Development of Kilowatt-Scale Fuel Cell Technology

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Project ID#: FC070

Overview

Timeline

- Project start date: 6/01/2008
- Project end date: 6/30/2012
- Percent completed: 40%

Barriers

- Barriers addressed

  -Long term catalyst and fuel cell durability

  -System thermal management

Budget

- Total project funding
  - DOE share: $1,180,800
  - Contractor share: $296,433
- Funding received in FY09

  $250,722
- Funding for FY10

  $220,922

Partners

- The Ohio Coal Development Office
- FirstEnergy Corp.

Objectives - Relevance

Overall: 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.

2009

- Evaluate the long term anode and cathode catalyst activity as well as interconnect durability.
- Improve the coal injection and fly ash removal units.

2010

- Determine the effect of CO_2 product on the performance of the coal fuel cell.
- Study the long term electrochemical oxidation of coal.
- Investigate the integration of fuel cells in series and parallel for the coal fuel cell stack.
- Test the operating conditions of a steel coal injection unit.

Plan & Approach

Task 1: Investigate the effect of CO_2 on the anode catalyst activity and the performance of the coal fuel cell

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.

Task 4: Improve the coal injection and fly ash removal units.

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.

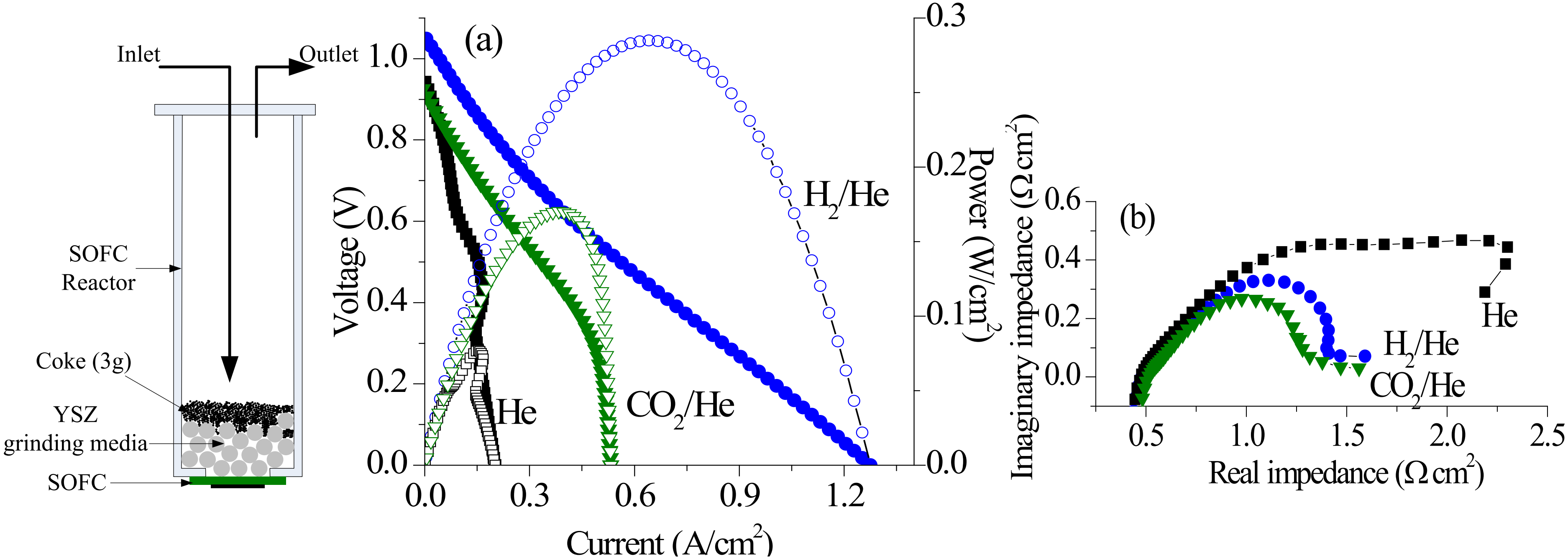
Technical Accomplishments/ Progress/Results

Milestones	Progress	Comments
Effect of CO_2 on the activity and performance of the coal fuel cell.	Exposure of the Ni anode to CO_2 has been demonstrated to improve the fuel cell performance by increasing formation of CO via the Boudouard reaction with solid carbon ($C + CO_2 \rightarrow 2CO$).	Cu and Ce oxide will be added to the Ni anode to enhance the activity of the anode catalyst for the electrochemical oxidation of C and CO.
Test of the long term electrochemical oxidation of coke on the fuel cell.	Long term electrochemical oxidation of coke was demonstrated .	The fuel cell energy conversion efficiency during long term testing will be further analyzed.
Integration of fuel cells in series and parallel for coal fuel cell stack.	Integration of the fuel cells in parallel were found to produce maximum power densities 30% higher than integration in series.	The performance of the stack cells will be analyzed in coke fuel, evaluating energy conversion efficiency.
Test of coal injection unit.	Injection of coal with a steel auger was investigated. Coal feeding rates higher than 0.1 g/min are needed to produce highly reactive coke fuel.	Different coal feeding rates and heating profiles will be investigated.

