Energy Materials Network
U.S. Department of Energy

HydroGEN
Advanced Water Splitting Materials

Thin-Film, Metal-Supported High-Performance and Durable Proton-Solid Oxide Electrolyzer Cell

Tianli Zhu
United Technologies Research Center

6/13/2018

Project # pd154

NREL BERKELEY LAB Sandia National Laboratories INL Idaho National Laboratory Lawrence Livermore National Laboratory SRNL

Project Overview

Thin-Film, Metal-Supported High-Performance and Durable Proton-Solid Oxide Electrolyzer Cell

Tianli Zhu, United Technologies Research Center

Partner organizations: UConn, ElectroChem Ventures

Award #	EE0008080
Start Date Year 1 End Date Project End Date	10/1/2017 9/30/2018 9/30/2020
Total DOE Share Total Cost Share Year 1 DOE Funding	$1.0M $0.25M $0.25M

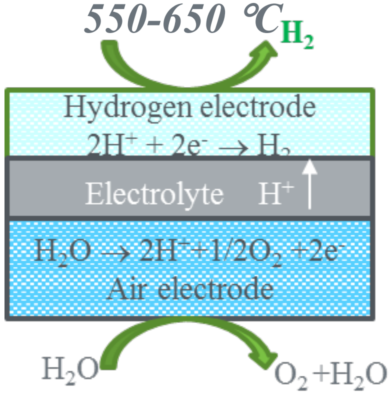
Project Vision

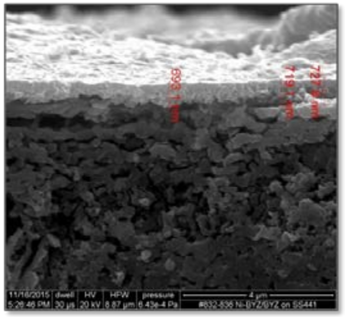
Develop a highly efficient and cost competitive high temperature electrolysis for H_2 generation, by a thin-film, high efficiency and durable metal-supported solid oxide electrolysis cell (SOEC) based on proton-conducting electrolyte at targeted operating temperatures of 550-650ºC.

Project Impact

Accelerate the commercialization of high-temperature electrolysis, and advance reversible-SOFC technology for renewable-energy applications.

Proton conducting electrolyzer 550-650 ℃





Thin film deposition for electrolyte

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

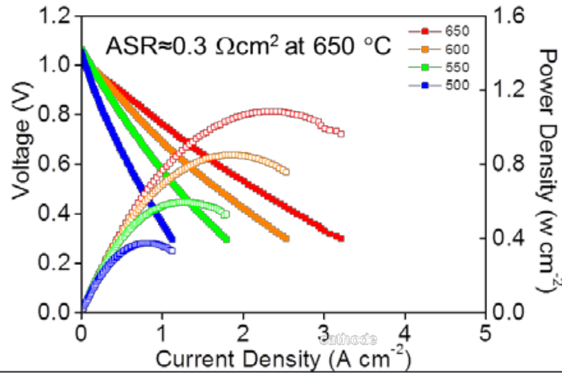
United Technologies Research Center

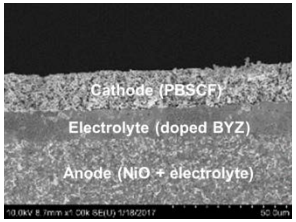
UCONN

Approach- Summary

Project Motivation

Anode supported p-SOFC button cell (ARPA-E REBELs)





Key Impact

Metric	State of the Art	Proposed
SOEC Performance	1 A/cm² at 1.4 V at 800 ºC	≥1 A/cm² at 1.4 V at 650 ºC
SOEC Durability	(1-4)% per 1000 h	<0.4% per 1000 h (~4 mV per 1000 h)
H_2 production Cost	>\$4/kg H_2	\$2/kg H_2

Barriers

-. Low cost deposition of ceramic layers:

Deposition process without high T sintering: RSDT, SPS, LBNL co-sintering/metal infiltration

-. Metal alloy durability

Proper selection of metal alloys and protective coatings through durability tests

-. Steam electrode and electrolyte stability

INL's high-throughput methodology; molecular dynamics modeling

Partnerships

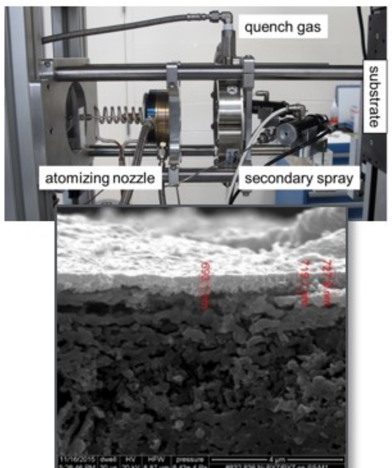
- University of Connecticut (Prof. Radenka Maric): Cell Fabrication (RSDT)
- UTRC SPS Vendor/PW: Suspension Plasma Spray (SPS)
- ElectroChem Ventures (consultant): Metal-supported cell design
- EMS nodes: LBNL, INL & NREL

