Development of Kilowatt-Scale Coal Fuel Cell Technology

Steven S.C Chuang (PI)
The University of Akron
May 15, 2012

Project ID #
FC070

Overview

Timeline

- Project start date: 6/01/2008
- Project end date: 05/31/2012
- Percent complete: 90%

Barriers

- Barriers addressed
  - Long term catalyst durability
  - System thermal management

Budget

- Total project funding
  - DOE share: $ 1,675,800
  - Contractor share: $ 475,068
- Funding received in FY11: 0
- Funding for FY12: 0

Partners

- Ohio Coal Development Office (OCDO)
- FirstEnergy Corp.

Project 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.

- 2011
  - Develop a low cost process for the large scale fabrication of fuel cell components by tape casting and screen printing methods.
  - Test the long term durability of fuel cell components

- 2012
  - Test the effect of operating conditions (Temperature, Voltage load, and concentration of CO, CO_2 and H_2O) on the performance and energy efficiency of the coal fuel cell.
  - Investigate the integration of coal fuel cells in series and parallel stack configurations.

Approach – Milestones (I)

Planned Milestone	Progress Notes	Comment	% Comp
Investigate the factors governing the anode catalyst activity.	Determined the effect of H_2O on the activity of the anode catalyst for electrochemical oxidation of carbon in coal	Addition of 3 wt% H_2O to the anode compartment of the coal fuel cell produce current densities as high as 180 mA/cm^2, representing an 40% performance improvement	90%
Investigate the nature of carbon fuels on the fuel cell performance	Investigated the reactivity of different carbon fuels by IR spectroscopy and impedance spectroscopy	The fuel cell performance (voltage –current characteristics) were correlated to the –CH and -OH functional groups of the carbon fuel	90%

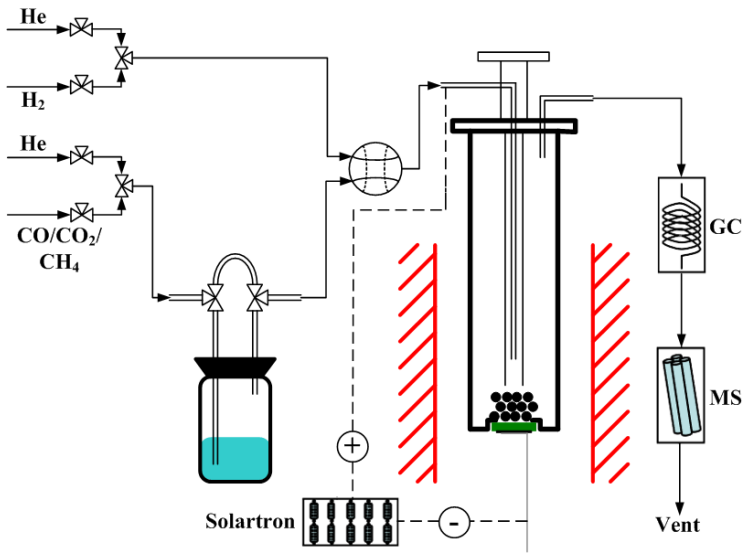
Approach – Milestones (II)