Technical Accomplishment - 1

Flowing CO_2 increases the performance of the coke fuel cell

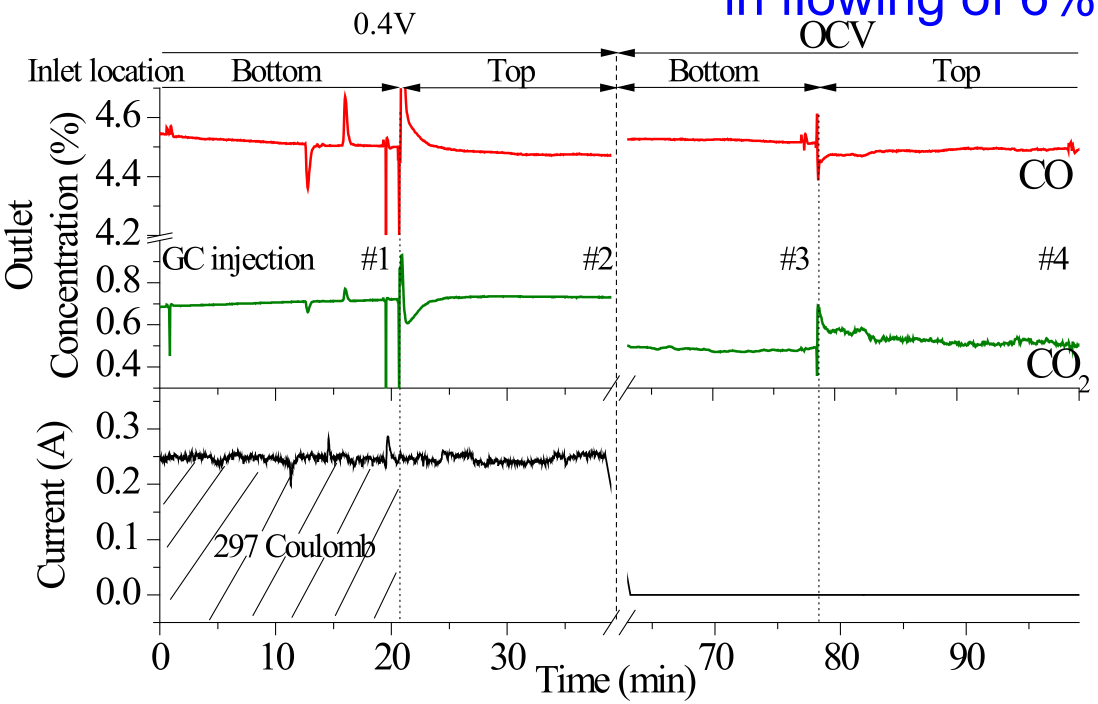
T = 775±25 C, Flow rate of H_2/He= 35/200 cc/min, CO_2/He = 35/200 cc/min

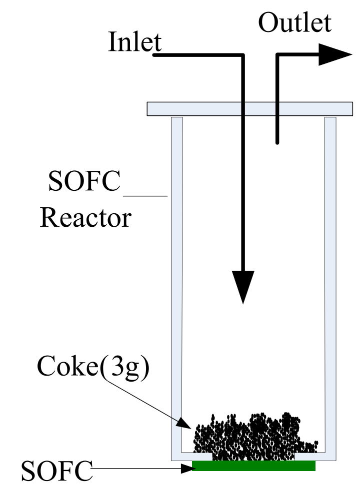


- 3 g of coke on a layer of YSZ pellets in contact with the Ni anode produced a max. power density of 0.09 W/cm² in flowing He, 0.180 W/cm² in flowing 15% v/v CO_2/He and 0.29 W/cm² 15 % v/v H_2/He.
- The ohmic resistance remained constant in flowing CO_2/He for 24 h.
- The power density in flowing He correlates to high polarization resistance.

Technical Accomplishment - 2

Determination of coke fuel cell energy efficiency at 775±25 °C in flowing of 6% CO_2





Setting			Inlet (%)		Effluent (%)			
#	Volt(V)	Inlet	CO_2	He	O_2	N_2	CO	CO_2
1	0.4	Bottom	6.08	93.92	0	<0.5	4.49	0.71
2	0.4	Top	6.08	93.92	0	<0.5	4.46	0.74
3	OCV	Bottom	6.08	93.92	0	<0.5	4.53	0.49
4	OCV	Top	6.08	93.92	0	<0.5	4.53	0.48

Thermodynamic efficiency calculation

$$\varepsilon_T = \frac{W_e}{\Delta H} = \frac{V \int I \cdot dt}{LHV \cdot F_{CO} \cdot U \cdot t} = \frac{0.4 \cdot 297}{282{,}980 \cdot 6.78 \times 10^{-4} \cdot 0.054 \cdot 20} = 57.3\%$$

