Energy Materials Network
U.S. Department of Energy

HydroGEN
Advanced Water Splitting Materials

Advanced Coatings to Enhance the Durability of SOEC Stacks

Sergio Ibanez (Principal Investigator)
Nexceris, LLC
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Project ID No. P188

DOE Hydrogen Program 2022 Annual Merit Review and Peer Evaluation Meeting

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

Project Overview

Award No.	EE0008834
Start/End Date	04/01/2020 - 03/31/2023
Project Funding	$1.0 M

Project Partners

Sergio Ibanez (Nexceris, LLC)

Prabhakar Singh (University of Connecticut)

Michael C. Tucker (LBNL)

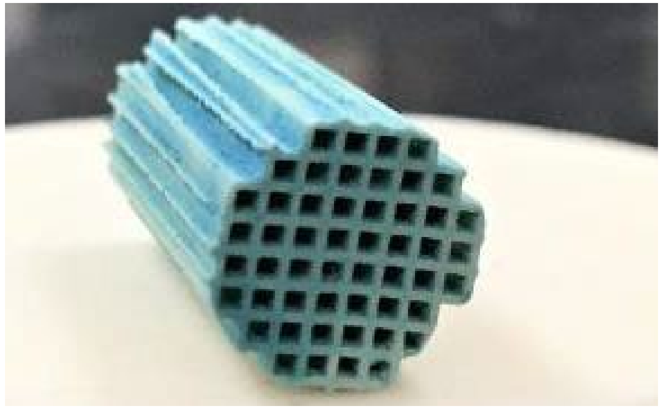
Dong Ding and Michael Glazoff (INL)

Project Vision

We are developing a comprehensive coating strategy to address the critical SOEC degradation mechanisms of metal corrosion and chromium evolution.

Project Impact

Efficient and durable SOEC systems will support the transition to renewable, energy-efficient, and low cost H_2, creating paths to more valuable utilization of methane in chemicals and fuels rather than heat.



Approach – Summary

Project Motivation

- Nexceris has 25+ years of experience in solid oxide cell technology and has successfully commercialized protective coatings for SOFCs.
- We are leveraging this expertise to advance SOEC technology readiness.
- We are developing an integrated two-coating strategy to enhance SOEC stability.

Key Impact

Metric	State of the Art	Expected Advance
Degradation Rate	*> 10 mV/kh*	*< 4 mV/kh*
Technology Adoption cost	*> $10/kW*	*< $3/kW*
Current Density *@ 1.4 V/cell*	*> 0.5 A/cm²*	*> 1.0 A/cm²*

