Regenerative Fuel Cell System (SBIR Phase II)

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Project ID: FC154

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Company Background

- Founded in 2010, located in Columbus, OH
- Mission: to develop and commercialize material-based products for alternative energy applications
- Primary focus on electrode materials
- Expertise in:
  - Catalyst synthesis, development, and scale-up
  - Fuel cell development
  - Commercialization of catalysts, advanced materials, and electrochemical devices
Fuel cells are of interest for energy storage applications, such as grid load leveling and renewable integration.

The fuel cells could potentially be operated in a reversible manner, allowing renewable energy to be stored in the form of hydrogen.

When operating in regeneration mode, degradation is even more pronounced for conventional catalysts because of the high voltages required.

In existing reversible systems, a separate electrode is typically used for oxygen evolution, adding to the already high system cost.

If a low-cost reversible fuel cell could be developed, it would be a key breakthrough for energy storage.
Overview

Timeline and Budget

- Phase II SBIR Project
- Project Start Date: 04/11/2016
- Project End Date: 04/10/2018
- FY17 Project Budget: ~$500,000
- Total Budget: $1,000,000

Barriers

- Barriers addressed:
  - Develop low-cost catalysts for reversible anion-exchange membrane fuel cells (oxygen and hydrogen electrodes)
  - Increase the durability/stability of catalysts with cycling
  - Integrate catalysts with membranes and GDLs into MEAs and stacks

- Targets:
  - 1,000 cycles above target operating efficiency and current density
  - 42% efficiency; >250 mA/cm² fuel cell; >50 mA/cm² electrolysis

Collaborators

- Giner, Inc.
- NREL
The DOE has a mission to develop lower cost and better performing fuel cell technologies, and develop technologies for energy storage. This project applies to both.

**Project Objectives**

- Demonstrate a reversible 25-cm$^2$ Anion Exchange Membrane Fuel Cell (AEMFC) for 1,000 cycles (42% round-trip efficiency; >250 mA/cm$^2$ power generation; >50mA/cm$^2$ energy storage).
- Incorporate Membrane Electrode Assemblies (MEAs) into regenerative stack.
- Perform economic analysis on reversible AEMFC system following DOE guidelines (Steward et al. NREL/TP-560-46719) for candidate grid energy storage technologies.
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<thead>
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<th>Tasks / Key Milestone</th>
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<td><strong>Task 1. Hydrogen Electrode Development</strong></td>
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<td><strong>Task 5.2 Delivered Electricity Projections</strong></td>
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In Phase I SBIR demonstrated stable steady-state ORR performance over 100 hours in half-cell testing using patented PGM-free catalyst:
In Phase I SBIR demonstrated stable steady-state OER performance over 100 hours in half-cell testing using patented PGM-free catalyst:

![Graph showing potential versus time for GDE Half-cell Testing with COR-2 CN_xP_y, 5 M KOH, 45°C, and 40 mA/cm².](Image)
Electrolyzer performance is much improved with GDEs vs. CCMs. Higher ionomer content can further improve electrolyzer performance, but sacrifice fuel cell performance.

Cathode: PtIr (0.75Pt+0.75Ir mg/cm², Ionomer=20%); Anode: PtRu/C (0.7 mgPtRu/cm², I/C=0.8)

Fuel cell testing conditions: H₂/O₂ flowing at 1000 ccm/min, at the temperature of 60 °C (relative humidity of 95%), and H₂/O₂ backpressure of 30 psia

- Electrolyzer performance is much improved with GDEs vs. CCMs
- Higher ionomer content can further improve electrolyzer performance, but sacrifice fuel cell performance
Accomplishments: Gas Diffusion Electrode (GDE) Configuration

Test conditions: \( \text{H}_2/\text{O}_2 \) flowing at 1000 ccm/min, at the temperature of 60 °C (relative humidity of 95%), and \( \text{H}_2/\text{O}_2 \) backpressure of 30 psia.

- COR-2 #1: ionomer, no hot-press; COR-2 #2: ionomer, with hot-press

- Fuel cell performance using COR-2 \((\text{CN}_x\text{P}_y)\) has reached the target
- Electrolyzer overpotential decreased by 0.4 V by feeding 0.1 M KOH solution

Graph:

- Fuel Cell Pol Scans
  - 60 °C, 95% RH
  - PtRu/C anode, PtIr cathode baseline
  - PtRu/C anode, COR-2 cathode #2
  - PtRu/C anode, COR-2 cathode #1

- Electrolyzer Pol Scans
  - 60 °C
  - Voltage drop > 0.4V
  - PtRu/C anode, COR-2 cathode #2 in 0.1 M KOH
  - PtRu/C anode, PtIr cathode baseline
  - PtRu/C anode, COR-2 cathode #2
  - PtRu/C anode, COR-2 cathode #1

Cathode: COR-2 (2 mg/cm\(^2\), Ionomer=20%);
Anode: PtRu/C (0.7 mg\(_{\text{PtRu}}/\text{cm}^2\), I/C=0.8)
Accomplishments
Platinum-Nickel Nanowires – Performance

- As-synthesized – higher surface area, activity at low Pt composition
- Hydrogen annealing – lattice integration, higher specific activity
- Mass activity 10 times greater than PGM baselines (Pt/HSC, PtRu/C)

Galvanic Displacement

H₂ Anneal

Pt Lattice Constant [Å]

Pt (100) [Pt, Pt, Pt (111)] [Å]
Accomplishments
Platinum-Nickel Durability and Comparisons

- Half-cell durability (30,000 cycles, -0.2 – 0.2 V versus RHE)
- No appreciable loss in activity
- Mass activity 10 times greater than PGM baselines (Pt/HSC, PtRu/C)

HER-HOR performance comparisons
- Mass exchange current densities (red) normalized to catalyst mass
- Specific exchange current densities (blue) normalized to surface area
- Dashed line – polycrystalline platinum
Accomplishments

- Screened catalysts for the hydrogen electrode:

![Graph showing voltage and power vs. current density for Pt/Ru Anode and Nano-Ni Anode.]

