Development of Kilowatt-Scale Fuel Cell Technology

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Overview

Timeline

- Project start date: 6/01/2008
- Project end date: 5/31/2012
- Percent complete: 15%

Barriers

- Barriers addressed
  - A. Long term catalyst durability
  - E. System thermal management

Budget

- Total project funding
  - DOE share: $1,180,800
  - Contractor share: $296,433
- Funding received in FY08

  $356,916
- Funding for FY07

  $255,912

Partners

- Ohio Coal Development Office
- First Energy Corp.
- Chemstress Corp.

Objectives

- **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.
- 2008:
  - Investigate the factors governing the anode catalyst activity for the electrochemical oxidation of carbon in coal.
- 2009
  - Evaluate the long term anode and cathode catalyst activity as well as interconnect durability
  - Refine the coal injection and fly ash removal systems.

Approaches and Plan (I)

- **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.

Approaches 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.

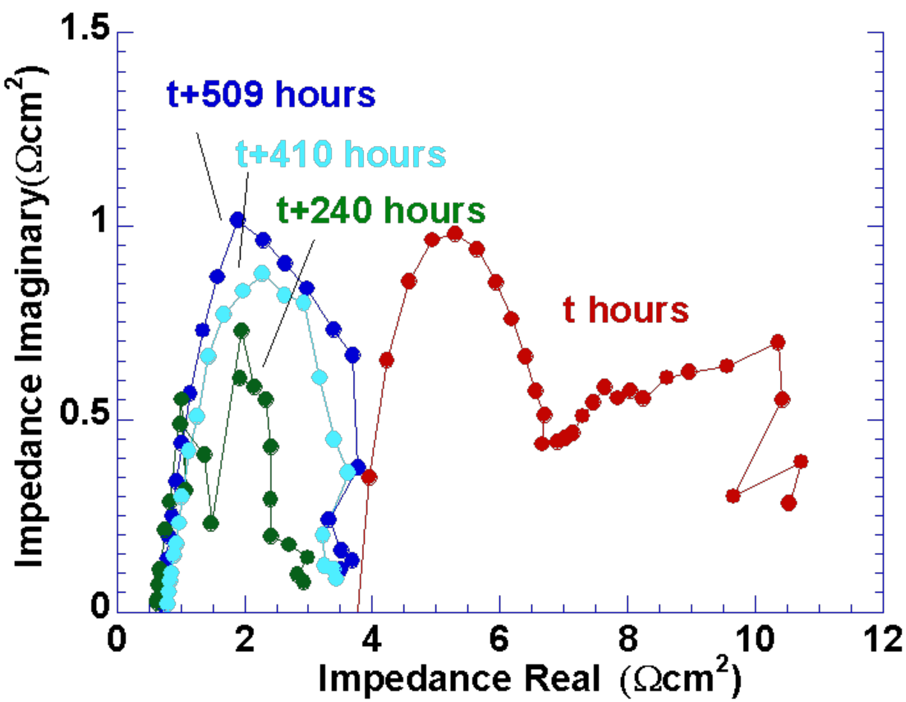
Technical Accomplishments/ Progress/Results

