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

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RTX Technology Research Center

EE0008080

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Project ID # p154

DOE Hydrogen Program 2023 Annual Merit Review and Peer Evaluation Meeting

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NREL Transforming ENERGY | BERKELEY LAB Bringing Science Solutions to the World | Sandia National Laboratories | INL Idaho National Laboratory | Lawrence Livermore National Laboratory

Project Overview

Project Partners
Tianli Zhu, Raytheon Technologies Research Center
Partner organizations: ElectroChem Ventures, UCONN

Project Vision

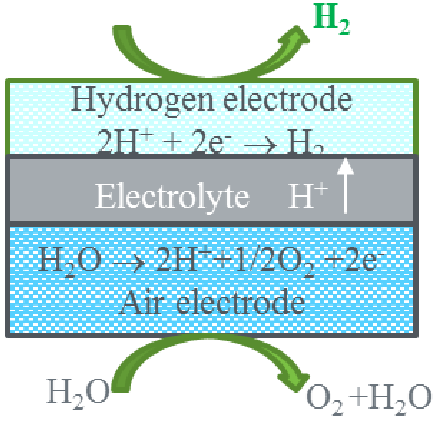
Develop a highly efficient and cost competitive high temperature electrolysis for H_2 generation, by a thin- film, high efficiency and durable metal-supported solid oxide electrolysis cell (SOEC) based on proton-conducting electrolyte at targeted operating temperatures of 550-650 °C.

Project Impact

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

Award #	EE0008080
Start/End Date	10/1/2017 – 3/30/2025
Project Funding*	$1.25M

Proton conducting electrolyzer 550-650 ℃

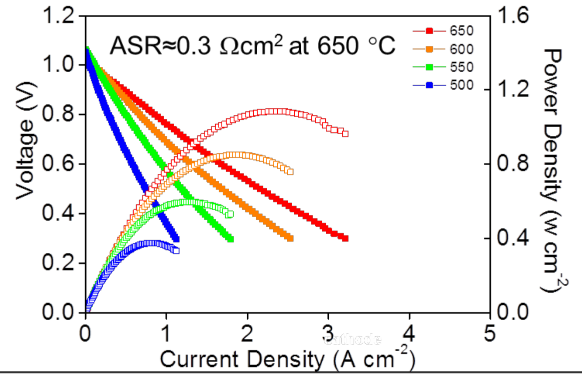


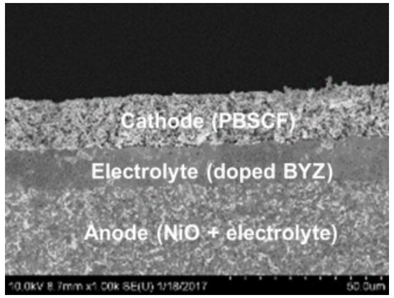
** this amount does not cover support for HydroGEN resources leveraged by the project (which is provided separately by DOE)*

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/cm^2 at 1.4 V at 800 ºC	≥1 A/cm^2 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

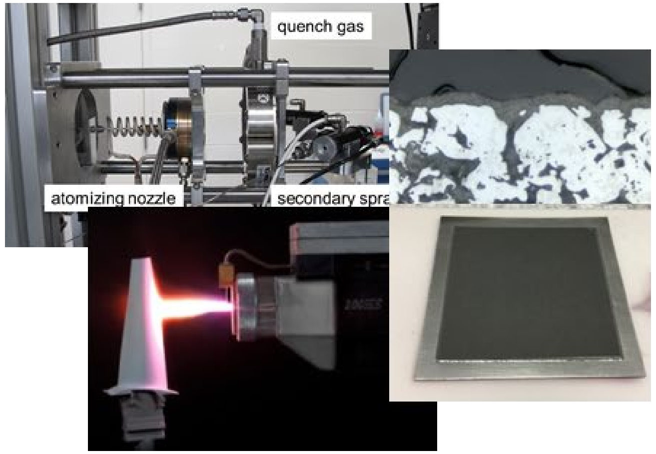
INL's high-throughput methodology; molecular dynamics modeling

