DOE Hydrogen and Fuel Cell Office
2023 Annual Merit Review and Peer Evaluation Meeting

Stable High-Performing Oxygen Electrode for SOEC Operating at Lower Temperatures

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DOE Project Award DE-LC-00000022

Project ID # ely-bil011

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Project Goal

- Develop SOEC to operate at 1.2 A/cm^2 at 1.3 Volt with <3.2 mV/khr degradation rate at <750^oC using novel oxygen electrode materials
- Identify a replacement for $(La_{0.6}Sr_{0.4})_{0.95}Co_{0.2}Fe_{0.8}O_3$ (LSCF) that would offer higher oxygen evolution reaction activity and long-term stability
- Electrode composition will be selected from three families of perovskite-based mixed ion and electron conductors:
  - cubic-type ABO_3
  - layered $AA'B_2O_6$
  - Ruddlesden–Popper (RP) $A_{n+1}BnO_{3n+1}$ phases

Overview

Timeline

- Project Start Date: 2/20/2024
- End: Project continuation and direction determined annually by DOE

Key Barriers Addressed

- Hydrogen Cost
- Manufacturing
- Renewable Electricity Generation Integration

Budget

- FY24 DOE Funding received: $1,000,000
- FY24 Planned DOE Funding: $1,000,000
- Total DOE Funds Received to Date: $1,000,000 (since the project started)

Partners

- Pacific National Laboratory
- Foster School of Business/University of Washington

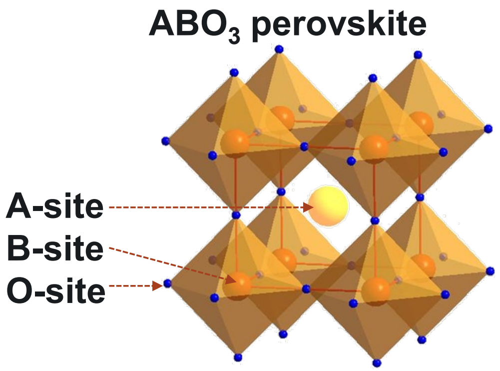
Potential Impact

- Support Hydrogen Earthshot's $1/kg H_2 target by performing R&D to improve SOEC performance and durability, thus reducing hydrogen cost and increasing hydrogen production

- The development and validation of highly active oxygen electrocatalysts with enhanced operational durability would enable meeting commercialization targets of H_2 production rate and H_2 production cost

Approach

- Identifying new compositions
  - Changing the electrostatic interactions of cations in perovskites
  - Sr-free
  - Co-free



- Engineering the nanocomposites
  - In situ composite synthesis to create 3-dimensional heterostructures with precise control of nanoparticles
- Identifying other factors controlling the OER rate, including electrode microstructure