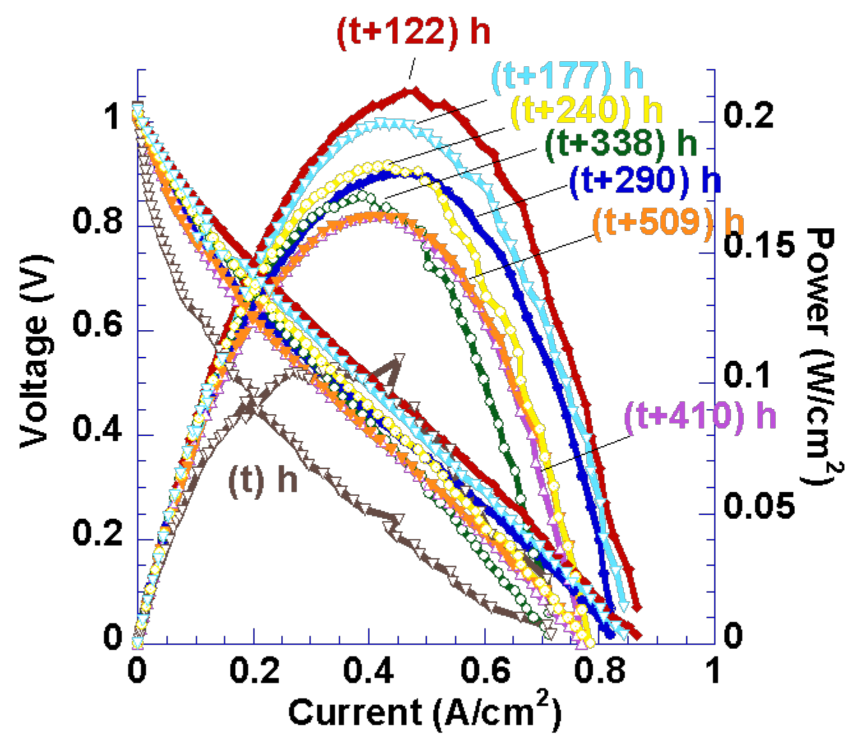
Milestones	Progress	Comments
Factors governing the anode catalyst activity	The Ni anode exhibit the activity for electrochemical oxidation of solid carbon fuel to CO as a major product at 850 °C	Cu and Ce oxide will be added to the Ni anode to enhance the electrochemical oxidation activity of the anode catalyst
Evaluation of long term durability of anode, cathode and interconnects	500 h of stable operation of anode, cathode and low cost interconnect has been demonstrated with H_2 fuel and air	The long term test will be conducted using low ash carbon as a fuel
Develop the process for fabrication of large scale fuel cell components	All of the fabrication equipment have been purchased and tested	Fabrication variables such as heating cycle and quality of slip will be evaluated
Coal injection and fly ash removal systems	Fabrication of the coal injection and fly ash removal system has been initiated	The system will be tested by the end of 6th quarter

Technical Accomplishment - 1

Stability of Low Cost Interconnect

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



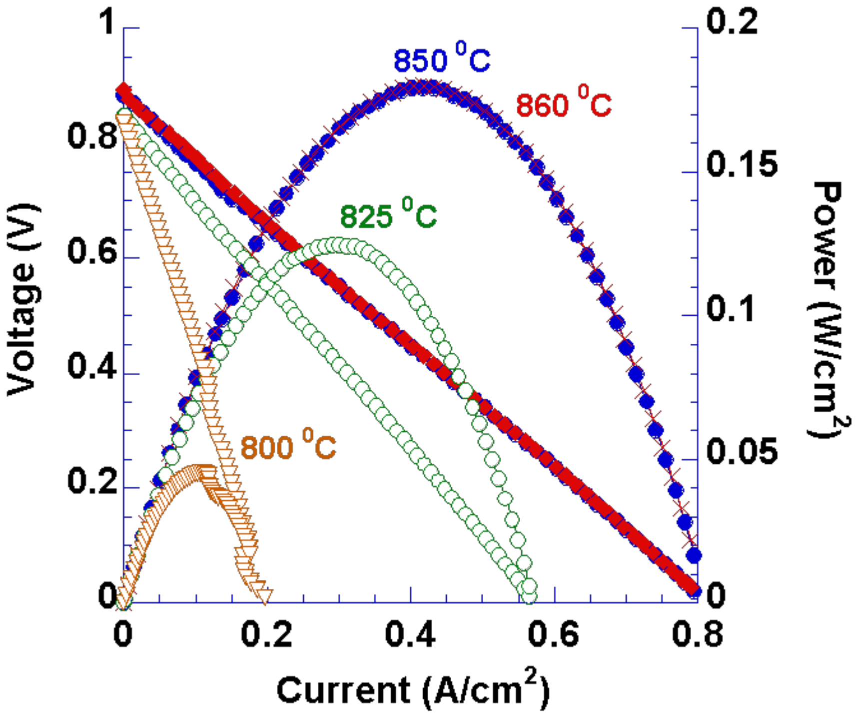


- No decrease in the Ohmic resistance was observed on the impedance plot after 500 h operation, showing the stability of the interconnect material.
- Increase in polarization resistance due to diffusion limitation of gas phase reactants and products led to decrease in the power density.
- The power density 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.