Partnerships

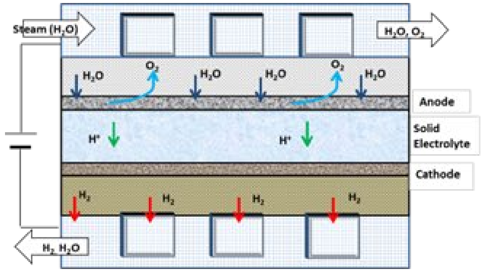
- University of Connecticut (Prof. Radenka Maric): Cell Fabrication (RSDT) – finished in BP1
- UTRC SPS Vendor/PW: Suspension Plasma Spray (SPS)
- ElectroChem Ventures (consultant): Metal-supported cell design
- EMS nodes: LBNL, INL & NREL

Approach- Innovation: Integrating Manufacturing, Material & Modeling

Low cost cell fabrication
Focus: electrolyte
Without high T sintering:
UTRC/PW (SPS), UConn (RSDT)

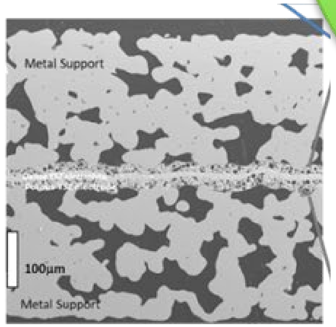


Metal alloy & coating selection
LBNL: oxidation study



Electrochemical modeling
NREL

Co-sintered metal cell
LBNL



Material optimization & button cell testing
INL: high throughput testing stands

Approach – Safety Planning and Culture

Safety Plan

- Required: Yes
- Comments were addressed with the HSP

Prioritizes safety and analyzes safety hazards

- **Risk Mitigation Plan according to** RTRC's Flammable Gas Standard:
  - Automated and manual shutoff, flow restrictors to limit flow
  - Minimize fittings in non-ventilated spaces, compression fittings are used for connections, tubing secured to solid surfaces.
  - Adequate ventilation in both storage and testing rig
  - Gas sensors are coupled to normally closed solenoid valves via a PLC.
- **Risk assessment of the lab & the rig process**
- **Standard operating procedures**
- **Training and equipment maintenance**

Incidents/near-misses and learning

- **Track Record on Safety**
  - Fuel cell research has been conducted at RTRC for > 20 years without any serious safety incidents.
- **Well established incident reporting and Investigation**
  - All emergency situations must be reported by dialing extension 7777 on RTRC phones (860-610-7777 from a cell phone). This will result in RTRC Security dispatching the appropriate responders to the event.
  - RTRC also encourages the reporting of "near misses," and RTRC has an on-line "Near Miss Notification" reporting tool for this purpose.
- **Centralized and dedicated internal website to EH&S matters**

Potential Impact

Project Objectives

Develop highly efficient and cost competitive high temperature electrolysis for H_2 generation, by a high efficiency and durable metal-supported solid oxide electrolysis cell (SOEC) based on proton-conducting electrolyte at targeted operating temperatures of 550-650ºC. Focus on developing a low cost, scalable fabrication of metal-supported cells and further material optimization for an efficient & durable p-SOEC.

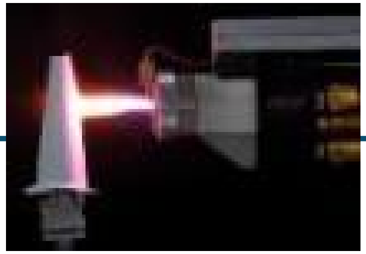
Project Impact

Enable <$2/kg H_2 production through high temperature steam electrolysis and advanced manufacturing

Metric	State of the Art	Project Target
SOEC Performance	**1 A/cm² at 1.4 V** at **800 ºC on o-SOEC**	**≥0.9 A/cm² at 1.4 V** on button cells at T ≤ 650 ºC (demonstrated in BP1); **Metal cell fabrication process feasibility demonstration, ≥0.9 OCV and ≥0.1 A/cm² at 1.4 V** on metal-supported cells at T ≤ 650 ºC (BP2)
SOEC Durability	(1-4)% per 1000 h	<1% per 1000 h (<10 mV per 1000 h)
H_2 production Cost	>$4/kg H_2	<$2/kg H_2 based on cost analysis in BP 1

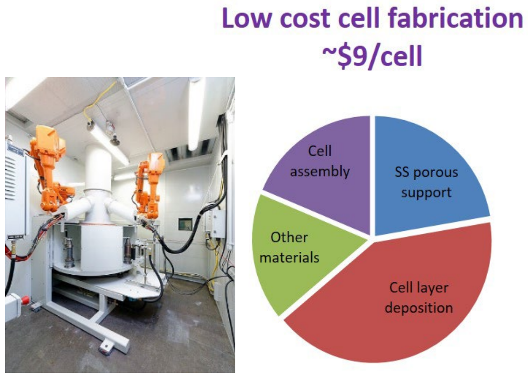
SPS Technical Advantages & Challenges

SPS- suspension plasma spray



Low cost fabrication

- Commercially available process
- Fast and scalable process
- Potentially eliminate sintering process