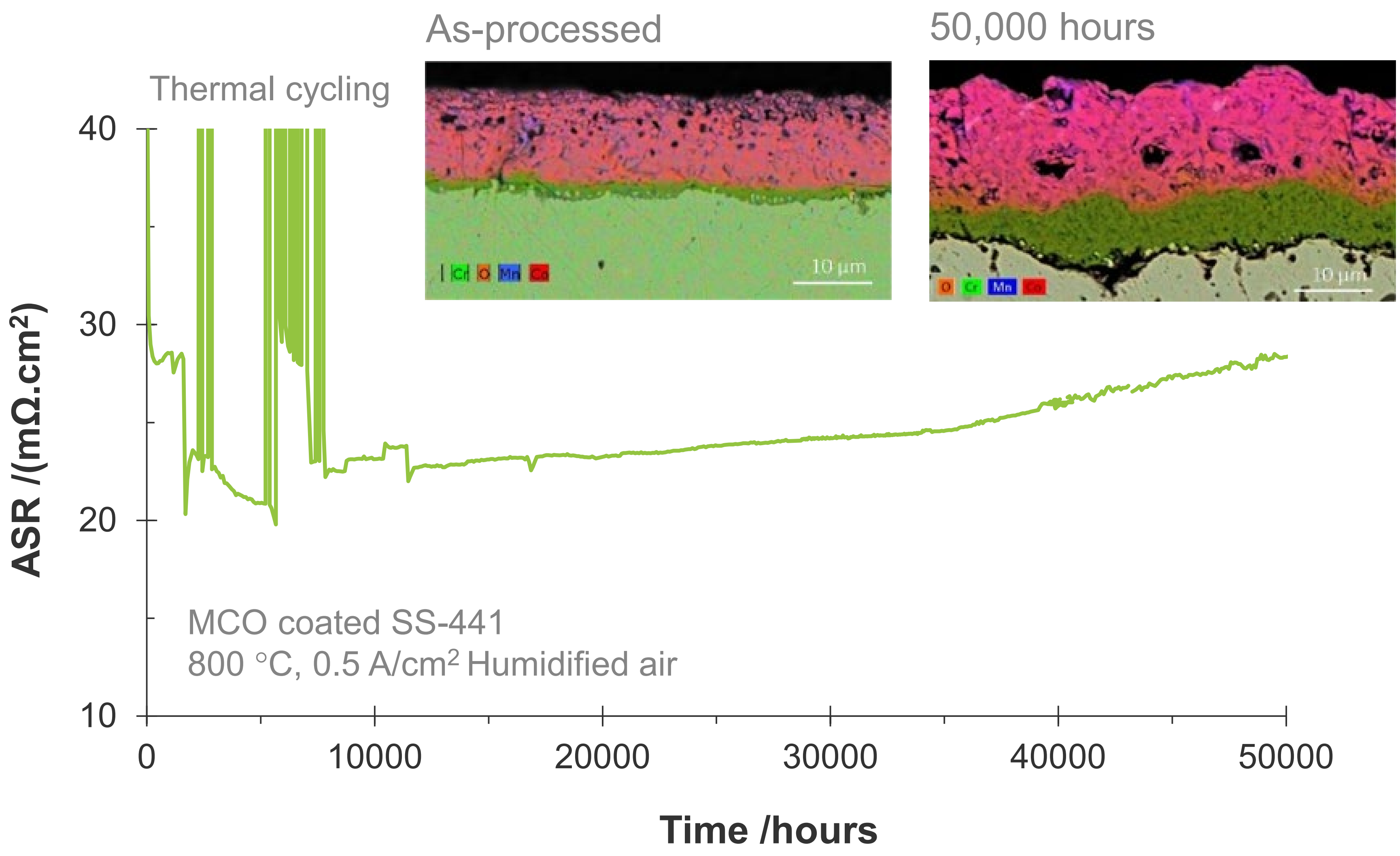
Barriers

- Deconvolution of degradation mechanisms: *Careful EIS analysis of cell performance.*
- Demonstration of coating technology at production relevant scale: *Use Nexceris' existing SOEC stack platform.*

Partnerships

- Dr. Singh brings an in-depth technical background in SOFCs and SOECs. His team at UCONN has developed a range of chromium-getter materials.
- HydroGEN node partners at INL and LBNL provide extensive experience with SOFC/SOEC fabrication, testing and modeling.

Approach – Innovation: Nexceris ChromLok™ Coating



Approach – Innovation: Dual Coating Strategy

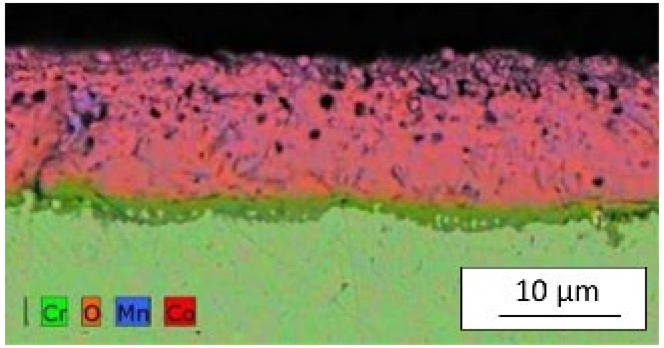
Innovation: Integrated Coating Strategy to Reduce SOEC degradation

1. Re-engineered IC coatings and Cr-getters tailored for SOEC
2. Novel two-component BoP coating

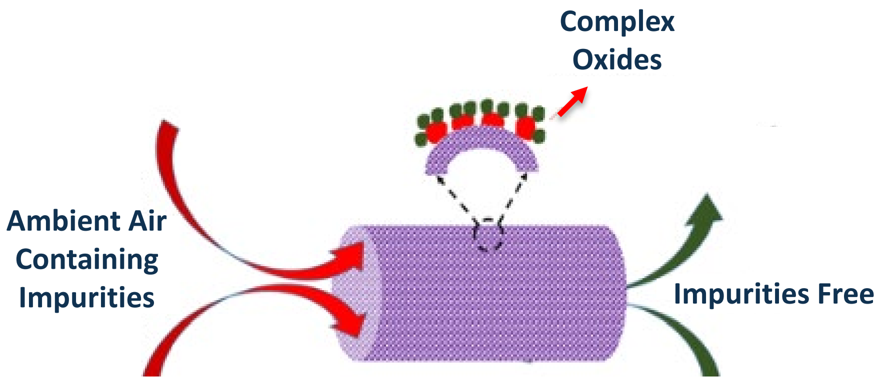
Budget Period 2: Optimize protective IC coating and develop BOP protective coatings for SOEC operation

- Down-selection of optimized coating formulations
- Demonstration of coating capability for BOP component protection
- Improved single-cell test that can achieve DOE target
- **Go/No-Go Decision:** Demonstrate the efficacy of the down-select IC coating and BOP coatings:

  (1) down-selected IC coating(s) achieve >25% reduction in rate of ASR increase at 800 °C and current density of 1 A/cm^2 tested in 30% O_2 in air with 3% H_2O) for >500 hours compared to the BP-1 baseline and (2) an inline Cr-getter that achieves >25% greater Cr retention based on Cr-transpiration testing. Degradation will be compared against baseline established in Year 1.



Mn-Co Oxide coating prevents chromium from reaching the surface.



Getter materials prevent chromium from reaching the SOEC stacks.