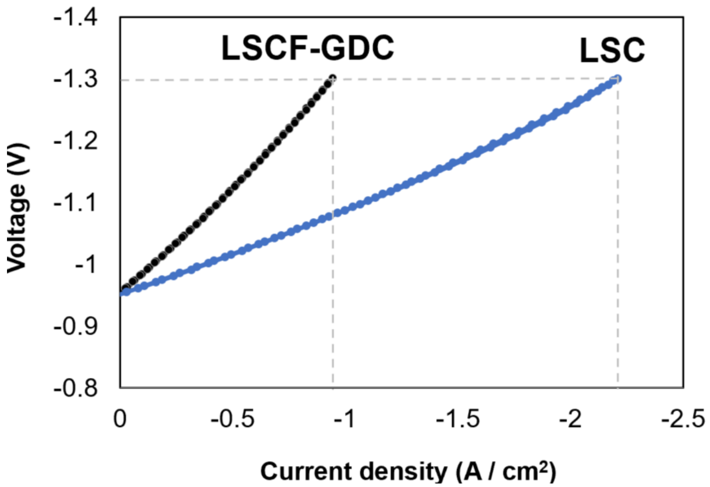
Milestones

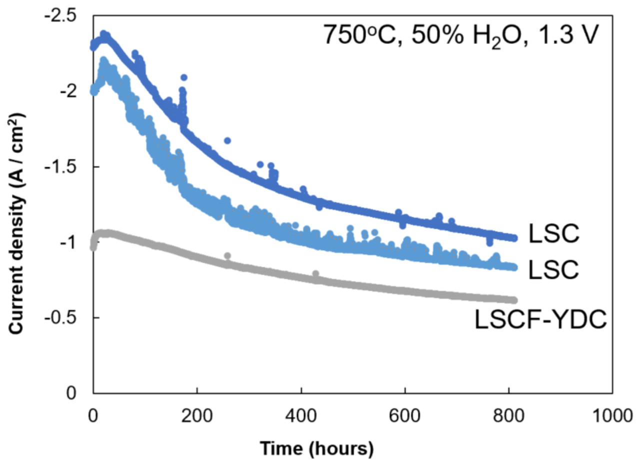
Date	Milestone/Deliverable	Complete
3/30	Identify 3 oxygen electrode compositions and synthesize oxide powders. Complete XRD studies to validate the method accuracy	10%
6/30	Synthesize 7 more oxygen electrode compositions and fabricate button and symmetric cells and initiate electrochemical testing	0%
9/30	Establish partnerships with MSI and NSBE	0%
Go/ noGo	Establish baseline performance and demonstrate 15% improvement over state-of-the-art materials	0%

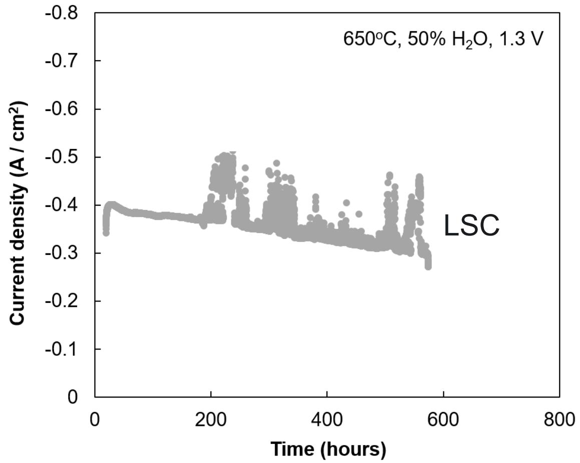
Approach: Safety Planning and Culture

- Project was not required to submit a safety plan to HSP
- Project follows strict PNNL safety requirements
  - Approved SOPs must be created, approved, and followed
  - Lab Assist activities must be created, approved, and followed for any work in the lab
  - All staff is required to take safety training related to the specific Lab Assist activities they are involved
  - Safety training must be completed to gain active access to the lab space
  - Safety training needs to be retaken following specific class requirements
- Specific to active work with hydrogen, all staff is also recommended/required to take an AIChE Hydrogen Laboratory Safety class

Accomplishments and Progress: Demonstrated That Performance Targets Are Achievable







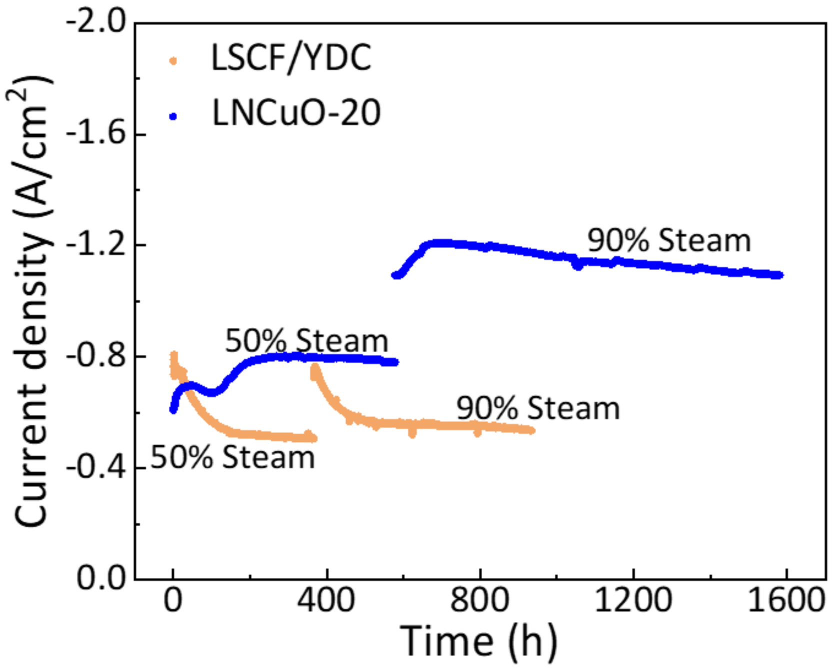
- LSC exhibits initially high performance that rapidly decreases in time