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

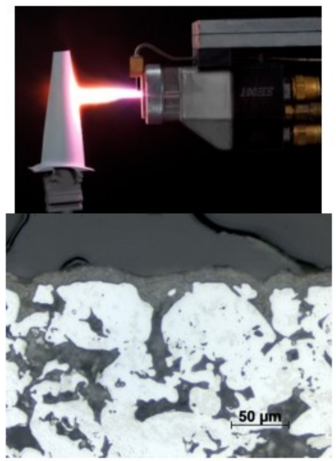
Approach- Innovation

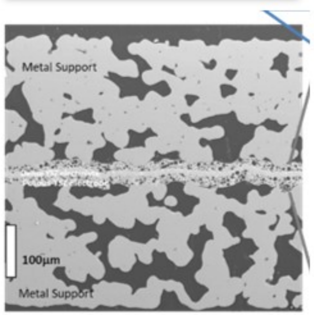
Low cost, scalable fabrication of metal-supported cell (focus on electrolyte), and further material optimization for an efficient & durable p-SOEC.

Reactive Spray deposition (RSDT) (<10μm)



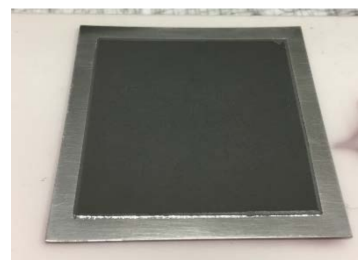
Suspension plasma spray (SPS), <15 μm





Co-sintered metal cell (LBNL)

Phase 1: focus on demonstrating the feasibility of the proposed concept via electrolysis performance demonstration of a Gen 1 metal-supported single cells



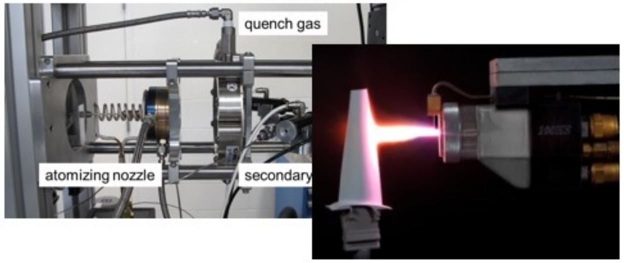
Material optimization

Project Performance target

Relevance & Impact

The successful demonstration of the concept should result in a path to low cost and durable p-SOEC for H_2 production at <$2/kWe.

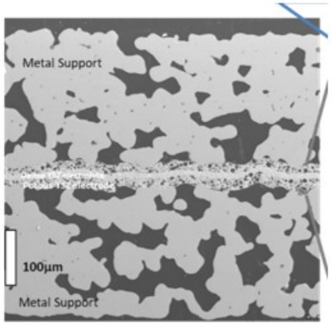
UTRC/UConn low cost cell fabrication



Metal supported p-SOEC

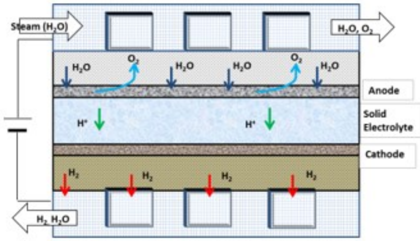
UTRC stack & system testing (up to 10kWe)

Metal alloy selection: oxidation rig at LBNL



Co-sintered metal cell LBNL

Material optimization: high throughput testing stands at INL



Electrochemical modeling at NREL

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

United Technologies Research Center UCONN

Accomplishments- Project Go/No Go Criteria

- GO/NO GO: Gen 1 metal-supported p-SOEC cell fabrication and performance demonstration complete.

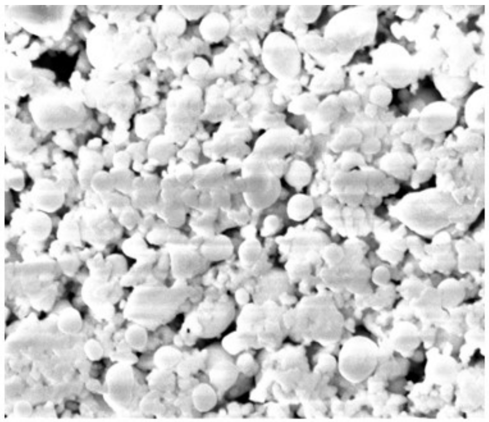
Technical criteria: under electrolysis operating conditions, SOEC cell meets the performance target of >0.8A/cm^2 at 1.4 V , and <1%/1000h at T<650 °C.

