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FY16 SBIR II Release 1: Regenerative Fuel Cell System

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Project ID: FC154

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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

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Project Background

- 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.

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Overview

Timeline and Budget

- Phase II SBIR Project
- Project Start Date: 04/11/2016
- Project End Date: 04/10/2018
- FY18 Project Budget: ~$250,000

Partners

- Giner Labs
- NREL
- Lockheed Martin

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/cm^2 fuel cell; >50 mA/cm^2 electrolysis

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Relevance

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

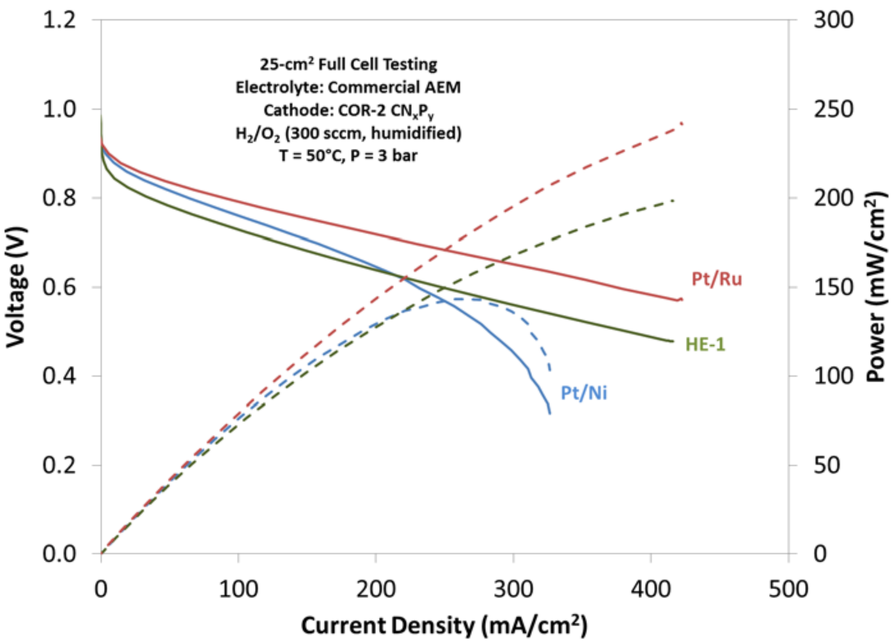
- Demonstrate a reversible 25-cm^2 AEMFC for 1,000 cycles (42% round-trip efficiency; >250 mA/cm^2 power generation; >50 mA/cm^2 energy storage).
- Incorporate MEAs into regenerative stack.
- Perform economic analysis on reversible AEMFC system following established DOE guidelines for candidate grid energy storage technologies.