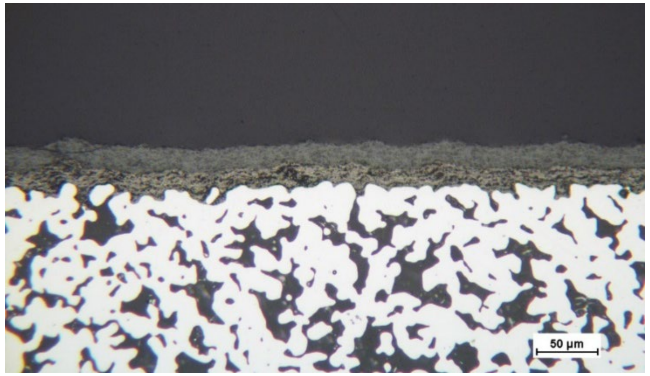


$1.35/kg H_2

(DOE Target $2/kg)

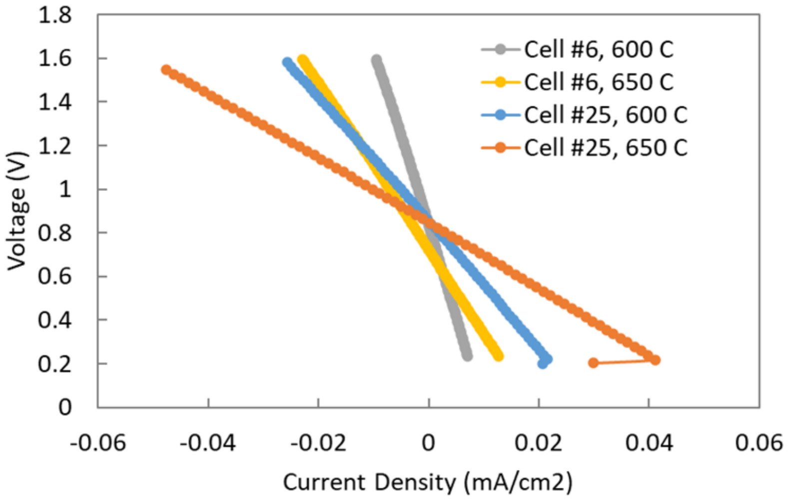
Enable metal-supported cells

- Capable of bridging large surface pores -- demonstrated
- No high T sintering -- demonstrated
- Capable of depositing porous or dense layers -- demonstrated



Remaining Challenges

- BaZrO3-based p-electrolyte poses special challenge, resulted in low performance
  - Ba evaporation
  - Balancing composition & density



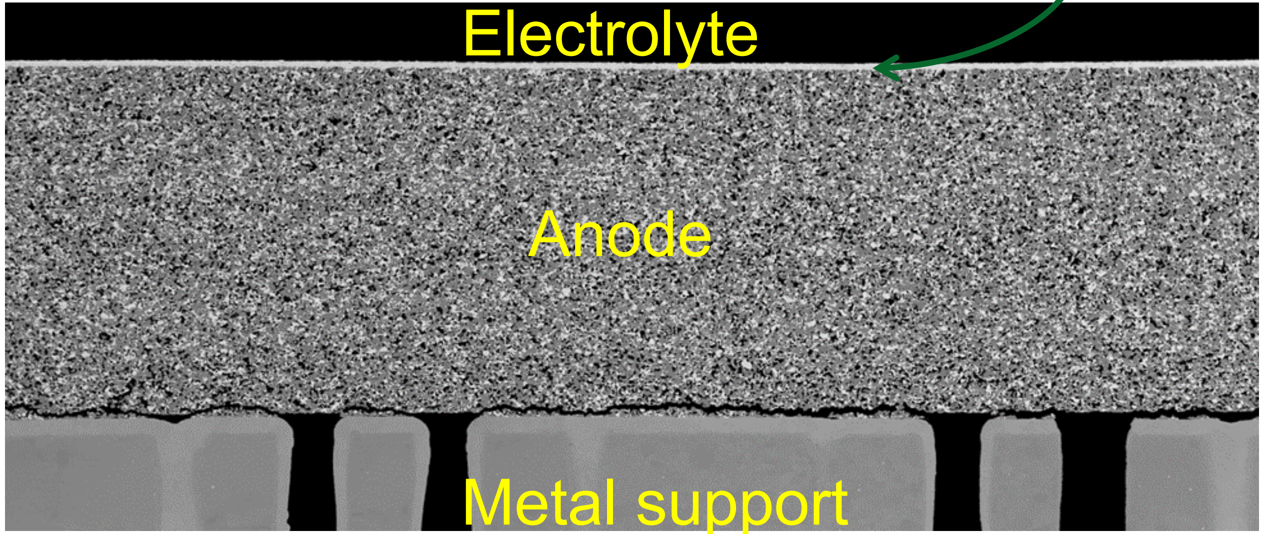
RTRC to focus on alternative scalable fabrication process, with low-cost potential, in remainder of BP2