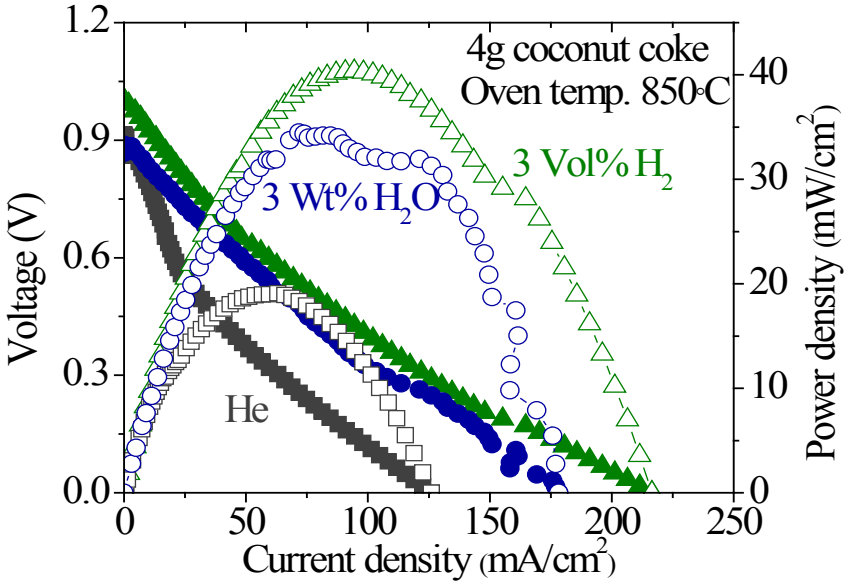
Planned Milestone	Progress Notes	Comment	% Comp
Develop a low cost process for fabrication of large scale fuel cell components	Developed a tape casting/screen printing procedure for the fabrication of low cost and reproducible fuel cells	Screen printing of LSM/YSZ cathodes (60/40 wt%) and firing at 1100 °C improved fuel cell reproducibility, facilitating production of batches as large as 100 units	90%
Integrate the fuel cell components into a coal fuel cell stack	Evaluated the integration of fuel cells in parallel and series configuration	Integration of the fuel cells in series configuration resulted in expected voltage build-up in coconut coke.	90%
Evaluate the long term anode and cathode catalyst activity as well as interconnect durability	Investigated the stability of the fuel cell integrated in series configuration	Testing of the fuel cell stack in series configuration in CH_4 fuel revealed high stability up to 100 h of continuous operation.	90%

Technical Accomplishment I

Investigate the factors governing the anode catalyst activity

Effect of H_2O on performance of coal based fuel cell



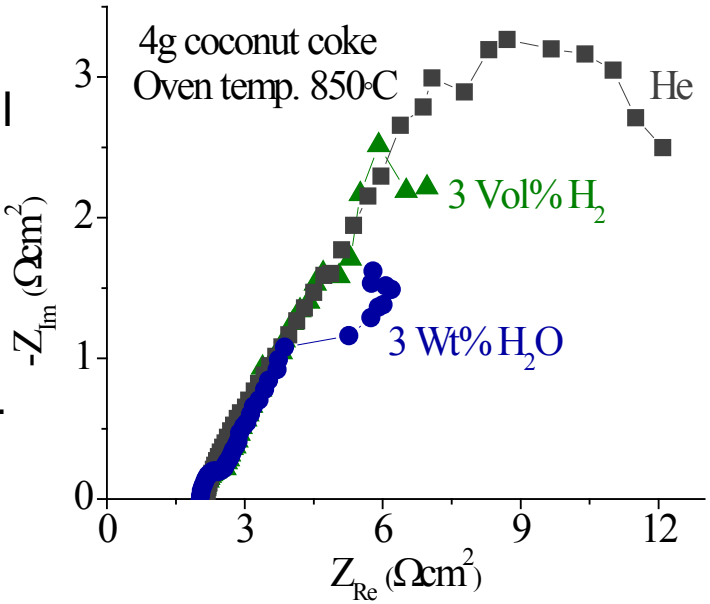


Coke + H_2O vs. Coke

- Enhanced the power density of coke fuel cell by 80%.
- Reduced polarization resistance by 50%.

Coke + H_2O vs. Coke + 3 Vol% H_2

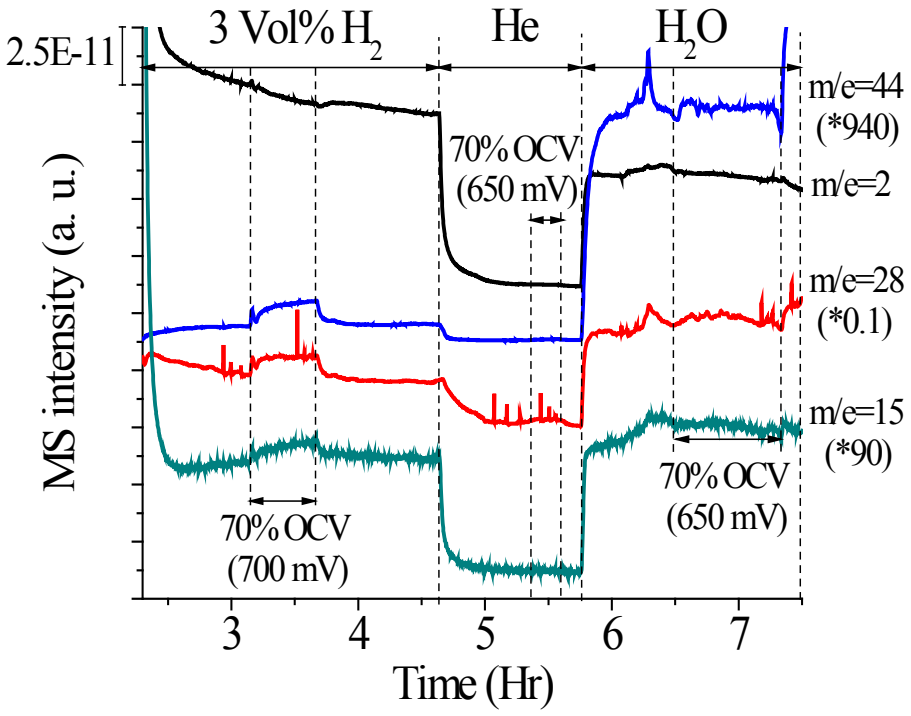
- 3 Vol% H_2 showed 15% more power density.
- Presence of H_2O reduced polarization resistance by 10%.

