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# High Performance Platinum Group Metal Free Membrane Electrode Assemblies Through Control of Interfacial Processes


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Organization: Proton OnSite


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Project ID: PD123


DE-EE0006958

# Overview

## Timeline

- Project Start: 8 May 2015
- Project End: 7 May 2017
- Percent complete: 0%

## Barriers

- Barriers addressed

  G: Capital Cost

| Table 3.1.4 Technical Targets: Distributed Forecourt Water Electrolysis Hydrogen Protoduction [a, b, c] | | | | |
|---|---|---|---|---|
| Characteristics | Units | 2011 Status | 2015 Target | 2020 Target |
| Hydrogen Levelized Cost [d] (Production Only) | $/kg | 4.2 [d] | 3.9 [d] | 2.3 [d] |
| Electrolyzer System Capital Cost | $/kg | 0.70 | 0.50 | 0.50 |
| | $/kW | 430 [e, f] | 300 [f] | 300 [f] |
| System Energy Efficiency [g] | %(LHV) | 67 | 72 | 75 |
| | kWh/kg | 50 | 46 | 44 |
| Stack Energy Efficiency [h] | % (LHV) | 74 | 76 | 77 |
| | kWh/kg | 45 | 44 | 43 |

## Budget

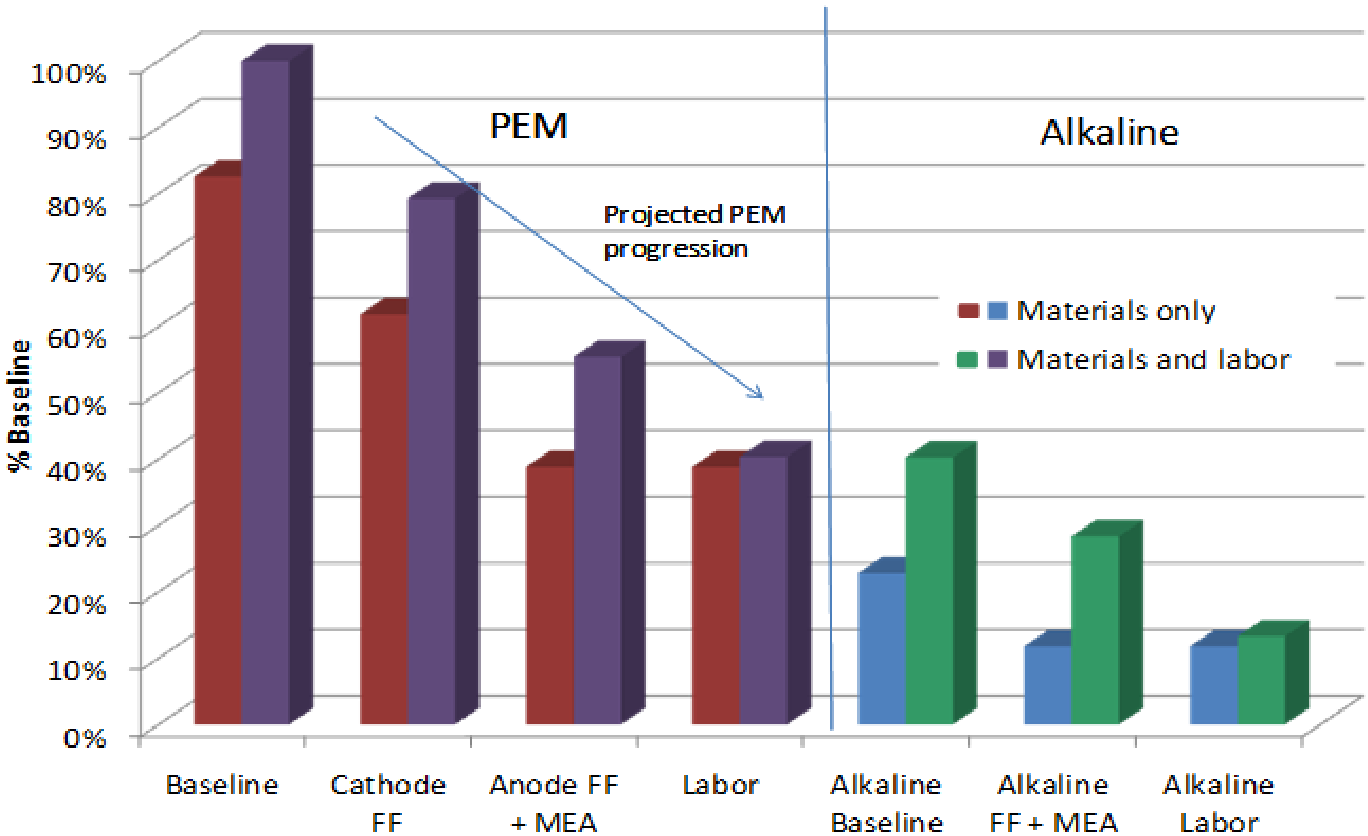
- Total project funding
  - DOE share: $1,000,000
  - Cost-share: $250,000
- Funding for FY15 to date
  - DOE share: $0

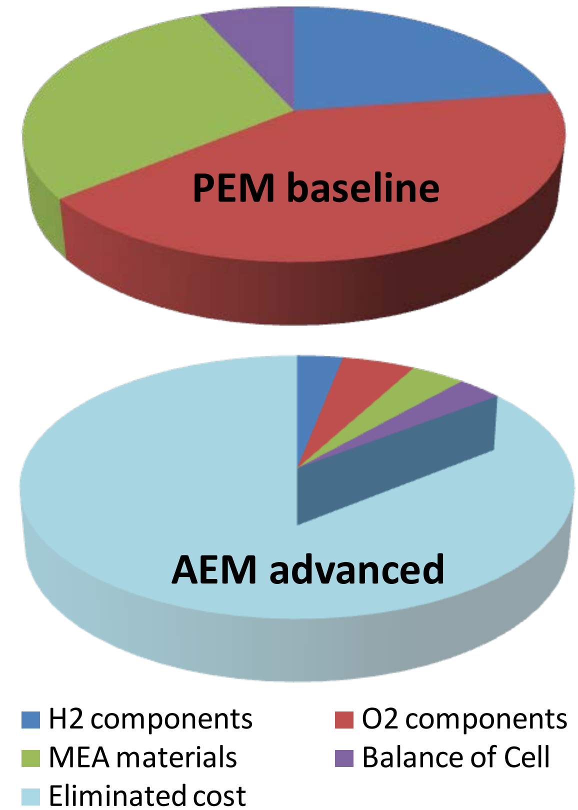
## Partners

- Northeastern University
- Pennsylvania State University
- University of New Mexico

# Relevance: Problem to be Addressed

- Capital cost reductions needed to overcome market barriers
- Anion exchange membranes (AEMs) gaining stability
  - Enable elimination of most expensive cell materials