$$LHV = Lower\ heating\ value\ of\ CO = 282{,}980 \left(\frac{J}{mol}\right)$$

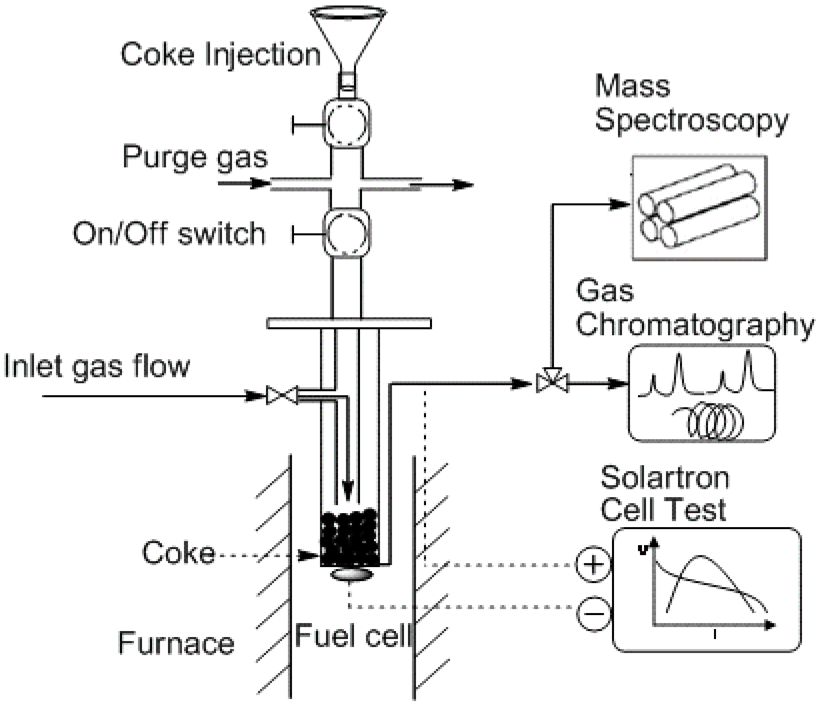
$$F_{CO} = Flow\ rate\ of\ CO\ produced\ from\ Boudouard\ rxn = 6.78 \times 10^{-4}\ (mol/min)$$

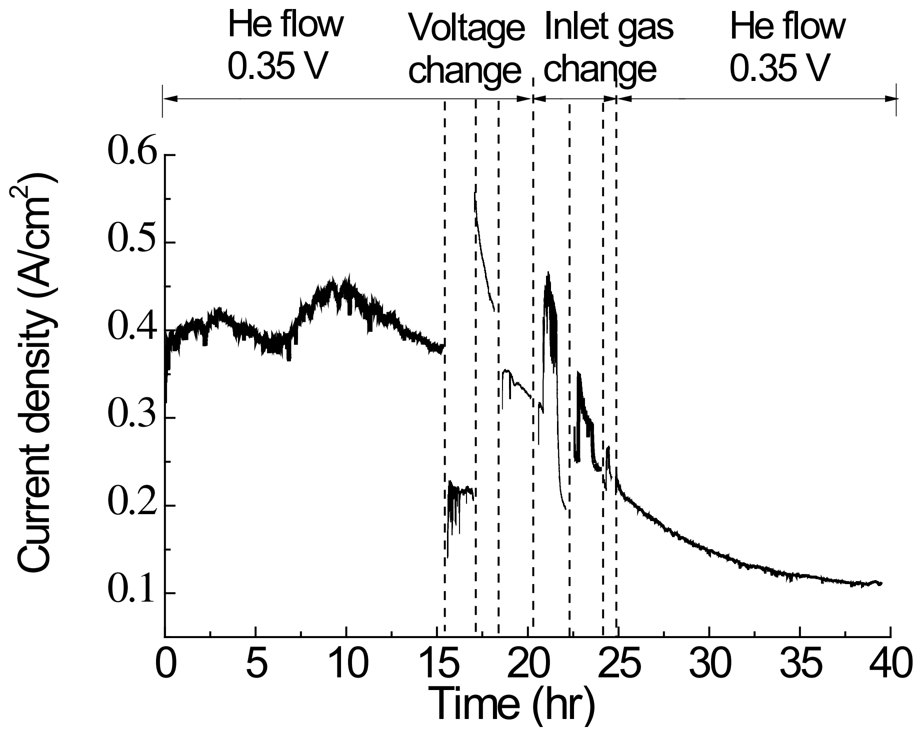
$$U = fuel\ utilization = 5.4\%$$

$$t = time = 20\ min$$

Technical Accomplishment - 3

Long term testing of the fuel cell in coke at 775 ± 25 °C

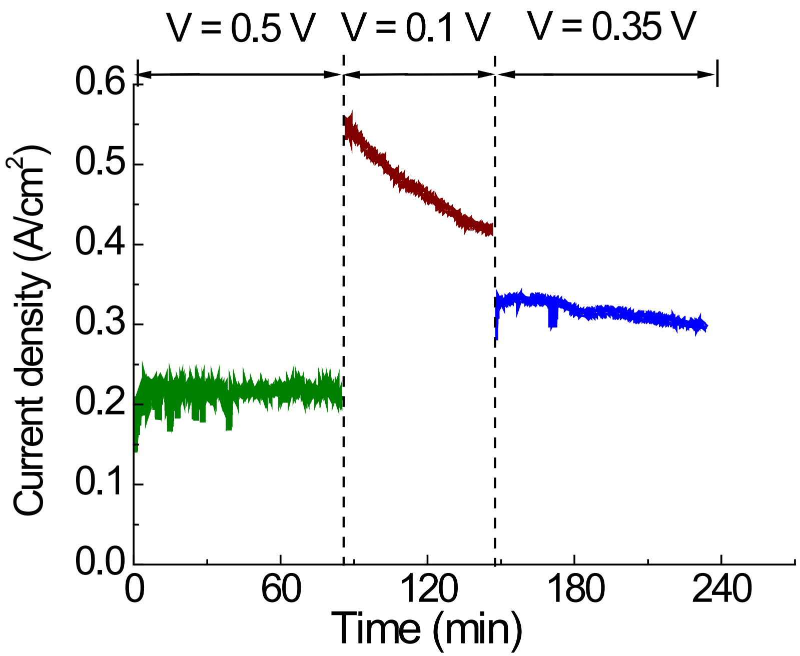




Note: 1. Voltage changed from 0.35 to 0.5, 0.1, and 0.35 volt, respectively
2. The inlet gas changed from He to He/H_2, He/CO_2, He/CO, respectively, while the voltage was kept at 0.35 volt