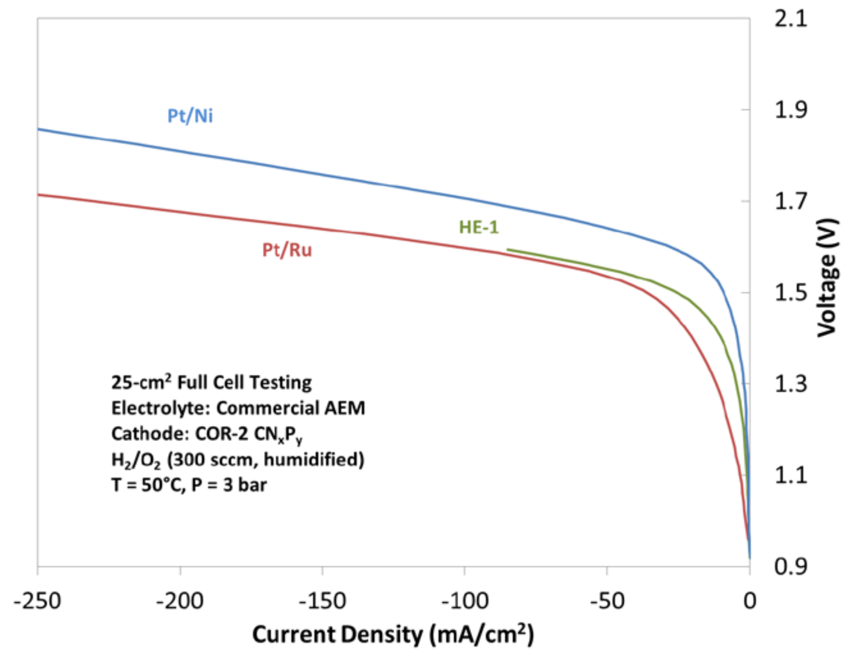
Approach

Tasks / Key Milestone	Quarter							
	1	2	3	4	5	6	7	8
Task 1. Hydrogen Electrode Development	■ ■	■ ■	■ ■	■				
Task 2. MEA and O_2 GDE Development								
Task 2.1 MEA Synthesis	■ ■	■ ■	■ ■	■ ■				
Task 3. Full Cell Testing								
Task 3.1 Performance Testing		■ ■	■ ■	■ ■				
> 250 mA/cm^2, >42% efficiency at 25-cm^2				•				
Task 3.2 Load Cycle Testing				■ ■	■ ■	■ ■		
1,000 cycles demonstrated						•		
Task 3.3 Post-test Characterization					■ ■	■ ■	■ ■	
Task 4. Stack Testing								
Task 4.1 Fabrication					■ ■	■ ■	■ ■	
Task 4.2 Stack Testing						■ ■	■ ■	■ ■
stack demonstrated								•
Task 5. Economic Modeling								
Task 5.1 Material Scale-up Projections	■ ■	■ ■	■ ■	■ ■				
Task 5.2 Delivered Electricity Projections				■ ■	■ ■	■ ■	■ ■	■ ■

Accomplishments

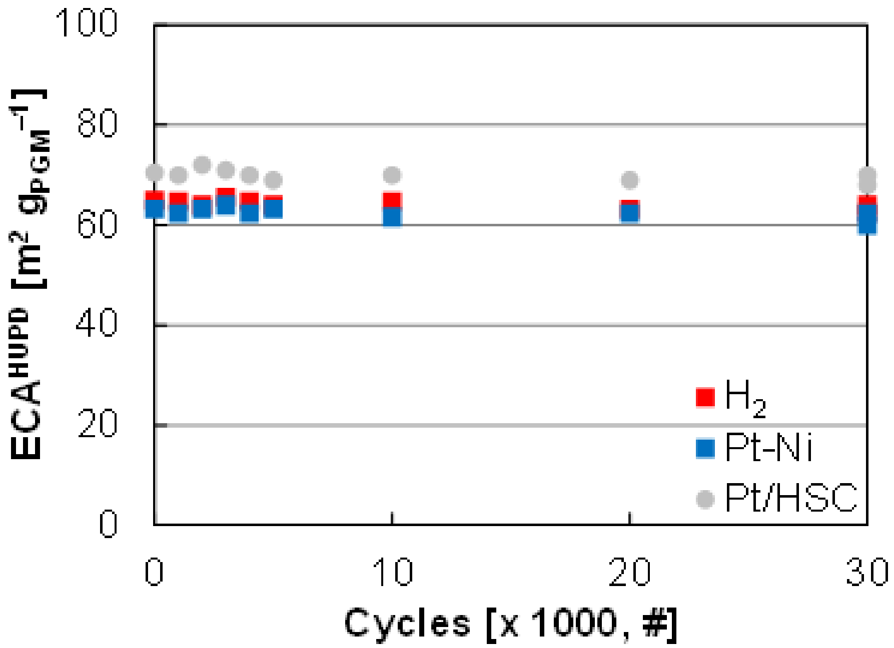
- Identified low Pt and Pt-free compositions with excellent performance, tested unitized 25-cm^2 cells:

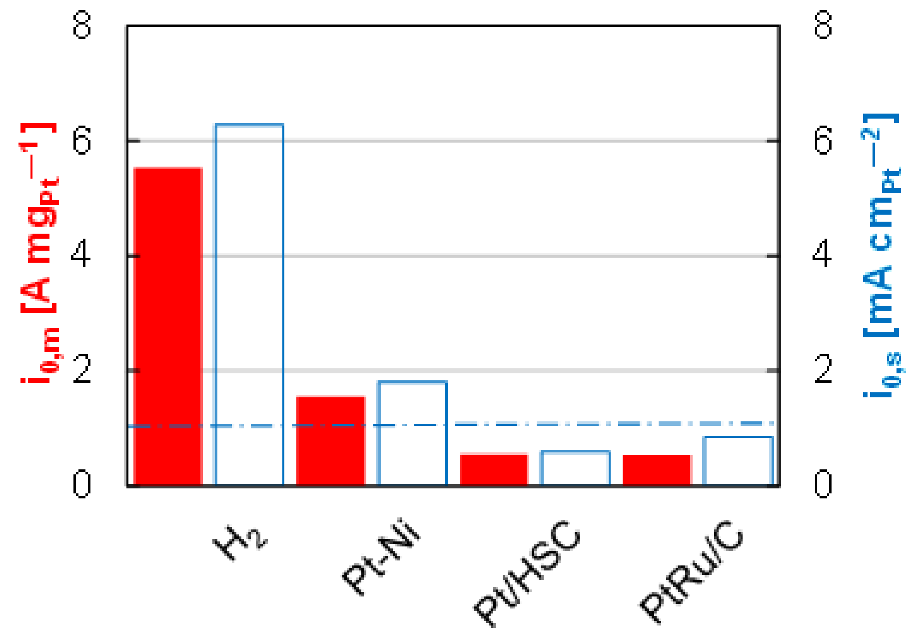




Accomplishments

- Half-cell durability (30,000 cycles, -0.2 – 0.2 V versus RHE)
- No appreciable loss in activity