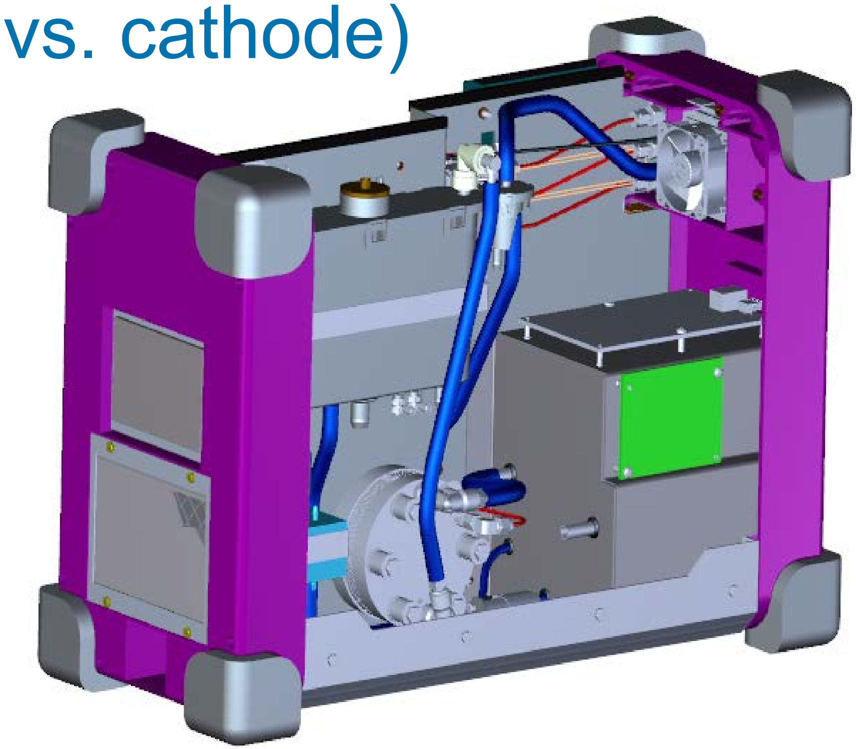

Comparison of proton exchange membrane (PEM) and AEM stacks

# Relevance: Hydrogen Value Proposition

- Hydrogen via electrolysis is ideally suited for:
  - Grid-buffering and energy storage
  - Transportation fuel
  - Renewable feedstock to high value chemical streams
  - Green production of fertilizer
  - Supplement to natural gas for higher efficiency
- Easily scalable; can independently scale charge, discharge, and storage capability

# Relevance: AEM Electrolyzer Concept

- Reconfigure PEM generator to operate as AEM system
- Leverage PEM products and AEM prototypes
- Eliminate platinum group metals (PGM) materials
- Revisit electrolyte feed (anode vs. cathode)
- Improve membrane durability
- Directly ties to FCTO mission by addressing capital cost targets for electrolyzers



AEM Prototype System



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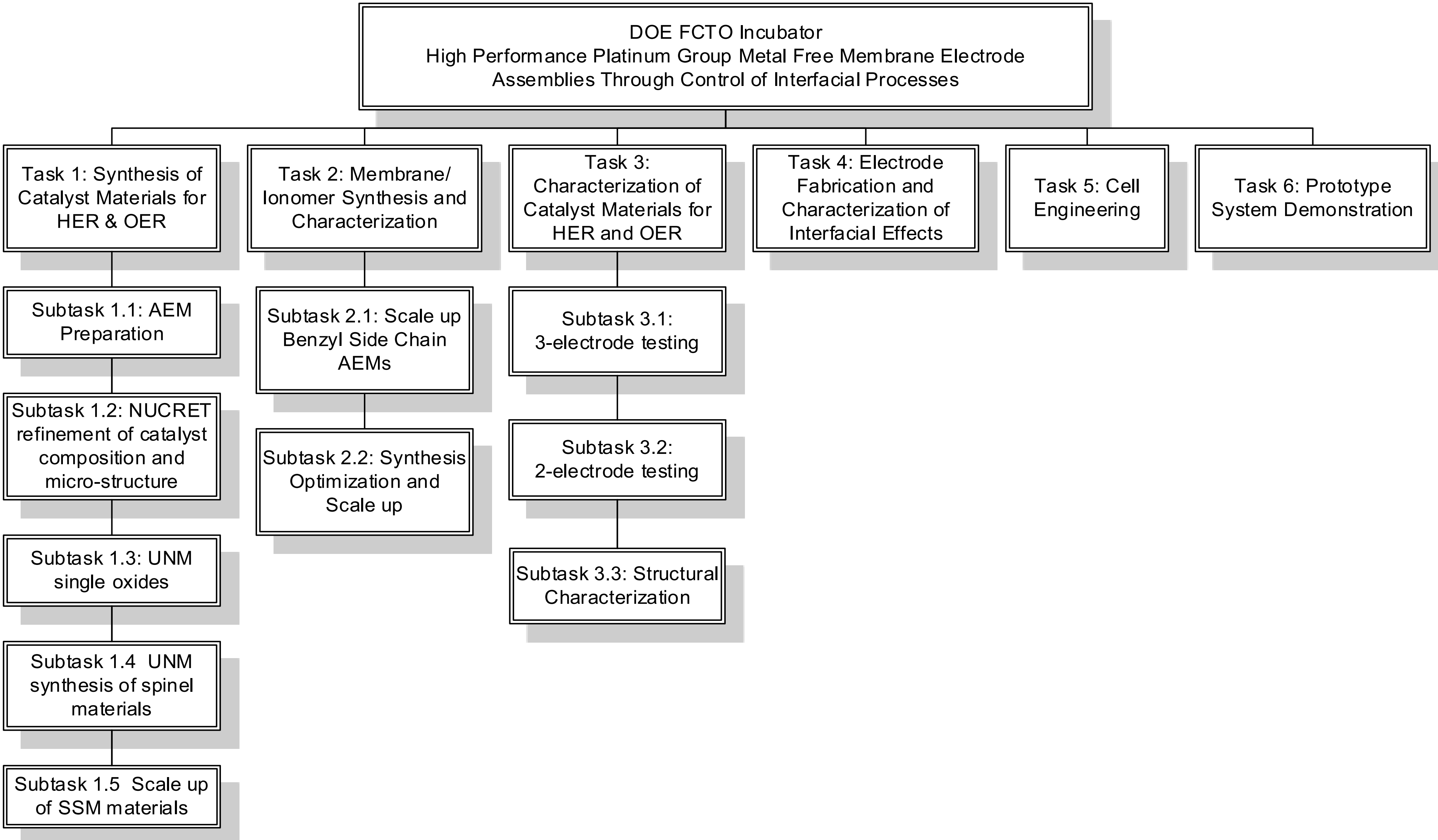
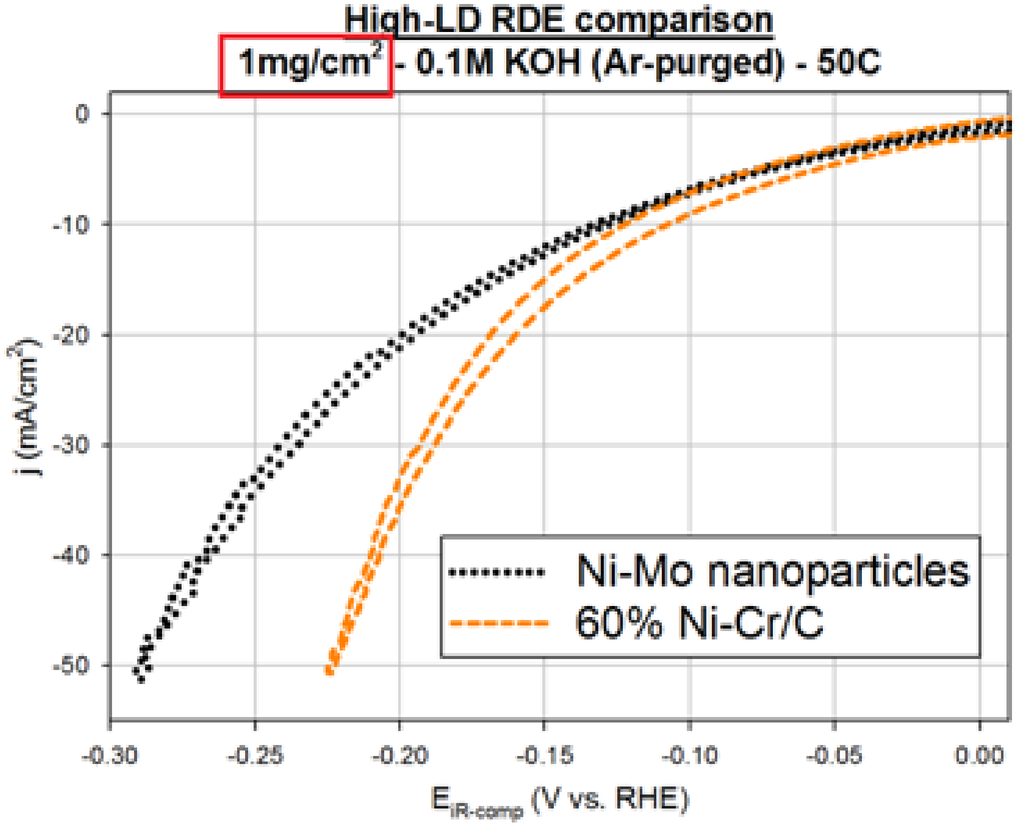
# Relevance: AEM Electrolysis