- Power generation from coke continued over 15 h at 775 °C (+/– 25 °C)

Fuel cell performance and exhaust composition of coke fuel cell under voltage load at 775 ± 25 °C



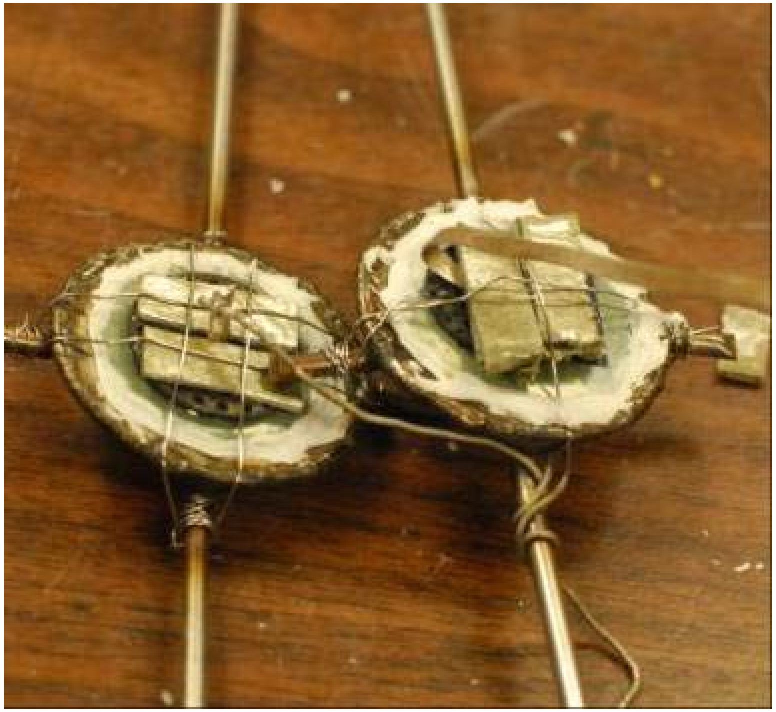
Voltage (V)	Current density (A/cm^2)	H_2 (%)	CO (%)	CO_2 (%)
	0.48	3..895	4.837	2.944
0.10	0.44	1.588	4.675	2.435
	0.40	---	4.618	2.281
0.35	0.29	0.634	3.903	1.087
0.50	0.22	0.290	3.890	1.086

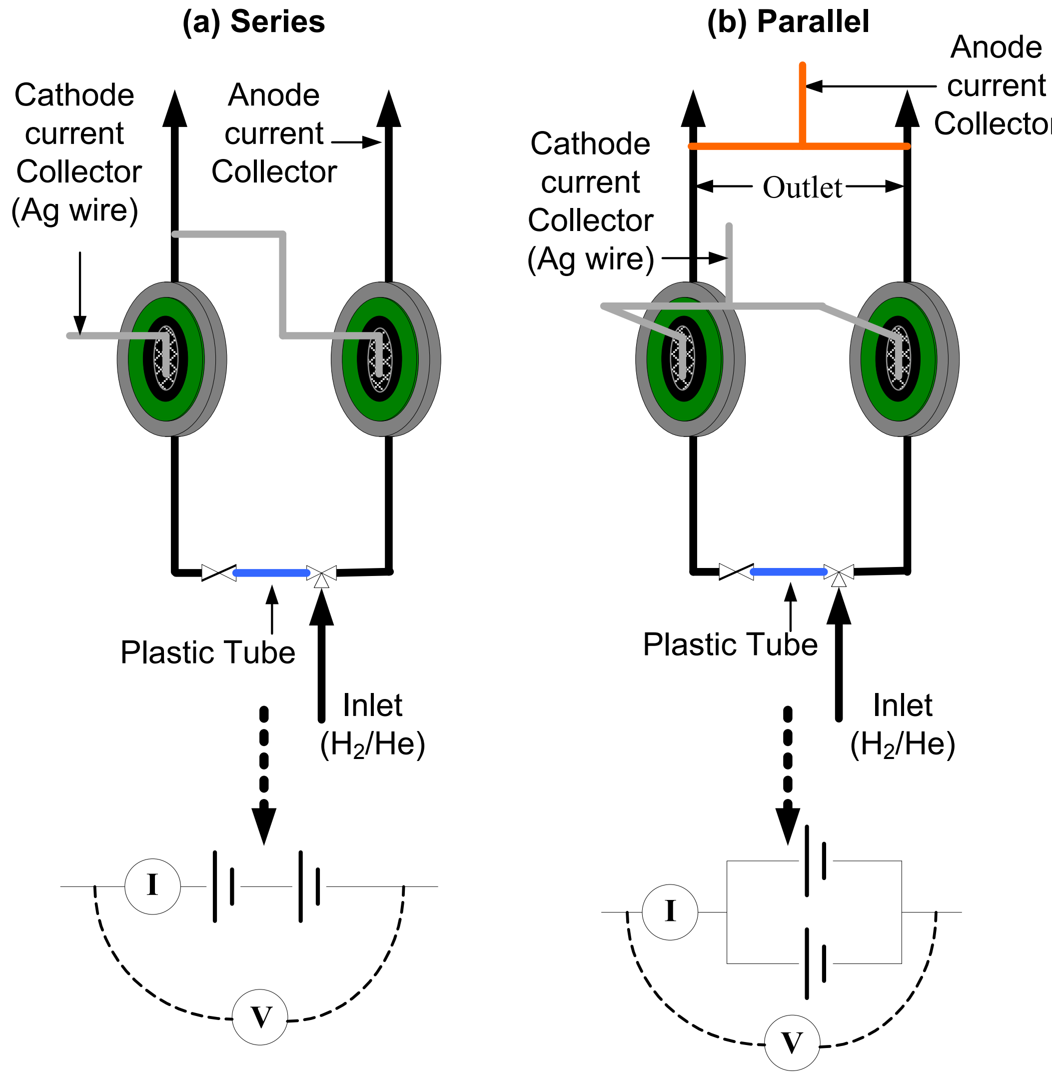
- The low voltage load had a decaying current densities versus time, whereas the current densities were relatively constant at high voltage loads.

