Energy Materials Network
U.S. Department of Energy

HydroGEN
Advanced Water Splitting Materials

High Efficiency PEM Water Electrolysis Enabled by Advanced Catalysts, Membranes and Processes

PI: Dr. Katherine Ayers
Presenter: Christopher Capuano
Proton OnSite
June 13, 2018

Project ID # PD155

NREL · Berkeley Lab · Sandia National Laboratories · INL Idaho National Laboratory · Lawrence Livermore National Laboratory · SRNL

Project Summary

High Efficiency PEM Water Electrolysis

Kathy Ayers, Proton OnSite
Iryna Zenyuk, Tufts University
Karren More, ORNL

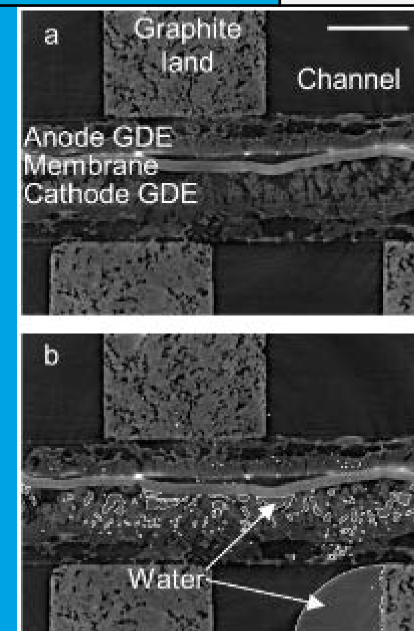
Award #	EE0008081
Start Date Year 1 End Date Project End Date	9/1/2017 8/31/2018 8/31/2020
Total DOE Share Total Cost Share Year 1 DOE Funding	$1.0M $0.25M $0.25M

Project Vision

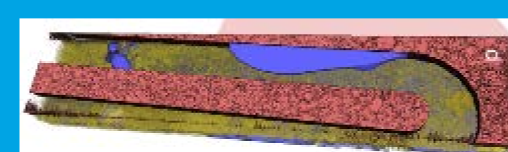
We are solving the cost barriers for PEM electrolysis by integrating advanced cell designs, materials and fundamental characterization of performance

Project Impact

The anticipated impact of Phase I is to define a reliable MEA configuration with high efficiency through new catalyst materials and optimized membrane processing



Example of tomography and colored liquid water image



Approach- Summary

Project history

Thinner membranes and alternate catalysts have shown promise for stable operation of PEM electrolyzers at improved efficiency. This project advances material performance and integrates components together, while leveraging fundamental characterization to understand and push design limits.

Proposed targets

Metric	State of the Art	Proposed
Membrane thickness	*175 microns*	*50 microns*
Operating temperature	*58ºC*	*80-90ºC*
Cell Efficiency	*53 kWh/kg*	*43 kWh/kg*

Barriers

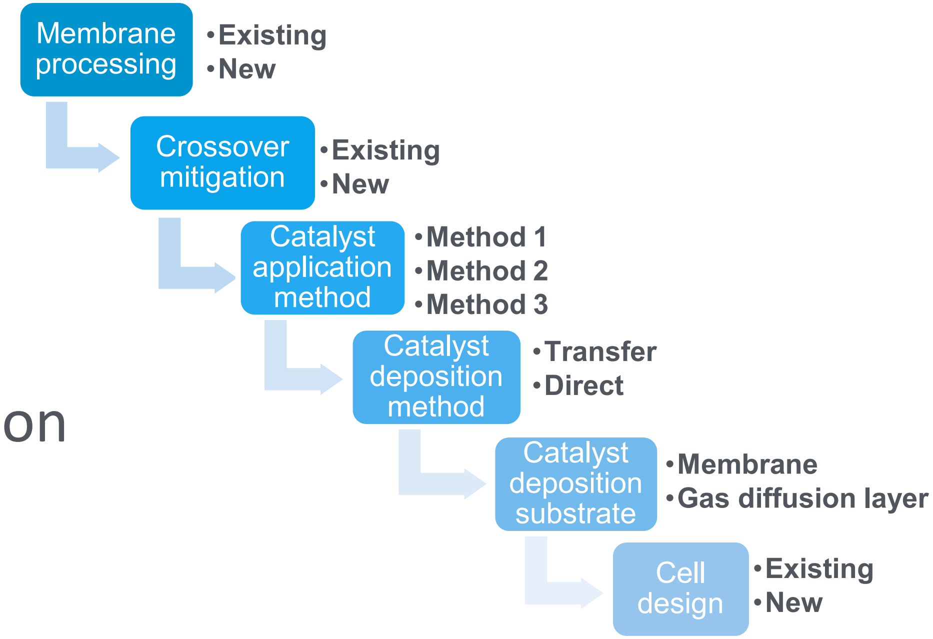
- Long term durability: understand degradation through accelerated tests and fundamental characterization
- Higher defect sensitivity with adv. materials and operation: refine cell design and characterize in situ

Partnerships

Iryna Zenyuk, Tufts: In situ tomography to characterize layers and water distribution
Karren More, ORNL: TEM of platinum group metal migration