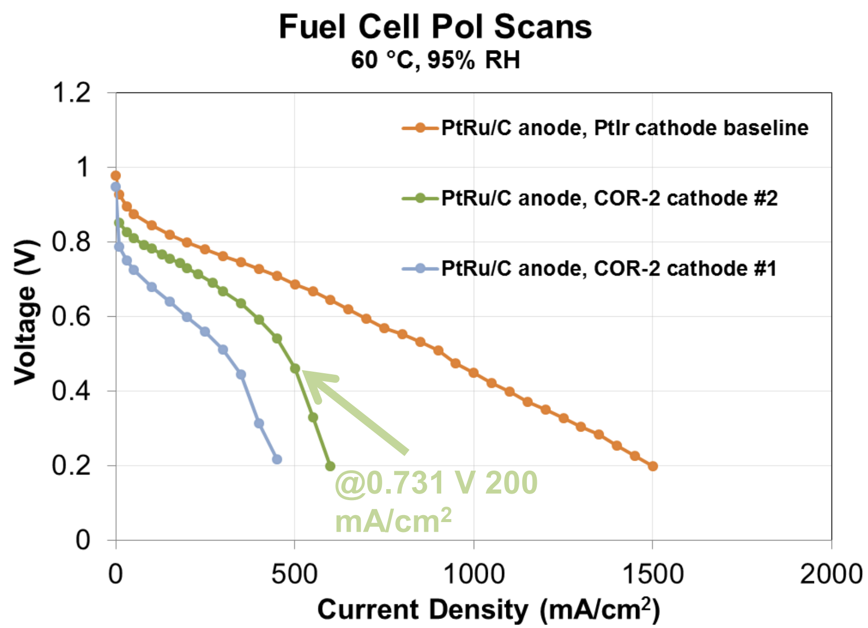


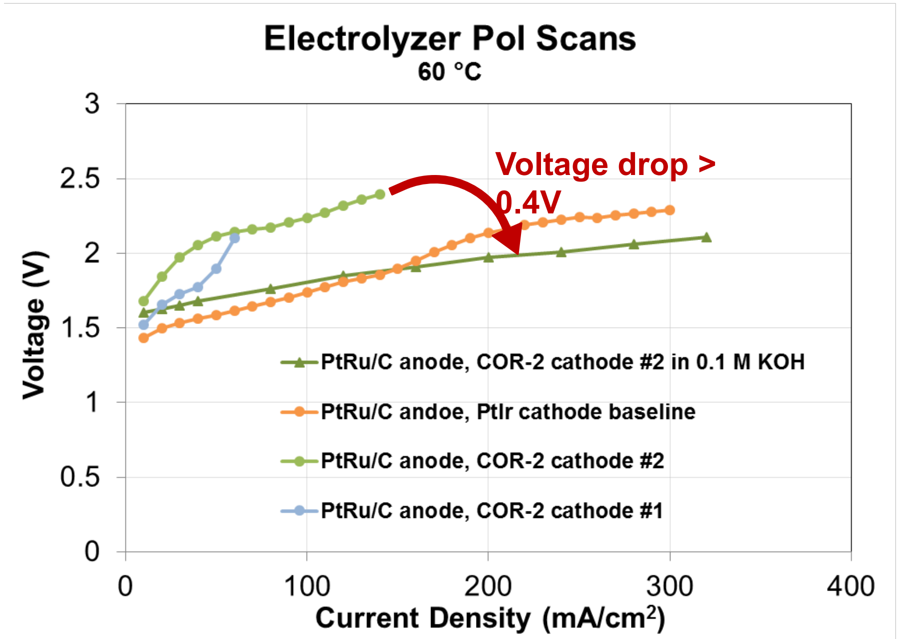


Mass activity 10 times greater than PGM baselines (Pt/HSC, PtRu/C)

Accomplishments

- Optimized COR-2 performance in GDE configuration:





Test conditions: H_2/O_2 flowing at 1000 ccm/min, at the temperature of 60 °C (relative humidity of 95%), and H_2/O_2 backpressure of 30 psia