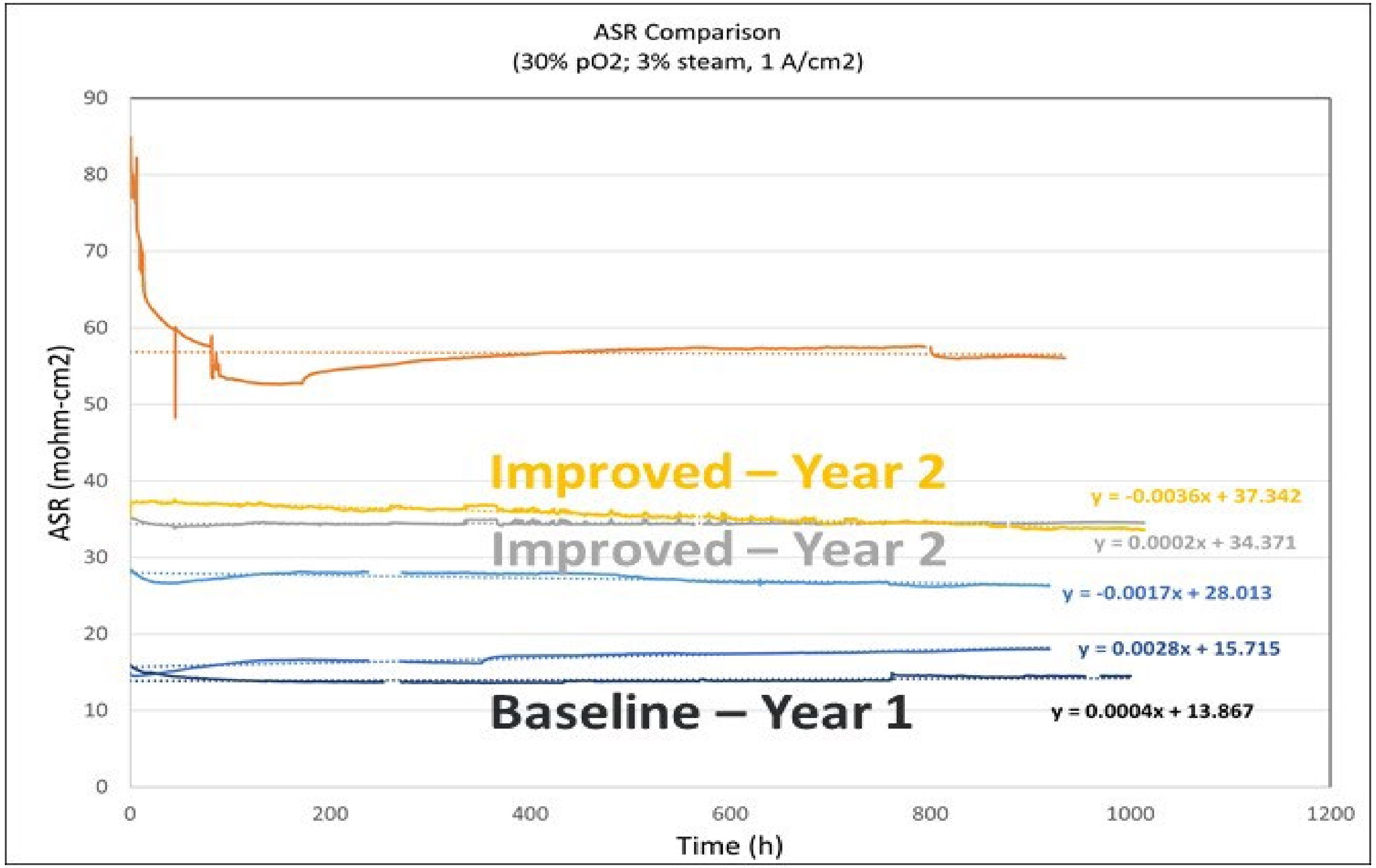
Relevance and Impact

- H2@Scale concept envisions sustainable, large-scale H_2 production from excess grid power generation.
- SOECs are not as commercially advanced as alkaline & PEM electrolysis, adoption limited by degradation.
- This project will develop new integrated coating strategies to address degradation caused by metal corrosion/chromium evolution from metallic components, to improve SOEC durability and accelerate commercialization.
- Focus on low cost, scalable technology that can be implemented.
- Nexceris is committed to collaboration and working with partners to transform powerful ideas into product solutions.
- This project allows Nexceris to strengthen relationships with partners within the HydroGEN Consortium.

Accomplishments: ASR Degradation Reduced

Demonstrate a further reduction in SOEC degradation derived from metal components through down-selected IC coating(s) that achieve >25% reduction in the rate of ASR increase at 800 C and current density of 1 A/cm² under anode (30% O_2 in air with 3 % H_2O) SOEC conditions measured over 500 hours compared to the Budget Period 1 baseline. COMPLETED.

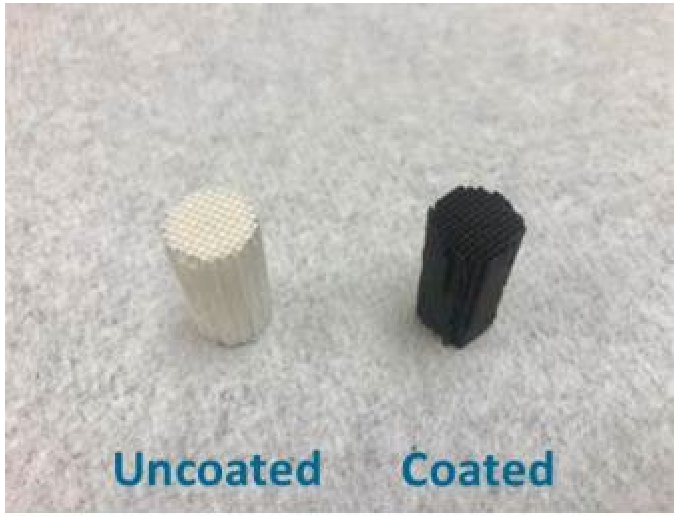
- Coated ICs with MCO using different processing conditions.
- Demonstrated 2 – 8X ASR performance (degradation) improvement over Year 1 baseline.