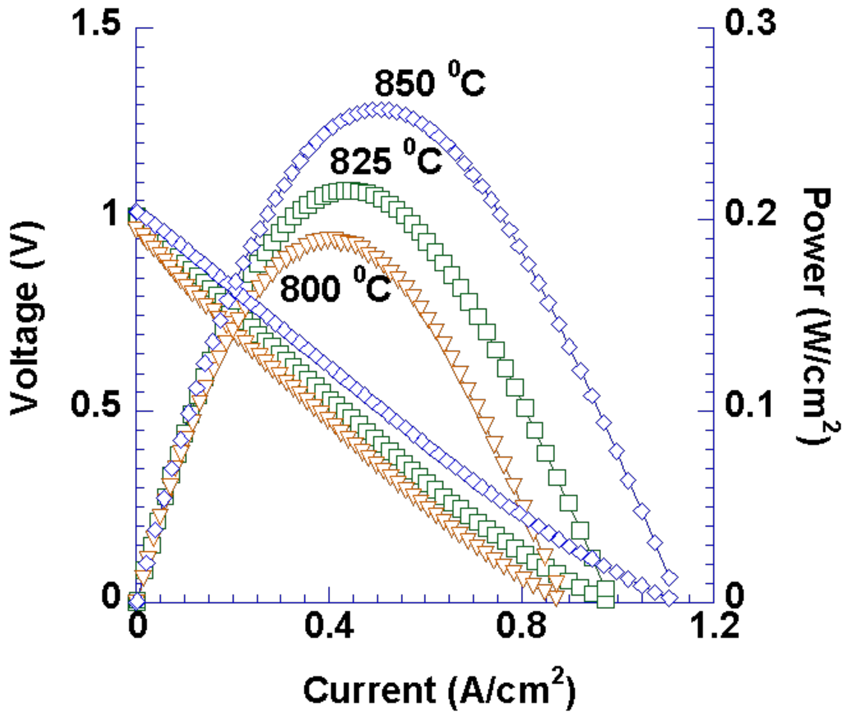
Technical Accomplishment - 2

V-I Performance of Low Ash Carbon Fuel at 800, 825 and 850 °C

(a) He/Low Ash Carbon over Ni/YSZ
Flow Rate He = 50 cc/min



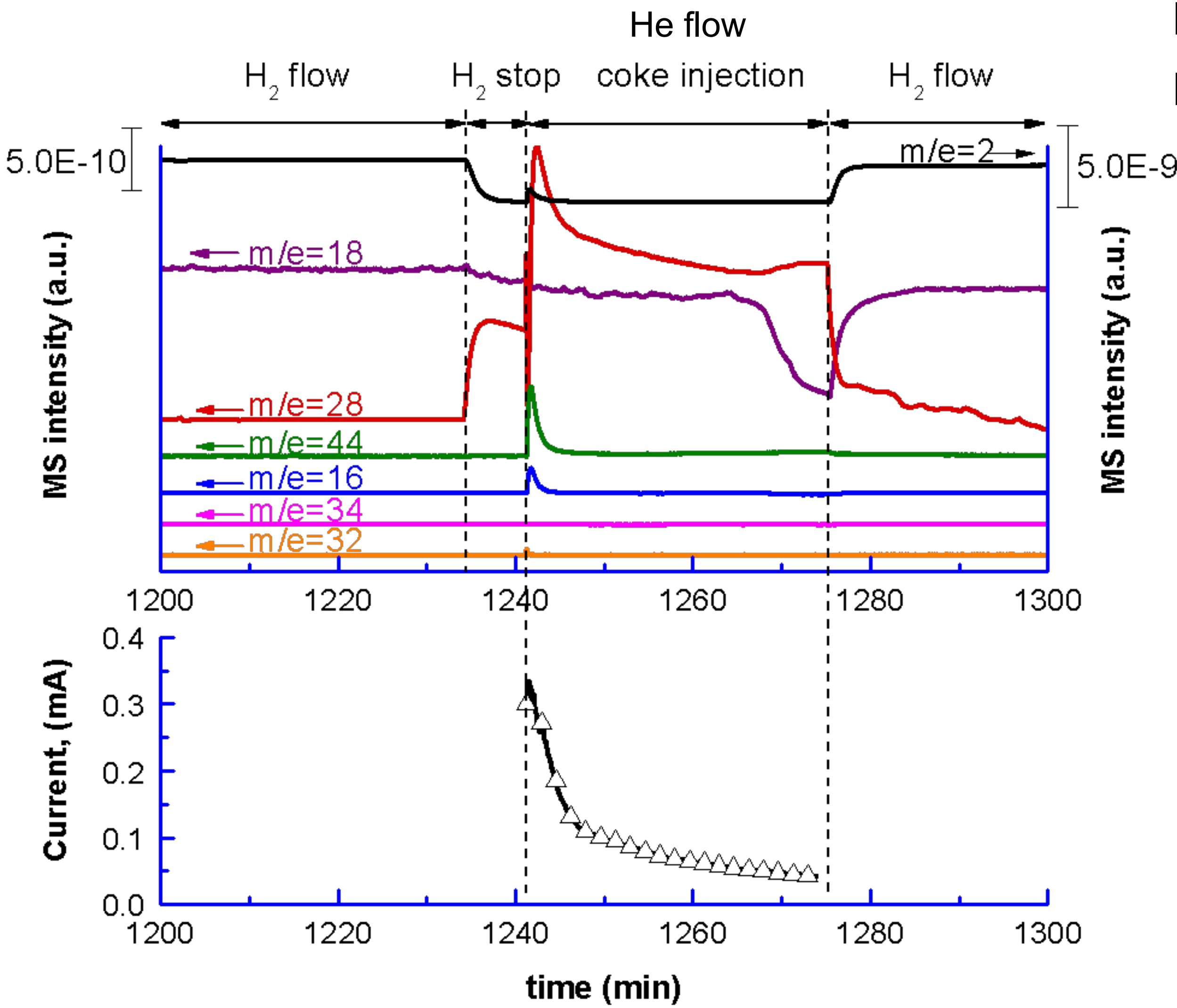
(b) He/H_2/Low Ash Carbon over Ni/YSZ
Flow rate He/H_2 = 80/80 cc/min



Electric power produced by Low Ash Carbon increased by 3.5 times when elevating the temperature from 800 to 850 °C.

Technical Accomplishment - 3

MS Profile and Current vs. Time Plot for Ohio #5 Coke SOFC at 800 °C



Flow rate H_2 = 80 cc/min

Flow rate He = 150 cc/min

- Major products are CO and CO_2.
- Current dropped from 300 mA to almost 0 mA in 40 minutes due to fly ash accumulation on the anode.

Technical Accomplishment - 4

Efficiency of Direct Carbon SOFC

- **Assumption - Electrochemical oxidation of Ohio#5 coke produced CO_2 .**
- **Efficiency calculated on the basis of data in the previous slide**

$$w_e = A \cdot V \cdot \int i \cdot dt$$

where

i = instantenous current density (A/cm^2)

A = Fuel cell active area (cm^2)

V = Fuel cell voltage $(Volt)$

dt = time (sec)

$$\int idt = 183\ (C/cm^2)$$

$$A = 1\ (cm^2)$$

$$V = 0.56\ (Volt)$$

$$w = 102.8\ (J)$$

$$\Delta H = LHV \cdot F_{CO_2} \cdot U \cdot t$$

where

U = fuel utilized (%)