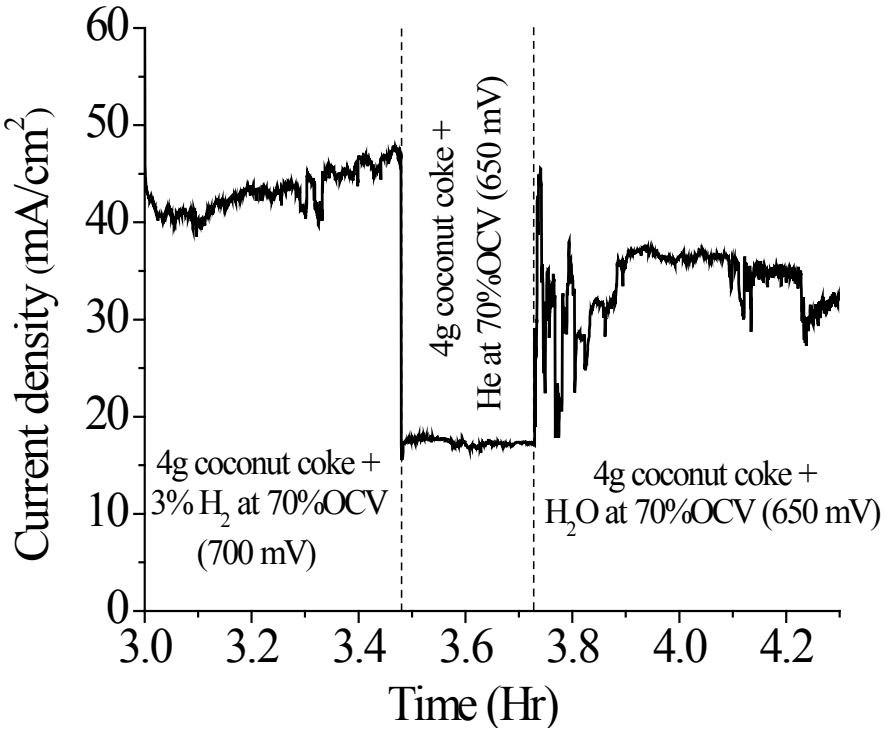


Technical Accomplishment I

Investigate the factors governing the anode catalyst activity

Formation of gas products during continuous testing with 3 wt% H_2O





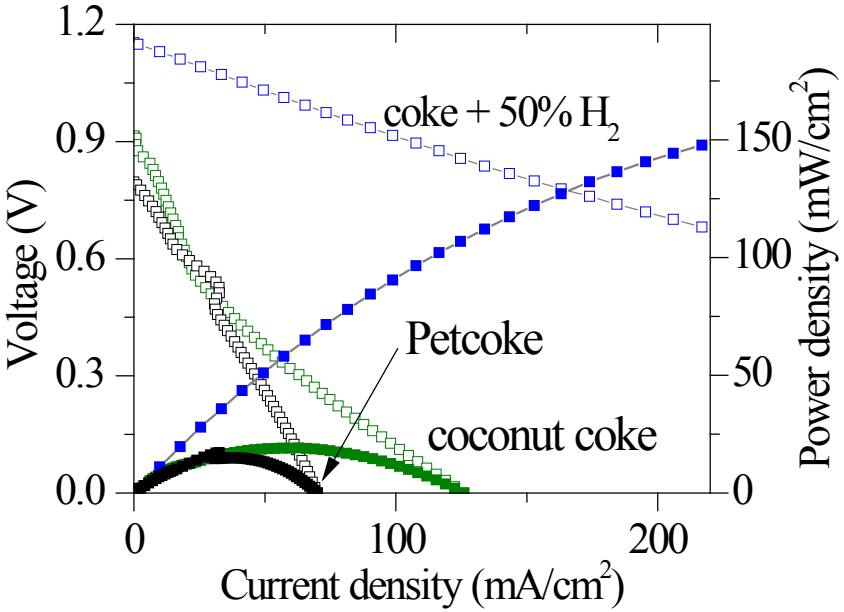
- Presence of H_2O increased the amount of CH_4, CO and CO_2 production
- Water could produce almost similar current density with 3 Vol% H_2.