- 2-cm² Cell
- Electrolyte: Commercial AEM
- O₂ Electrode: COR-2 CNₓPy
- H₂/O₂ (50 sccm, 1 atm)
- T = 50°C
- Identified low Pt and Pt-free compositions with excellent performance; tested fuel cell mode at 25-cm²:
- Identified low Pt and Pt-free compositions with excellent performance; tested electrolysis at 25-cm$^2$:

25-cm$^2$ Cell Testing
Electrolyte: Commercial AEM
Cathode: COR-2 CN$_x$P$_y$
H$_2$/O$_2$ (300 sccm, humidified)
T = 50°C, P = 3 bar
Accomplishments

- Developed Pt-free electrode with excellent durability for over 360 cycles:

  Hydrogen Electrode: HyROC-1
  Electrolyte: Commercial AEM
  Oxygen Electrode: COR-2 CNxPy
  H2/O2 (300 sccm, humidified)
  T = 50°C
  1 minute load cycle, 1 minute OCV
Performed economic sensitivity analysis for grid storage applications; stack lifetime is the key unknown variable:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low Value</th>
<th>Baseline</th>
<th>High Value</th>
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<tbody>
<tr>
<td>Lifetime</td>
<td>1 year</td>
<td>4 years</td>
<td>16 years</td>
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<tr>
<td>Efficiency</td>
<td>32%</td>
<td>42%</td>
<td>54%</td>
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<tr>
<td>Power Density</td>
<td>150 mW/cm²</td>
<td>200 mW/cm²</td>
<td>350 mW/cm²</td>
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<td>Anode Loading</td>
<td>3.0 mg/cm²</td>
<td>4.9 mg/cm²</td>
<td>16 mg/cm²</td>
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Collaborations

- **Giner (sub-award):**
  - Electrode processing optimization
  - Reversible stack design
  - Water management

- **NREL (sub-award):**
  - Patented Pt/Ni alloy catalyst
  - Advanced characterization techniques
Remaining Challenges

- Further improve economics with higher power, lower over-potential, and less ionomer
- Increase cell durability to over 1,000 cycles
- Demonstrate long-term operation over 1,000 hours
- Incorporate cells into regenerative stack with humidity control
- Reliability
Proposed Future Work

- Characterize the electrodes before and after cycling to better understand degradation mechanisms
- Demonstrate durability over 1,000 cycles
- Demonstrate regenerative stack (5 cells, 500 hours, 250 mA/cm², 42% efficiency)
- Refine economic analysis for micro-grid applications

Any proposed future work is subject to change based on funding levels
- **IP being used:**
  - Licensed catalyst composition from Ohio State University
  - pH Matter’s oxygen electrode and hydrogen electrode compositions
  - NREL’s Pt/Ni electrode materials
  - Giner’s reversible stack design

- Planning partnerships with strategic investors and system integrators for demonstration of 10-kW storage system

Reversible fuel cells are a potentially economical energy storage technology for a number of applications, including grid load-leveling and renewables storage.

pH Matter, Giner, and NREL are developing a reversible AEMFC; the technology could be a breakthrough for energy storage applications.

Stable 25-cm$^2$ cells have been demonstrated for over 300 cycles at target operating conditions.

Future work aims to achieve performance and durability targets at the stack level.
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Supporting Info
GDE Optimization: Transfer from C Paper to Ti Sinters

SEM images of gas diffusion layers:

- Ti paper will be used as the gas diffusion layer for durability test in electrolyzer mode
- The porous layer of Ti paper needs to be optimized for fewer porous layers than C paper
- Mesoporous layers is introduced onto Ti paper
Half-Cell Testing
Established Performance Baselines

- Ink composition – loading, ionomer
- Half-cell experiments – glass, electrolyte purity, counter electrode

Robust baselines and durability protocols established
Nanowire Synthesis
Cost Analysis

- Nickel nanowires - cost approaches Ni cost at high volume

- SGD
  - Displacement by $K_2PtCl_4$ in water
  - Greater than 95% yield with small batches

- ALD – MeCpPtMe$_3$ deposition

ALD Cost Analysis, courtesy of ETFECS
DOE/EERE, Contract No. DE-AC02-76SF00515
Membrane Electrode Assembly Testing
COR-2 Performance

- HFR consistent with PGM AEM Fuel Cells
- Performance within half of PGM O₂ electrodes

Achieved high MEA performance with COR/HCOR catalyst

MEA Details
- Membrane, Ionomer: Gen 2 PFAEM
- Cell: 5 cm², 60°C
- H₂ Electrode: 1 mg/cm² PtRu/Vu
- O₂ Electrode: 4 mg/cm² COR2/HCOR3