Approach- Innovation

- PEM electrolysis has the potential for significant efficiency improvement – challenge is integrating and extending what we know, where complex interactions exist
- Project combines and advances promising directions in multiple areas
  - Catalyst composition
  - Stable 3-D structures
  - Thinner membranes
  - Robust manufacturing
  - Optimized interfacial layers
- Fundamental characterization
  - Water transport
  - Catalyst migration

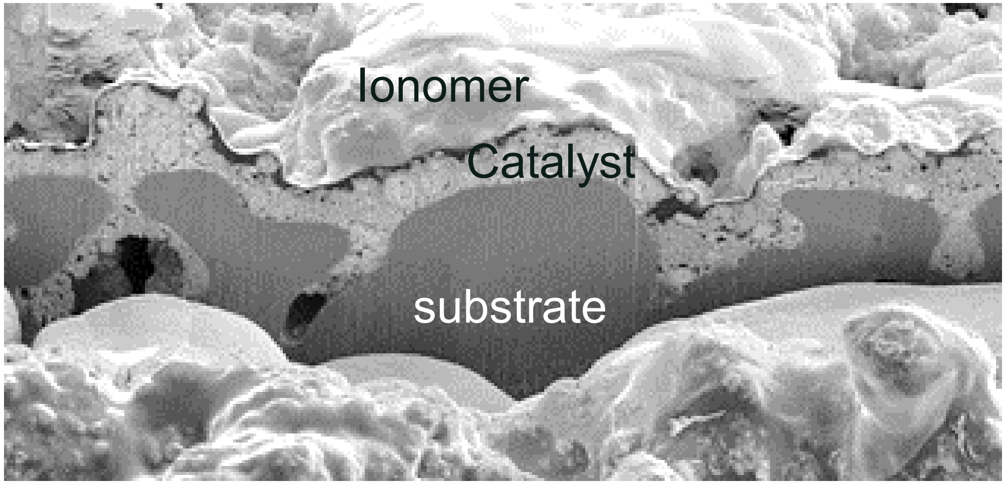


Approach - Innovation

- Holistic view of problem including interaction with EMN nodes
- Understanding of catalyst dissolution and membrane hydration to support formulations and methods of manufacture

Electrodes are complex and non-ideal

- Porous substrates, uneven distribution, coatings
- Need to understand impact of deposition methods, synthesis conditions, binders etc.



Project Tasks – Scope of Work

Task	Goal	Partner and Node Support
1: Membrane Processing - Demonstrate operability of thin membranes at 80-90ºC	1. Characterize chemical, mechanical, and electrochemical properties 2. Measure dimensional changes and hydrodynamic forces on adjacent components vs. hydration conditions	Proton, LBNL
2: Advanced MEA Fabrication - Characterize MEAs fabricated via ultrasonic spray internally and externally	1. Develop formulation and deposition parameters 2. Characterize water distribution through X-ray tomography	Proton, Tufts, NREL
3: Advanced Catalyst – Develop stable high activity alloy for OER	1. Synthesize alloyed and high surface area materials 2. Microscopy and performance characterization	Proton, ORNL, NREL
4: Program Management	1. Ensure work is coordinated towards targets	Proton

Relevance & Impact

- PEMWE have significant development opportunities for increased electrical efficiency, without sacrifice in durability through:
  - Integration of membranes ≤ 50 µm thick, capable of 80-90 ^{o}C operation, while controlling mechanical creep and gas crossover
  - Reducing the catalyst loading by at least 1/10th on both electrodes, while controlling water distribution and the PTL/CL electrochemical interface
  - Synthesis of higher activity OER catalysts and refinement of electrode fabrication process
  - Integration of these characteristics into a full MEA
- Supporting National Labs and subcontractors will assist in characterizing materials and process modification
  - Accomplished through material characterization, in-operando analysis, and advanced modeling of membrane and PTL interactions
- Final deliverable of the project will be an advanced electrolysis stack producing H_2 at 43 kWh/kg and at costs of \$2/kg H_2

Accomplishments: Budget Period 1 Quarterly Milestones

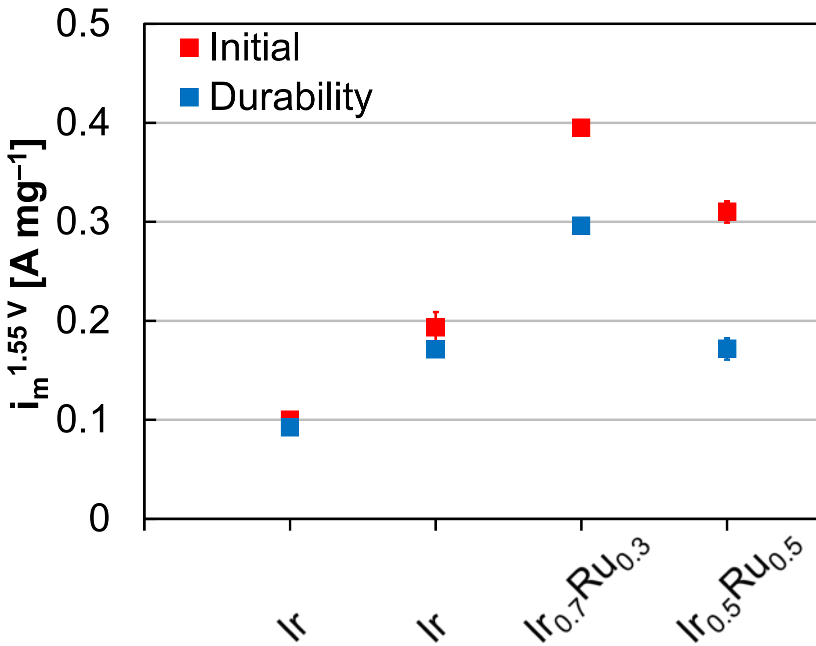
BP 1 (12 months) Milestones	Quarter	Completion
Develop project target tracking sheet based on preliminary data and define baseline current hydrogen costs	1	100%
Demonstrate MEA performance of 1.85V with N117 at 80°C	2	100%
Quantify water distribution in operating cell with XRT	3	50%
Complete membrane mechanical testing vs. hydration condition and evaluate options for downselect	3	20%
Demonstrate 1.8A/cm^2 at 1.7V for advanced MEA*	4 (go/no go)	25%