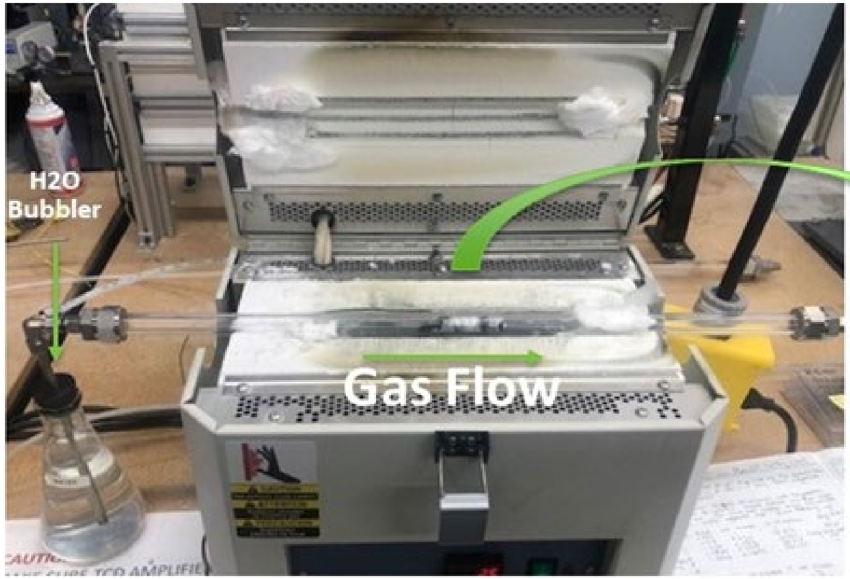


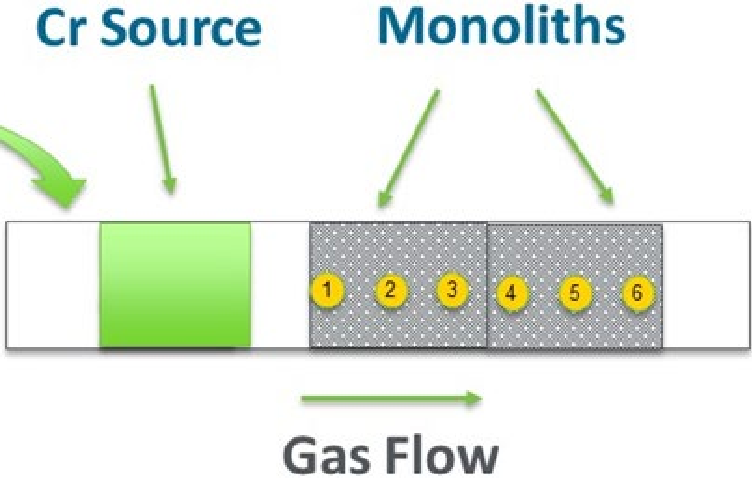
Accomplishments: Chromium Getter Materials

Testing Approach

- Coated monoliths for chromium sequestration testing.
  - Used SrNiO (SNO) and SrMnO (SMO) as Cr getters
- Placed two monoliths inside a quartz tube.
- Introduced Cr_2O_3 pellets (~6 g) inside tube, upstream of gas.
- System ran for 1000 hours at 800 C in 400 SCCM humidified 30% O_2/N_2
- Cross-sectional SEM was performed to determine Cr retention and distribution.



