High Performance and Robust Proton Conducting Solid Oxide Electrolysis Cells Enabled by New Materials, Interfaces and Fabrication Methods

Dong Ding

Idaho National Laboratory

DOE project award #: ELY-BIL009

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DOE Hydrogen Program

2024 Annual Merit Review and Peer Evaluation Meeting

STI#: INL/CON-24-77368

Project Goals

- Demonstrate proton conducting solid oxide electrolysis cells (P-SOEC) with ≤5 mV/khr degradation rate, FE >90% and current density of >1.0 A cm^{-2} at 1.3 V (≥50% steam, ≤600^{o}C) by implementing the innovative materials, interface and fabrication methods.
- Prototype 10 cm×10 cm single unit cells (SUCs) with current density ≥80% of analogous button cell.
- Document protocols for Faradaic efficiency (FE) evaluation and hydrogen production rate measurement.
- Transfer the materials, methodologies, and knowledge developed under this project to other lab call team(s), FOA funded teams, and the P-SOEC community as needed.

Overview

Timeline and Budget

- Project Start Date: 02/01/2024
- FY24 Planned DOE Funding: $1,070,000
- Total DOE Funds Received to Date: $1,070,000

Partners

- **Project lead**: Dong Ding, Idaho National Laboratory
- **Co-PI**: Wei Wu, Joshua Y. Gomez, Zeyu Zhao, Meng Li (Idaho National Laboratory)
- **Potential collaborators (as part of H2LinkSc)**: Sossina M. Haile (Northwestern University), HEISs/EFRC

Barriers

- **Barrier**: Limited oxygen electrode materials (OEM) and large area specific resistance (ASR) related
- **Target**: Develop active but robust OEM and demonstrate its ASR values of <0.08 Ω cm^2 under steam >30 % at 600^{o}C
- **Barrier**: Challenge of fabricating high-performing P-SOECs due to the difficulties of cell processing (High sintering temperatures, Ba evaporation, unknown mechanical properties, etc)
- **Target**: Demonstration of 10 cm × 10 cm P-SOECs with current density ≥80% of button cells (current density >1.0 A cm^{-2} at 1.3 V)
- **Barrier**: Relatively low FE and unproven durability
- **Target**: Demonstration of P-SOECs with FE >90% under optimized operation with ≤5 mV/khr degradation rate

