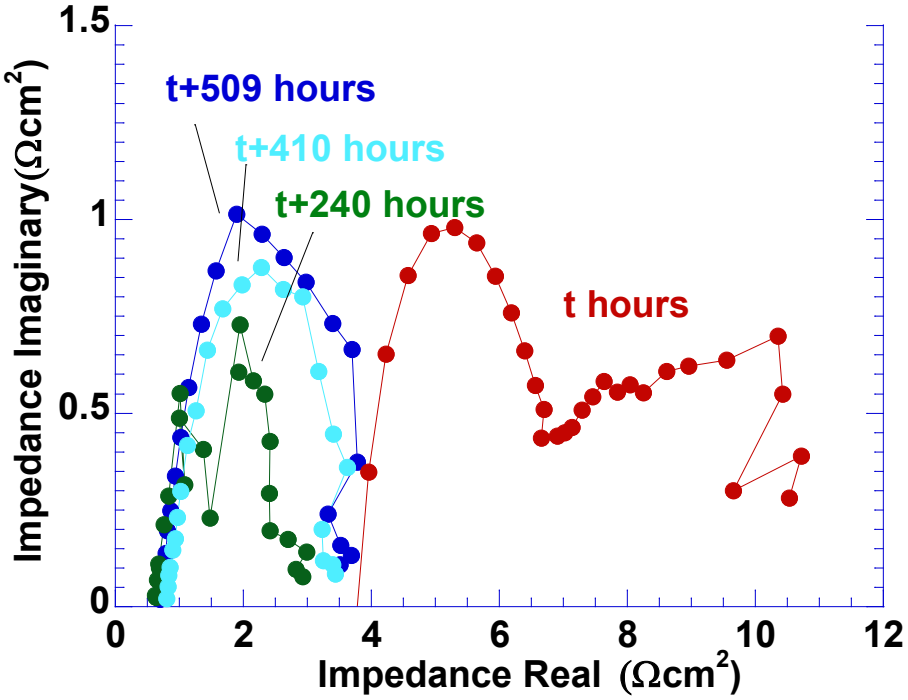
Fuel / Composition	K %	Ca %	Br%	Cl %	Fe%	S %	Ni %	Cr%
Coconut coke	63.1	13.80	8.91	8.81	2.40	2.09	0.93	
Ohio coke #5	4.0	4.9						

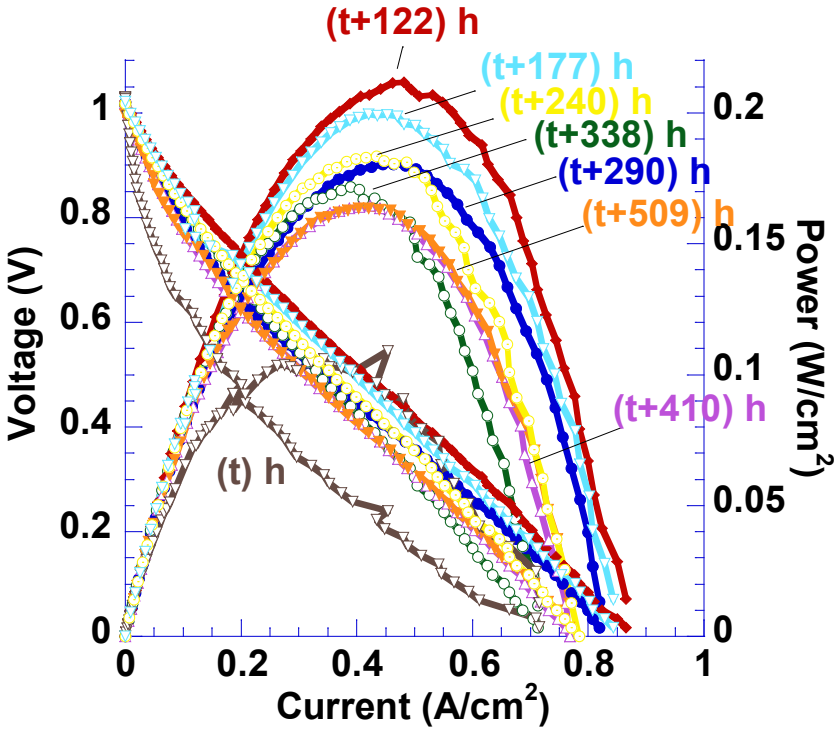
*Carbon is excluded from the composition

Technical Accomplishment - 4

Durability of Low Cost Interconnect

T = 800°C, Flow rate of He/H_2 = 80/80 cc/min





No decrease in the Ohmic resistance was observed on the impedance plot after 500 h operation, showing the stability of the interconnect material.

Increase in polarization resistance due to diffusion of gas phase reactants and products led to decrease in the power density.

The power density decreased from 0.21 to 0.16 W/cm^2 over 400 h and remained stable at 0.16 W/cm^2 over another 100 h.

Collaboration

- Partners
  - The Ohio Coal Development Office: focusing on the fundamental research on determination of the fuel cell efficiency.
  - FirstEnergy Corp: addressing practical issues of the scaling up fuel cell stack.
- Technology Transfer:
  - Coal fuel cell Inc.: developing the design of the large scale fuel cell stack.

Future Work

- Completing and testing of the coal injection and flyash removal system. Investigating the distribution of flyash particles on the anode surface.
- Evaluating the long term anode and cathode catalyst activity as well as interconnect durability.
- Design, fabrication, and test of a small scale (1-10 kW) coal fuel cell system
- key milestones:
  - Identification of the composition of the anode catalyst which catalyzes the formation of CO_2 with more than 80% selectivity at 750 ^{o}C.
  - Completion of the design of the fuel cell stack and selection of the key components.
  - Long term testing of the carbon fuel cell (1 month continuous operation)

Summary Table 1

Effect of CO_2 concentration on the carbon fuel cell power densities at 750°C		
CO_2 concentration (vol.%)	**Fuel**	**Maximum Power (mW/cm^2)**
0	Low Ash Carbon	38
25	Low Ash Carbon	41
50	Low Ash Carbon	39
75	Low Ash Carbon	69
100	Low Ash Carbon	51

Summary 1

- Relevance: Development of an effective anode catalyst for the electrochemical oxidation of coal/coke will significantly increase ($\geq$ 50%) the efficiency of the use of fossil fuels for electrical power generation with nearly zero emission.
- Approach:
  - Identification and test of the low cost anode catalysts, interconnect, fuel cell components for the design and fabrication of the coal fuel cell stack.
  - Development of an integrated coal fuel cell stack for the conversion of coal to highly concentrated CO_2 and electricity.

Summary 2

- Technical Achievements:
  - Effect of CO_2 concentration on the performance of the carbon fuel cell was studied. Addition of 75 vol.% CO_2 increased the fuel cell maximum power density up to 81% at 800 ^{0}C.
  - Maximum power density of 69 mW/cm^2 achieved at 800 ^{0}C with Low Ash Carbon.
  - Ceramic cement sealant materials exhibiting low leakage at high temperature (1.6-5.3% of inlet flow rate) have been identified.
- Technology Transfer/Collaboration:
  - Collaboration with the Ohio Coal Development Office and FirstEnergy Corp.
  - Working with Chemstress for the design of a fuel cell stack.
- Proposed Future Research:
  - Identification of the catalyst composition for the effective electrochemical oxidation of solid carbon fuels.
  - Investigation of the distribution of carbon and flyash particles on the surface of anode catalysts and inside of the fuel cell.