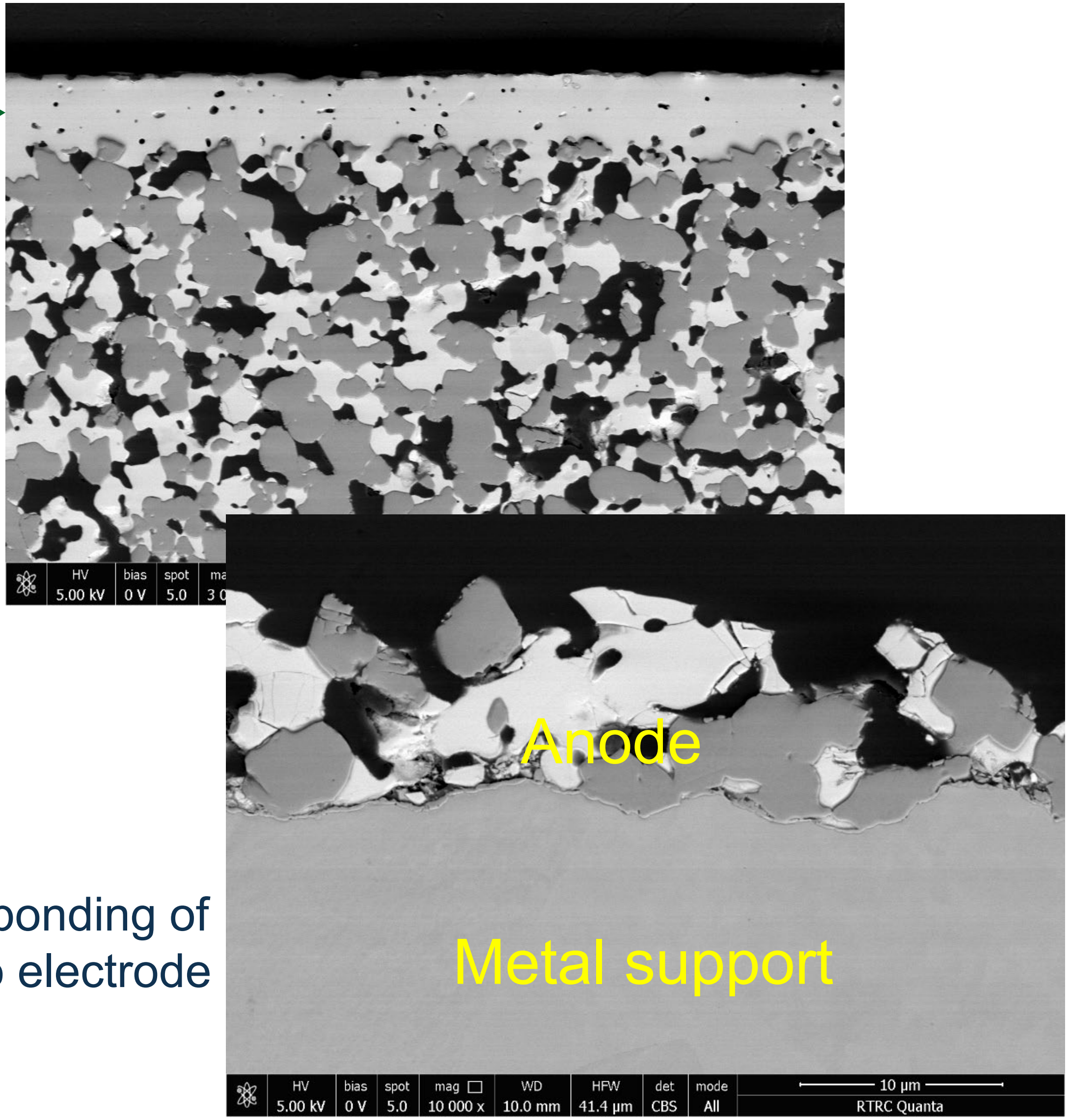
Objective of BP2 Effort (ended 9/30/2023)