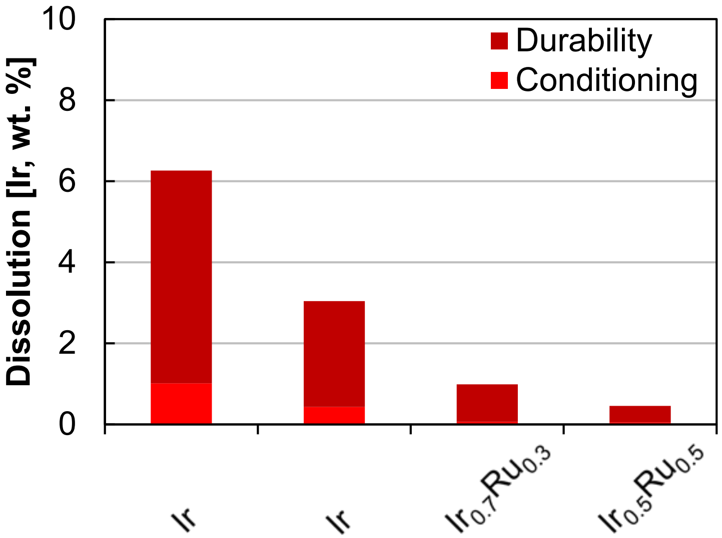
*** Q4 milestone success is required to meet project targets of $2/kg H_2**

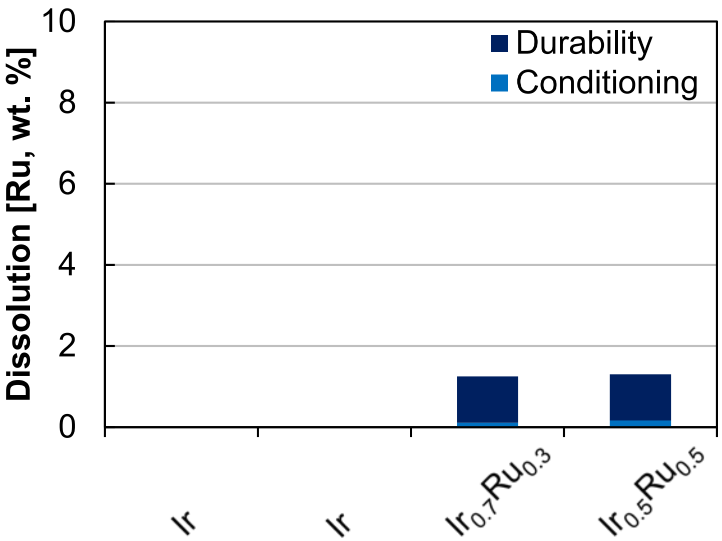
Accomplishments to Date

- Synthesized matrix of 6 OER catalysts: 2 methods, 3 compositions
  - Method 1 successful: data next slides
  - Method 2 failed; found issues in process and repeating
    - Catalysts showed low activity in cell testing
- Ex-situ characterization by NREL: RDE/ICP for changes in activity resulting from dissolution of OER catalysts
- In-situ characterization by Proton: Polarization curves, steady state
- Met catalyst milestone: translating to higher efficiency membrane
  - Working on membrane process internally in parallel under cost share funding
  - Compatible with existing fabrication processes with minor modifications
  - Advanced processes being evaluated in parallel