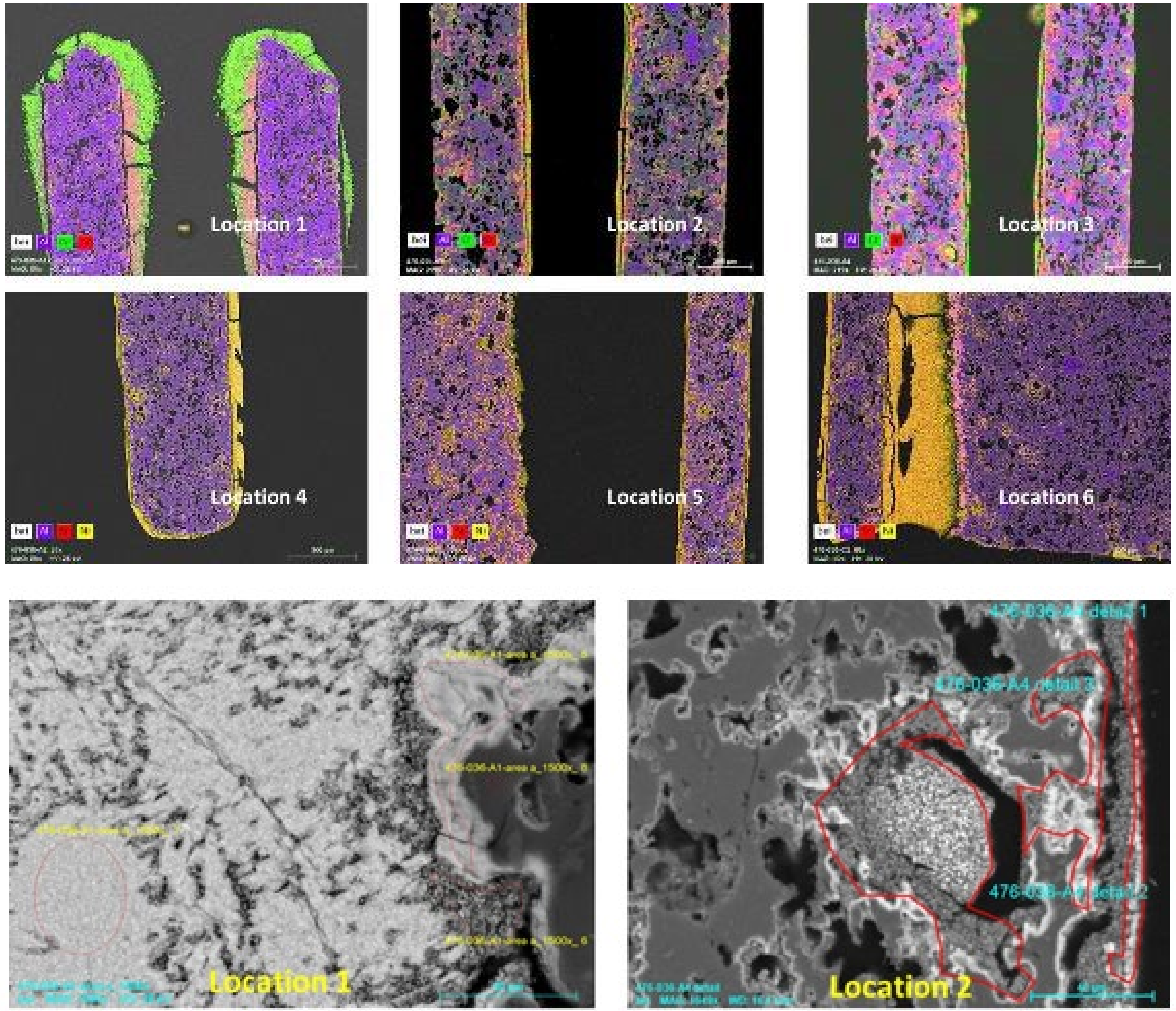




Accomplishments: Chromium Getter Materials (SNO Based)

SNO (Sr,Ni oxide based) coating was used as chromium getter.

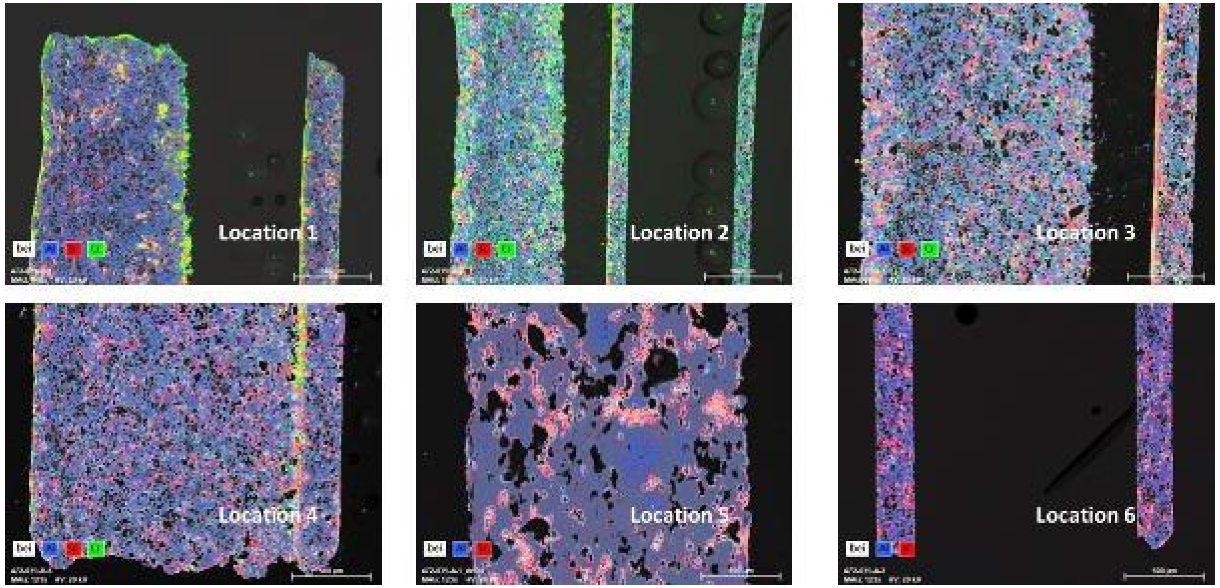
- Powder received from UCONN was milled, prepared into suspension and coated on monoliths.
- The monoliths were exposed to chromium source for 1000 hours.
- Cross-sectional SEM/EDS performed to understand chromium distribution.
- Results indicate that chromium getter is very effective.
- The highest chromium concentration is captured at the vicinity to the source.