- **Catalyst**:
  - *Goal*: Improve translation of activity from solution to membrane, with less than 50 mV gap in performance at 500 mA/cm$^2$
- **Membrane and ionomer**:
  - *Goal*: Increase in membrane and ionomer stability, with voltage decay rates reduced to less than 50 mV/hr
  - *Goal*: Control water uptake in the membrane for improved mechanical stability under electrolysis operation
- **Cell Design**:
  - *Goal*: Stack and system water distribution improvements through alternative feed operations and tuning of gas diffusion layers (GDLs)

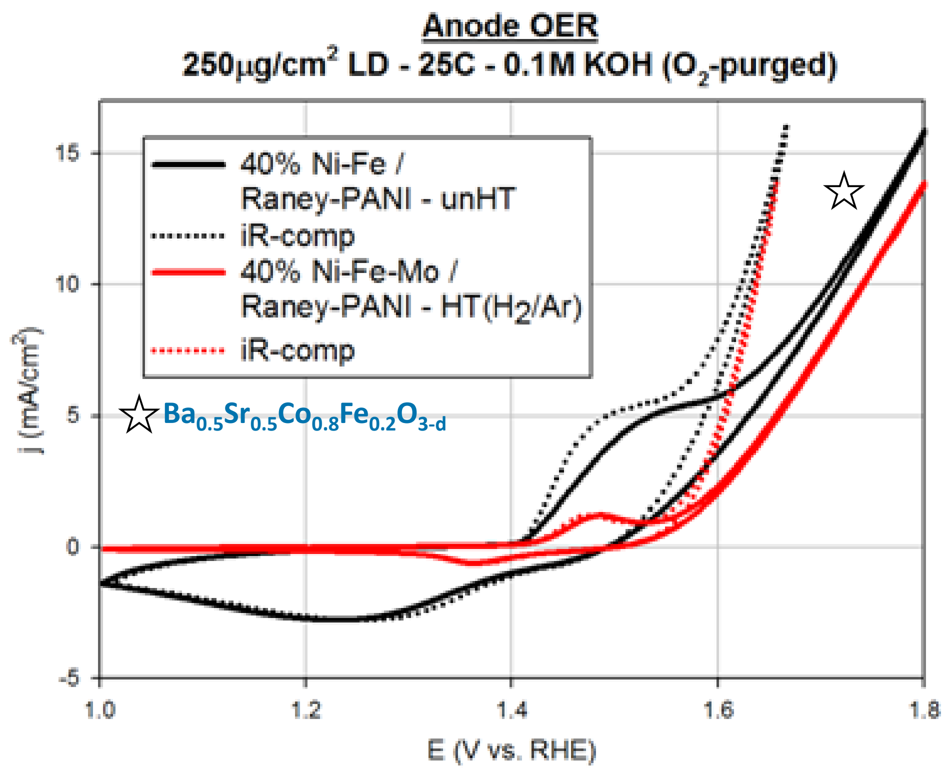
# Approach: Task Breakdown



# Approach: Catalyst Development




- Optimize composition and activity of non-PGM catalysts
- Better utilization through more effective gas diffusion electrode (GDE) structure

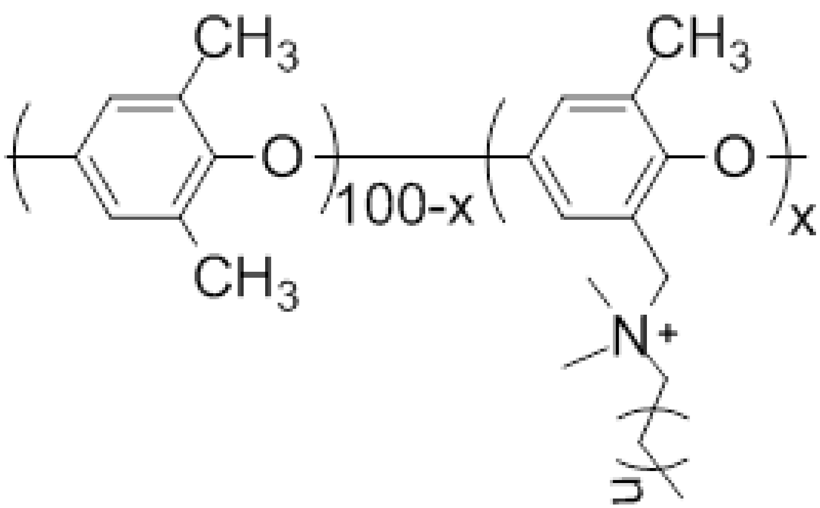



**Comparison of previous work at NUCRET on alkaline HER (above) and OER (right) to state-of-the-art Ni-Mo and perovskite nanoparticles.**