Accomplishments to Date Advanced Catalysts –Dissolution





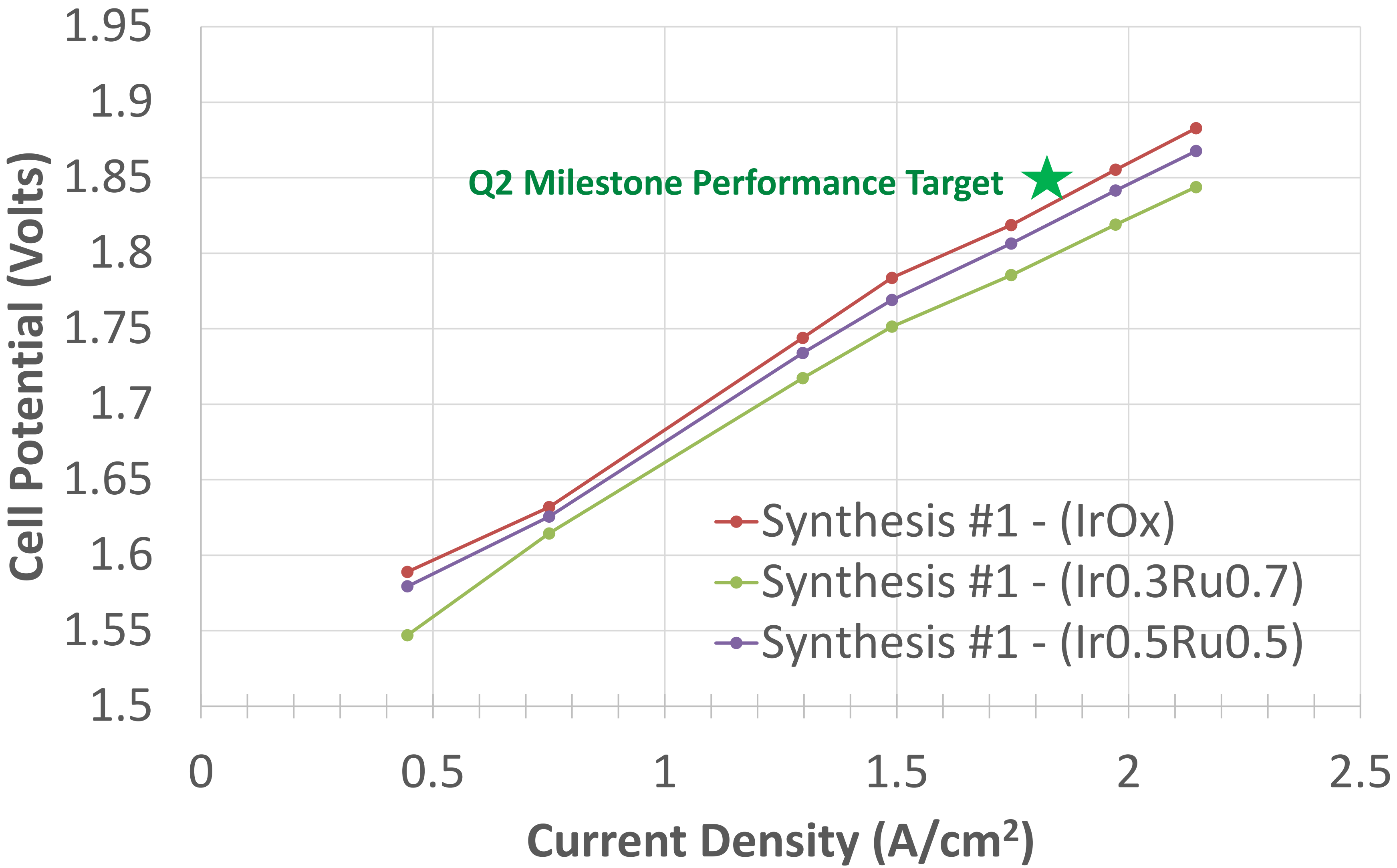


- Activities at 1.55 V
- Durability following 2.0 V hold, 13.5 h
- Dissolution relatively low (oxides)
- Less Ru dissolution than expected

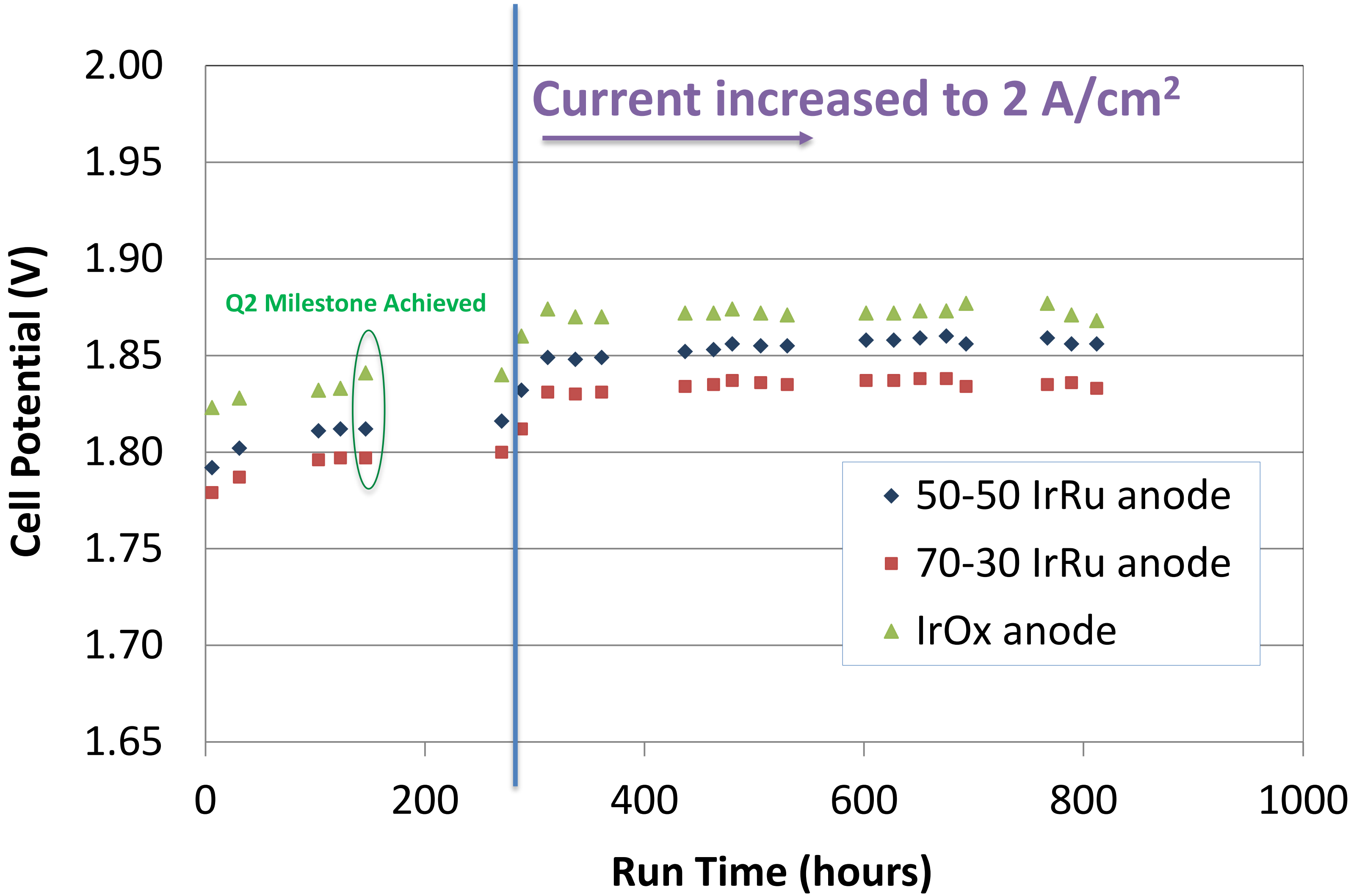
Accomplishments to Date
Advanced Catalysts – Cell Testing