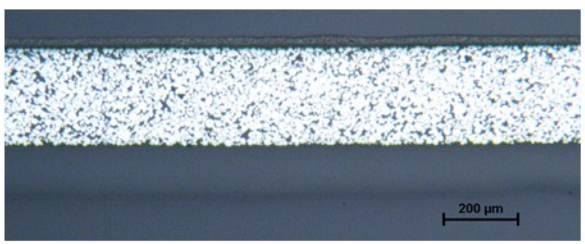
Tasks	Milestone description	Anticipated Month	Status
Gen 1 single cell stack design & fab.	Complete single SOEC cell mechanical design.	M3	100%
Gen 1 single cell stack design & fab.	Demonstrate bilayer (H2 electrode/electrolyte) thin film deposition.	M6	90% (>90% density and <50 um, OCV to be demonstrated
Gen 1 single cell stack design & fab.	Complete Gen 1 SOEC single cell fabrication, demonstrating dense electrolyte and ~1.0 OCV measurement at T=550-650 °C.	M9	10%
Gen 1 single cell stack perform. demon	Demonstrate electrolysis performance & short term durability (Go/No-Go).	M12	
Gen 1 single cell stack perform. demon	Evaluate SOFC-SOEC reversibility.	M12	

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

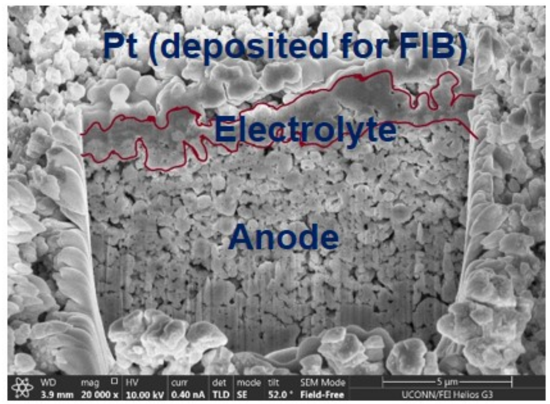
Half Cell Fabrication Process in Development

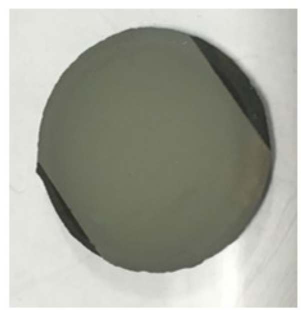
- Hydrogen electrode deposition on porous metal support is complete
- Electrolyte deposition by RSDT and SPS in progress, focus on process optimization