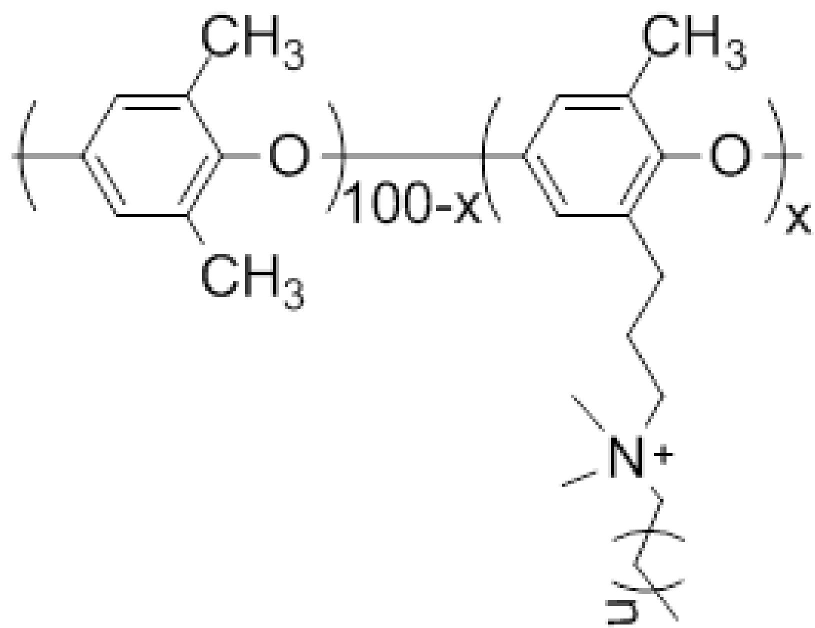
# Approach: Membrane and Ionomer

- PPO is a highly stable backbone for AEMs
  - Absence of electron withdrawing groups in the main chain
  - Cation spacer polymers have 5-10X greater hydroxide stability than side chain benzyl-linked cation

*Side chain benzyl dimethylalkyl ammonium*

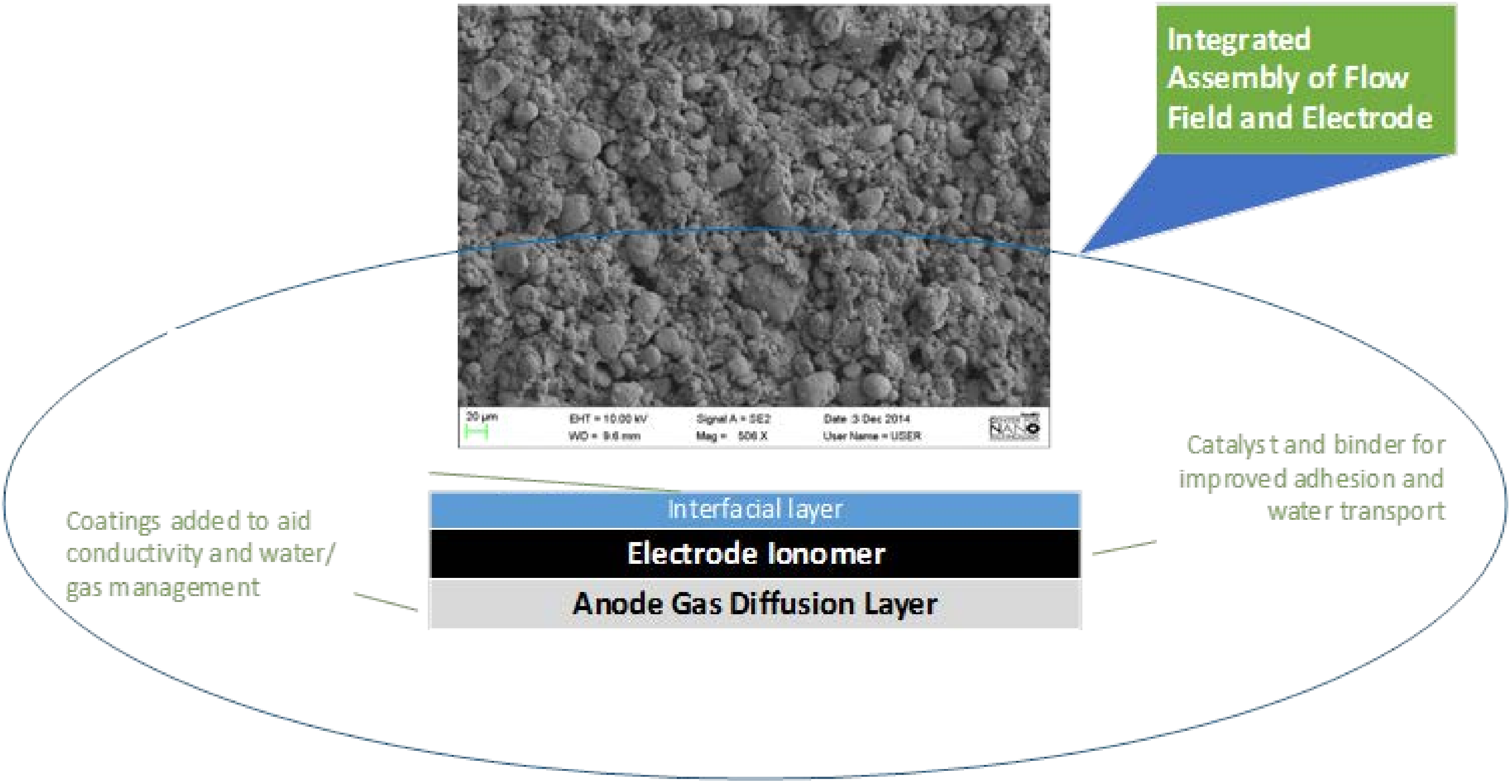



*Cation spacer dimethyldialkyl ammonium*



# Approach: Membrane and Ionomer

- Gas diffusion electrodes will be fabricated with Penn State ionomers.
  - Water management through modification of layers



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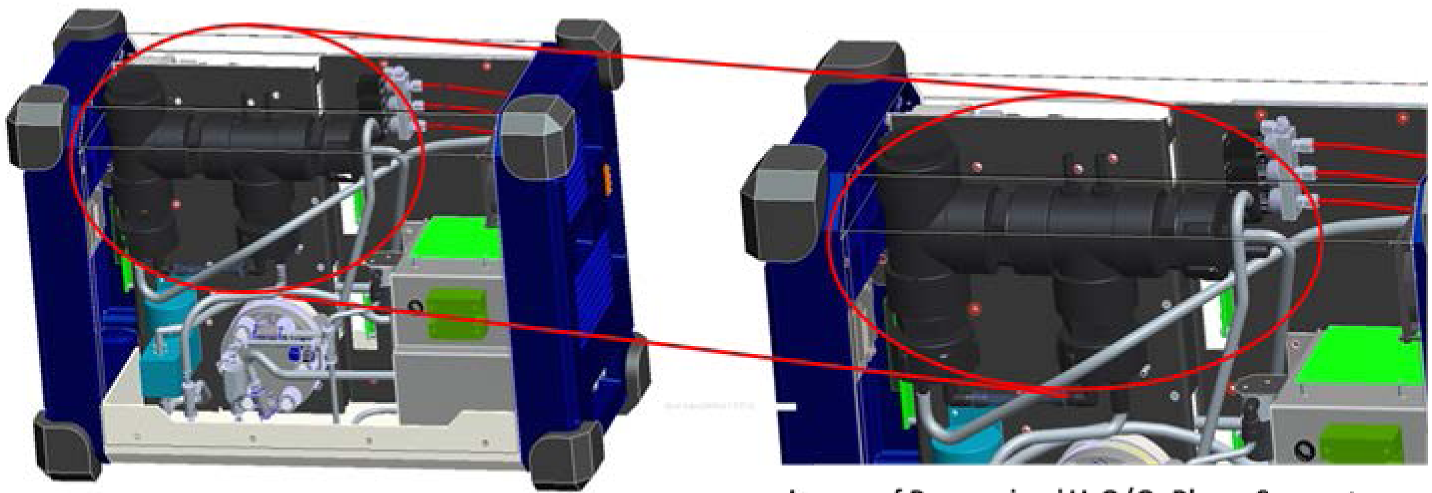
# Approach: AEM System Design