- All tests performed with same hydrogen evolution electrode configuration, flow fields, and gas diffusion layers
- 28 cm^2 commercial cell hardware used for 30 bar operational testing
- Durability testing conducted at Proton while monitoring
  - Cell potential,
  - Applied current,
  - Operating temperature,
  - Hydrogen differential pressure,
  - Water flow rates,
  - Water quality,
  - Concentration of H_2 in O_2,
  - Test duration

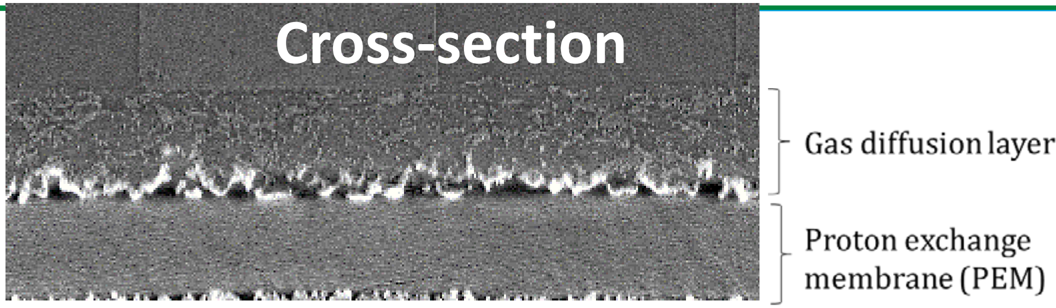
Accomplishments to Date
Advanced Catalysts – Cell Testing