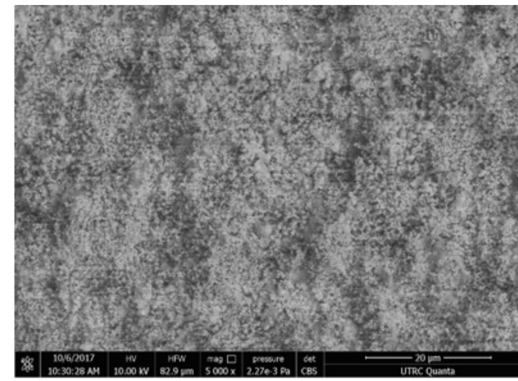


Sintered Ni-Electrolyte H_2 Electrode





RSDT button cell



3X3 cm²

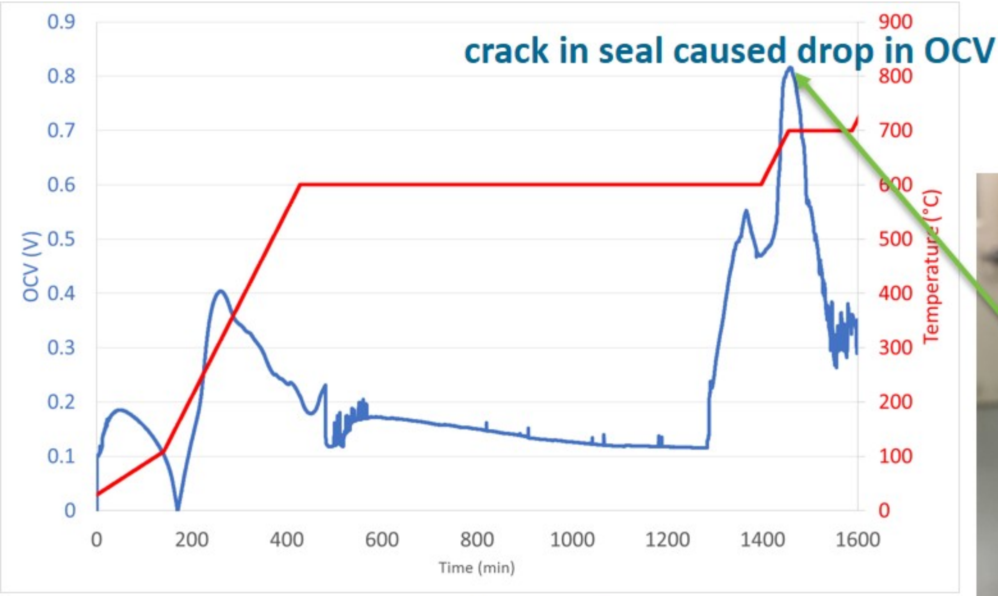
5x5 cm²
(with cathode)

SPS (<10% porosity)

Electrolyte deposition

Half Cell Fabrication Process in Development

- OCV results of the electrolyte indicate density of electrolyte needs further improvement (OCV=0.8-0.9 on cells with either RSDT or SPS electrolyte)
- Effort on RSDT of single oxide steam electrode started: precursors and solubility



RSDT electrolyte/anode/porous metal

Steam electrode precursors in solvent (25g Toluene + 10g IPA + 5g ethanol)

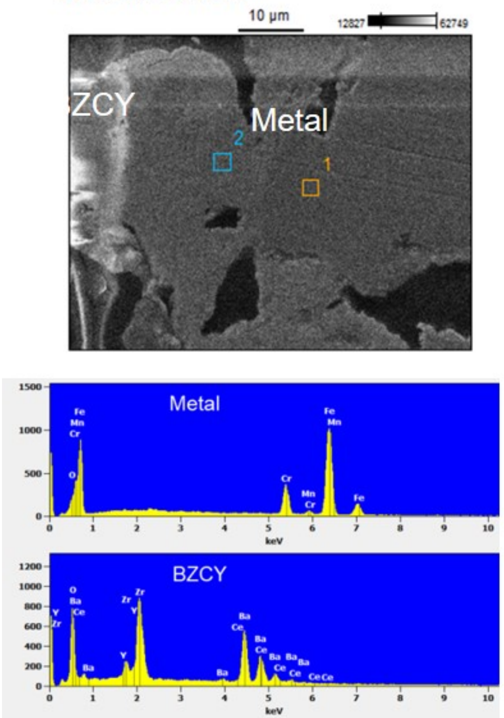
Any proposed future work is subject to change based on funding levels

United Technologies Research Center
UCONN

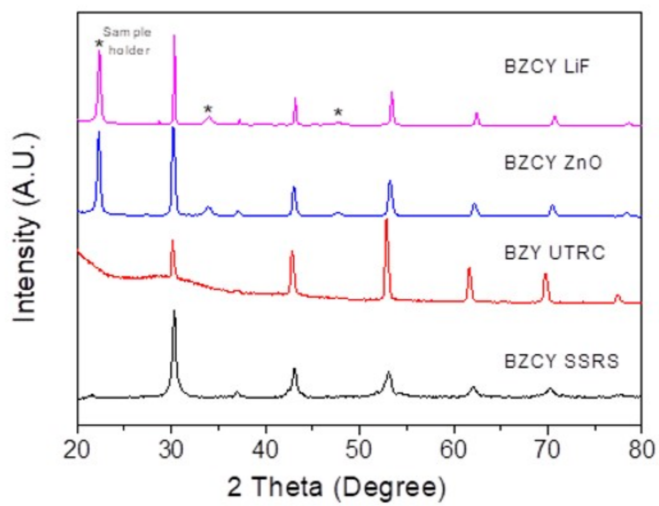
Alternative Cell Fabrication: LBNL Co-sintering

- Doped BYZ compatible with Stainless Steel Support Material and Processing Conditions
- Processing conditions dictated by stainless steel: 2% Hydrogen, 1450°C

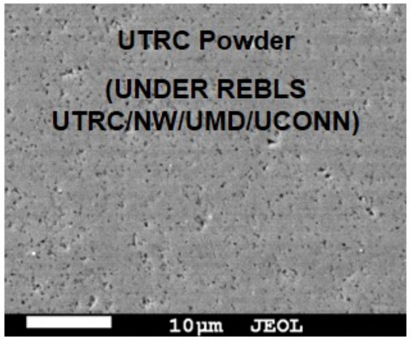
Interdiffusion of BZCY/metal not observed