- Demonstrating the feasibility of metal-supported SOEC cell fabrication
- The cell performance for water electrolysis shall be demonstrated through metal-supported button cell testing. At the end of BP2, the p-SOEC metal cell shall demonstrate ≥ 0.9 OCV and >0.1 A/cm^2 at 1.4 V. ---- BP2 GO/NO GO

Accomplishment: Demonstrated Metal Button Cell Fabrication

Thin dense electrolyte layer

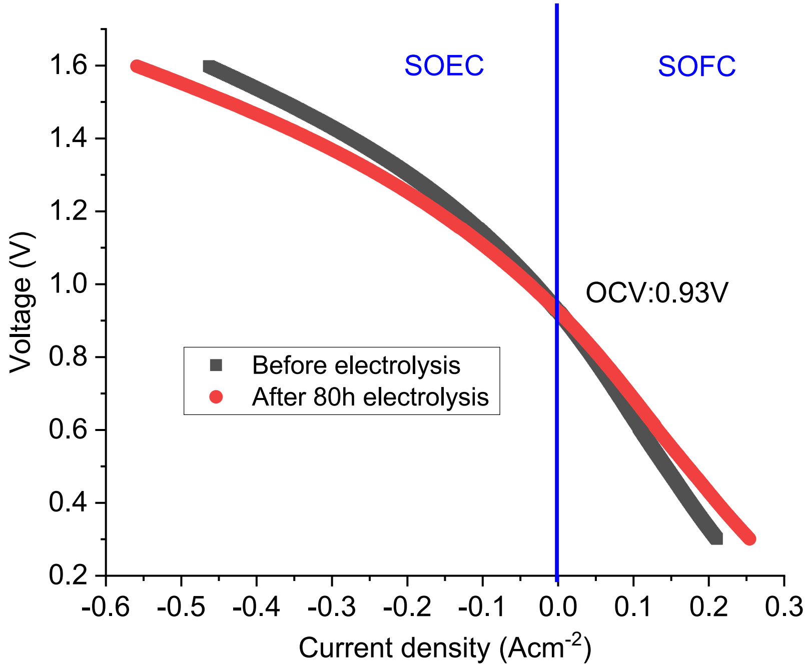




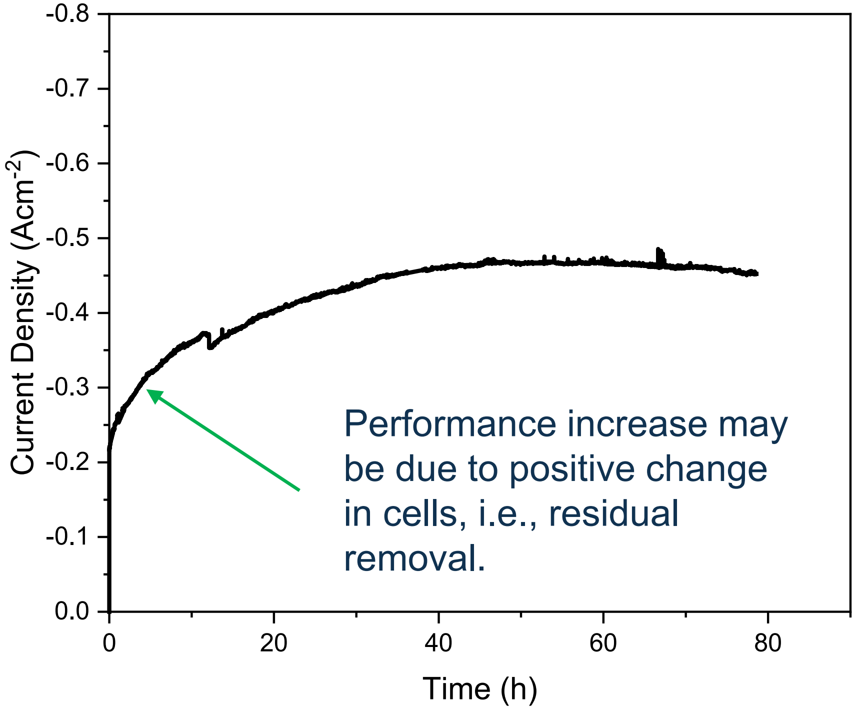
Strong bonding of metal to electrode

Accomplishment: Metal-Supported Cell performance exceed BP2 Target

