HydroGEN: Low Temperature Electrolysis

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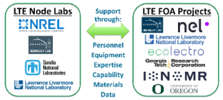
Project Overview

In low temperature electrolysis (LTE), it is imperative to both enhance and explore durability and demonstrate the opportunities for anion exchange membrane-based water electrolysis (AEMWE). The advantage of alkaline-based systems is primarily reduced capital cost: high pH enabling platinum group metal (PGM)-free catalysts and coatings, and the enhanced stability of those components compared to proton exchange membrane (PEM) –based systems. Compared to the water-only fed AEMWE in previous LTE 2.0 work, supporting electrolytes can allow for a significant improvement in performance through higher site-access and stability by reducing utilization and overpotential stresses that lead to catalyst layer delamination.

Approach

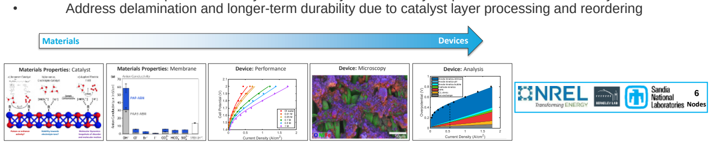


HydroGEN LTE Projects

- Historically supported 8 FOA projects with 41 nodes
- LTE 2.0 with 6 nodes
- Planning to support HydroGEN FOA-awarded (Seedlings) and Lab call projects

LTE 2.0 Goals: Determine the role of the supporting electrolyte and the limiting factors behind water operation in AEM electrolysis

- Evaluate AEM's ability to approach PEM performance/durability
- Elucidate interactions at the ionomer/catalyst interface to assess ionomer stability and catalyst poisoning
- Understand the impact of catalyst layer composition on performance in a supporting electrolyte
- Delineate the impact of electrolyte conductivity and alkalinity on performance and durability
- Address delamination and longer-term durability due to catalyst layer processing and reordering



Approach: LTE 2.0 QPMs, Milestone

Q1 QPM: Correlate physical catalyst layer properties in microscopy (ionomer distribution, pore structure) to relative kinetic (Tafel and catalyst layer resistance) performance in an aqueous electrolyte for > 3 membrane electrode assemblies.

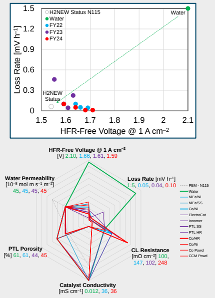
Q2 QPM: Leverage ex and in situ resistance/impedance measurements to separate sources for electronic and ionic resistance for $\geq$ 2 membrane electrode assemblies varying catalyst layer deposition approach. Correlate to modeling to demonstrate consistency in overpotential sources and compare kinetic performance (cell at 1 A cm^{-2}) and catalyst layer utilization (cell-level model) data to down select catalyst layer fabrication approach.

Q3 QPM: Develop a measure of ionomer fragment stability on Ni-based catalyst surfaces through ab-initio simulations for 3 ionomer types. Correlate and demonstrate consistency to their relative stability in ex-situ testing through the decrease in electrode current over $\geq$ 10 h.

Q4 Milestone: Testing of at least 3 membrane electrode assemblies with commercial materials for at least 500 h to set a benchmark performance decay rate and understand relevant degradation processes. These tests will vary the materials evaluated and/or operation parameters, and leverage HydroGEN nodes to determine how losses are observed and the component/process involved.

Relevance and Impact

AEMWE hold promise for clean hydrogen production with reduced cost, mainly from the materials perspective. It is the primary technology pathway being studied under LTE for HydroGEN 2.0. Since the onset of HydroGEN 2.0, significant progress and understanding have been achieved in the technology, especially with the focus of increasing performance and understanding operating motifs with supporting electrolytes to accelerate the technology readiness, and ultimately meet DOE Earthshot Hydrogen shot goal by reducing the cost of H_2 to $1/kg in 1 decade.

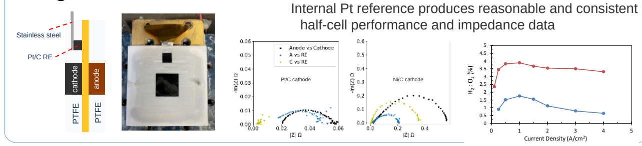


Accomplishments and Progress

Diagnostics

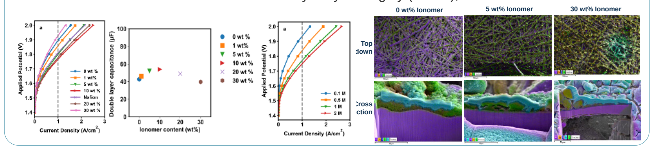
In-line monitoring of hydrogen crossover rates

Internal Pt reference produces reasonable and consistent half-cell performance and impedance data

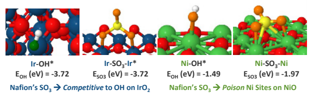


Role of the Ionomer

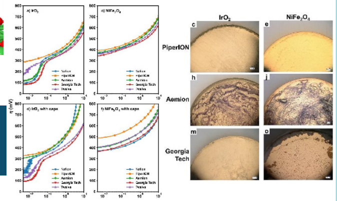
Best performance for samples with intermediate ionomer content, associated with improved surface area and site-access. Ionomer needed for catalyst layer integrity (binder), not ion conduction.

