A Novel Stack Approach to Enable High Roundtrip Efficiencies in Unitized PEM Regenerative Fuel Cells

Dr. Katherine Ayers
Nel Hydrogen
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Project ID #fc331
Project goal

The overall project goal is to demonstrate a Unitized Reversible Fuel Cell (URFC) system based on Polymer Electrolyte Membrane (PEM) technology that can achieve 50% round trip efficiency and reliable performance under relevant duty cycles, with projected costs below $1,750/kW.
OVERVIEW

Project Overview

• Time and budget
  • Project start date: April 1, 2020
  • Project end date: December 31, 2023
  • Total project budget: $2.5M
    • Total recipient share: $500K
    • Total federal share: $2M
    • Total DOE funds spent*: $308,030

• Partners
  • EPRI: Brittany Westlake
  • Southern Company: Noah Meeks
  • LBNL: Nem Danilovic and Adam Weber
  • Gaia: Whitney Colella

• Barriers
  • Barriers addressed
    • No regenerative fuel cell specific barriers
    • Optimization between fuel cell and electrolyzer barriers:
      • Fuel cells
        • Durability
        • Cost
        • Performance
      • Hydrogen production
        • Capital cost
        • System efficiency
        • Electricity cost

*As of 03/31/2021
Past work with URFC’s

- Learnings from static feed fuel cells
- Extreme water management challenges
  - Strong understanding of transport and cell design effects
  - Limited to low current densities
- Current project leverages fundamentals for high efficiency and current density
OVERVIEW

Fuel cells vs. electrolyzers

- This project combines an electrolyzer and fuel cell into a single system
- Electrolyzer is optimized to compliment fuel cell operating conditions
  - Reduced operating voltage and pressures of electrolyzer reduces stack cost

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fuel cell (automotive)</th>
<th>Electrolyzer</th>
<th>URFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative humidity</td>
<td>cycling</td>
<td>constant at 100%</td>
<td>controlled</td>
</tr>
<tr>
<td>Differential pressure</td>
<td>&lt; 50 psi</td>
<td>&gt; 400 psi</td>
<td>50-100 psi</td>
</tr>
<tr>
<td>Cell voltage</td>
<td>&lt; 1.0 V</td>
<td>&gt; 1.8 V</td>
<td>&lt; 1.0 V, &gt; 1.55 V</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>freeze/thaw</td>
<td>&gt; 5°C</td>
<td>&gt; 5°C</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>80°C</td>
<td>50°C</td>
<td>50-65°C</td>
</tr>
<tr>
<td>Fluid flow – O₂ loop</td>
<td>O₂/water vapor</td>
<td>liquid water/O₂</td>
<td>alternating</td>
</tr>
<tr>
<td>Lifetime expectations</td>
<td>&gt; 5,000 hours</td>
<td>&gt; 50,000 hours</td>
<td>&gt; 5,000 cycles</td>
</tr>
</tbody>
</table>
OVERVIEW

Relevance and impact

• Technology
  • An efficient RFC enables long term, utility scale storage to enable higher renewable energy penetration
  • Hydrogen has advantages over batteries for storage durations greater than 8 hours
  • Ideally a Unitized RFC (URFC) would eliminate a stack and balance of plant to simplify and reduce cost

• Outreach
  • Utility participation enables consideration of integration issues and optimization for best use cases
  • Public education of benefits of this technology to balance renewables on the utility grid
Key project tasks

• Stack optimizations
  • Hardware design and material selection
  • Optimization of cell water management

• System modification
  • Build integrated test system to demonstrate URFC

• RFC system testing
  • Test and benchmark performance under application specific duty cycles

• System analysis
  • Techno-economic analysis to optimize CAPEX and OPEX costs
  • Modeling of use cases
  • Interconnection considerations