- The composition of effluents changed when the voltage load was lowered to 0.1 (volt).

Technical Accomplishment - 4

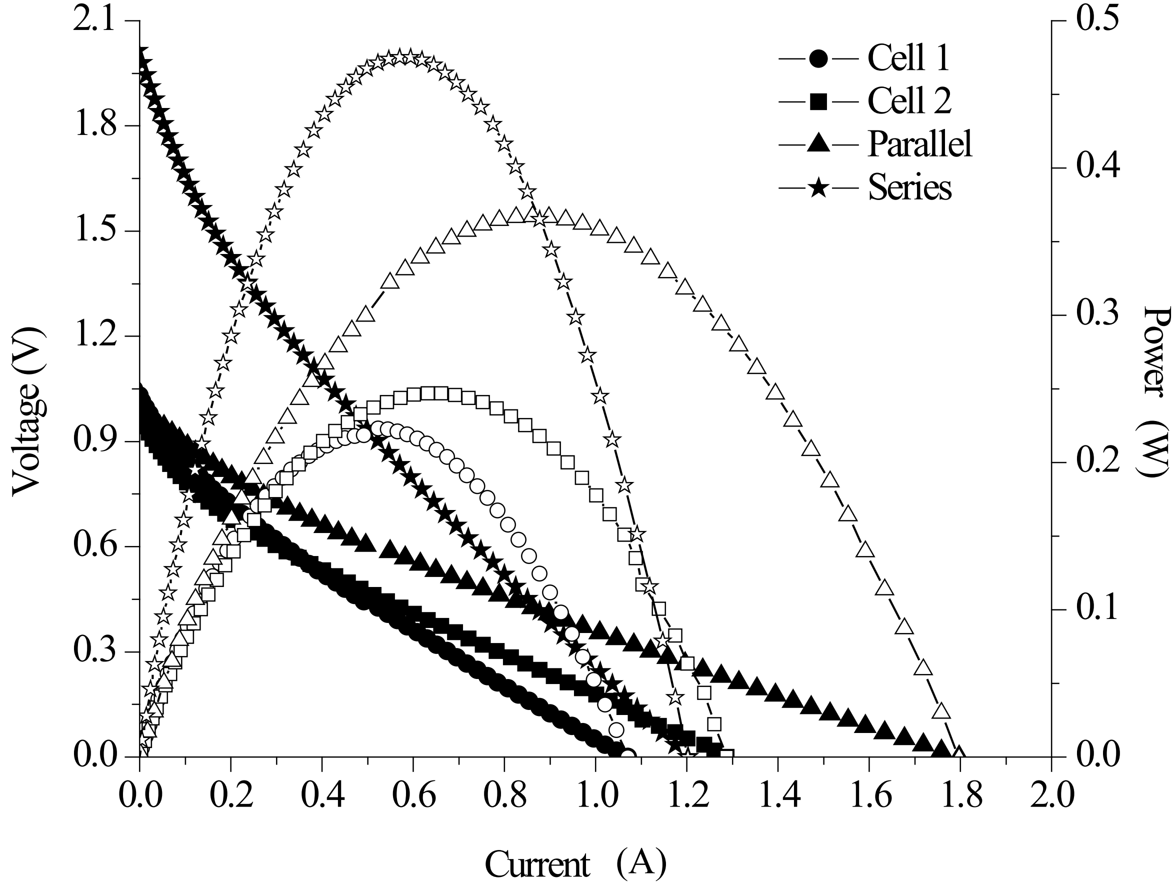
Integration of fuel cells in series and parallel





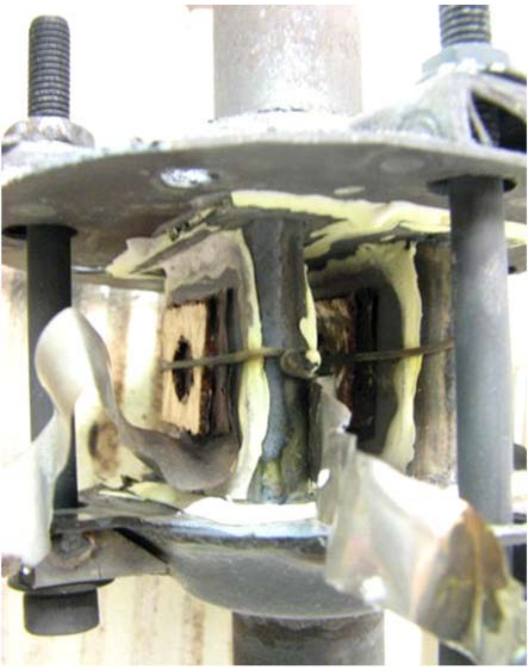
- Ag wire is connected to the cathode current collector.
- Fuel cell housing and tubing is connected to the anode.