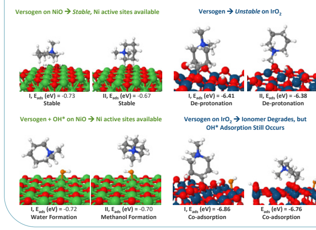


Understanding Catalyst-Ionomer Interactions



Theory can identify *key limitations or advantages* to specific ionomers, **critical to our understanding of the ionomer/catalyst interface**





Experiment and theory assessed the stability of three ionomers (Nafion, Georgia Tech, Versogen):

On NiO, IrO_2: ***Versogen*** is the most advantageous, allowing for OH* adsorption for OER

Nafion may adsorb too strongly, *poisoning active sites*

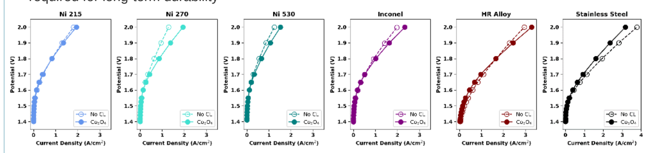
Georgia Tech may reduce activity by *introducing competing reactions to OER*

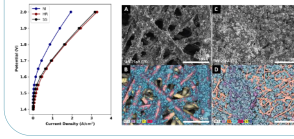
Role of the Transport Layer

Improved activity through the addition of other elements and/or the improved morphology

Nickel transport layers less active, likely required for long-term durability

PTL	Composition	Thickness (µm)	Top Layer Fiber Dimension (µm)	Porosity (%)	Average Pore Size (µm)	HFR-free V @ 1 A/cm²	
						No CL	Co_3O_4
Ni 215	100% Ni	215	20	84	44	1.770	1.751
Ni 270	100% Ni	270	20	61	18	1.845	1.746
Ni 530	100% Ni	530	20	60	16	1.877	1.808
Inconel	60% Ni, 25% Cr, 15% Fe	600	12	65	22	1.737	1.719
HR Alloy	60% Ni, 22% Cr, 16% Mo, 2% Fe	290	4	45	7	1.591	1.632
Stainless Steel	65% Fe, 18% Cr, 14% Ni, 3% Mo	430	2	44	9	1.663	1.628

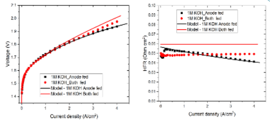


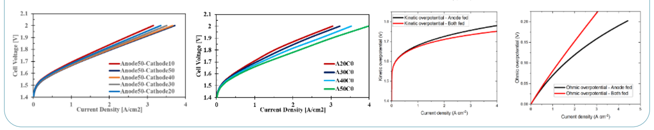


Catalyst layer morphology depends on the PTL, and in particular catalyst layer uniformity and coverage is higher for the SS PTL, with no visible fibers. Leaching of Fe and Cr still occurs with a catalyst layer, but is minimized.

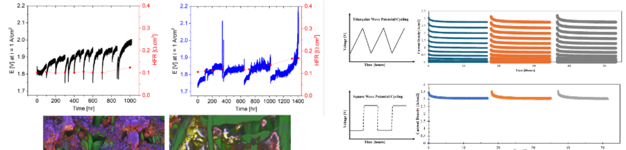
Operational Parameters

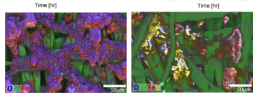
Agreement between modeling and cell testing when incorporating different flow parameters, particularly with decreasing HFR at higher current density during dry cathode operation





Durability and Accelerated Stress Test (AST) Development





NiFe Catalyst Layer, Initial

NiFe Catalyst Layer, After Test

Probing durability through extended operation to determine loss mechanisms and to evaluate operational strengths/vulnerabilities. Developing ASTs at the component- and cell-level.

Project Summary

- Ionomer stability can range considerably depending on the catalyst material, even on the typically non-reactive model NiO and on the benchmark PGM IrO_2
- Established the role of the ionomer in catalyst layers and probed the impact of various ionomers on catalyst reactivity and stability, leveraging modeling to understand catalyst-ionomer interactions
- Demonstrated performance improvements through the screening of transport layers and optimization of ionomer content and ionomer integration strategies, leveraging microscopy to understand performance differences between catalyst/transport layers
- Began durability testing to establish loss mechanisms and to development component- and cell-level accelerated stress tests

Collaboration: Effectiveness

- Interfacing between HydroGEN and IEA Annex 30, HydroGEN and ElectroCat
- Contributions to the Meta Data development for the HydroGEN Data Center
- Advanced Water Splitting Technology Benchmarking and Protocols Workshop – September 20-22, 2023; Next meeting planned for June 11-12, 2024.

LTE 2.0 Team

NREL	Berkeley Lab	Sandia National Laboratories
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Ross Larsen	Adam Weber	
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Proposed Future Work

- Evaluate OH* coverage effects on ionomer stability; determine transition state barriers to oxygen evolution in the presence of the ionomer to assess changes to OER activity
- Establish an understanding of how various ionomer chemistries and catalyst compositions modify catalyst layer reactivity-stability relationships
- Optimize catalyst layer composition and processing technique to improve site-access, catalyst layer resistances, and device performance and durability
- Understand the impact of catalyst layer electronic and ionic conduction on catalyst layer resistance and cell performance
- Establish benchmark performance decay rates and understand relevant degradation processes; create durability testing framework for component- and cell-level stress tests.
- Leverage HydroGEN nodes to enable successful HydroGEN FOA and Lab call projects