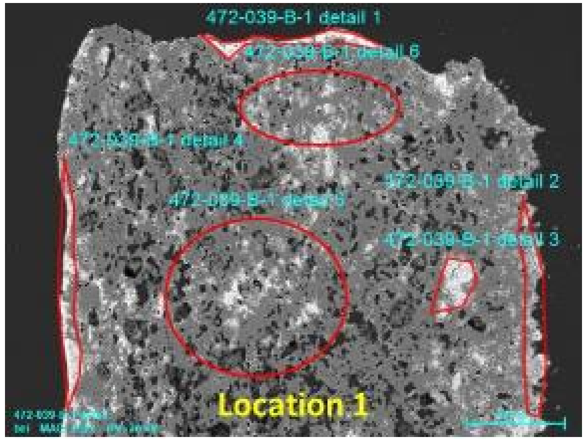


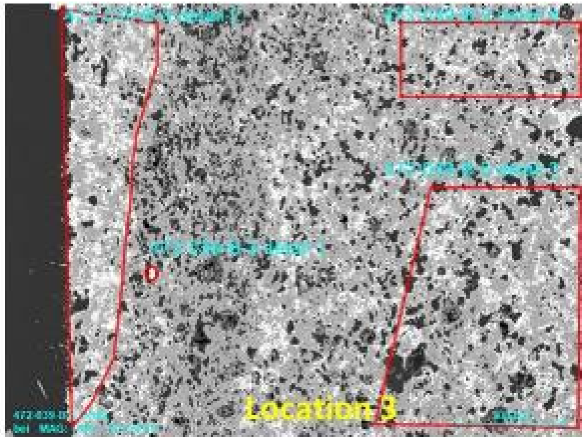
Accomplishments: Chromium Getter Materials (SMO Based)

SMO (Sr,Mn oxide based) coating was used as chromium getter.

- Powder prepared into suspension and coated on monoliths.
- The monoliths were exposed to chromium source for 1000 hours.
- Cross-sectional SEM/EDS results show a thinner SMO layer (compared to SNO).
- Chromium getter ability is not as effective as with SNO, but this could be due to layer thickness.
  - Yet no chromium is detected on the second monolith (locations 5 and 6).





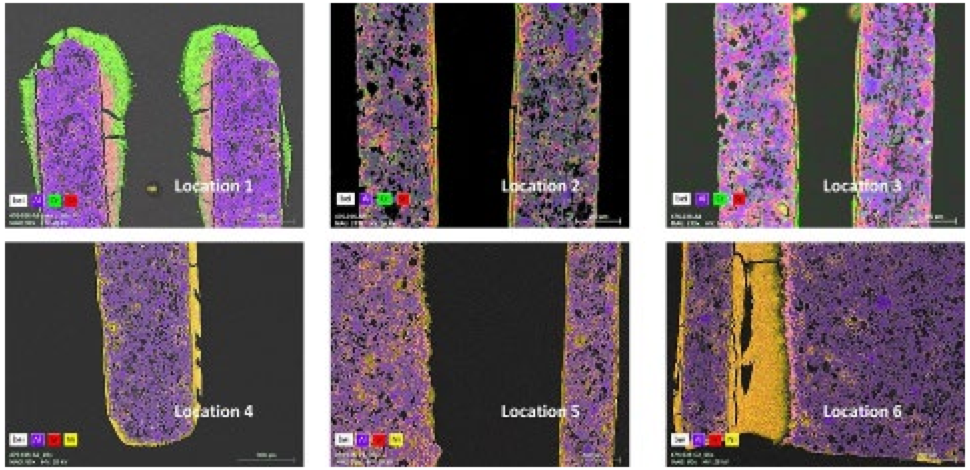


Accomplishments: Chromium Getter Materials

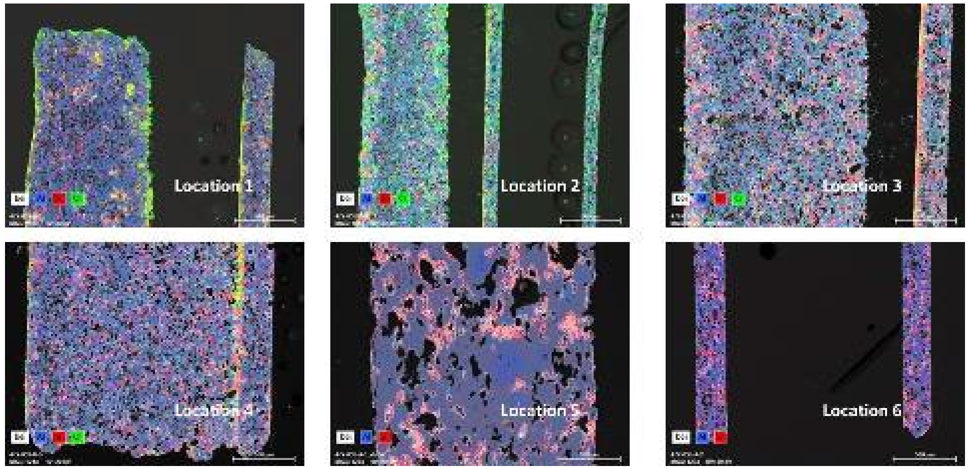
Go/No-Go Milestone (Year 2): *Demonstrate a further reduction in SOEC degradation derived from metal components through an inline Cr-getter that achieves >25% greater chromium retention based on Cr-transpiration/experimental testing. Degradation will be compared against the baseline established in Year* 1. **COMPLETED.**

- Both SNO and SMO materials showed excellent chromium-getter ability.
- Both materials retain at least 50% more Cr than an uncoated monolith (baseline).
- Coating thickness can be explored in the next phase of work.