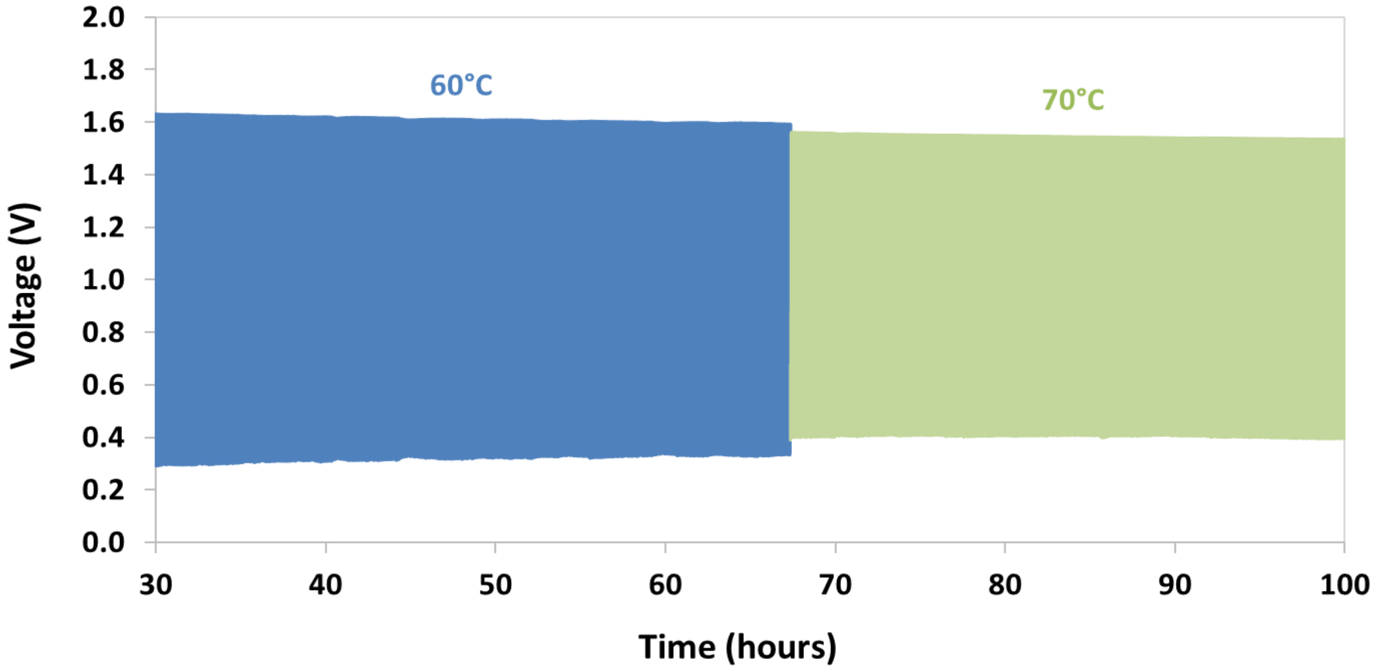
Cathode: COR-2 (2 mg/cm^2, Ionomer=20%);
Anode: PtRu/C (0.7 mg_{PtRu}/cm^2, I/C=0.8)

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

- ➢ Fuel cell performance using COR-2 has reached the target
- ➢ Electrolyzer overpotentional decreased by 0.4 V by feeding 0.1 M KOH solution

Accomplishments

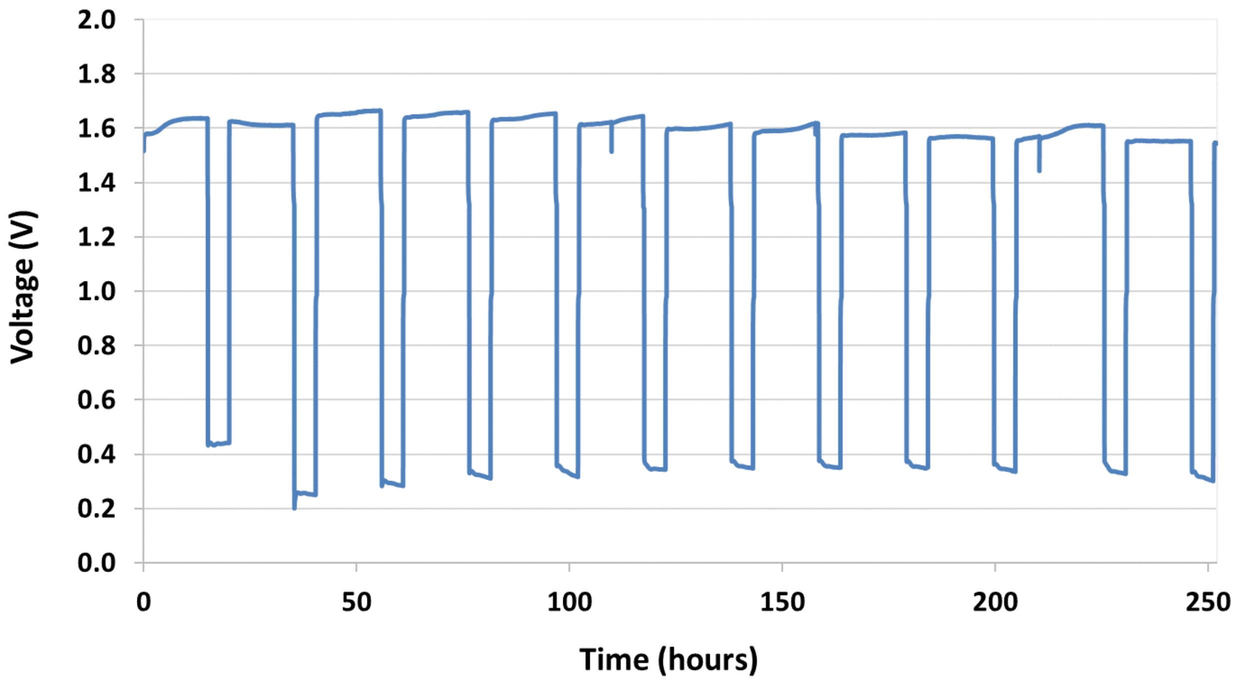
- Developed Pt-free cell with durability for over 360 cycles above Go/No-Go targets, and 1,000 cycles at lower fuel cell performance:



>1,000 Cycles
Hydrogen Electrode: HE-1
Electrolyte: Developmental
Oxygen Electrode: COR-2 CNxPy
H2/O2 (300 sccm, humidified)
1 minute load, 1 minute OCV
-50 / 150 mA/cm^2

Accomplishments

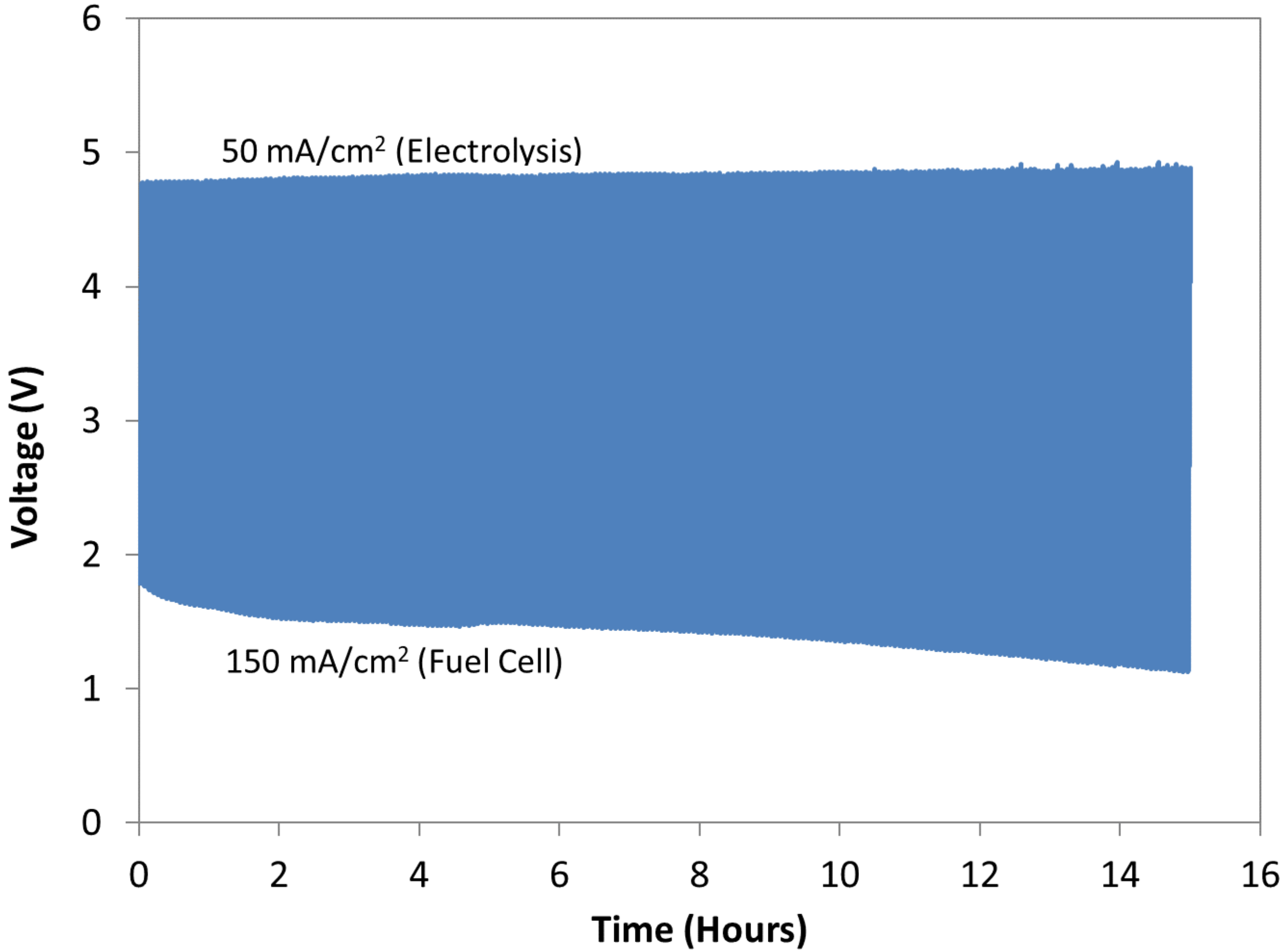
- Simulated cell operation over 250 hours:



Hydrogen Electrode: HE-1
Electrolyte: Developmental
Oxygen Electrode: COR-2 CNxPy
H2/O2 (300 sccm, humidified)
P = 3 bar, T = 60°C
50 mA/cm^2 electrolysis for 15 hours
150 mA/cm^2 fuel cell for 5 hours

Accomplishments

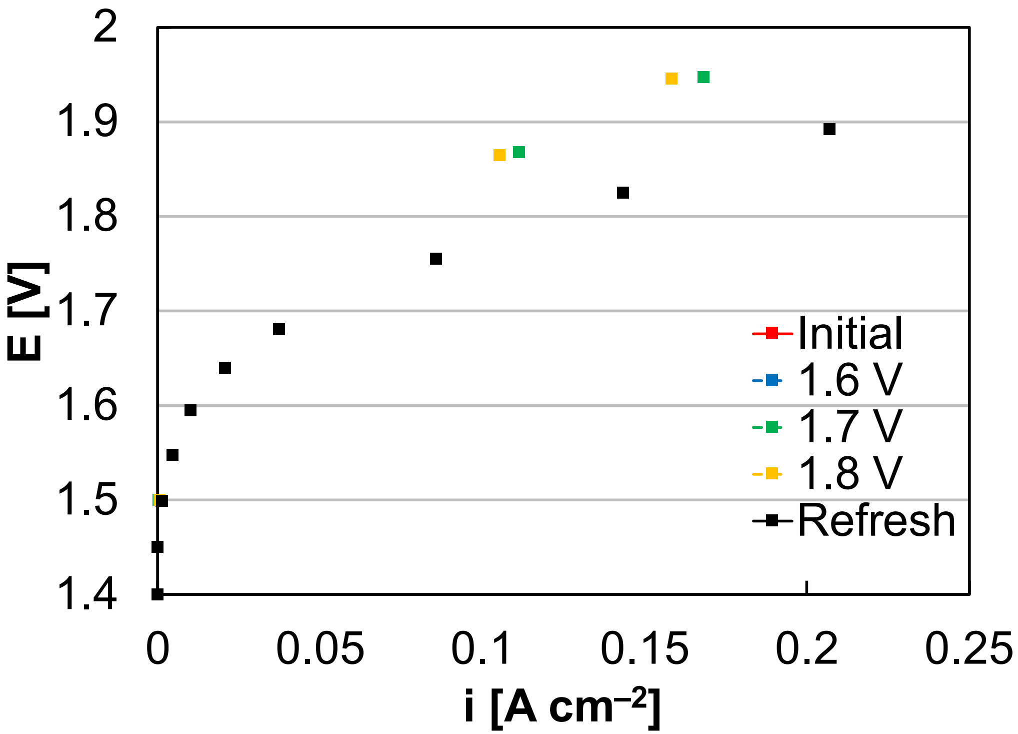
- 3-cell (25-cm^2 each) stack performance demonstrated over 200 cycles:



Hydrogen Electrode: HE-1
Electrolyte: Commercial AEM
Oxygen Electrode: COR-2 CN_xP_y
H_2/O_2 (300 sccm, humidified)
1 minute load cycle, 1 minute OCV
P = 3 bar, T = 50°C

Accomplishments

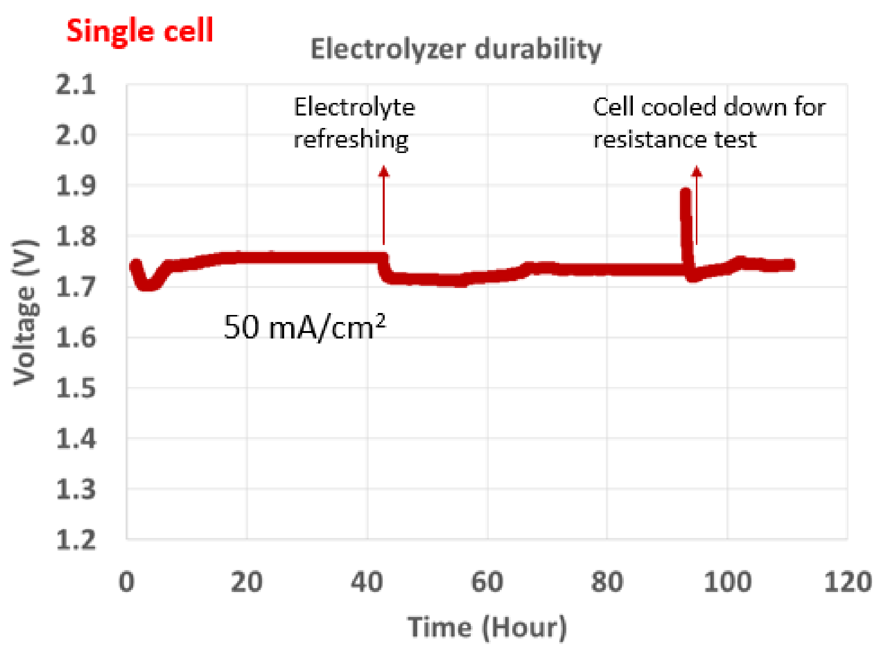
- Long-term testing at progressively higher voltages; 3 days at each voltage:

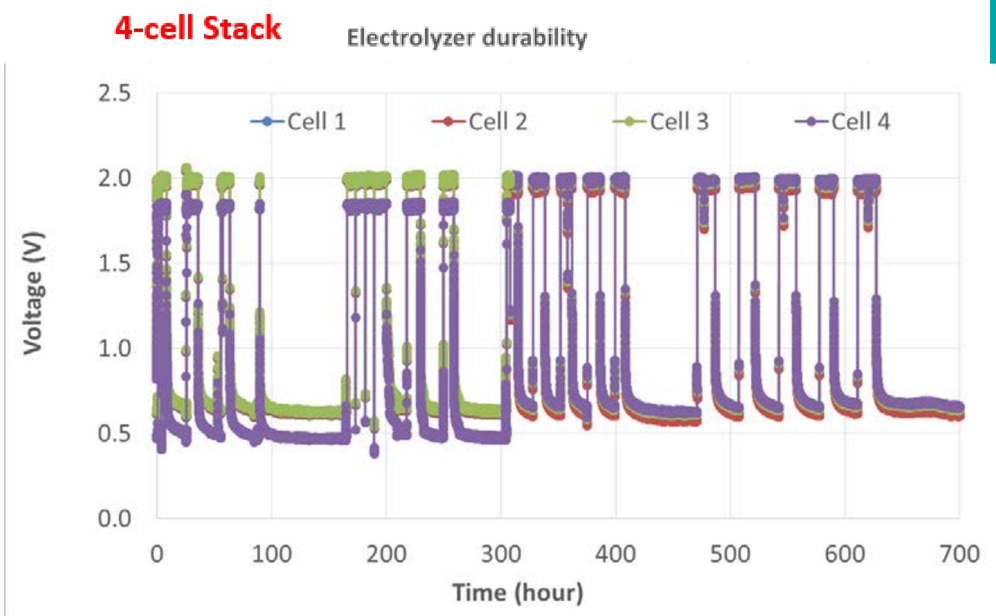


- Sources of loss to address
  - Electrolyte carbonation – recovered
  - Current collector
- Minimal loss after 9 days
  - Membrane – Small change to HFR (20 mΩ cm^{-2})
  - Catalyst –small change in performance

Accomplishments

- Testing in commercial electrolyzer stack design:





Single cell electrolyzer test conditions: 60 °C, 0.1 KOH solution on both electrodes; Cathode: COR-2+COR-3 (2 mg/cm², Ionomer=20%); Anode: HE-1 (2 mg/cm², Ionomer=20%); Electrolyzer stack test conditions: 70 °C (set point), 0.1 KOH solution on both electrodes; Cathode: COR-2+COR-3 (2 mg/cm², Ionomer=20%); Anode: HE-1 (2 mg/cm², Ionomer=20%), four 50 cm² MEAs

- EC performance is stable in 0.1 M KOH solution
- Single cell performance is better than stack due to the component Ohmic resistance loss and electrolytic current loss in the stack, as well as temperature control issues

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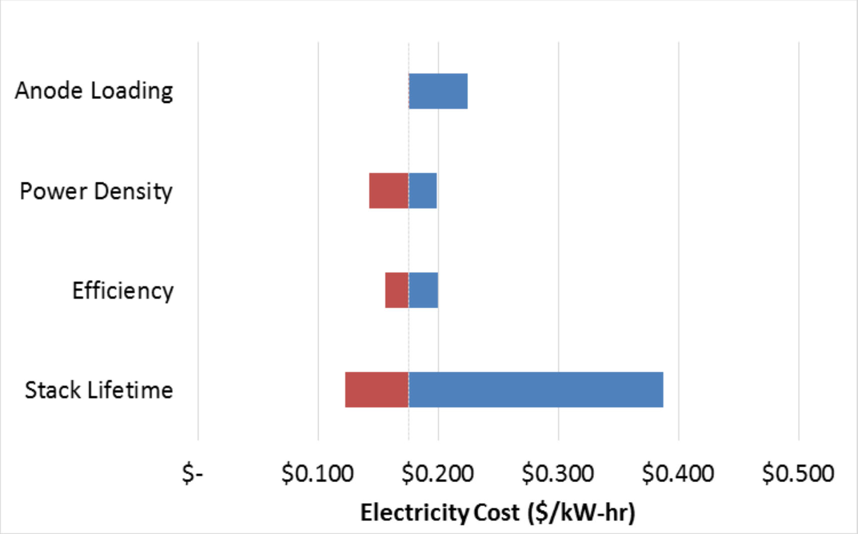
Accomplishments