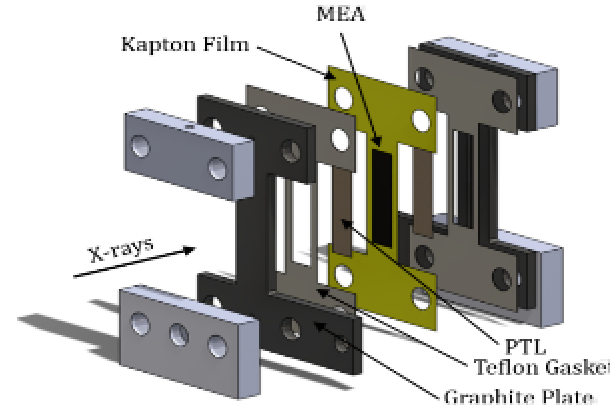


Steady State Data: 1.8A/cm², 80°C, 30 bar

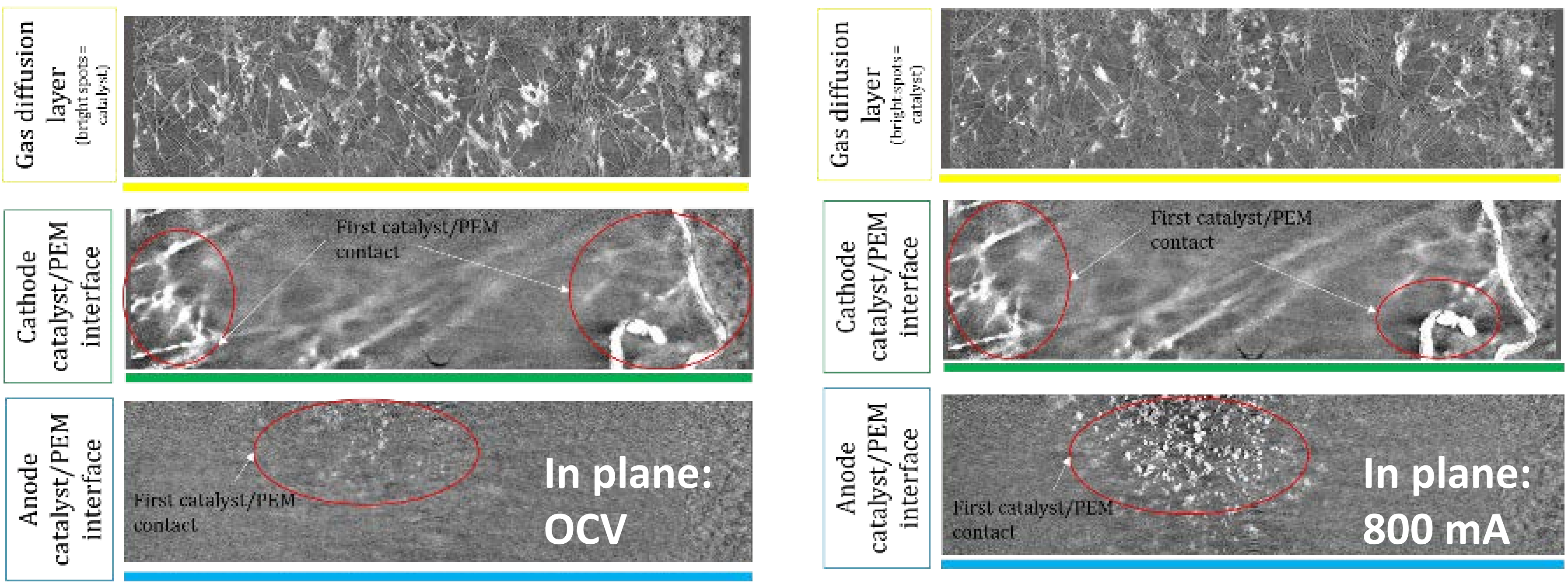


Tomography Studies

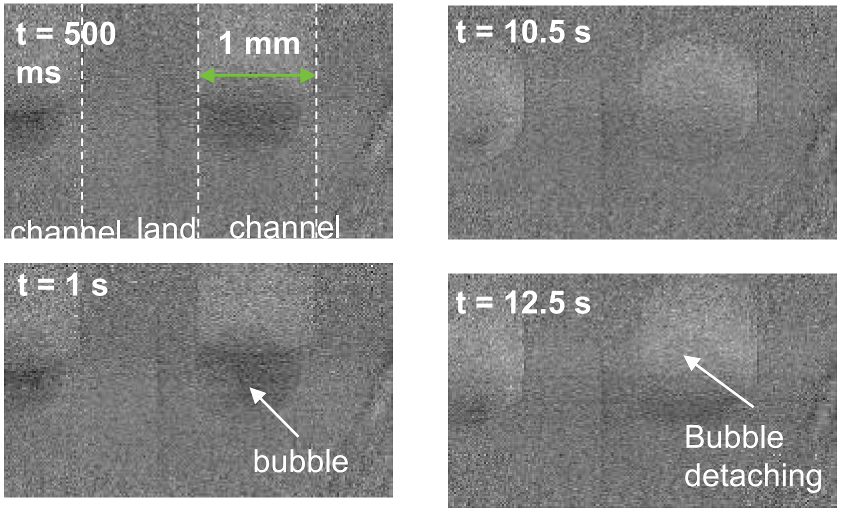


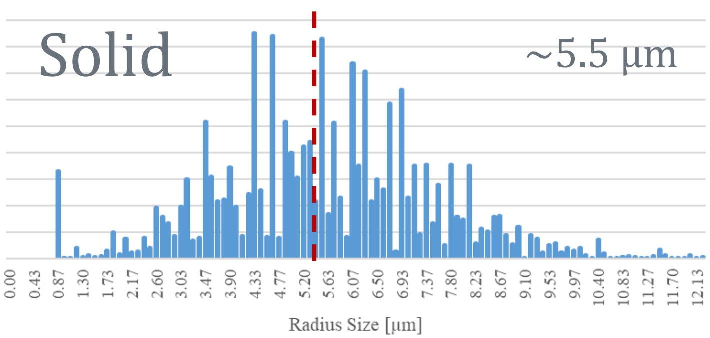


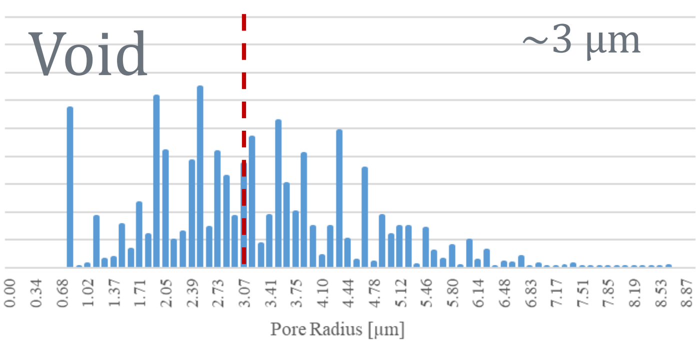
- Test cell refined for in-situ imaging during operation: ~1 cm^2
- Clearly see distribution of catalyst on electrode at interface