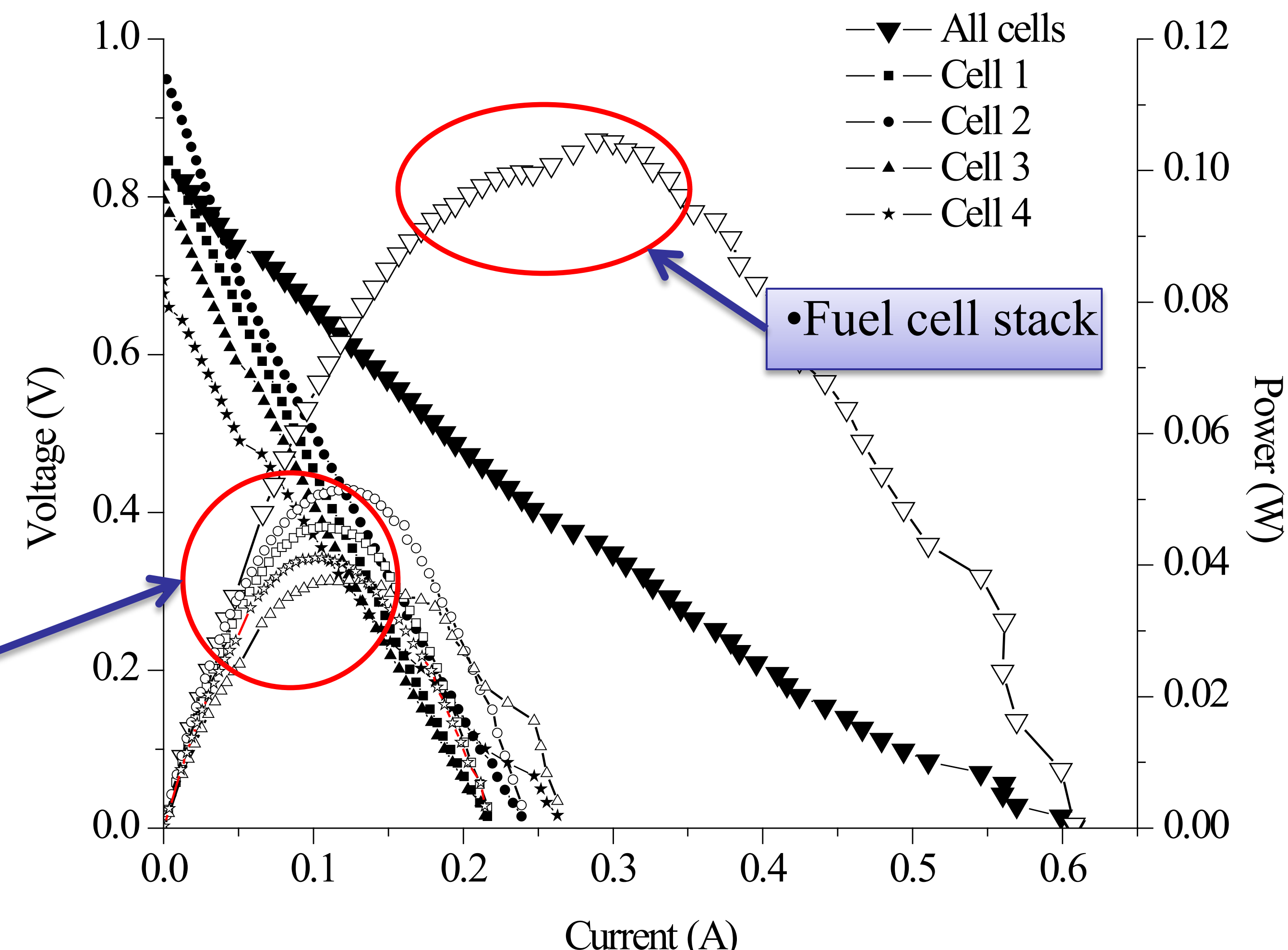
Fuel cell stack: series vs. parallel performance at 775± 25 °C



Fuel cell/Stack	OCV(V)	max I(A)	max P(W)	Ohmic R(ohm)	Polarization R(ohm)
Cell 1	1.03	1.05	0.223	0.52	1.68
Cell 2	0.96	1.26	0.247	0.38	2.02
Parallel	1.00	1.79	0.367	0.38	0.97
Series	1.98	1.18	0.475	0.81	3.19