Correct Phase Formed



Sufficient Sintering Achieved



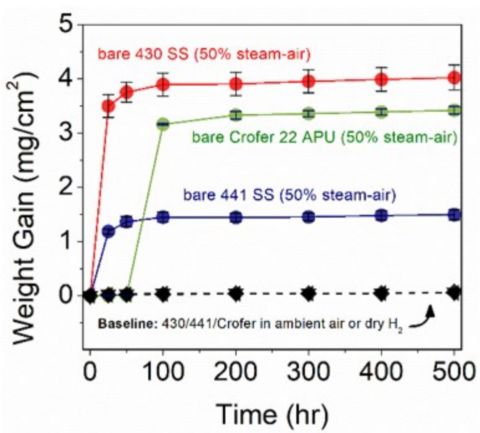
No connected porosity, 95% density

BERKELEY LAB

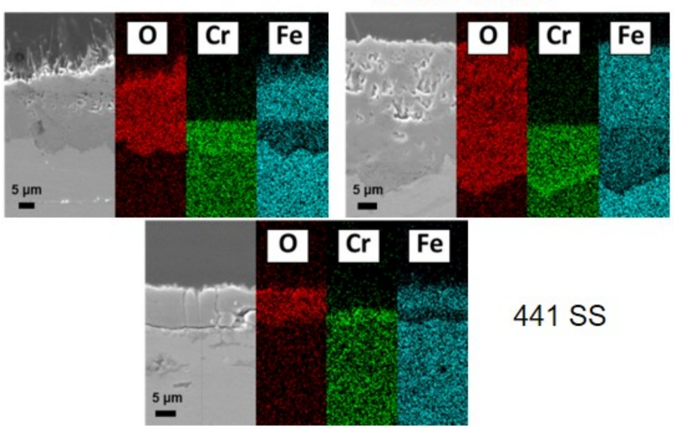
Selection of Interconnector Alloy and Coating through Oxidation Study in SOEC Conditions (LBNL)

- Severe oxidation of uncoated SS metal alloy in 50% steam-air (650 °C)
- Minimal oxidation observed with coated metals in 50% steam-air (650 °C)