SNO



SMO



Accomplishments: BOP Coating Development

Coatings for protecting BOP components were developed and implemented in single-cell SOEC testing.

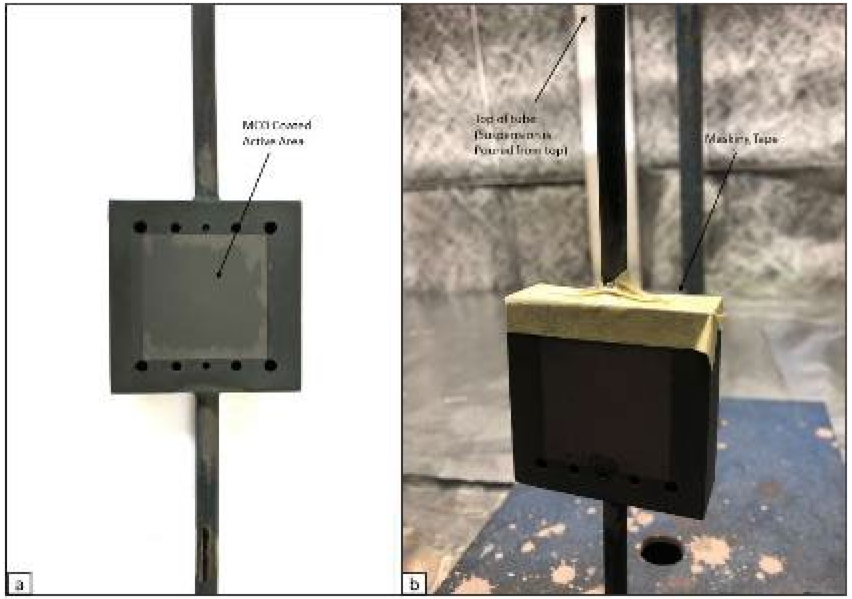
Dual Alumilok/SMO coating was applied to inside of tubing and manifold.

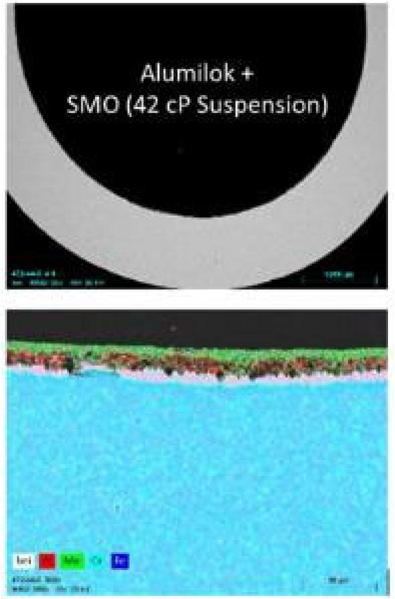
- Alumilok protects against Cr volatilization from metal components & creates roughness to aid in overlay coating adhesion.
- SMO adsorbs Cr from the gas stream.

Suspensions were optimized to produce uniform coatings by slip-coating.

Different annealing conditions were explored to ensure adherence of applied coatings.

Manifold coating approaches





SEM of coated tube pre-testing

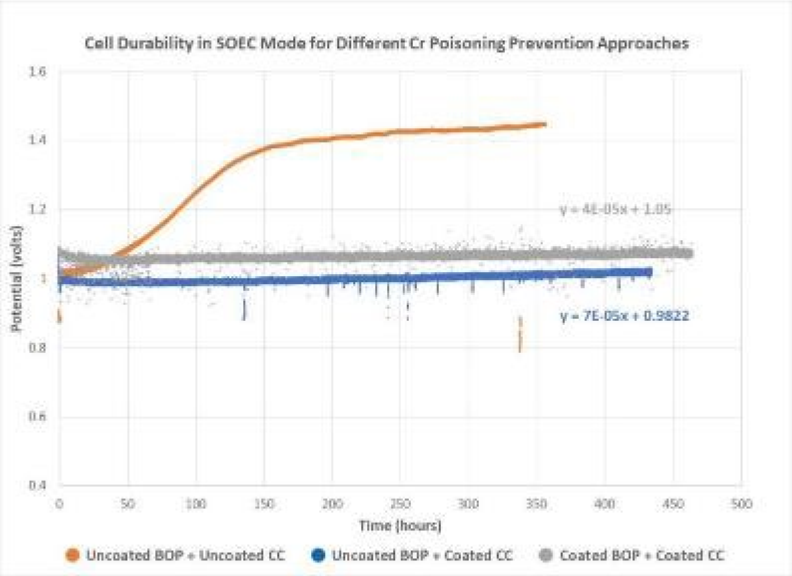
Accomplishments: BOP Coating Development