Cell #7: 0.24 A/cm² at 1.3V at 600 °C
0.93 V OCV



No significant degradation was observed after 80h at 1.3V



Testing at INL

Cell size: Φ1” with active area of 0.73 cm²

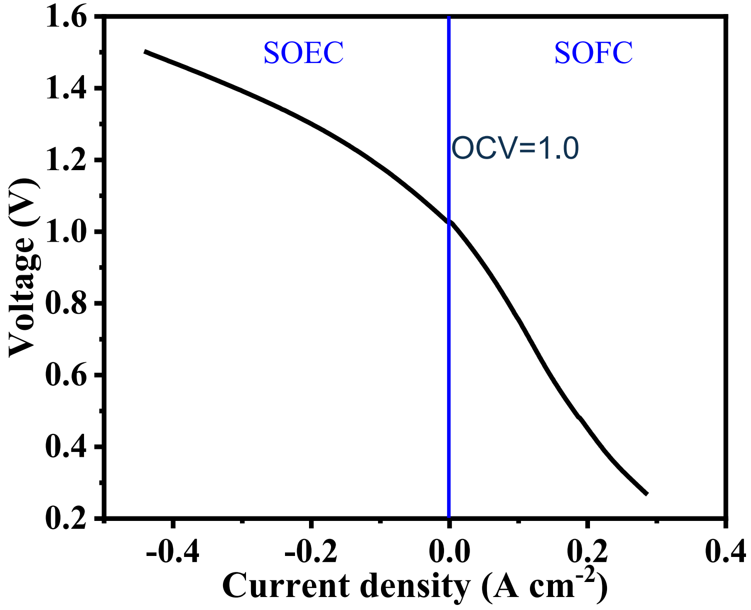
Temperature: 600°C

Atmosphere: 40ml/min H_2 + 70ml/min O_2 & 30ml/min H_2O (30% Steam)

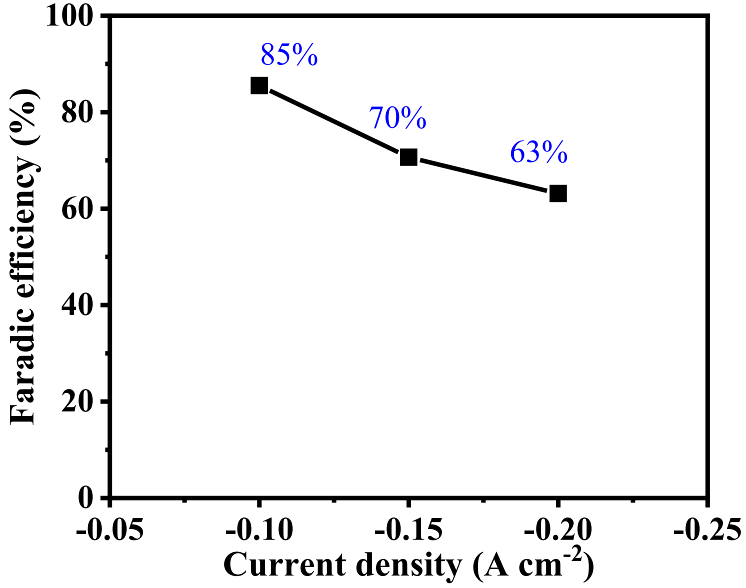
Accomplishment: Additional Metal-Supported Cell performance

Consistent cell performance

Cell #11: 0.20 A/cm^2 at 1.3V at 600 ° C
1.0 V OCV



FE is ~5-10% less than corresponding ceramic cell at same voltage, may be due to the use of pure O2