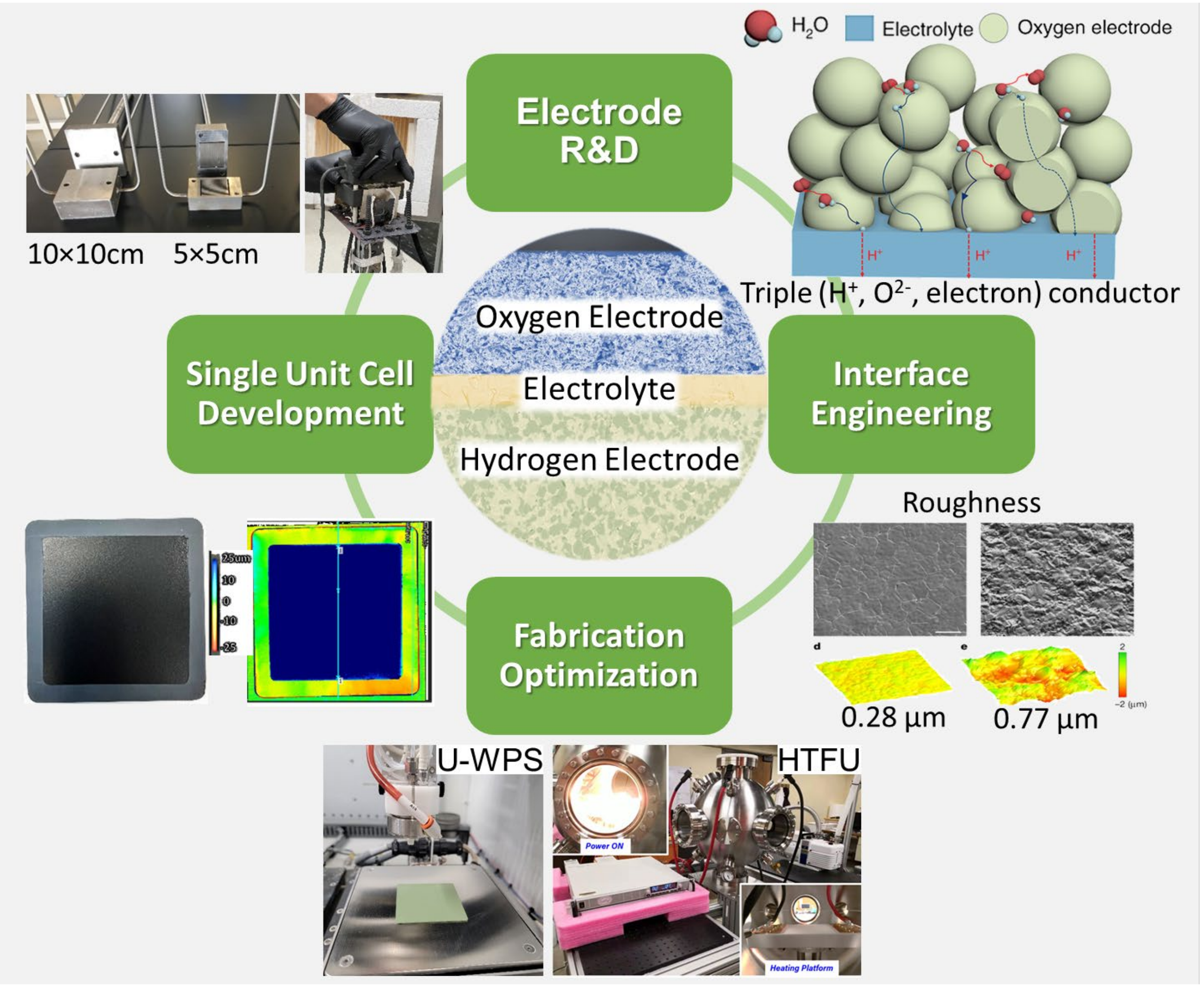
Potential Impact

- **Technical Impacts:**
  - Discover and provide more options in oxygen electrode materials that can expedite P-SOEC commercialization.
  - Improve the manufacturability of the cells and benchmark its mechanical properties.
  - Improve the Faradaic efficiency of P-SOEC and demonstrate its long-term durability.
  - Prototype of large sized P-SOEC SUCs.
  - Technology transfer.
- **DOE Impacts:**
  - Strengthen DOE-EERE-HFTO hydrogen production portfolio
  - Extend the research content beyond the existing HydroGEN consortium.
  - Provide a focused blueprint for one of most promising technology pathways
  - Hasten the achievement of DOE's Hydrogen Shot
- The overall target is to meet the Clean Hydrogen Electrolyzer program goal of $2/kg target for electrolytic hydrogen production by 2026 and enable the Hydrogen Shot goal of $1/kg by 2031.

Approach

Technical Approach

- Electrode material research and development (R&D) to enhance P-SOEC performance and lower temperature operation
- Improvement of manufacturability and mechanical properties
- Interface engineering for degradation mitigation and FE enhancement
- P-SOEC SUC fabrication, testing protocol development, and performance validation



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Approach

Milestones and Go/No-Go Decisions

- **Q1**: Brief update report submitted to HQ, including status of recently initiated work and planned tasks/roles for each team member. Report via email/powerpoint slides with additional virtual meeting if desired.
- **Q2**: Baseline oxygen electrode materials with ASR values of <0.10 Ω cm^2 under steam concentration >30 % at 600oC based on symmetric cell measurement in SOEC mode
- **Q3**: Integrate baseline electrode and achieve a current density of 0.8 A cm^{-2} at 1.3 V and ≤600oC with steam concentration ≥50% on button cells with active size ≥1.0 cm^2.
- Year 1 Go/No-Go: Demonstrate the cells (active size ≥1.0 cm2) have a current density of ≥0.9 A cm-2 and FE>85% at 1.3 V and ≤600^{o}C with steam concentration ≥50% by integrating the achievements in reducing sintering temperatures and interface engineering
- **CBP**: Set SMART goals for three areas: i) DEIA; ii) Energy Equity and iii) Workforce Implications with the current state assessment and progressive layouts for the key activities to be implemented.