- Operating at 650°C

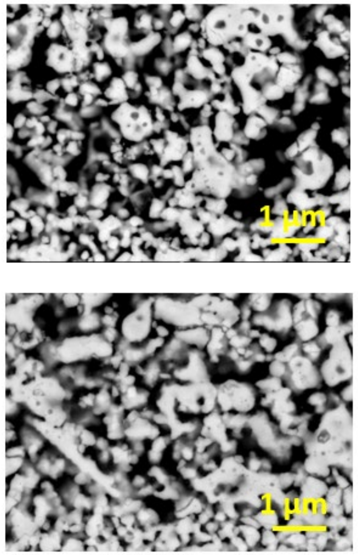
Another example is 3.1 and 4 A/cm² with bimodal structured nanocomposite $Sm_{0.5}Sr_{0.5}CoO_{3-\delta}$-$Ce_{0.8}Sm_{0.2}O_{1.9}$ electrodes at 1.3V at 750 and 800°C, respectively (*H. Shimada et al, Nanocomposite electrodes for high current density over 3 A cm^{-2} in solid oxide electrolysis cells, Nat. Commun.* ***2019,*** *10, 5432)*

Accomplishments and Progress: Different Degradation Trends Observed for Nickelate-Based Electrodes

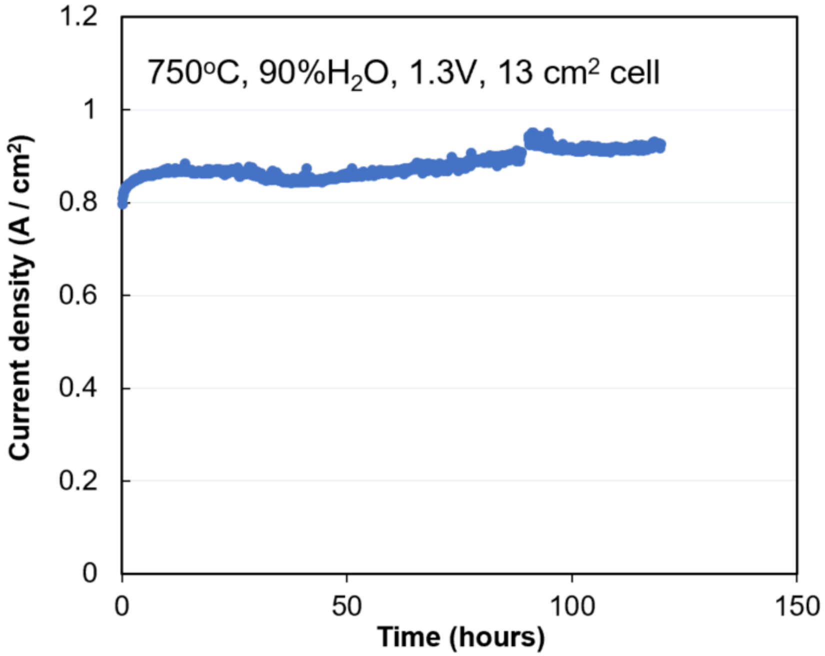
- Cu-Doped Nickelates, $La_4Ni_{0.8}Cu_{0.2}O_4$, show no break-in period



As fabricated



After 1,500 h of testing



Karki et al, ECS Transactions, 111 (6) 201-209 (2023) 10.1149/11106.0201ecst

Karki et al, in preparation

Responses to 2023 Reviewers' Comments

- New project, not previously reviewed

Collaboration and Coordination

- Preparing the sub-contract with UW
- Reached out to MSI and HBU to established collaborations
- Developing strategy for targeted outreach and recruitment activities within MSI to promote awareness of and generate interest in careers in energy and environmental sciences
- H2NEW and HydroGEN will assist in large cell testing and DFT materials screening

Remaining Challenges and Barriers

- This project is newly awarded
- All the equipment is available
- 2 postdoctoral positions have been open

Proposed Future Work

- Perovskite-based compositions will be synthesized via GNP and their sintering and electrocatalytic properties will be evaluated
- Depending on the results, electrode materials optimization will be performed (chemistry and/or microstructure) and all tests will be repeated
- Different techniques for nano-engineering oxygen electrode architecture will be tested
- Specific chemistries will be identified as needed
- Multiple compositions will be rationale designed via combinatorial screening

Note: Any proposed work is subject to change based on funding levels.

Summary

- An oxygen ion conducting SOEC that operates at 1.2 A/cm^2 at 1.3V with <3.2mV/khr degradation rate at <750^oC using novel oxygen electrode materials will be developed to replace a state-of-the-art LSCF which critically limits SOEC performance and long-term stability
- Electrode composition will be selected from three families of perovskite-based mixed ion and electron conductors, cubic-type ABO_3, layered $AA'B_2O_6$, and Ruddlesden–Popper $A_{n+1}BnO_{3n+1}$ phases
- Electrode composition and microstructure will be tailored to reduce the polarization losses by nanoengineering the nanoparticles in situ during materials synthesis creating in situ 3-dimensional heterostructures with precise control of nanoparticles