• Outreach/Project management
**APPROACH**

Key milestones

**Budget period 1**

<table>
<thead>
<tr>
<th>Period</th>
<th>Quarter</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY 2020</td>
<td>Q3</td>
<td>Develop system requirements</td>
</tr>
<tr>
<td></td>
<td>Q4</td>
<td>Complete cell stack design</td>
</tr>
<tr>
<td></td>
<td>Q1</td>
<td>Down-select membrane/catalyst candidates</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>100 hours of electrolysis operation</td>
</tr>
<tr>
<td></td>
<td>Q3</td>
<td>Initial assessment and analysis of system cost</td>
</tr>
<tr>
<td></td>
<td>Q4</td>
<td>Integrated URFC system online</td>
</tr>
</tbody>
</table>

**Budget period 2**

<table>
<thead>
<tr>
<th>Period</th>
<th>Quarter</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY 2022</td>
<td>Q3</td>
<td>Demonstrate 1-hour cycles in integrated URFC system</td>
</tr>
<tr>
<td></td>
<td>Q4</td>
<td>Go/No go</td>
</tr>
<tr>
<td>FY 2023</td>
<td>Q1</td>
<td>100 hours of electrolysis operation</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>Fuel cell performance of &gt; .75 V</td>
</tr>
<tr>
<td></td>
<td>Q3</td>
<td>Define optimal electrolyzer output pressure</td>
</tr>
<tr>
<td></td>
<td>Q4</td>
<td>Single cell demonstrate &gt;50% roundtrip efficiency</td>
</tr>
<tr>
<td>FY 2024</td>
<td>Q1</td>
<td>Multi-cell demonstrate &gt;50% roundtrip efficiency</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>250 hours operation at down-selected duty cycle</td>
</tr>
</tbody>
</table>

* A 9 month no-cost extension was approved in Q1 2021 to accommodate resource constraints for test stand building at Nel due to COVID-19. The schedule shown reflects the project extension.
ACCOMPLISHMENTS

Accomplishments to date

• Product Requirements Document (PRD)
• URFC stack design
• Down-selected membrane/catalyst candidates
• Durability testing
• Defined use case studies
• Defined compression study parameters
• Planned and kicked off webcasts
ACCOMPLISHMENTS

URFC stack design

• Optimize basic electrolyzer cell for low pressure, thin membrane operation
  • Lower sealing load and lower profile seal features
  • Membrane support optimization

• Optimize flow field and GDL/PTL for fuel cell water management
  • Channel geometry to allow liquid flow but deter flooding
  • Hydrophobicity tuning for effective water removal in fuel cell mode
  • Supported by LBNL water distribution/transport modeling

Completed stack assembly
ACCOMPLISHMENTS

Cell optimization – multi-phase, multi-physics electrolyzer model

- Model calibrated and validated to experimental polarization curves with good agreement for both high and low current densities
- Optimal membrane and catalyst down-selected

<table>
<thead>
<tr>
<th>Membrane</th>
<th>HER catalyst</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (180um)</td>
<td>50 wt% Pt/C</td>
<td>80°C</td>
</tr>
<tr>
<td>B (50um)</td>
<td>29 wt% Pt/C</td>
<td>50°C</td>
</tr>
</tbody>
</table>

Symbols: experimental data
Solid lines: model results
Red: 29 wt% Pt/C
Blue: 50 wt% Pt/C
ACCOMPLISHMENTS

Cell optimization – membrane testing

- Subscale electrolyzer testing was conducted to down-select membrane candidates
- Focused on 50um thick membranes

Polarization curve of the four membranes evaluated at 50°C and 80°C

Short-term durability data of membrane candidates
ACCREDITED 

Cell optimization – catalyst testing

- Subscale electrolyzer testing was conducted to down-select catalyst candidates

![Polarization curve of catalyst candidates collected at 50°C and 80°C](image1)

![Short-term durability data of catalyst candidates](image2)

Polarization curve of catalyst candidates collected at 50°C and 80°C

Short-term durability data of catalyst candidates
ACCOMPLISHMENTS

Outreach

• Developed a series of webcasts targeted at Electric Utilities:
  ✓ Intro to hydrogen – history, current and future uses (March 2021)
  • Types of hydrogen production (June 2021)
  • Applications for hydrogen (September 2021)
  • Hydrogen safety (November 2021)
  • International outlook for hydrogen (February 2022)
  • Reversible fuel cell/electrolysis development (May 2022)
## Collaboration