Approach: Safety Planning and Culture

Top to Bottom Safety Focus

- **Design**
  - HAZOP
  - Subject Matter Expert review
  - Hydrogen and flame detection systems
- **Procurement**
  - Quality procurement program
  - Hydrogen material compatibility awareness
- **Installation**
  - Qualified and trained installation
- **Pre-operational Testing**
  - Inspections and monitoring for hydrogen and other leaks
- **Operation**
  - Alarms and operator aids
  - Routine checks and inspections of operating systems

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- **Work Control**
  - What is and isn't authorized
  - Test plan reviews
- **Stop work**
  - If conditions are unsafe, anyone can call for a work stoppage.
- **Questioning mindset**
  - Briefings prior to the start of a new activity
  - Asking what could go wrong?
- **Training**
  - On-site training to facilitate broad institutional awareness of the safety considerations for hydrogen work.
  - NFPA 2 training
- **Flexible electrolysis system test platform**
  - Fully instrumented single unit cell and stack test platform – vendor independent
  - Atmospheric testing with hydrogen recycle
  - Separate "Hot Box" module

Accomplishments and Progress

- Funding received at INL and completed Scope of Work (SOW) with the budget plan and received the DOE's approval.
- Updated the work control document (lab instruction, LI) with newly-allocated lab space, and received the lab manager's approval.
- Developed the pipeline with the alignment of DEIA plan.
- Checked the chemical inventory and got all chemicals as precursors ready to fabricate.
- Started to upgrade the hardware for testing and characterizations.
- Initiated oxygen electrode materials R&D.
- Started for mechanical properties characterization for baseline establishment.
- Drafted the GEN1 protocol for Faradaic efficiency evaluation.
- Begun the H2LinkSC activities as planned (details see slide#10).

This is a new project and has not been reviewed previously

Collaboration and Coordination

- **Project collaborators:**
  - Prof. Yi Xie (Purdue University)
  - **Project roles**: Responsible for High Temperature Ultra-Fast sintering capability to achieve high quality and performance of cells while reducing the energy input for high temperature sintering/densification of the half cells.

- **Planned project collaborators:**
  - HEISs (Hydrogen in Energy and Information Sciences) Center, Prof. Sossina M. Haile (Northwestern)
  - **Project roles**: Provide HEIS's fundamental understanding of hydrogen transport in inorganic solids as the guidance of material R&D and interface engineering to improve P-SOEC performance.

Collaboration and Coordination

- **H2-LinkSC objective:**
  - The aim is to "link" basic science research with applied office activities with the applied R&D efforts of HFTO with increasing coordination of Office of Science (SC)-funded activities
  - Specifically, the project will "link" to a SC-funded Energy Frontier Research Center (EFRCs), Hydrogen for Energy and Information Sciences (HEISs) center, led by Prof. Sossina Haile at Northwestern University. we expect to advance fundamental understanding of the technical barriers that limit P-SOEC technology and develop solutions.
  - The overall goals of the proposed H2-LinkSc work are to 1) facilitate the exchange of information and expertise between the two programs, H2-LinkSc and HEISs, 2) accelerate advancement of P-SOECs, and 3) implement engagement in depth between SC and EERE-HFTO.

- **H2-LinkSC Activities/Progress:**
  - A seminar given by Prof. Haile will be held at INL in June.
  - A HEISs Co-PI at MIT hired a postdoc who will be sent to INL for training on P-SOEC fabrication.
  - Samples have been sent to another HEISs Co-PI at MIT for characterization and a joint publication is expected.
  - Several project members plan to attend HEISs' annual meeting.

