Development of Kilowatt-Scale Coal Fuel Cell Technology

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Project ID #
FC070

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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, CO₂ and H₂O) 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)

<table>
<thead>
<tr>
<th>Planned Milestone</th>
<th>Progress Notes</th>
<th>Comment</th>
<th>% Comp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigate the factors governing the anode catalyst activity.</td>
<td>Determined the effect of H(_2)O on the activity of the anode catalyst for electrochemical oxidation of carbon in coal</td>
<td>Addition of 3 wt% H(_2)O to the anode compartment of the coal fuel cell produce current densities as high as 180 mA/cm(^2), representing an 40% performance improvement</td>
<td>90%</td>
</tr>
<tr>
<td>Investigate the nature of carbon fuels on the fuel cell performance</td>
<td>Investigated the reactivity of different carbon fuels by IR spectroscopy and impedance spectroscopy</td>
<td>The fuel cell performance (voltage –current characteristics) were correlated to the –CH and -OH functional groups of the carbon fuel</td>
<td>90%</td>
</tr>
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## Approach – Milestones (II)

<table>
<thead>
<tr>
<th>Planned Milestone</th>
<th>Progress Notes</th>
<th>Comment</th>
<th>% Comp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop a low cost process for fabrication of large scale fuel cell components</td>
<td>Developed a tape casting/screen printing procedure for the fabrication of low cost and reproducible fuel cells</td>
<td>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</td>
<td>90%</td>
</tr>
<tr>
<td>Integrate the fuel cell components into a coal fuel cell stack</td>
<td>Evaluated the integration of fuel cells in parallel and series configuration</td>
<td>Integration of the fuel cells in series configuration resulted in expected voltage build-up in coconut coke.</td>
<td>90%</td>
</tr>
<tr>
<td>Evaluate the long term anode and cathode catalyst activity as well as interconnect durability</td>
<td>Investigated the stability of the fuel cell integrated in series configuration</td>
<td>Testing of the fuel cell stack in series configuration in CH₄ fuel revealed high stability up to 100 h of continuous operation.</td>
<td>90%</td>
</tr>
</tbody>
</table>
Coke + H₂O vs. Coke
- Enhanced the power density of coke fuel cell by 80%.
- Reduced polarization resistance by 50%.

Coke + H₂O vs. Coke + 3 Vol% H₂
- 3 Vol% H₂ showed 15% more power density.
- Presence of H₂O reduced polarization resistance by 10%.
Presence of H$_2$O 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.
Maximum current density of the fuel cell operated with coconut coke was 19 % of that with H₂, while Petcoke produced 9 % of that with H₂.

Ohmic resistance and polarization losses of the fuel cell with Petcoke were higher than those with coconut coke.
Coconut coke has more active –CH, -OH surface functional groups and more reactive toward gasification with CO₂ and O₂.


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

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*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

**High performance fuel cells:**
- Max. current > 160 mA/cm²
- OCV > 900 mV

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

**Other causes of failure**
- 17%

**Fuel cell delamination**
- 26%

**Delamination caused by leakage**
- 78%

**Other causes**
- 22%
Two parallel stacks in series

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 CH₄

Operating temperature: 750°C
Gas stream: 100 sccm He/CH₄/CO₂ (25 vol% CH₄, 25 vol% CO₂)

- 3-Ni/YSZ anode fuel cells in series configuration exhibited long term stability in CH₄ 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.