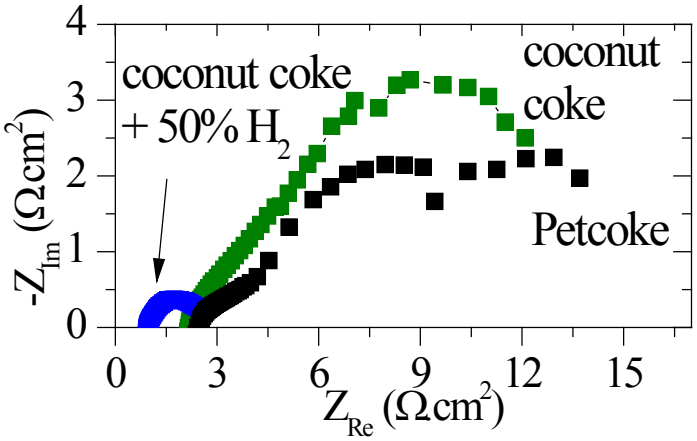
- Water could be a good substitution for H_2 in coal based fuel cells due to its similar performance and higher rate of coke gasification reactions.

Technical Accomplishment II

Study of the reactivity of carbon fuels

Performance of coal-based fuel cell in coconut coke and Petcoke



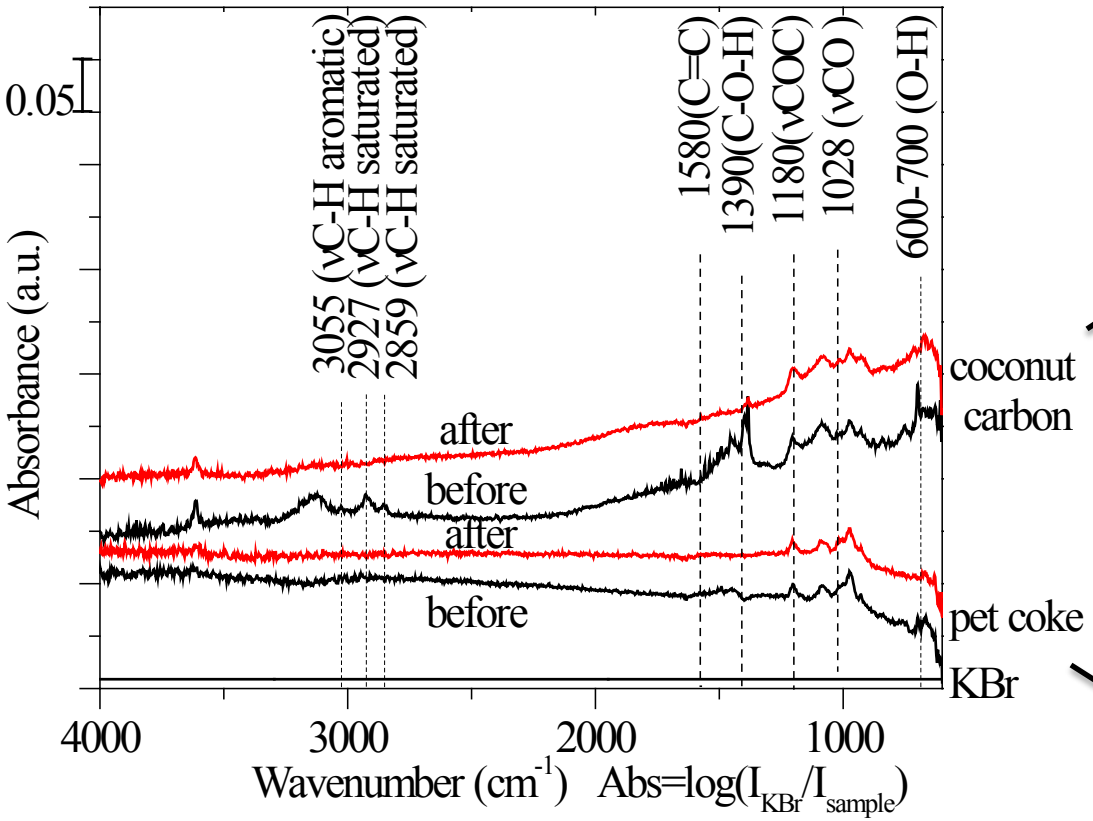


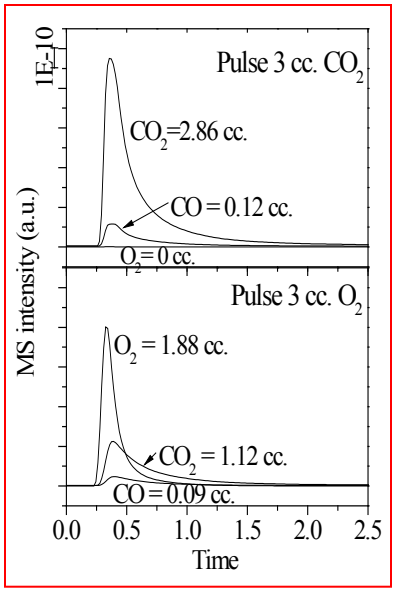
- Maximum current density of the fuel cell operated with coconut coke was 19 % of that with H_2, while Petcoke produced 9 % of that with H_2.
- Ohmic resistance and polarization losses of the fuel cell with Petcoke were higher than those with coconut coke.

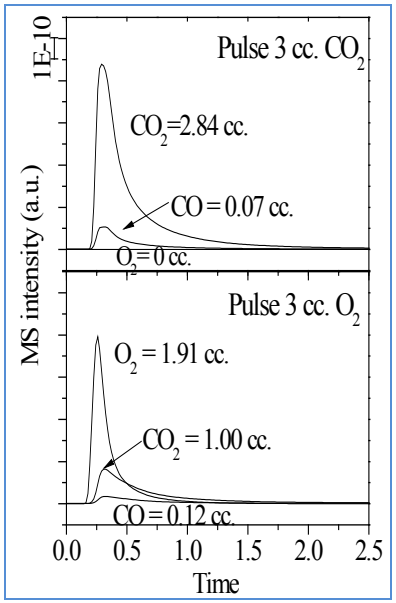
Technical Accomplishment II