- Performed economic analysis for grid storage applications:



Variable	Low Value	Baseline	High Value
Lifetime	1 year	4 years	16 years
Efficiency	32%	42%	54%
Power Density	150 mW/cm^2	200 mW/cm^2	350 mW/cm^2
Anode Loading		4.9 mg/cm^2	16 mg/cm^2

	Discrete	Unitized
Upfront Power Cost ($/kW)	Fuel Cell* + Electrolyzer**	Reversible Cell Stack
Capacity Cost ($/kW)	$23***	$35
RT Efficiency	43%	43%
Delivered Energy ($/kW-hr) Steward et al. case	0.223	0.175

* Expected PEMFC cost based on DOE automotive estimates
** Reversible AEMFC as the electrolyzer is best option; similar to alkaline electrolyzer but w/o compressor
*** Only H2 tank assumed for PEMFC

Note: Discrete may have advantages with longevity, customizable sizing for load cycles, and lower PEMFC cost with automotive adoption; unitized may have size/weight advantage.

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Response to Reviewers

- ## Response to Previous Year Reviewer's Comments:

The project is overly ambitious . . . just focus on one or two technological barriers . . . far away from commercialization.

The primary challenges we see with commercialization of this technology are 1) reducing hydrogen electrode cost, 2) oxygen electrode durability, and 3) membrane durability. We chose not to take on membrane/ionomer durability in this project as there are a number of parallel projects working on that. We have been successful at lowering the hydrogen electrode cost to targets that enable commercialization. The oxygen electrode durability needs improvement for applications with frequent cycling, but for initial niche commercial applications, the cycling durability is sufficient. It's also worth noting that the membrane challenges with carbon dioxide adsorption are alleviated in the closed system design.

Very little information about the developed catalysts. If the structure of catalysts are trade-secret, it should be less favorable project and DOE should reconsider supporting such a project.

We provided information about the oxygen electrode and will publish details in the patent literature. It should be noted that SBIR projects have different data protection rules from the typical DOE projects regarding what needs to be published.

Understanding of real life dual mode requirement is not clear. . . clearer understanding of where the market is for this application and what targets needs to be met

There are many stationary energy storage applications, the cycle testing presented was an accelerated degradation test. The project examined a typical load cycle for a back-up power application, and are working with customers to test requirements.

Carbon based catalysts are fundamentally unstable an ill-advised for this application.

NREL tested the limits of the COR-2 CNxPy catalyst in terms of voltage and current density. Some carbon oxidation is observed but long-term electrolysis was demonstrated (to the limits of available membranes).

Limiting the current of the electrolysis duty cycle coupled to wind that is variable also doesn't make sense, load following is one of the advantages of electrolyzers.

Operating targets were chosen to mimic the Steward et al. case for renewable storage. We tested the limits for electrolysis voltage and current (NREL's work). For off-grid energy storage (early-adopter market) the electrolyzer may run at a low current for months at a time.

Recommended changes were added in this presentation or explained above.

Collaborations

- Giner Labs:
  - Industry Partner
  - Subcontract:
    - Electrode processing optimization
    - Stack design and testing
    - Water management
- NREL:
  - Federal Lab Partner
  - Subcontract:
    - Patented Pt/Ni alloy catalyst
    - Advanced characterization techniques
- Lockheed Martin:
  - Industry partner, military, aerospace, and commercial applications outside of DOE Hydrogen and Fuel Cells Program

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Remaining Challenges

- Further improve economics with higher power and lower over-potential
- Demonstrate higher pressure operation
- Demonstrate long-term operation over thousands of hours
- Demonstrate stack at kW scale

Proposed Future Work

- Address remaining technical challenges
- Integrate with hydrogen storage
- Commercial partnerships for specific applications of the technology

Any proposed future work is subject to change based on funding levels

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Technology Transfer

- IP being used:
  - Licensed catalyst composition from Ohio State University
  - pH Matter's patent-pending oxygen electrode and hydrogen electrode compositions
  - pH Matter's patent-pending cell design
  - NREL's patented Pt/Ni electrode materials
  - Giner's proprietary reversible stack design

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

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Summary

- Reversible fuel cells are an interesting 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.
- 25-cm^2 cells have been demonstrated for over 1,000 cycles and 3-cell stack for >200 cycles.
- Phase II target of 250 hours of simulated reversible operation demonstrate.
- Economic analysis of shows excellent potential for long-duration energy storage applications.

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