50% steam-air, 650 °C, 500 h



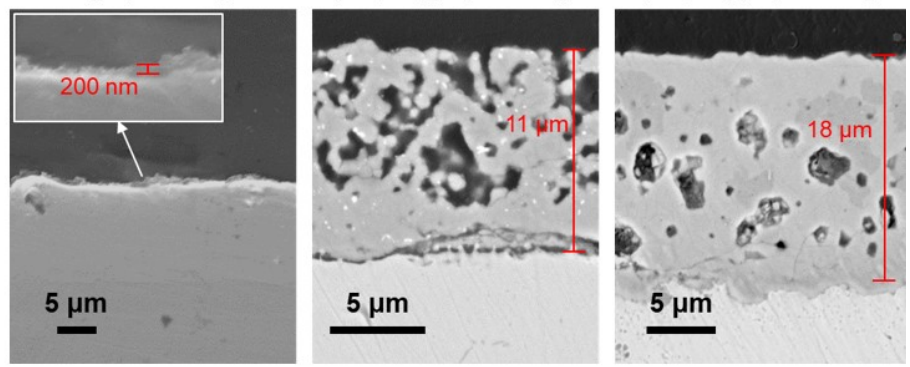
430 SS | Crofer 22 APU



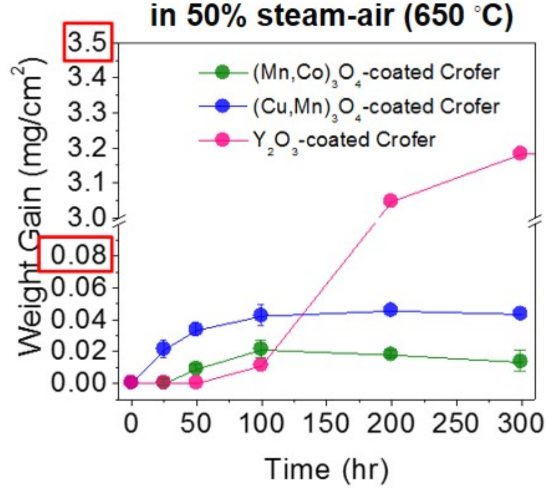
441 SS

Potential protective coating

Y_2O_3 coating | $(Mn,Co)_3O_4$ coating | $(Cu,Mn)_3O_4$ coating

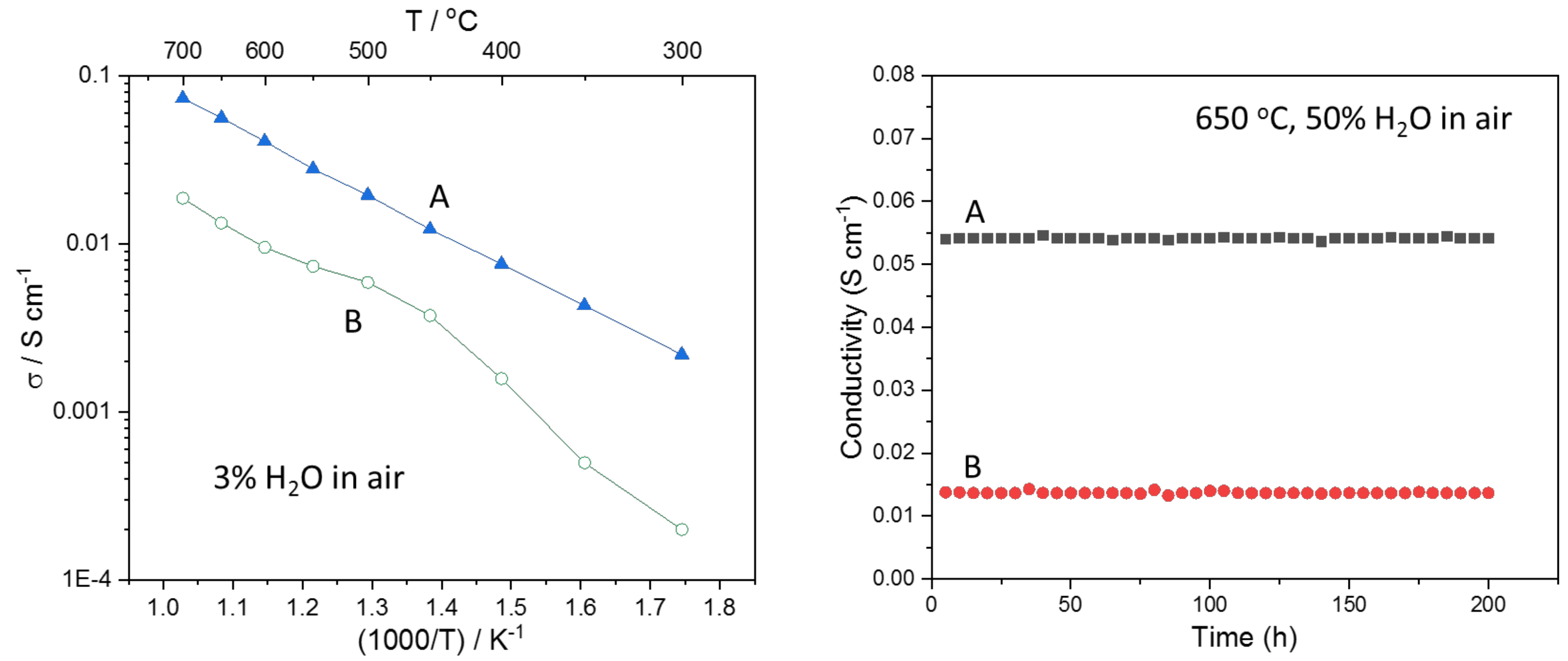


Minimal oxidation for MnCo- and CuMn-coated metals in 50% steam-air (650 °C)



Electrolyte and Electrode Material Optimization (INL)

- BZCY-based electrolyte performance comparable to similar materials in the literature
- Stable performance of electrolyte in steam/air at targeted electrolysis T