Study of the reactivity of carbon fuels

Carbon characterization – Gasification with 3-cc pulse of CO_2 and O_2 at 600 °C







➢Coconut coke has more active –CH, -OH surface functional groups and more reactive toward gasification with CO_2 and O_2

Technical Accomplishment III: Fabrication of large scale fuel cells

Revise fuel cell material selection to improve performance to achieve the milestone of developing low cost process for fabrication of large scale fuel cell components

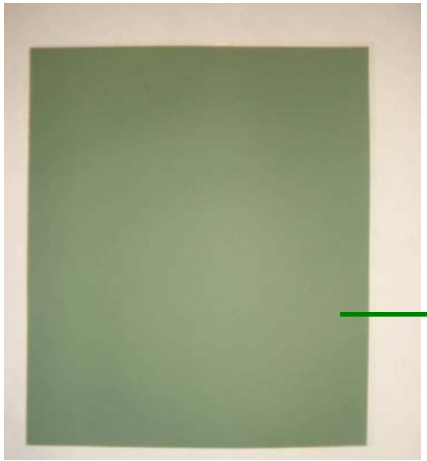
- Cathode modification:

a) Changing LSM/YSZ ratio from 60/4%0 to 70/30 %

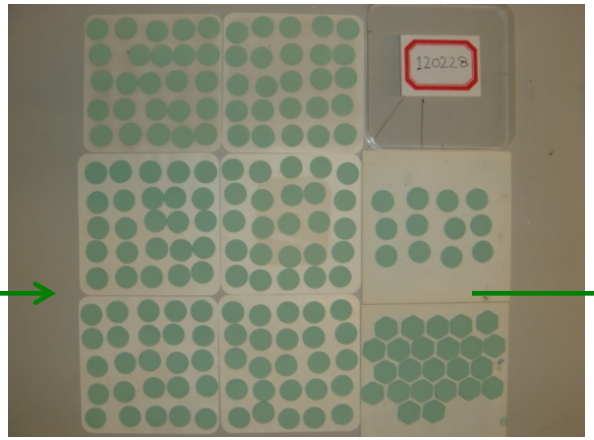
b) Decreasing the cathode sintering temperature from 1250 C to 1100 C. Maximum current density increased ~30 %.