DEIA/Community Benefits Plans and Activities

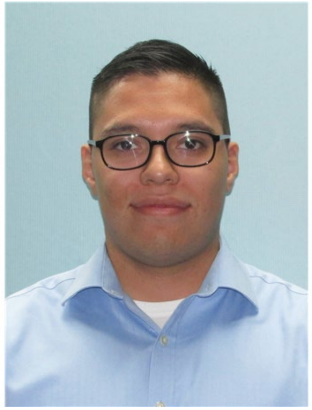
- **Plan**: 1) Advance diversity, equity, inclusion, and accessibility; 2) Contribute to energy equity; 3) Invest in America's workforce; 4) Contribute to the President's goal that 40% of the overall benefits of federal investments in climate and energy flow to disadvantaged communities (the Justice40 Initiative); 5) Increase collaboration with Office of Science funded researchers.

Activities:

- **DEIA:** Promoted a GEM fellow and hired a postdoc from the underrepresented organization and a Ph.D student from a Hispanic-Serving Institution (HSI).

- **Energy Equity:** Initiated to build a high-performing, competitively compensated team which elevates the tax base of Justice40 communities surrounding the host institutions. The team will seek out opportunities to participate in activities which relate to the growth of DOE's hydrogen research capability within INL.

- **Workforce Implications:** Started the conversion on partnering with workforce experts within INL to quantify and model the availability of key skills needed for the long-term sustainability of green hydrogen science and engineering.



Mr. Joshua Gomez came to INL through the laboratory's partnership with the National GEM Consortium (GEM). Josh joined EES&T's research staff in 2021 after completing his master's degree from New Mexico State University (a Hispanic-serving institution). Now he has become a lab operation lead to oversee all P-SOEC lab activities

Dr. Samuel Koomson is an underrepresented postdoctoral fellow and he will be an important participant for INL's P-SOEC projects.

Remaining Challenges and Barriers

To be determined as a new funded project!

- Unexpected longer lead time in procurements delayed the project advancement;
- Acquisition of talents in a timely manner is challenging that will impact the project progress;
- Acquisition of high-quality and reproducible data in high-temperature electrochemistry is another challenge, because of more uncertainties in cell fabrication, integration, assembly and curing.

Proposed Future Work

FY24: Baseline establishments and work task initiations

- Baseline and integrate oxygen electrode materials (ASR <0.10 Ω cm^2)on button cells to achieve a current density of 0.8 A cm^{-2} at 1.3 V and ≤600^{o}C with steam concentration ≥50%
- Demonstrate the sintering temperature is reduced at ≤1400^{o}C, and over two interface engineering approaches are assessed
- Initiate the fabrication of single unit cells (SUCs) with larger active areas.
- **GNG Point**: Demonstrate the cells (active size ≥1.0 cm^2) have a current density of ≥0.9 A cm^{-2} and FE>85% at 1.3 V and ≤600^{o}C with steam concentration ≥50%

FY25: Further enhance P-SOEC performance by conducting the oxygen electrode material R&D efforts and involving interface engineering approaches. Improve the mechanical strength of P-SOECs with optimized manufacturing procedures and integration of advanced fabrication techniques.

FY26: Large format SUC fabrication with improved mechanical strength and optimized interfaces to demonstrate hydrogen production with ≥80% of analogous button cells

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

Summary

- This is a newly funded project focused on P-SOEC technology, an emerging but promising pathway to help achieve DOE's Hydrogen shot goal.
- The project is focused on four primary tasks by implementing R&D innovations in materials, interface and fabrication methods to overcome the P-SOEC barriers and expedite the technology advancement.
- The project is "linking" to a funded EFRC, HEISs and leveraging the fundamental knowledge from there to facilitate P-SOEC development.
- CBP is on track and the team embraces HFTO's vision of accelerated hydrogen RD&D which simultaneously brings direct, meaningful, and measurable benefits to historically marginalized, underserved, underprivileged, and underrepresented communities.

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Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.