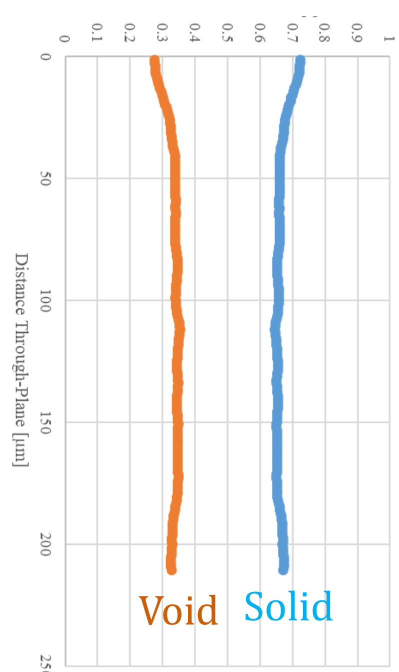


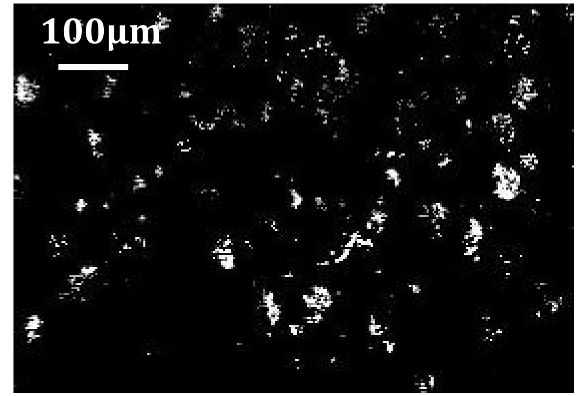
PTL and Catalyst Layer Morphology

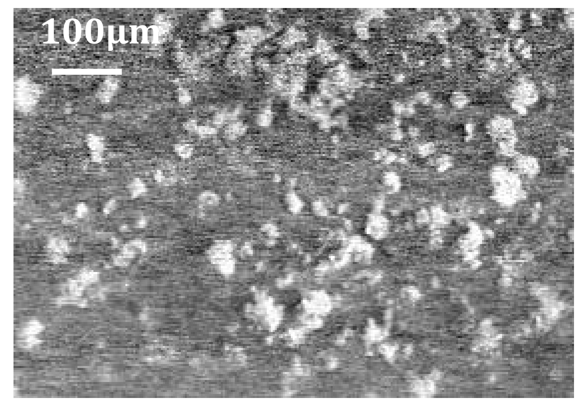


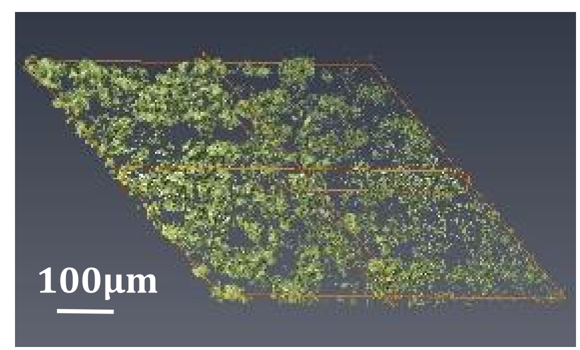








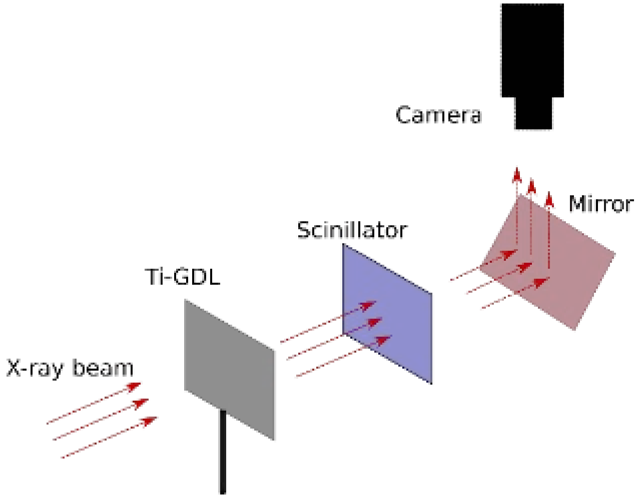


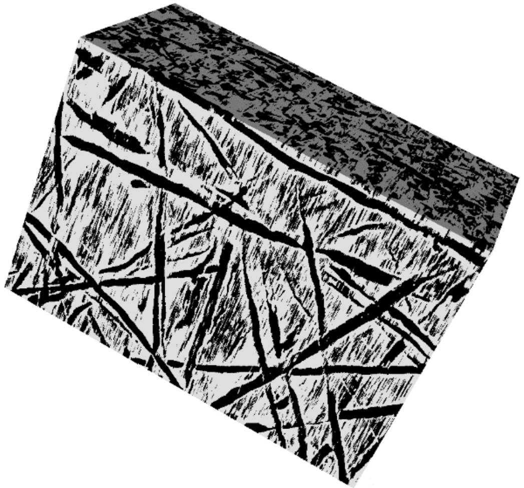


XCT imaging of Electrolyzer GDLs

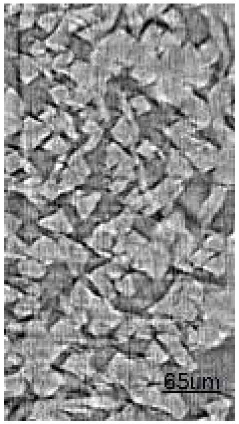
X-ray computed tomography (XCT) done at advanced light source (ALS), beamline 8.3.2.