- Replacing 8YSZ by 6ScCeSZ

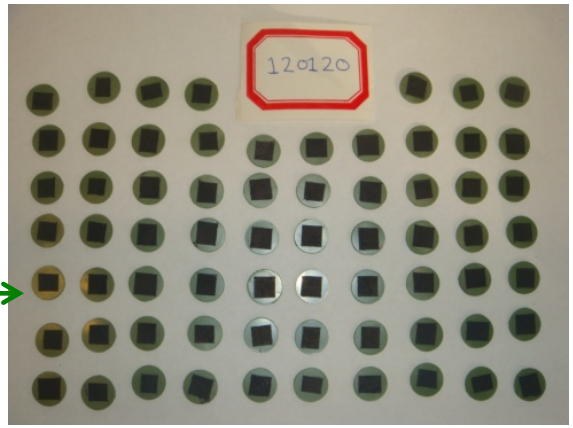
Maximum current density with respect to those of 8YSZ electrolyte cells increased by a factor of ~ 2.



Co-cast cell Layers



Cut tapes with laser cutter

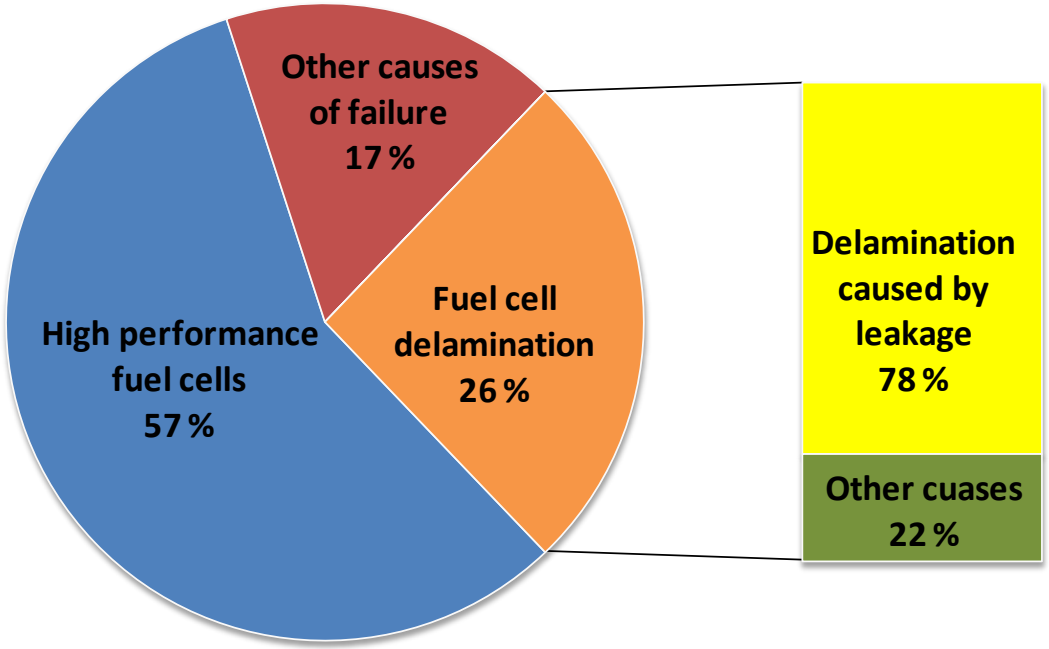


Firing and Screen Printing

Technical Accomplishment III

Statistical analysis of fabricated fuel cells and failure reasons

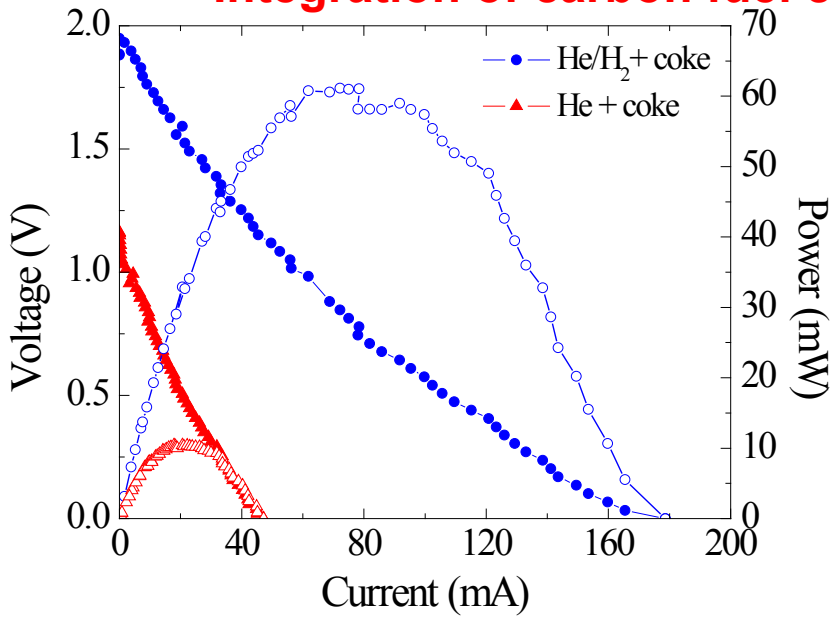
Batch No.	% of high performance fuel cells	Causes of low performance
110822	50% (4 of 8)	Cell deformation, Contamination
110613	50% (2 of 4)	Others
110719	20% (1 of 5)	Setup failure
110919	70% (9 of 13)	Poor cathode current collector
110617	80% (4 of 5)	Others