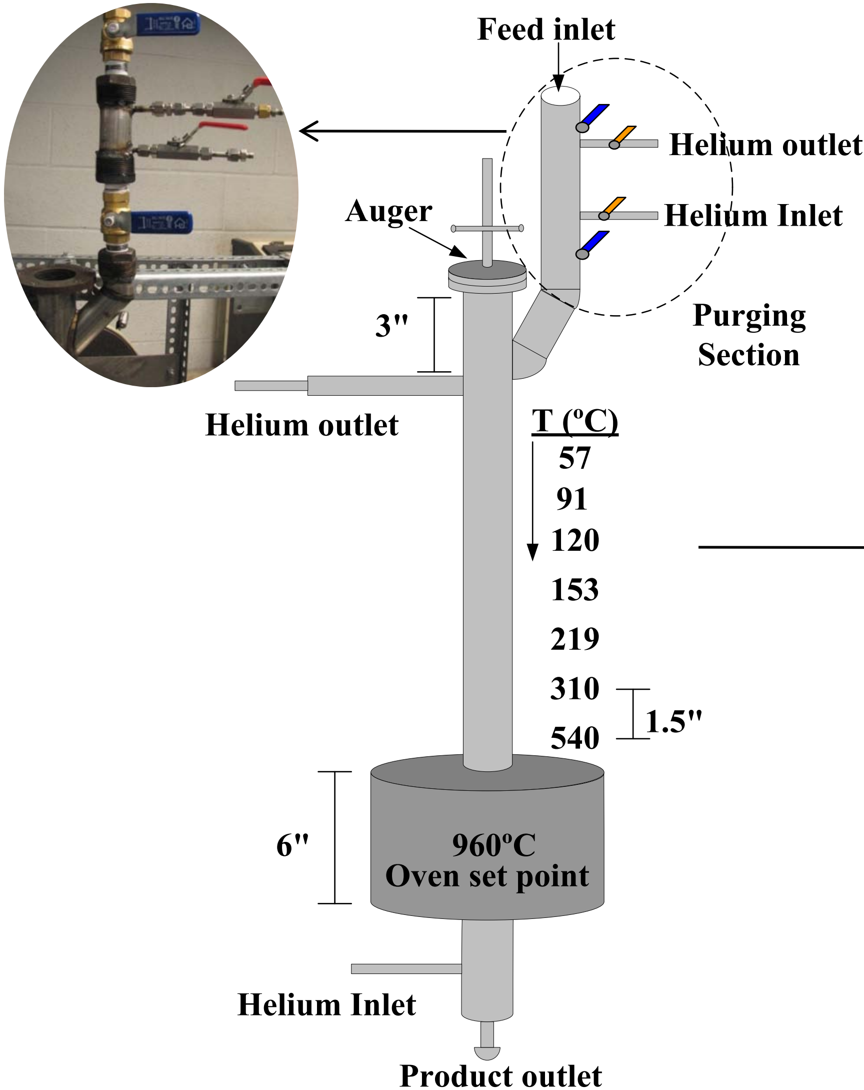
Fuel cell stack: Performance (2 cells/housing)



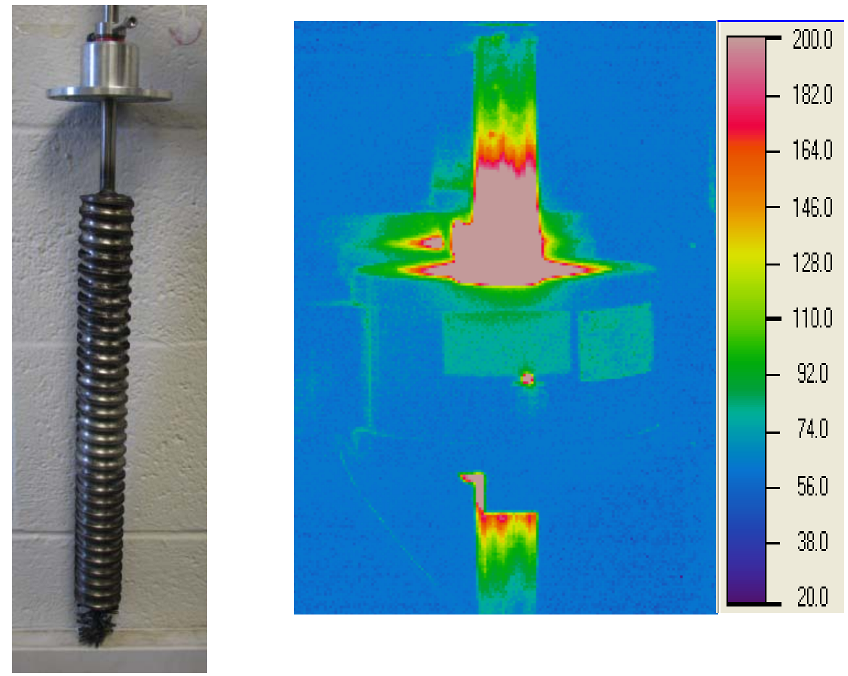


Technical Accomplishment - 5

Test of the coal injection unit with steel auger – Temperature distribution



Schematic of the coal injection equipment showing steady state temperature distribution



Temperature distribution along the auger at steady state (MikroSpec RT-M7500); the color scale is calibrated for 20-200 C.