LHV = Lower heating value of Carbon (J/mol)

F_{CO_2} = CO_2 flowrate (mol/sec)

U = fuel utilized (%)

t = time (sec)

$$F_{CO_2} \cdot t = 575\ \mu mol$$

$$U = 100\%$$

$$LHV = 355.2\ (kJ/mol)$$

$$\Delta H = 204.2\ J$$

The **efficiency** ξ was calculated as

$$\xi = \frac{102.8\ J}{204.2\ J} = 50.3\%$$

Summary Table 1

Comparison of Power Densities for Low Ash Carbon at 800, 825 and 850 °C		
Temperature (°C)	**Fuel**	**Maximum Power (W/cm^2)**
800	He/Low Ash Carbon	0.05
825	He/Low Ash Carbon	0.13
850	He/Low Ash Carbon	0.18
800	He/H_2/Low Ash Carbon	0.19
825	He/H_2/Low Ash Carbon	0.22
850	He/H_2/Low Ash Carbon	0.26

Summary Table 2

Comparison of Efficiency of Various Fuels in SOFC				
T (°C)	Fuel	Efficiency calculated as the ratio of electrical work over enthalpy change of the oxidation (ξ_V %)	Electrochemical Efficiency (ξ_V %)	Net Efficiency [1,c] (ξ_{Net} %)
800	H_2	34.3	57	40
800	Ohio #5 Coke	50.3[a]	54.6	54.8
850	Low Ash Carbon	58.6[a]	44.1	44.2
850	Low Ash Carbon	25.6[b]	44.1	44.2

a = Assumed that electrochemical oxidation of carbon resulted in CO_2 only
b = Assumed that electrochemical oxidation of carbon resulted in CO and CO_2 only
c = 100% fuel utilization

Ideal thermodynamical efficiency $\rightarrow$ $\xi_{T,ideal} = \frac{\Delta G(T,P)}{\Delta H(T,P)} = 1 - \frac{T \cdot \Delta S(T,P)}{\Delta H(T,P)}$

Electrochemical efficiency $\rightarrow$ $\xi_V = \frac{V(i)}{E^o}$

Net efficiency [1]$\rightarrow$ $\xi_{Net} = \left(\frac{\Delta G_T}{\Delta H_{298}}\right) \times \frac{V(i)}{E^\circ} \times \mu$

V(i) = Fuel cell operational voltage, E^0= Ideal Nernst potential, μ = Fuel utilization

1. Cooper J.F.,Cherepy,N.,Berry,G.,Pasternak, A., Surles, T., Steinberg, M., *Proc. – Electrochem. Soc.* **2001,** 2000-20, (Global Climate Change), 78-90

Summary Table 3

Stability Test Results of a Low Cost Interconnect	
Time (h)	**Power Density (W/cm^2)**
t	0.1
t+122	0.21
t+177	0.20
t+240	0.18
t+290	0.17
t+338	0.18
t+410	0.16
t+509	0.16

Summary 1

- Relevance:
  Development of an effective anode catalyst 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.

Summary 2

- Technical Achievements:
  - Stable performance for 500 h of a low cost interconnect has been demonstrated with H_2 fuel and air.
  - Maximum power density of 0.18 W/cm^2 achieved at 850 ^0C for Low Ash Carbon.
  - Thermodynamic efficiency of more than 50 % has been demonstrated for carbon-based SOFC at 800 ^0C.

- 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.

Future Work

- Identify the most effective anode catalyst composition for the long-term electrochemical oxidation of solid carbon fuels at 800 ^{o}C.
- Identify the low cost interconnect materials.
- Completion and testing of the coal injection and fly ash removal system. Investigation of the distribution of flyash particles on the anode surface.
- Design, fabrication, 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 ^{o}C.
  - 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: 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:
  - Chemstress Co: developing the design of the large scale fuel cell stack.