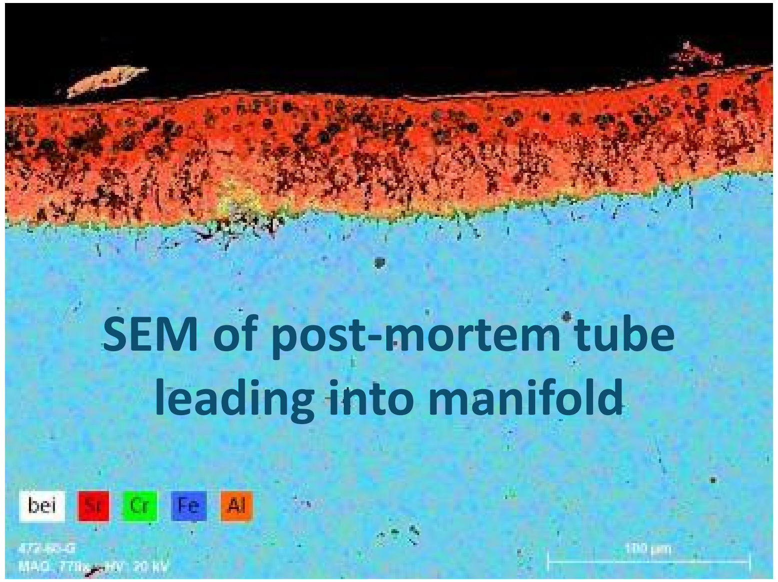
Single-cell test was set up using different Cr prevention approaches.

- Inside of manifold and tubing (BOP) was coated with Alumilok/SMO.
- Manifold surface (active area) was coated with MCO.
- Current collector mesh was coated with MCO..

Cell was tested for ~500 hours in SOEC mode.

- Degradation was lower than what was observed at the end of BP1.
- SEM of post-test tube reveals Cr is contained at the interface of metal and Alumilok coating.





Collaboration: Effectiveness

Collaborated with Dr. Singh (UConn) in the development and testing of chromium getter materials.

- Maintained open discussions to ensure correct application of experimental designs.
- Leveraged previous knowledge for selection of materials and deposition on monolith.
- Received SNO powder from UCONN for evaluations.

Worked closely with Michael Tucker (LBNL) to get thermal cycling and dual atmosphere data on coated coupons provided by Nexceris.

- Significant advancement was made in understanding the effect of extreme testing conditions on MCO coatings.
- Dual atmosphere test focused on developing a test fixture made from ceramic to avoid Cr poisoning. Potential seals were identified to complement the new test fixture approach.

Technical support to the project provided by Dong Ding and Michael Glazoff (INL).

- ASR testing of coated and uncoated coupons under realistic SOEC conditions was executed, which confirmed superiority of ChromLok coating in preventing degradation. More tests in harsher conditions will be carried out.
- An extensive literature review was performed to create a database of protective coatings. This database was analyzed using and Artificial Neural Network, which suggested that further ASR improvements may still be possible.

Participated in HydroGEN Advanced Water Splitting Benchmarking Workshops.

Proposed Future Work

BP3 work involves demonstration of manufacturability and commercial readiness. In this phase of the project, coating manufacturing will be scaled up for both cost model building and stack testing implementations. The milestones for this phase of work, required work, and important considerations are as follows:

- **Milestone 5.1:** Demonstrate that interconnect coatings can be produced reproducibly (<10% variation in coating thickness with >90% yield). *Work will involve coating of 100 parts (50 parts at 75 cm^2 and 50 parts at 250 cm^2) using automated sprayer. Coating variation will be assessed in the green state, and yield will be calculated after annealing.*
- **Milestone 5.2:** Create a roadmap to scale IC coating technology to high volume production of less than $3/KW of additional stack cost. *Individual cost models will be combined to create an integrated manufacturing cost model. The different operations related to coatings (MCO coating of IC/meshes and BOP coatings) will be quantified to calculate cost in the stack.*
- **Milestone 6.1:** Demonstrate SOEC stack operation (up to 10 cell, 1.3 KW) for a minimum of 1000 hours, targeting a degradation rate of less than 4 mV/1000 h. *Up to 50 cells will be manufactured using Nexceris' optimized cell configurations to ensure degradation does not come from the cells. To further improve stability under SOEC operation, the 10-cell stack will be protected from Cr poisoning by incorporating interconnect and BOP coating technologies.*

Summary Slide

Approaches

- Develop high performance SOEC cells.
- Develop robust SOEC coating approaches.
- Combine new cell generations with advanced coating approaches.
- Reduce degradation rates.
- Provide advancements at reasonable adoption cost.

Accomplishments

- Explored advanced IC coatings under aggressive SOEC conditions and current density and demonstrated >25% reduction in ASR compared to BP1.
- Identified up to 8X accelerated IC degradation conditions.
- Demonstrated fabrication and operation of inline Cr getter which achieved at least 50% more Cr retention.
- Demonstrated improved and stable cell operation with ChromLokTM coating of interconnects and protective coatings of BOP components.