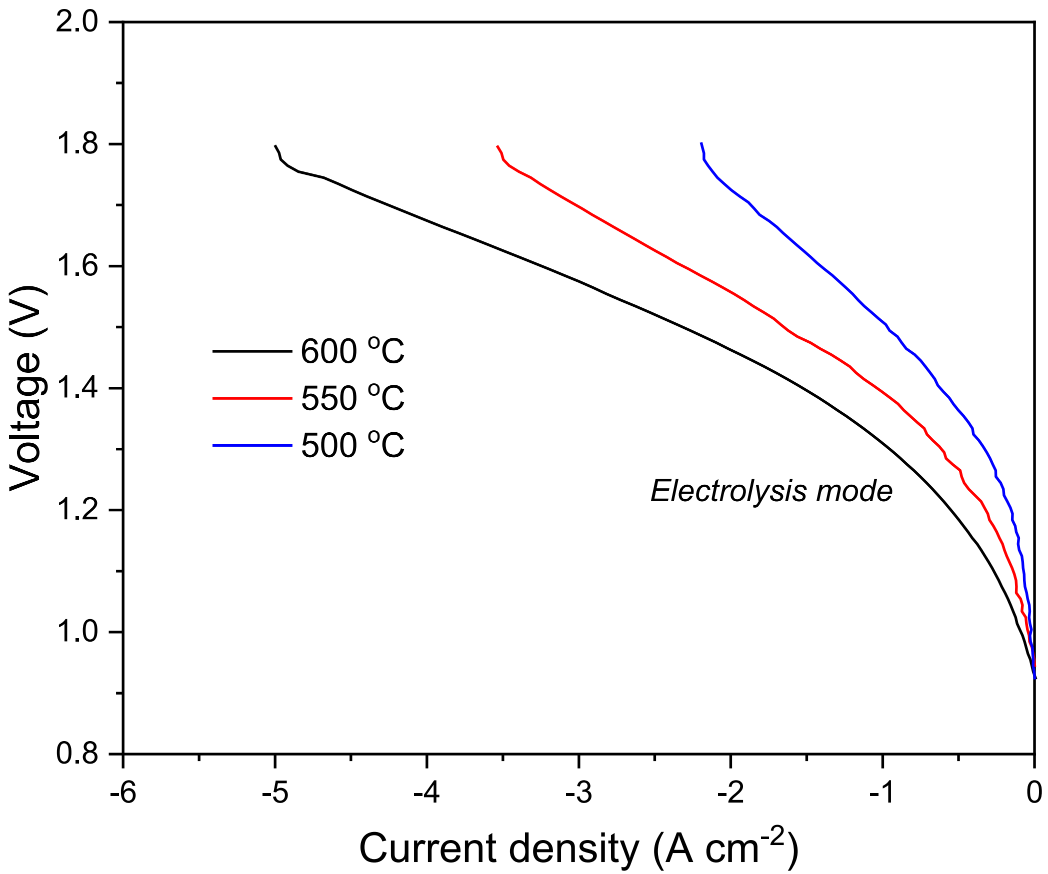


Electrical conductivities and durability of two BZCY-based electrolyte materials

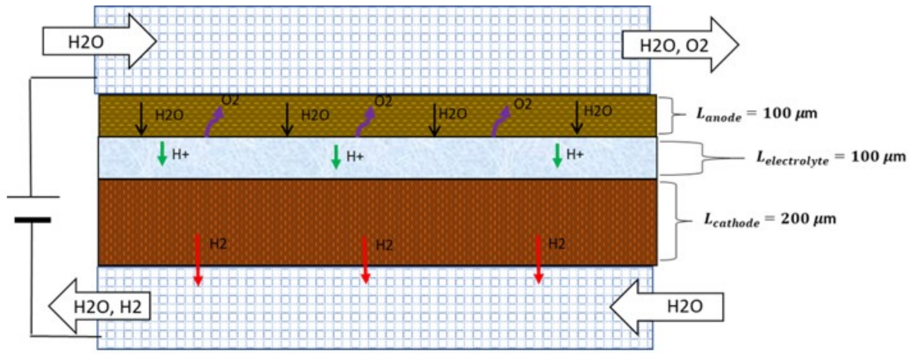
Electrolyte and Electrode Material Optimization (INL)

- High water electrolysis performance was obtained on anode-supported cells with BZCY-based electrolyte and IDL's new steam electrode

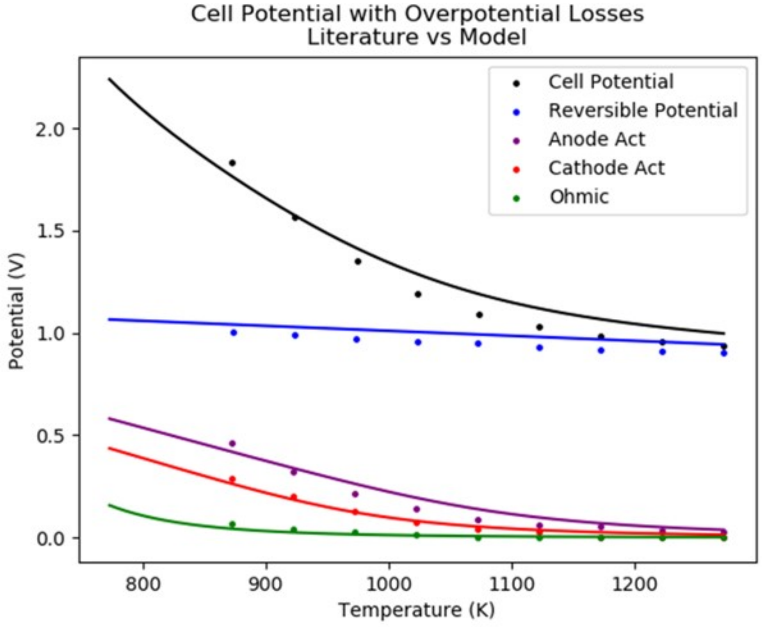
=> Promising path to meet p-SOEC performance target for the project

