Performance Validation of a Thermally Integrated 50 kW High Temperature Electrolyzer System (INL/Con-21-69783)

DE-FOA-0002300: Grant 13163665
2021 SOFC Virtual Project Review Meeting

This presentation does not contain any proprietary, confidential or otherwise restricted information
Project Goals

• Accumulate ~3,000 hrs operating a reversible solid oxide electrolysis (rSOC) system
  - A SOC system at INL will be modified for reversible operations:
    • 30-kW electrolysis mode/10-kW fuel cell mode
    • SOC stacks will incorporate improved catalyst in fuel electrode
    • Operation of rSOC system will be coupled to a steam generator programmed to mimic an industrial source of low-grade heat

• Thermodynamic analysis will demonstrate potential to achieve > 85% system efficiency in electrolysis mode

• Technoeconomic analysis (TEA) will demonstrate potential to produce hydrogen at a cost of $2/kg on a cost of electricity of $30/MWhr.
  - Project Start Date: 10/01/2020
  - Project End Date: 06/30/2023
Relevance

• **DE-FOA-0002300 AIO 2:**
  - Improving the cost, performance and reliability of reversible rSOC systems for clean hydrogen and clean power production
  - rSOC systems have opportunities to enter the marketplace but need proven system cost, performance, and reliability
  - rSOC systems can use the same system components (stacks, heat exchangers, piping, power converters, etc.) to reduce capital cost and maximize equipment capacity factor (% of time at maximum power)
  - May be deployed at small scale to meet needs of diverse users for clean energy utilization, storage, and supply (supports environmental justice)
    • Full design of BOP system will be open-access
Approach

• Task 1: Revise Project Management Plan
• Task 2: Stack manufacturing (OxEon)
• Task 3: e² Catalyst Development (MIT)
• Task 4: Reconfigure 50 kW SOC system
• Task 5: System integration and testing
• Task 6: Technoeconomic Analysis
• Task 7: Data analysis
• Task 8: Final Report
Challenges and Barriers

• Multiple SOC systems are being tested in a shared facility
  – Bloom >100 kW system: completed 2,000 hours in Sept. 2022
  – 30 kW rSOC system: plan to start testing in Dec. 2022
  – HFTO 50 kW open-architecture SOEC system: plan to start testing in Feb. 2023
  – FuelCell Energy 250 kW SOEC system: plan to start testing summer 2023

• Manufacturing delays
  – Weld qualification challenges (now performing 100% x-ray radiography on welds with design temperature >500 °C)
  – COVID-19 issues have slowed procurement
    • For example, >10 month delay obtaining heat exchangers
OxEon Energy, LLC

Utah R&D/Mfg Facility – Founded in 2017 after successful 30-year collaboration with founders of previous affiliation
- New 24,000 ft² (2230 m²) office, laboratory, and manufacturing facility
- NASA, DOE, DOD and Commercial funding
- Tape casting, cell and stack production, and testing
- End-to-end power to synfuels pilot plant in operation

Solid Oxide Fuel Cell and Electrolysis Stacks
- Longest running solid oxide fuel cell & electrolysis group in world
- Only flight qualified, TRL 9 SOEC unit in history
- 30kW/10kW reversible system test program in process

Fuel Reformation and Generation
- Plasma Reformer – H₂ and Syngas for flare curtailment
- Fischer-Tropsch Reactors – Modular design for transportation fuel production from H₂ and Syngas
**OxEon’s Solid Oxide Heritage**

**Key Milestones**

- **1986** - SOFC R&D began
- **2002** - Solid Oxide Electrolysis R&D began
- **2003** – OxEon founders and INL co-authored initial nuclear hydrogen proposal that started our nearly 30-year collaboration
- **2017** - OxEon Energy formed to develop commercial products and build on ISRU developments

- Cumulative Solid Oxide R&D investments >$150 Million with founders' participation

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**2002 - 2004**

SBIR & SECA Contracts: Co-fired Cells, Low Temp Materials

**1999**

McDermott DOE-NETL

**2006**

2kW CO2 Electrolyzer

**2005 - 2011**

ONR/DOE: Steam-CO2 Electrolysis

**2011 - 2013**

Conoco Phillips SOEC

**2010 - 2013**

Low Electrolyzer Degradation

**2010 - 2017**

DOE: Bio-Oil Electrolysis

**2013 - 2017**

DOE: High Temp Water Splitting

**2014 - 2017**

NASA: MOXIE

**2016 - 2019**

DOE: Bio-Oil Electrolysis
Stack Manufacturing at OxEon

OxEon stacks for this project are suitable for electrolysis and fuel cell operations as well as other applications.