Infrared characterization of coal and coke produced from the coal injection unit

Experimental procedure

coal

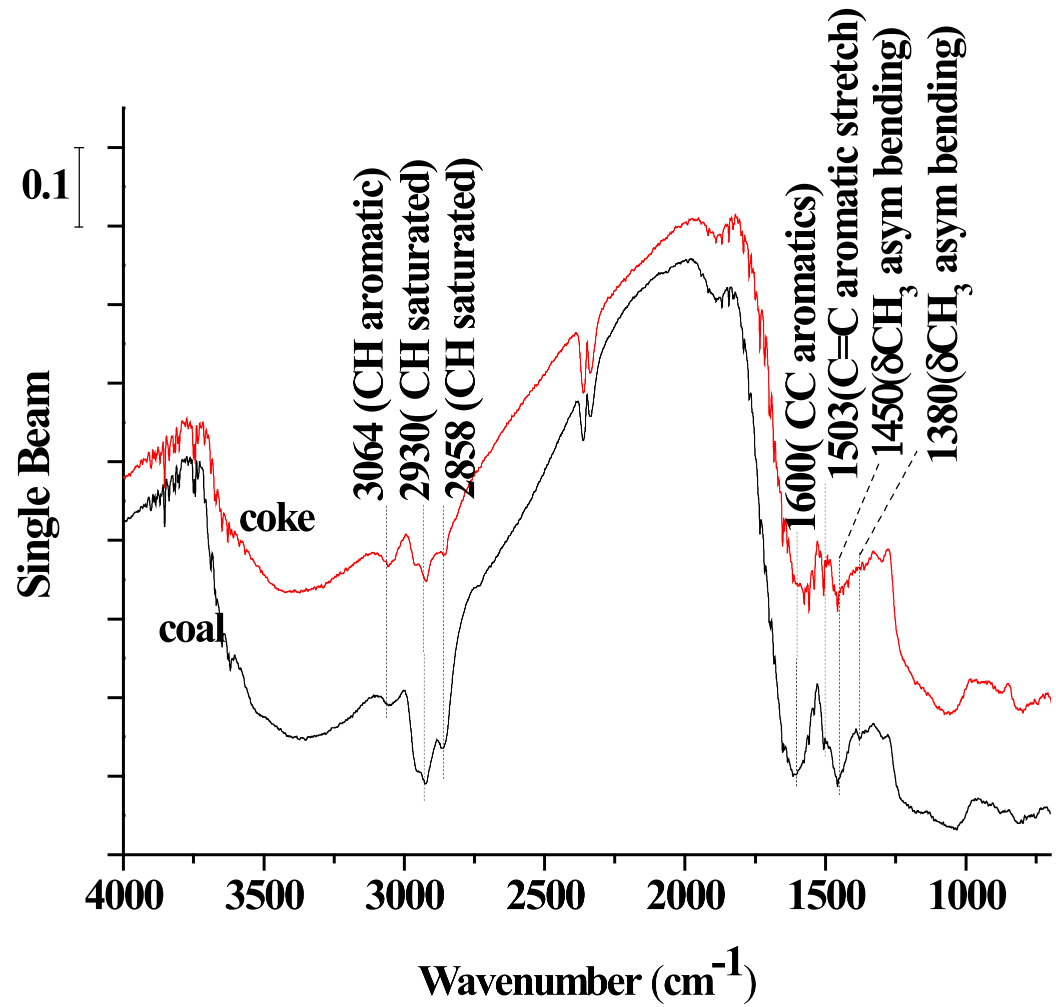
Purging with He for 1 hour (flow rate of 50 cc/min)

Heat to 960°C (heating rate: 4°C/min)

Screw feed the coal (inlet rate of 0.1 g/min)

coke

DRIFT spectra of Mansfield unit1 coal and coke



Summary Table 1

Comparison of power densities in coke flowing He, CO_2, and H_2 at 750 C		
Fuel	**Maximum Current (A/cm^2)**	**Maximum Power (W/cm^2)**
He/coke	**0.210**	**0.09**
He/coke/CO_2 (6% v/v)	**0.340**	**0.10**
He/coke/CO_2 (15% v/v)	**0.530**	**0.18**
He/coke/H_2 (15% v/v)	**1.270**	**0.29**

Summary

Relevance: Development of a high performance fuel cell for the electrochemical oxidation of coal/coke will significantly increase (>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.

Technical Achievements:

- The performance of the coke fuel cell was found to be higher in flowing CO_2 than in flowing He. Thermodynamic efficiency of more than 57 % has been achieved for coke fuel cell at 750 °C in 6% v/v CO_2.
- Long term testing of fuel cell for 15h has been demonstrated with coke fuel, producing a maximum power density of 0.1 W/cm^2 at 775 ^{0}C.
- The use of a steel auger for injection of coal was carried out. Heating profiles and coal feeding rates were evaluated.

Future Work

- Identify the most effective anode catalyst composition for the long-term electrochemical oxidation of solid carbon to CO_2 at 700-800 °C.
- Identify the low cost interconnect materials
- Complete testing of the coal injection and flyash removal units. Investigate of the distribution of flyash particles on the anode surface.
- Design, fabricate, and test of a small scale (1-10 kW) coal fuel cell system
- key milestones:
  – Identification of the composition of the anode catalysts which catalyzes the formation of CO_2 with more than 80% selectivity at 800 ^oC.
  – Identification and successful development of interconnects which cost 50% less than the present interconnects.
  – Completion of the design of the fuel cell stack and selection of the key components.

Collaboration

- Partners
  - The Ohio Coal Development Office (State): Focusing on the fundamental research on determination of the fuel cell efficiency.
  - FirstEnergy Corp (Industry): Addressing practical issues of the scaling up fuel cell stack.

- Technology Transfer:
  - Chemstress Co (Industry): Designing of the large scale fuel cell stack.