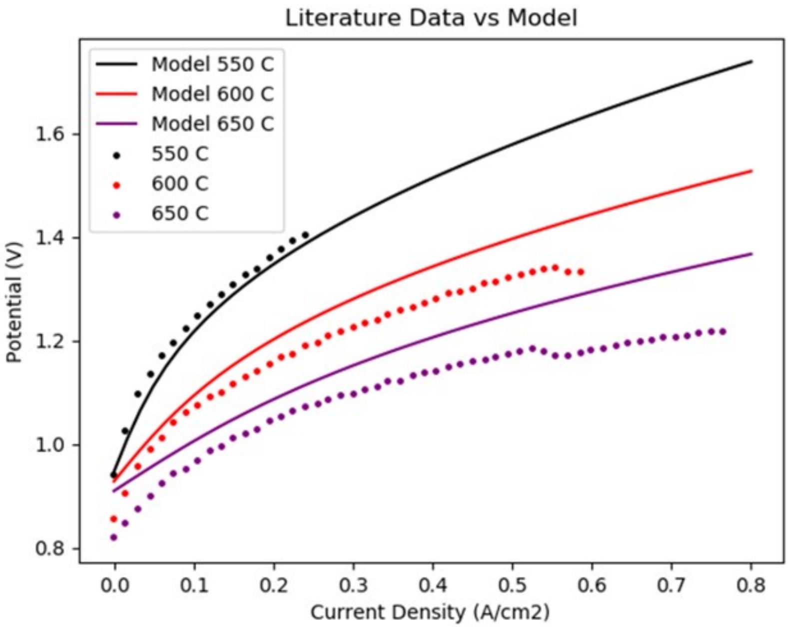


Thermal/Electrochemical Modeling of SOEC (NREL)



- Focused on proton-conducting SOEC modeling with reference to broad SOEC/SOFC modeling works.
- Calibrated various cell overpotentials vs. operating conditions.
- Modeled the variation of V-I curves.





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

Collaboration: Effectiveness

- Close collaboration with the EMN node experts
  - Monthly meeting with EMN nodes, material and data exchange
  - With LBNL team: collectively determined metal alloy candidates, oxidation testing conditions, electrolyte powder and process for co-sintering
  - With INL team: team discussion on electrolyte sintering, INL supports testing on UTRC metal-supported button cell (in progress)
  - NREL team in early stage of establishing SOEC model establishment, more close interaction expected later
  - UTRC/INL/LBNL discussions on sintering, powder process
- Quarterly reports, review presentations and data were uploaded on the HydroGEN data hub, providing platform for collaboration within team members, and later for HydroGEN Consortium.

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

Proposed Future Work

- **Budget Period 2**: Focus on optimization of p-SOEC performance through material and fabrication improvement; complete the fabrication of Gen 2 cell based on new material composition and improved fabrication process.
- **Budget Period 3**: focus on demonstrating the performance of Gen 2 cell, for both electrolysis performance and long term durability, as well as techno-economic analysis of the p-SOEC system.

Estimated Budget: $750 (Fed)

- Project goal: Enable a high temperature electrolysis system that can meet all of the DOE performance targets, with a cell ASR <0.3 Ωcm^2 & decay rate < 0.3%/1000h at 550 -650 °C.

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

Project Summary

- Significant progress has been made on half cell fabrication (anode/electrolyte) on metal support, further optimization of electrolyte is in progress to obtain denser layer.
- Collaboration with EMN nodes provided critical supports to address technical barriers in metal alloy durability, and electrode/electrolyte material optimization and stability.

Acknowledgement

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Fuel Cells Technology Office (FCTO) Award Number DE-EE00080808, Technology Manager: Dr. David Peterson.

Organization	Team Members
UTRC	Tianli Zhu, Justin Hawkes, Mike Humbert
ElectroChem Ventures	John Yamanis
UCONN	Radenka Maric, Lenoard Bonville, Ryan Ouimet
LBNL	Mike Tucker, Ruofan Wang, Conor Byrne
INL	Dong Ding, Hanping Ding
NREL	Zhiwen Ma