- Water management within the system will be explored.
  - Durability and performance, as a function of feed water delivery.
  - Cathode versus anode feed of DI $H_2O$
- System will serve as test station for stack durability tests and proof of concept for a cheaper laboratory generator



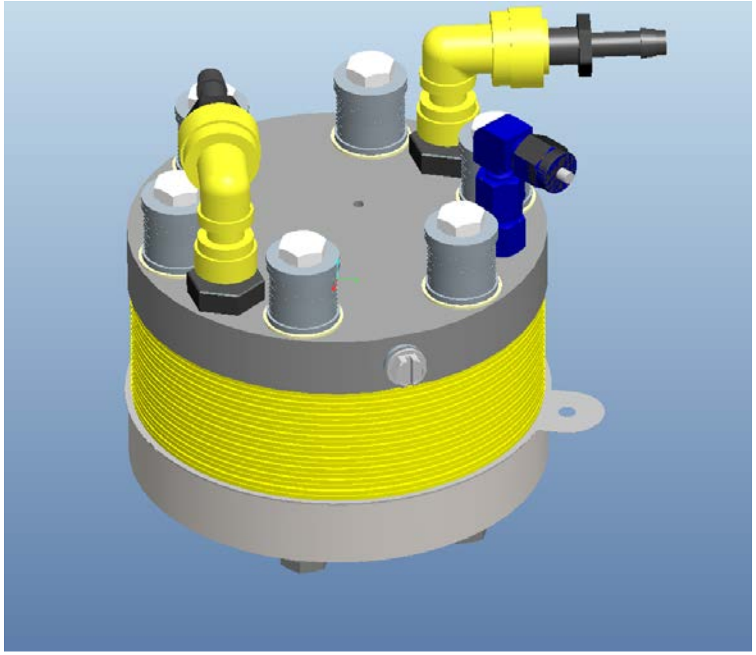
Full 1L/min System

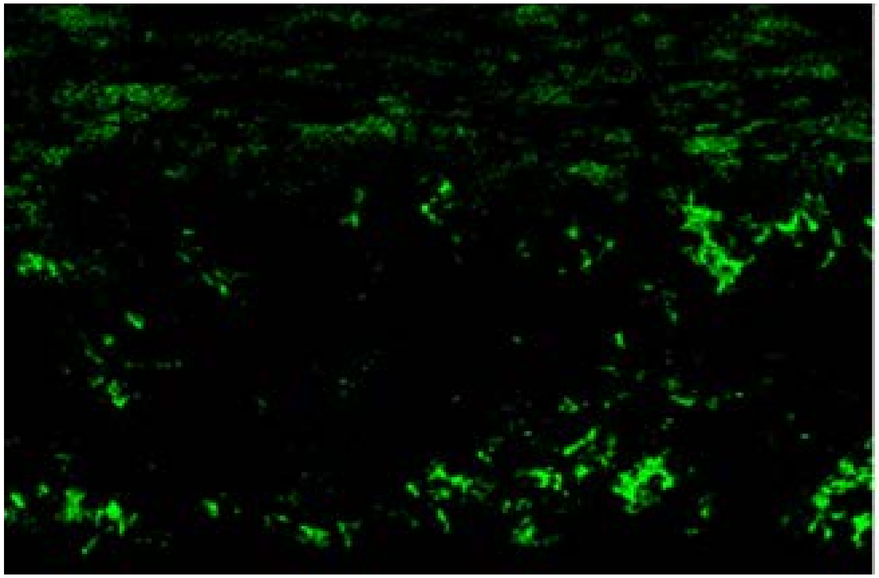
Image of Pressurized $H_2O/O_2$ Phase Separator

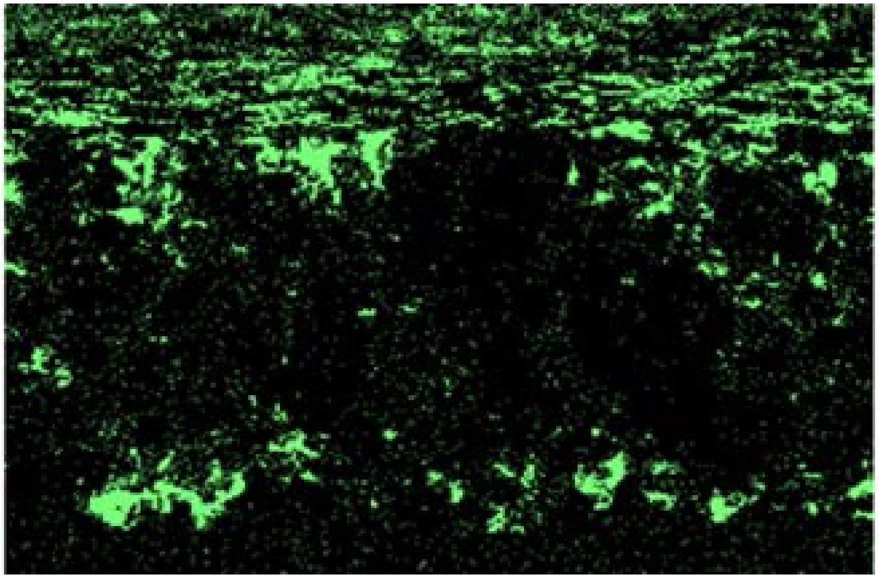
**Anode feed operation in this mode**

# Approach: AEM Stack Design

- Incorporate cost-reduced materials for cell and stack parts.
- Tune of gas diffusion layers for stable operation of the AEM-WE