- 400ms per exposure
- Approximately 20 minutes for each scan (2560 projections)
- 10x objective, 0.65μm/pixel

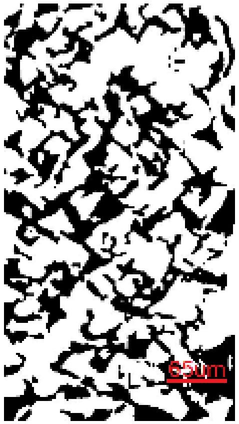




XCT volume data of fiber-based GDL



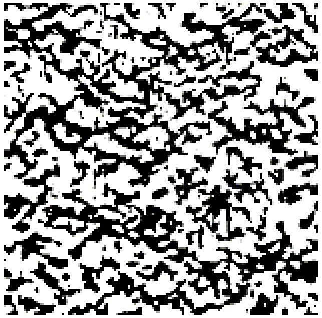
Original grayscale slice



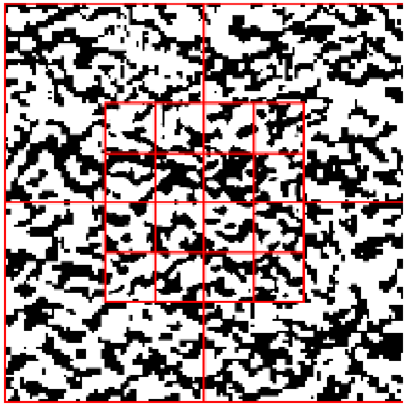
Segmented image

Test bridge from XCT Imaging to Modeling Framework

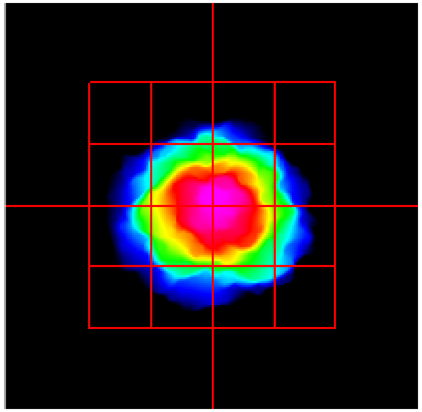
- We are developing 2D and 3D continuum solvers based on XCT scan data
- Goal is to support engineering analysis and optimization of GDL and mechanical environment
- Initial investigations focused on simple anisotropic permeability
- Next: 2-phase flow solvers in 3D



XCT slice data of particle-based GDL



Adaptive computational model of XCT domain



Porous media pressure from hypothetical H2 generation site

Effective Leveraging of the EMN Resource Nodes: LBNL/NREL

- Fundamental characterization of catalyst and membrane
  - Activity screening and hydration modeling/measurement
  - Characterization of catalyst in situ/ex situ with operation
- Component characterization/manufacturing
  - High throughput catalyst deposition methods
  - Segmented cell development
- Regular contact established and materials exchanged

Accomplishments Summary

- Q1 and Q2 milestones have been met
- On track to meet Q3 and Q4 ahead of milestone due dates
- Performance target of < 1.85V at 1.8 A/cm^2 achieved with several high activity oxide catalysts synthesized at Proton
  - Additional work at NREL has helped to characterize stability through RDE
- In operando image analysis has shown feasibility
  - Provides data on PTL and catalyst interactions
  - Data provided to LBNL for use in computational modeling
- Development of a non-supported electrode ink, manufacturing process, and MEA quality control has been initiated at NREL

Future Work - Next Steps

- Efforts are on track in meeting BP1 milestones
- Current activities are focused on completion of milestones for Q3 and Q4
  - Processing membrane samples for mechanical evaluation at LBNL
  - Tufts to continue in situ electrode imaging and water transport measurements
  - Image analysis will be used as inputs for modeling at LBNL
- Parallel effort on defining membrane processing conditions for thinner material (alternate supplier evaluation)
- Integration of high activity catalysts with new membrane will follow with catalyst screening and manufacturing support from NREL
  - Required operating temp to meet target should decrease
  - Close to 1.7V go/no go target at 90°C

Project Summary

- Objectives: Develop a highly efficient MEA through membrane processing improvements, OER catalyst development, and refinement of electrode deposition and inspection methods.

- Relevance & Impact: Activities directly support achieving DOE targets of $2/kg H_2. The work will also demonstrate feasibility of characterization techniques for use in industry to better screen new materials for PEMWE.

- Collaboration Effectiveness: Engagement across groups has helped to accelerate characterization and downselect of methods and materials.

- Accomplishments:
  - Near-term performance targets have been exceeded with 1.85V achieved at 2.0 A/cm^2.
  - Imaging feasibility shown at Tufts University for in operando analysis
  - Catalyst durability characterization and testing at NREL has shown good alignment with device testing at Proton

- Future work: Investigate membrane processing conditions and integrate with advanced catalysts