Testing at INL

Cell size: Φ1” with active area of 0.73 cm^2

Temperature: 600^{o}C

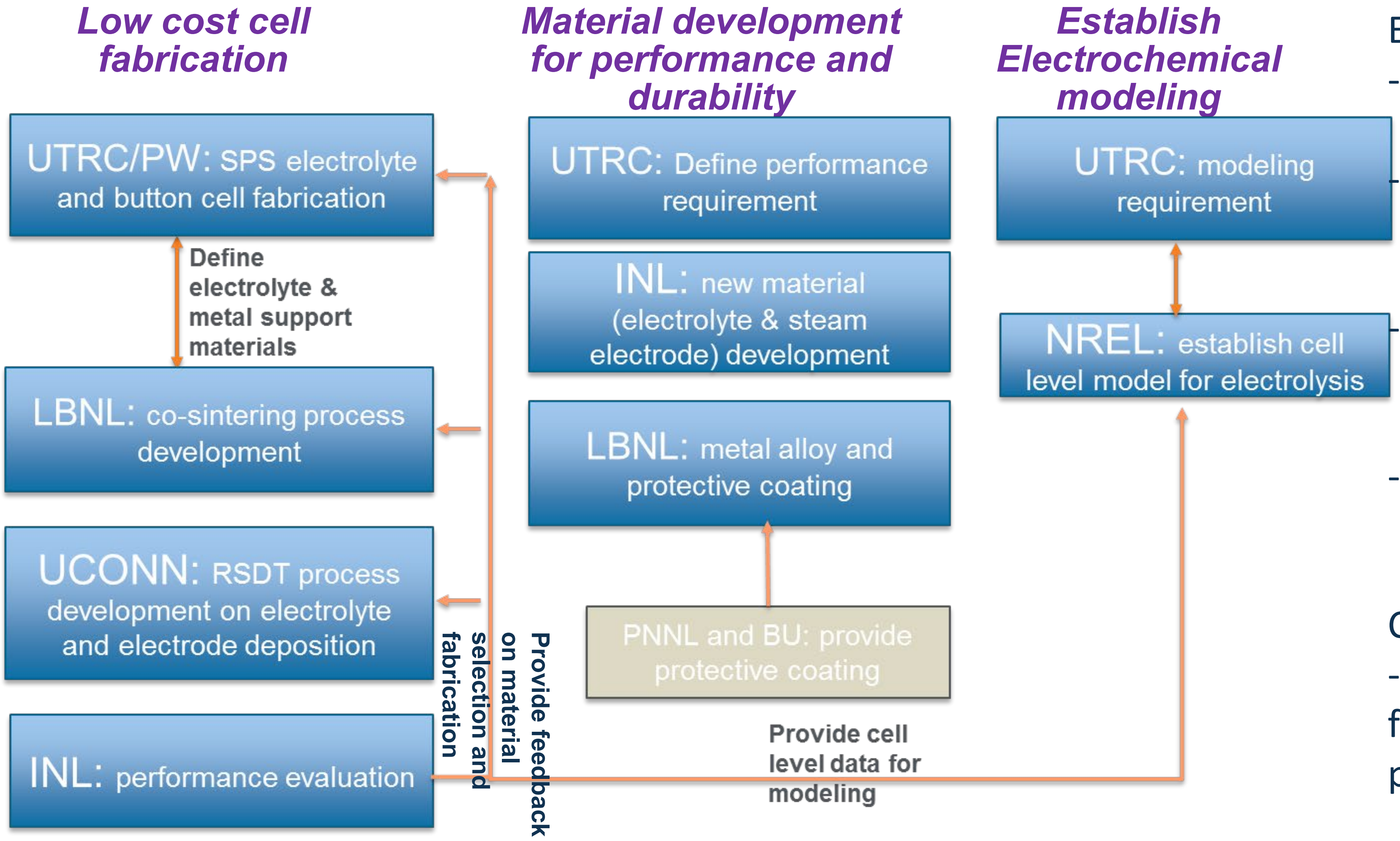
Atmosphere: 40ml/min H_2 + 70ml/min O_2 & 30ml/min H_2O (30% Steam)

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

This project has not been previously reviewed

Collaboration: Effectiveness

Current effort mainly involve INL support



Earlier work:

- Research data sets added to the Hub
- Cell sample exchange between LBNL and RTRC, INL and RTRC
- Collaboration on model validation between NREL and INL
- Co-authored several journal papers

Current work:

-. Work with INL on cell fabrication and performance testing

Proposed Future Work

BP3 (2024):

Focus on consistent and durable performance of metal cells

- Metal cell fabrication process optimization for improved performance
- Metal cell performance demonstration, focus on performance repeatability and short-term durability