**Analysis of part without treatment for water management (top) versus treated (bottom).**



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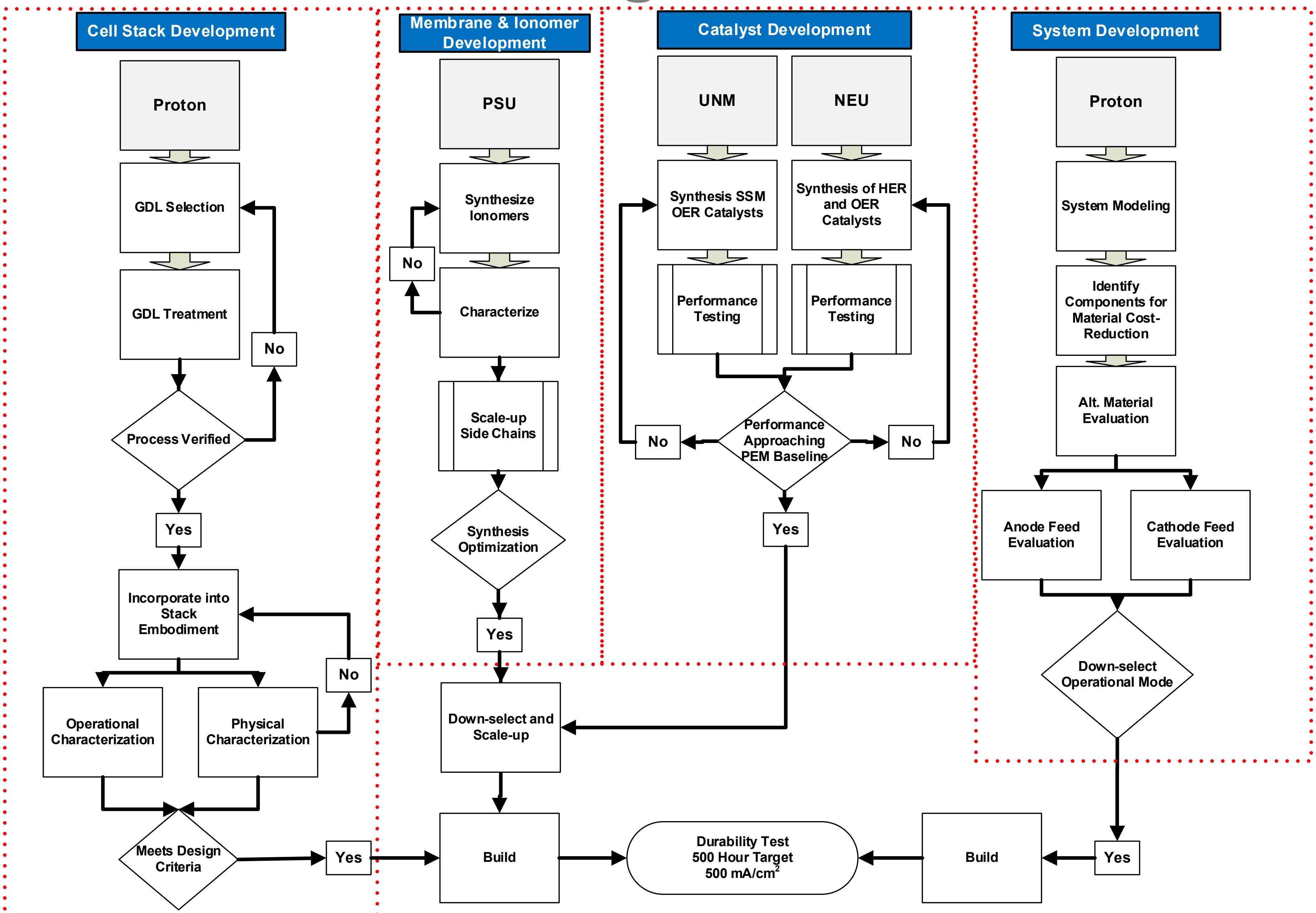
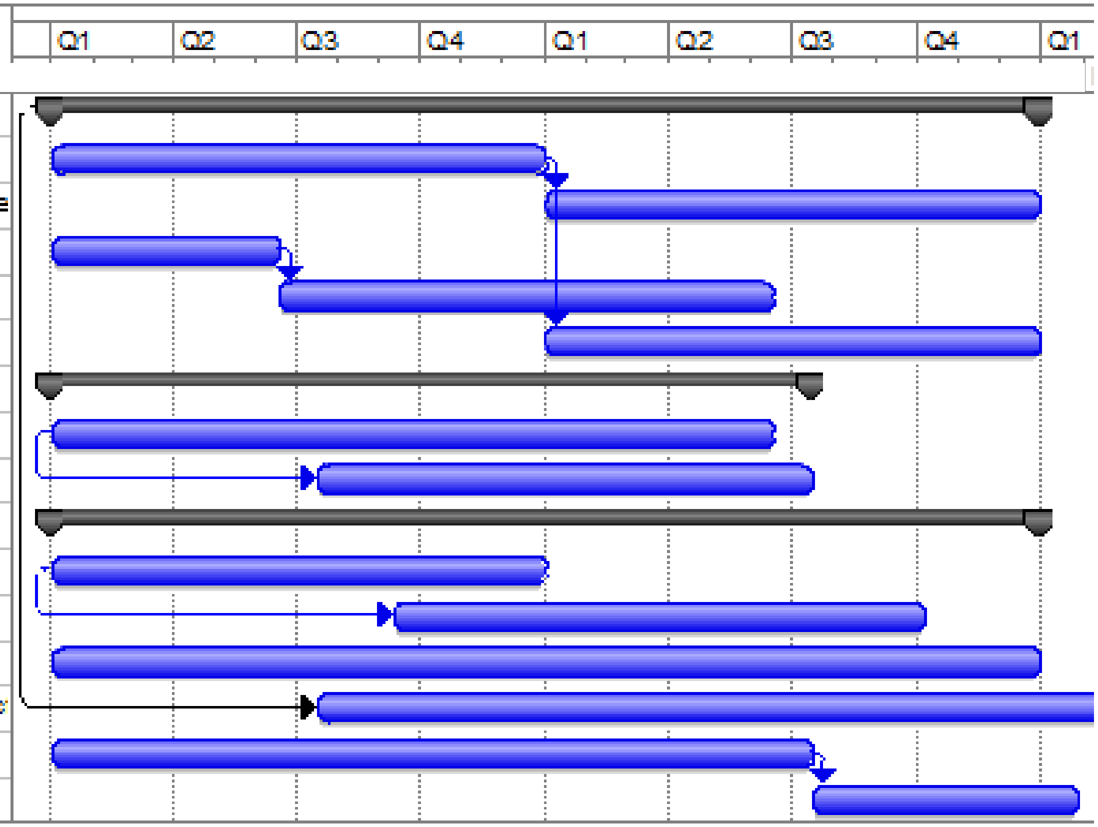
# Approach: Overall Program