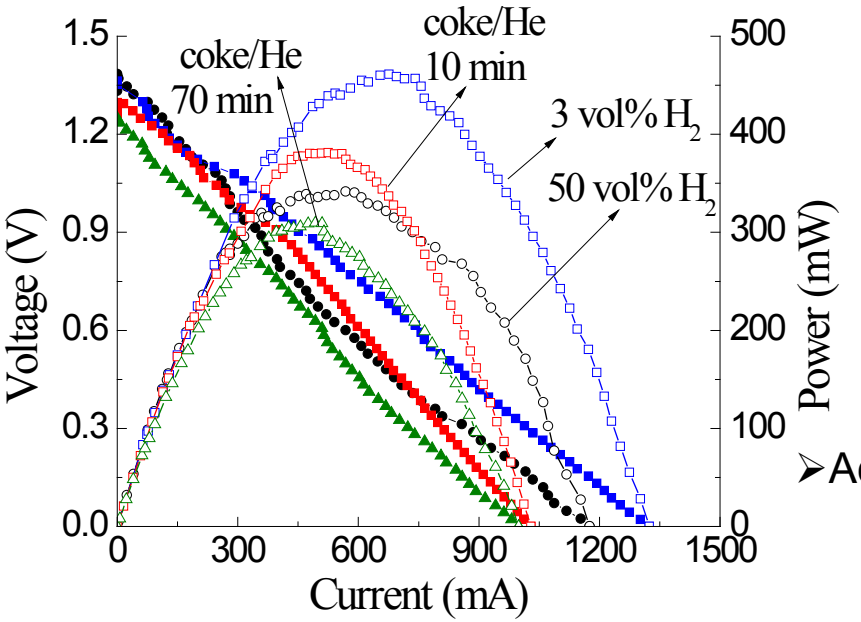


High performance fuel cells:
Max. current > 160 mA/cm^2
OCV > 900 mV

Technical Accomplishment IV

Integration of carbon fuel cells in series and parallel configuration



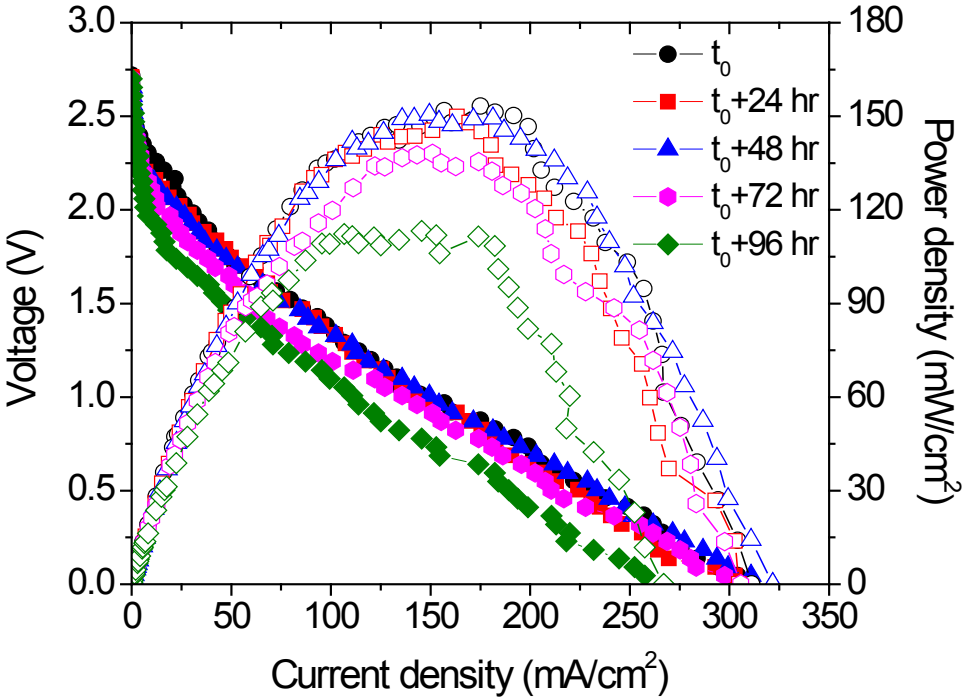


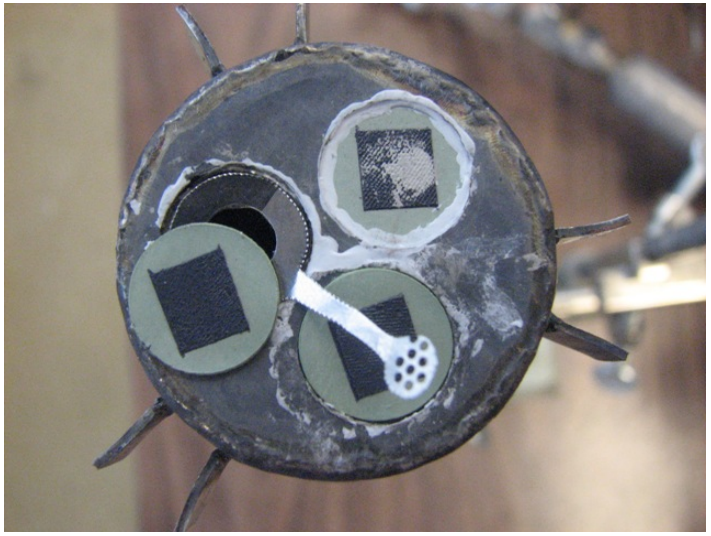
- Achieving high voltage by series connection of fuel cells

Technical Accomplishment V

Evaluation of long term anode catalyst activity

Continuous operation of series fuel cell stack in CH_4





Operating temperature: 750˚C

Gas stream: 100 sccm He/CH_4/CO_2 (25 vol% CH_4, 25 vol% CO_2)

➢ 3-Ni/YSZ anode fuel cells in series configuration exhibited long term stability in CH_4 fuel. The performance dropped by 12% after 100 hr of operation.

Collaboration

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

- Technology Transfer:
  - Chemstress Co (Industry): Large scale fuel cell stack design.

Future Work

- Further testing of the coal injection and fly ash removal units.
- Demonstrate the long-term performance and durability of the fuel cell stack in series and parallel configuration.
- Further test of a small scale (< 10 kW) coke/coal fuel cell system.

Key milestones:

  - Improve the coal injection and fly ash removal system.
  - Integrate the fuel cell components into the coal fuel cell stack.
  - Develop a operation and control system for the coal fuel cell stack.

Summary I

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.

Summary II

- **Technical Achievements**

-The fuel cell performance was correlated to the –CH and -OH functional groups of the carbon fuel. Presence of surface functional groups makes the carbon fuel more reactive toward gasification with CO_2 and O_2.

- Screen printing of LSM/YSZ cathodes (60/40 wt%) and firing at 1100 °C improved fuel cell reproducibility, facilitating production of batches as large as 100 units

- Integration of the fuel cells in series resulted in expected voltage build-up and showed high stability up to 100 h of continuous operation in CH_4.

- **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:**

- Improve the coal injection and fly ash removal system.
- Integrate the fuel cell components into the coal fuel cell stack