Cost-effective, Intermediate-temperature Fuel Cells for Carbon-free Power Generation

Project ID: ARPAE-15

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Overview

Timeline
• Start: November 2017
• End: August 2019
• Percent complete: 80%

Budget
• Total Project Value
  – ARPA-E $1,100,000
  – Cost-share $ 122,222
• Funding received in FY18
  – $ 510,000
• Funding for FY19
  – $ 450,000

Barriers
Fuel Cells
• A – Durability
  – Longer operation
  – Lower degradation
• B – Cost
Manufacturing
• F – High cost and complexity of processing
• I – Lack of standardized BOP components

Partners
• University of Maryland
• TechOpp Consulting Inc.
Objective: develop and demonstrate a transformational technology that cost-effectively and efficiently converts the chemical energy of ammonia fuel directly into electricity at a reduced temperature (≤650°C) through the design and manufacturing of an advanced IT-SOFC with unique hierarchical structures.

Targets

<table>
<thead>
<tr>
<th>Metric</th>
<th>State of the Art</th>
<th>Proposed</th>
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<tbody>
<tr>
<td>Delivered SUE Cost</td>
<td>&gt; $0.3 /kWh</td>
<td>~ $0.3/kWh</td>
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<tr>
<td>Max operating temperature</td>
<td>800~900°C</td>
<td>≤ 650°C</td>
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<tr>
<td>Current density at 0.75V</td>
<td>0.4 A/cm²</td>
<td>0.3 A/cm²</td>
</tr>
<tr>
<td>Electrical efficiency</td>
<td>52~60%</td>
<td>&gt; 55%</td>
</tr>
<tr>
<td>Cell degradation rate</td>
<td>&gt; 1%/1kh</td>
<td>&lt; 0.3%/1kh</td>
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Approaches

- Catalysts & implementation process development
- Strategies for performance enhancement
- Advanced manufacturing process development

Materials Development
  - NH₃ catalyst – nano metal oxides
  - Cathode catalysts

Cell Fabrication Process Development
  - Cathode deposition optimization
  - Anode fabrication process development
  - Scale-up

IT-SOFC Experimental Evaluation
  - Button sized cells (2 cm²/cell)
  - Single cells (100 cm²/cell)

Technology-to-Market (T2M)
  - Techno-economic analysis (TEA)
  - T2M development
21-month Project (11/2017 – 08/2019)

○ Concept development phase (12-month) focusing on materials development & evaluation, advanced process development, and T2M plan development

○ Scale-up phase (9-month) focusing on scaling up & large-cell evaluation for proof-of-conception (PoC) demonstration, and T2M plan updating

Concept phase (12-month):

Critical cell components development, cathode, catalysts, anode fabrication processing, small cell fabrication, T2M plan initialization

Development Phase (9-month):

Cell materials integration, large cell fabrication (100 cm²/cell), single cell construction, & evaluation, T2M plan updating
Challenges for Direct NH$_3$ Fueled SOFCs

Freshly reduced anode

After exposure to NH$_3$ fuel at 650ºC

Pristine Ni mesh

After hundreds hours test under NH$_3$ environment at 650ºC
Technical Accomplishments – NH₃ Cat.

- Evaluated eight NH₃ catalyst candidates
- Standard Ni+YSZ doesn’t possess sufficient catalytic effects on NH₃ decomposition at T ≤ 700ºC
- A few catalysts showed near complete NH₃ conversion (100%) ≤ 50 sccm (7137 h⁻¹)
Measurement of ohmic ASR changes under NH₃ environment by 4-point method

Three samples:
1. blank substrate (anode support);
2. w/ Cat-2
3. w/ Cat-6

Pt meshes for current collection

650°C

NH₃ flow rate @ 20 sccm (2854 h⁻¹)

Stability: Cat-6 >> Cat-2 >> anode base substrate
Electrolyte Optimization

(a) our standard cell (project onset), ~ 12 µm

(b) second generation cell (Q3), 8~9 µm;

(c) third generation cell (Q4), 5~6 µm;

(d) an example of electrolyte defect (~ 2 µm thick)
3rd Gen Button Cell Performance

Button cell baseline performance with H\textsubscript{2} at various temperatures (800ºC – 650ºC)

Button cell performance comparison between H\textsubscript{2} and NH\textsubscript{3} at 650ºC

<table>
<thead>
<tr>
<th>T, ºC</th>
<th>OCV, V</th>
<th>Power density @ 0.75V, W/cm\textsuperscript{2}</th>
<th>Peak power density, W/cm\textsuperscript{2}</th>
<th>ASR, Ωcm\textsuperscript{2}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H\textsubscript{2}\textsuperscript{*}</td>
<td>NH\textsubscript{3}</td>
<td>H\textsubscript{2}</td>
<td>NH\textsubscript{3}</td>
</tr>
<tr>
<td>650</td>
<td>1.188</td>
<td>1.122</td>
<td>0.377</td>
<td>0.308</td>
</tr>
<tr>
<td>700</td>
<td>1.183</td>
<td></td>
<td>0.692</td>
<td></td>
</tr>
<tr>
<td>750</td>
<td>1.176</td>
<td></td>
<td>1.108</td>
<td></td>
</tr>
<tr>
<td>800</td>
<td>1.167</td>
<td></td>
<td>1.514</td>
<td></td>
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Button Cell Continuous Test with NH$_3$

- Batch-17 #H105 (2cm$^2$), 650°C, NH$_3$ @40sccm (5710 h$^{-1}$)/air
- Current density @ 0.75V
- Cell power density @ 0.75V
- M4.3 @ 11/14/2018: 0.3 W/cm$^2$ for 24 hours

Elapsed time, hrs

Current density or power density, A/cm$^2$ or W/cm$^2$

Cell temperature, ºC

M4.3 @ 11/14/2018: 0.3 W/cm$^2$ for 24 hours
Scale-up Cell Performance w/ NH$_3$ Fuel

VI sweep characteristics of a single cell (100cm$^2$/cell) tested with NH$_3$ from 800°C to 650°C
Long-term test results of a single cell at 650°C with NH₃ (200 hrs) and 60% H₂-N₂ (500 hrs)
Proposed Future Work

By Q3 FY2019

- Complete long-term tests of single cells (100 cm²/cell) directly fed with ammonia fuel at 650°C, demonstrating the degradation rate < 0.3%/1khr over 500 hours @ 0.225 W/cm² @ 0.75V
- Update T2M
- Complete TEA

Beyond 2019

Look for partners who can help transitioning the advanced laboratory technologies into marketable products

- Scale-up demonstration at a kW stack scale
- System integration and demonstration at a kW level
- Investors (private & government)
Summary – Documented Progress toward Targets

➢ Successfully developed and implemented an ammonia catalyst system for preserving SOFC electrode functionality and mechanical integrity

➢ Improved manufacturing processes for SOFCs performance enhancement and suitable for cell scaling up

➢ Completed technical milestones on schedule