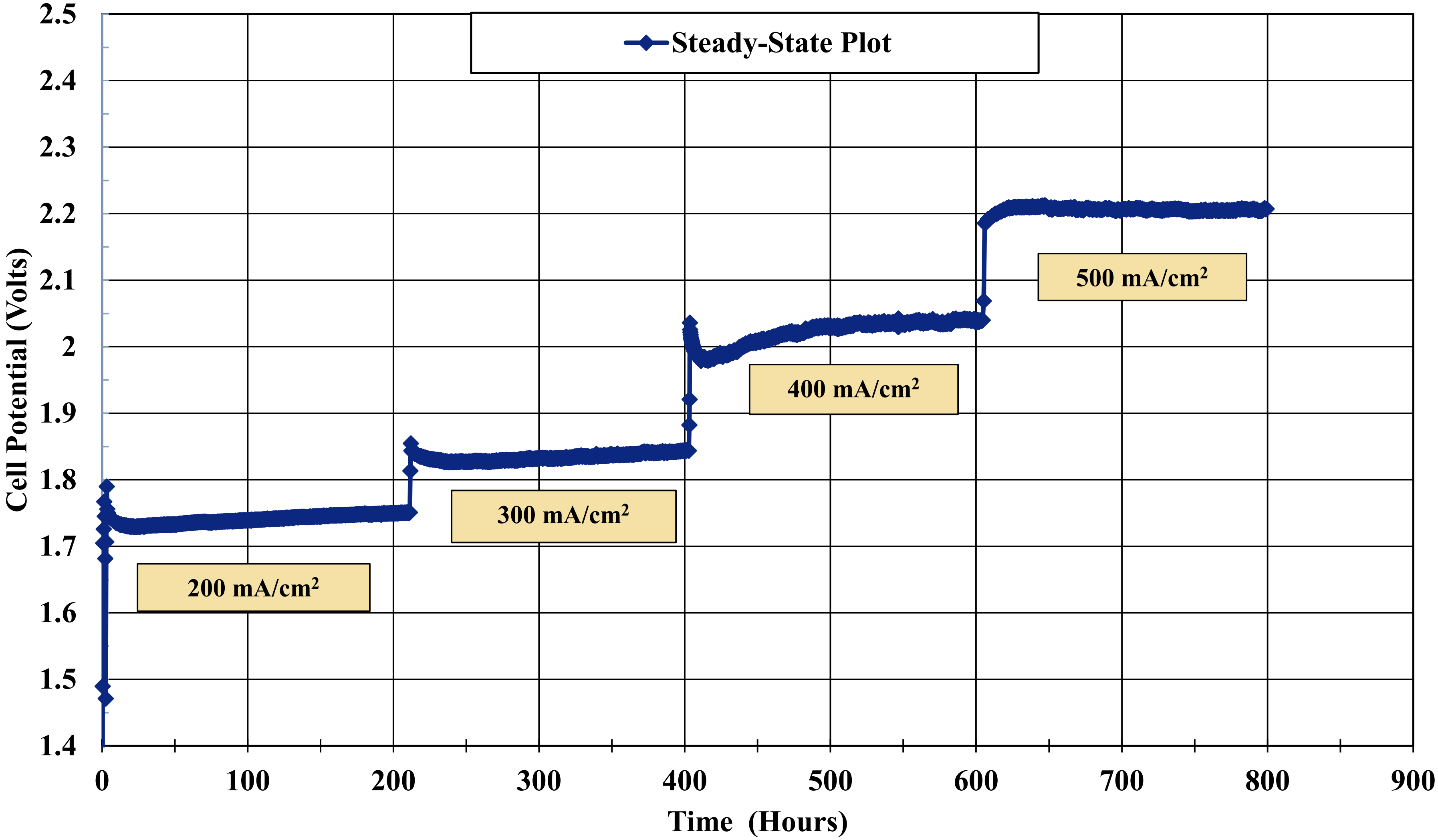


# Technical Accomplishments: Timeline

| ID | | Task Name |
|---|---|---|
| 1 | | Task 1: Synthesis of Catalyst Materials for HER & OER |
| 2 | | NUCRET catalyst component identification |
| 3 | | NUCRET refinement of catalyst composition and micro-structure |
| 4 | | UNM single oxide synthesis |
| 5 | | UNM synthesis of spinel materials. |
| 6 | | Scale up of SSM materials up to 25g |
| 7 | | Task 2: Membrane/Ionomer Synthesis and Characterization |
| 8 | | Scale up Benzyl Side Chain AEMs |
| 9 | | Synthesis optimization and Scale Up |
| 10 | | Task 3: Characterization of Catalyst Materials for HER & OER |
| 11 | | 3-electrode testing |
| 12 | | 2-electrode testing |
| 13 | | Structural Characterization |
| 14 | | Task 4: Electrode Fabrication and Characterization of Interfacial Effec |
| 15 | | Task 5: Cell Engineering |
| 16 | | Task 6: Prototype/System Demonstration |