<table>
<thead>
<tr>
<th>Partners</th>
<th>Project Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Power Research Institute</td>
<td>System analysis, outreach</td>
</tr>
<tr>
<td>Southern Company</td>
<td>System analysis, outreach</td>
</tr>
<tr>
<td>Gaia Energy Research Institute</td>
<td>Techno-economic analysis</td>
</tr>
<tr>
<td>Lawrence Berkeley National Laboratory</td>
<td>Multi-physics transport modeling</td>
</tr>
</tbody>
</table>
Challenges and barriers

• Electrolyzers currently use thick membrane to tolerate the high differential pressure
  • Retuning of the cell design to enable the use of more efficient, thinner membranes

• Fuel cell operation is more sensitive to flow field geometry and gas-diffusion layer wettability
  • Leverage Nel cell optimization experience to make cell stack design compatible with efficient fuel-cell operation
  • Utilize basic Computational Fluid Dynamic modeling (CFD) to optimize flow field geometry
  • Use LBNL model to understand the water transport in the URFC cell with respect to membrane properties and operating conditions
Planned future work

• Budget period 1
  • Test stand modifications
  • Begin use case analyses

• Go/No go decision by 2/28/2022

• Budget period 2 (assuming go/no go passed)
  • Feedback from utilities for optimal URFC applications
  • Define optimal electrolyzer output pressure
  • Demonstrate up to 200 hours of operation under down-selected duty cycle with 50% roundtrip efficiency
System analysis

- Southern Company has developed the use case scenario for analysis
  - Long duration storage
  - Scale will depend on renewables mix on grid (solar vs. wind)
    - Expect GWh scale for Southern Company’s territory
  - Working with analytics expert to model long duration energy storage based on level of renewables penetration

- EPRI will support system modeling activities

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Compression trade study

- Gaia will develop a comparison for 30 bar outlet pressure from the electrolyzer vs. electrochemical or mechanical compression

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Stack pressure (bar)</th>
<th>Outlet pressure (bar)</th>
<th>Final delivery pressure (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (baseline)</td>
<td>30</td>
<td>N/A</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>
Summary

• Objectives:
  • Balance design and operating conditions for optimal electrolysis and fuel cell performance

• Relevance and impact:
  • Target 50% roundtrip efficiency
  • Projected costs below $1,750/kW

• Collaboration effectiveness:
  • Cross-functional project team actively working on project
  • Developing relevant use case studies for utility scale applications
  • Webinars are being presented to educate utilities about hydrogen

• Accomplishments:
  • URFC stack design
  • Down-selected membrane/catalyst candidates
  • Durability testing
  • Defined use case studies
  • Defined compression study parameters
  • Planned and kicked off webcasts

• Future work:
  • Test stand modifications
  • System analysis
Technical backup & additional information
Technology transfer activities

• Anticipate tech transfer from others to Nel for eventual incorporation into a commercial product
• Project is still in early stages, but we will pursue additional funding sources as opportunities arise
Progress toward DOE targets or milestones

• URFC metrics are under development, but this project addresses both electrolyzer and fuel cell targets

**Electrolyzer**

<table>
<thead>
<tr>
<th>DOE Target Areas</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>Reduced operating pressure = reduced material costs. Targeting &lt;$1750/kW</td>
</tr>
<tr>
<td>System efficiency</td>
<td>Targeting 50% round-trip efficiency</td>
</tr>
<tr>
<td>Electricity cost</td>
<td>Leverage excess renewable generation</td>
</tr>
</tbody>
</table>

**Fuel Cell**

<table>
<thead>
<tr>
<th>DOE Target Areas</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>Targeting &lt;$1750/kW</td>
</tr>
<tr>
<td>Durability</td>
<td>Extended operation planned</td>
</tr>
<tr>
<td>Performance</td>
<td>Targeting &gt;0.75V @ 1A/cm²</td>
</tr>
</tbody>
</table>
number one by nature