OxEon scaled the MOXIE Mars stack for terrestrial applications.
Further Use of OxEon SOC stacks: Bio-CO$_2$ to E-Fuels (DOE-BETO award: DE-EE0008917)

- Existing EPT Waste Food Digester
- OxEon Solid Oxide Co-Electrolysis
  - CO$_2$
  - Separated biogas
  - CH$_4$
  - H$_2$O
- OxEon ATR Plasma Reformer
- OxEon Modular FT Reactor
  - O$_2$ Enriched Sweep air
  - Syngas
  - Steam from FT Cooling
  - Synthetic Liquid Bio-Fuels
  - Produced Water
- FTP Product Collection Skid
- Reformar Skid
- Fischer-Tropsch Reactor Skid
- O$_2$ Enriched Sweep air
- Syngas
Prof. Bilge Yildiz’s group at MIT is addressing catalyst performance and stability.

Electrolyte, electrode, catalyst, cell and stack production

Interconnect coating process in parallel with cell fabrication.

MIT-developed MIEC material showed higher initial performance than cells with standard materials set
Catalyst Development & Stack Manufacturing (M0-12)

• Catalyst development
  - Ni-Ce-based catalyst on fuel electrode developed to produce Ni pockets on electrode surface (INL project).
  - Proprietary catalyst on air electrode (privately funded).

• 10 Cell Stack (STK-57)
  - Materials set incorporates
    • Barrier layer developments (NETL-funded)
    • Air electrode modification (privately funded)
  - Stable performance in SOEC and SOFC operations
  - ~800 hour conditioning period
**System Design and Integration**

- **Standard SOEC/SOFC design**
  - High temperature heat exchangers (HXers) on fuel and air streams
  - HXer bypasses for incoming fuel and air streams in FC model
  - Trim heaters for EC mode
  - Fuel Condenser to separate water from product H2
  - H2 recycle loop with blower

- **Steam from electric boiler or nonfired boiler**
System Design & Integration

- High temperature piping design
  - Separate stack & HXer modules
  - Piping components supported on springs to allow thermal expansion; no bellows flanges

Combined fuel and air piping
System Design & Integration

- Welding on 30 kW rSOC system piping expected complete by ~Nov. 8, 2022
- Piping photos are of similar 50 kW system
  - Does not have HXer bypass for FC mode
System Design & Integration

- 30 kW rSOC system located in custom 20 ft container with doors on three walls
- System Design Description document will be publicly available (~Jan. 2023)
- 12 OxEon SOEC stacks arranged in quad configurations on manifold
<table>
<thead>
<tr>
<th>Milestone</th>
<th>Value</th>
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<tbody>
<tr>
<td>4.1 (M3)</td>
<td>Preliminary design ✓</td>
</tr>
<tr>
<td>2.1 (M6)</td>
<td>Receive materials for cell fab ✓</td>
</tr>
<tr>
<td>3.1 (M6)</td>
<td>Prepare samples for MIEC tests ✓</td>
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<tr>
<td>4.3 (M12)</td>
<td>Go/No-Go. SOEC stack assembly &amp; system</td>
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<tr>
<td>5.3 (M15)</td>
<td>Commission system with stacks</td>
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<tr>
<td>6.6 (M18)</td>
<td>Complete 500 hrs testing w/ DRTS</td>
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<tr>
<td>6.2 (M21)</td>
<td>Complete 2,000 hrs and TEA</td>
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<tr>
<td>8.1 (M24)</td>
<td>End of Project final report</td>
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Approach – Task 6: Technoeconomic Analysis (M15-20)

TEA will show potential to produce $H_2$ at $2/kg on a cost of electricity of $30/MWhr

- Will follow methodology used for previous reports

Source of Figures: J.H. Prosser, et al., 2022. Submitted for peer review (joint manuscript between Strategic Analysis & INL)
Summary

• Task 2 – Stack manufacturing
  – Manufacturing by OxEon is complete
• Task 3 – e² Catalyst development
  – Catalyst development complete
• Task 4 – Reconfigure 50-kW SOEC system
  – Engineering complete
  – Last major item to be received is the high temperature piping system – expected ~ Nov. 8, 2002
• Task 5 – System integration and testing
  – System integration – expected ~ Dec. 15, 2022
  – System will be instrumented to measure thermodynamic performance
  – System will be operated for 3,000 hrs (Jan. – Jul. 2023)
• Task 6 – Technoeconomic & thermodynamic analysis (TEA)
  – Thermodynamic analysis will demonstrate potential to achieve > 85% system efficiency in SOEC mode
  – TEA will show potential to produce H₂ at $2/kg on a cost of electricity of $30/MWhr.
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