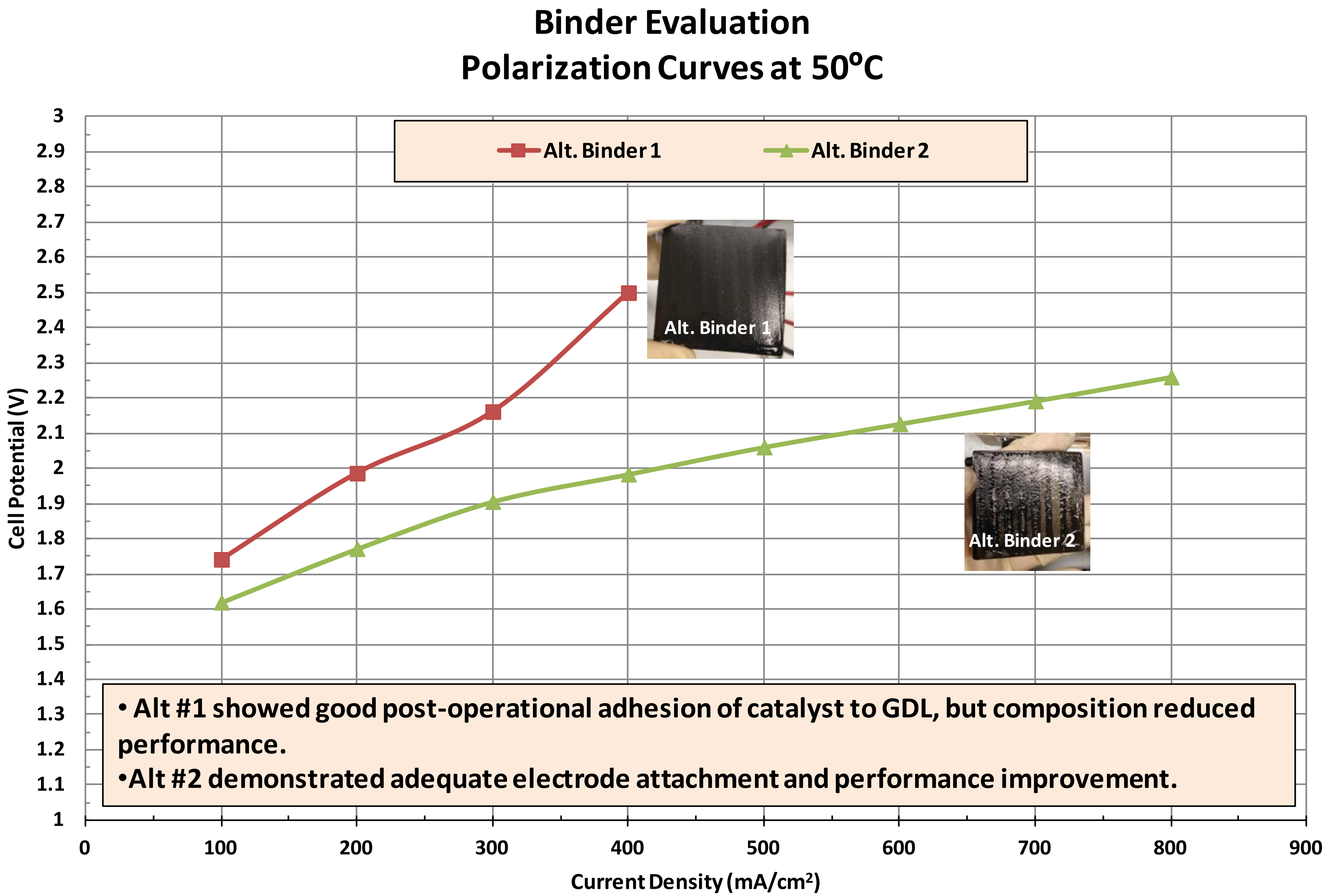


# Technical Accomplishments: Prior Work - Anode Feed

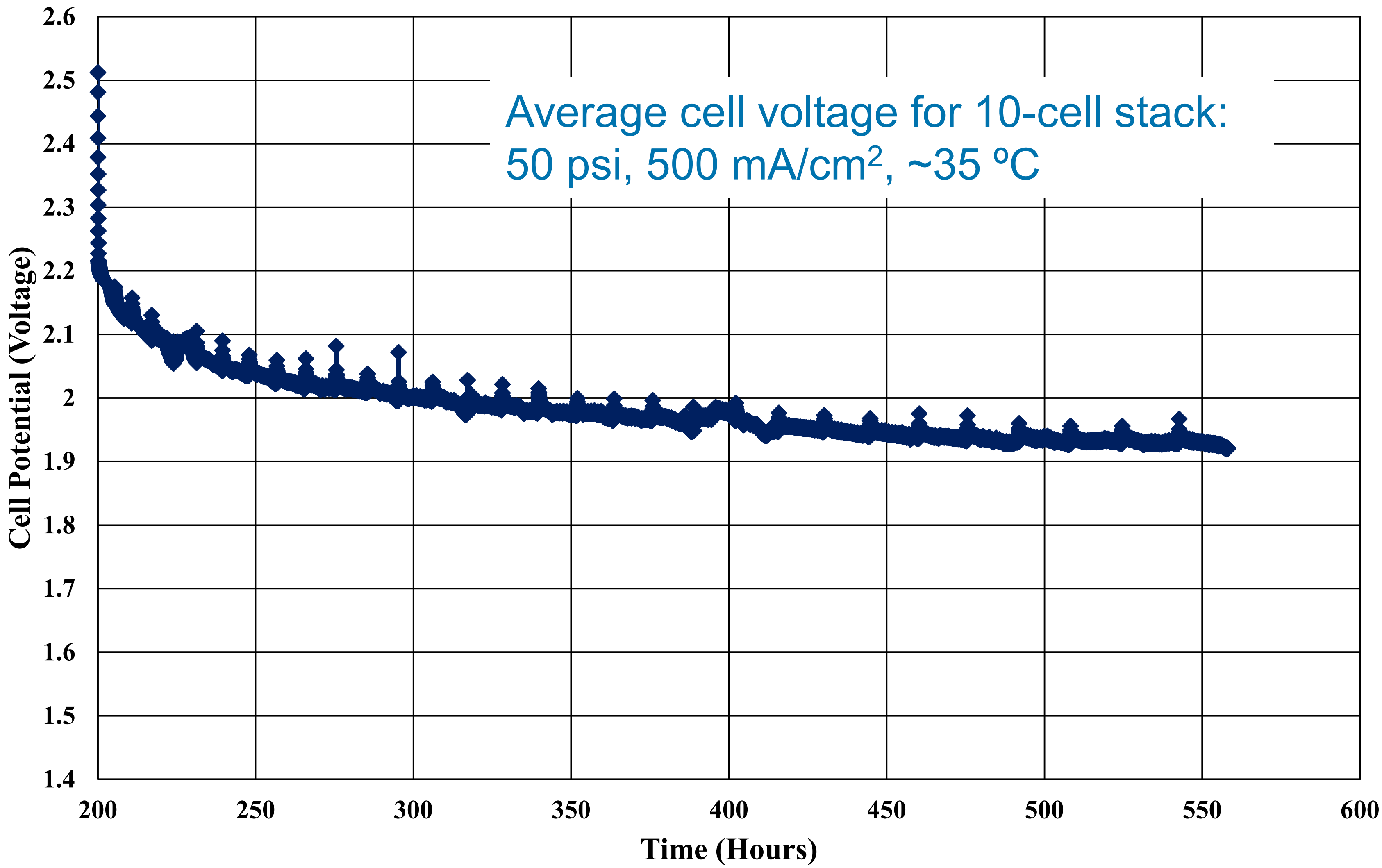



No current limitations observed in anode feed operation with PGM catalysts

# Technical Accomplishments: Prior Work - GDE Manufacture



# Technical Accomplishments: Prior Work - Stable Operation




**Stable operation of AEM cell with PGM Catalysts on Cathode**

# Future Work

- Catalyst
  - Use of sacrificial supports to synthesize un-supported mixed oxides or perovskite materials for OER.
  - Scale to 10-25g batches of catalysts
- Membrane and Ionomer
  - Maintain conductivity and improve stability of ionomers and membrane by >5X
  - Scale up to +100g batches
- Cell and System Design
  - Tune hydrophobicity, porosity, and geometry of the GDLs
  - Investigate alternate modes of water feed

# Collaborators

- Penn State
  - Synthesis and tuning of ionomer and membrane
  - Scale up batch sizes for use by partners and final test
- University of New Mexico
  - Preparation of sacrificial supports for pure oxides and spinel materials for OER
  - UNM will optimize sacrificial support ($SiO_2$ vs MgO), metal precursor type, heat treatment parameters, and sacrificial support removal conditions
- Northeastern University
  - $M/M_{Ox}$ work on HER catalysts and the effects of various post-synthesis heat-treatments.
  - Electrodeposited ternary Ni-Fe-X (X=Co, Mo,etc.) GDEs
  - Wet synthesis of composite Ni-Fe-X materials with carbon nanotubes (CNTs) or other conductive nano-polymers (CNPs)

# Summary

- **Relevance:** The goal of the proposed effort is to produce a high-performance anion exchange membrane water electrolyzer (AEM-WE) completely free of PGMs
- **Approach:**
  - Optimization of electrocatalyst conductivity, dispersion and utilization; understanding of catalyst-membrane-ionomer interfaces and how they differ from liquid electrolyte
  - AEM stability and robustness at high potentials and gas evolution conditions; water management
  - Cheaper materials of construction for cell stack and system to further reduce total $/kg $H_2$
- **Collaborations:**
  - Penn State (Hickner): membranes and ionomers
  - University of New Mexico (Atanassov): New non-PGM catalysts and support architectures
  - Northeastern (Mukerjee): catalyst-electrolyte interface and new non-PGM catalysts
- **Proposed Future Work:**
  - Synthesize PGM free HER and OER catalysts
  - Synthesize alternative AEM and ionomer for improved stability
  - Optimize cathode and anode GDEs to improve water management for operational stability
  - Evaluate operational mode with electrolysis system for stability (cathode vs anode feed)
  - Reduce cost of stack and system components for total electrolyzer reduction in cost