U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

High-Performance AEM LTE with Advanced Membranes, Ionomers and PGM-Free Electrodes

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University Partners

Georgia Tech — IONOMER AND MEMBRANE DEVELOPMENT

Poly(norbornene) Block Copolymer

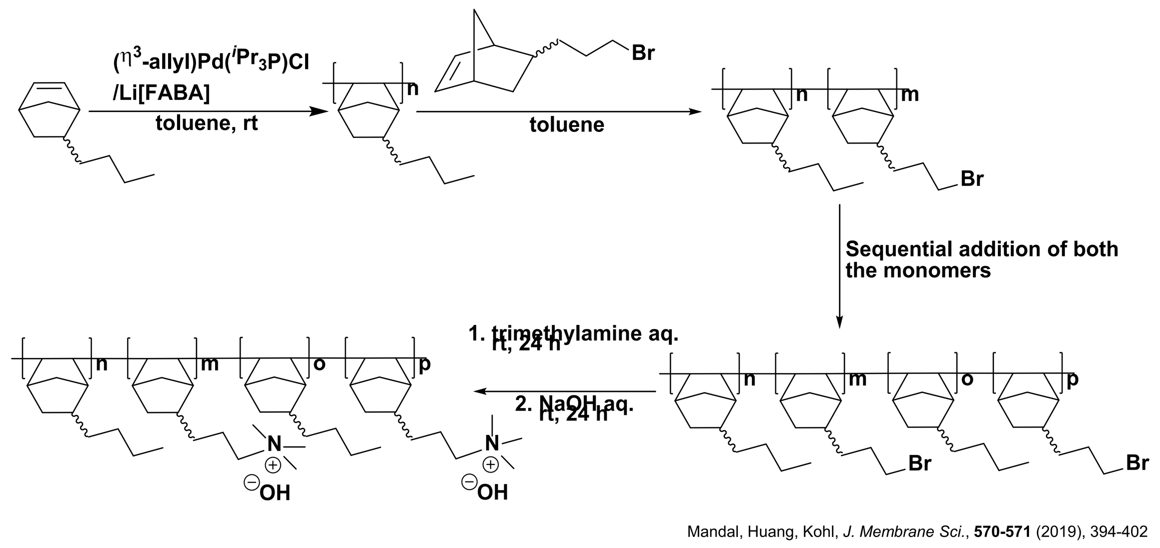
Excellent chemical stability
- All-hydrocarbon backbone
- Tethered cation

High ionic conductivity
- Phase segregated block copolymer
- High ion exchange capacity (IEC), controlled water uptake (WU)
- High mobility (σ/IEC)

Robust mechanical properties
- High T_g (350 °C), higher device T
- Thin, reinforced membrane

Low cost and scalability
- Dicyclopentadiene precursor

Synthesis of tetrablock copolymers
- Monomers are prepared from dicyclopentadiene
- Dicyclopentadiene is low-cost and produced in large quantities in the steam cracking of naphtha and gas oils
- Multiblock copolymers synthesized by the sequential monomer addition



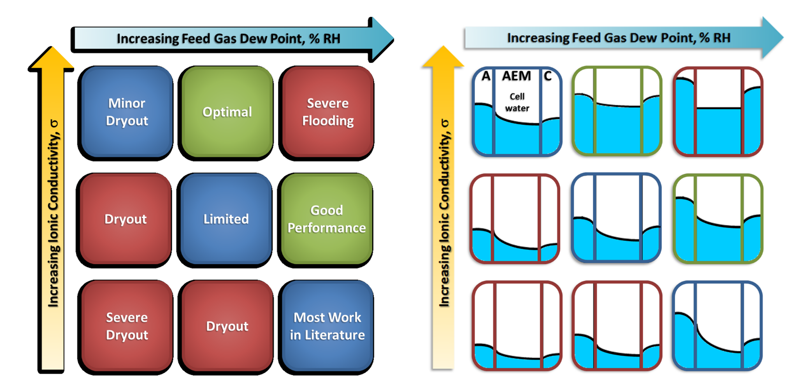
Mandal, Huang, Kohl, *J. Membrane Sci.*, **570-571** (2019), 394-402

Polymer	Cross-linker %	OH⁻ Conductivity (mS/cm)		IEC, meq/g	IEC, meq/g	σ/IEC	Ionic ASR (Ohm-cm²)	%WU	Hydration number
		25 °C	80 °C						
GT82	5	109	212	3.84	3.8	55	0.04	122	17.6
GT64	5	84	181	3.34	3.3	54	0.05	90	15.0
GT32	0	62	123	1.88	1.8	65	0.08	63	18.6

Extremely high IEC without loss of μ
- IEC values approaching 4 meq/g can be made and used without significant penalties: (i) mobility or (ii) water uptake.
- % Water uptake must be viewed considering hydration number and mobility. Free vs bound water must be optimized for efficient electrolysis

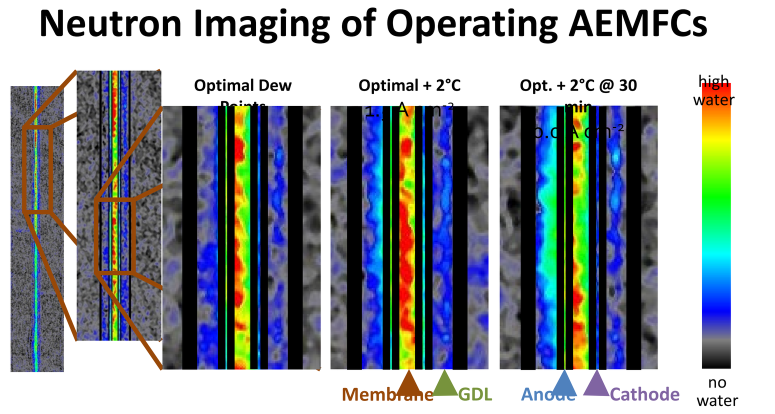
University of South Carolina — ELECTRODE DESIGN AND OPERATIONAL CONDITIONS

Using ionomers and AEMs from Georgia Tech with catalysts provided by Pajarito Powder
- Provide a standard baseline MEA configuration and production method
- Develop a design of experiments matrix for the relative amounts of ionomer:catalyst:PTFE in each electrode
- Understand and optimize water balance in LTE configuration

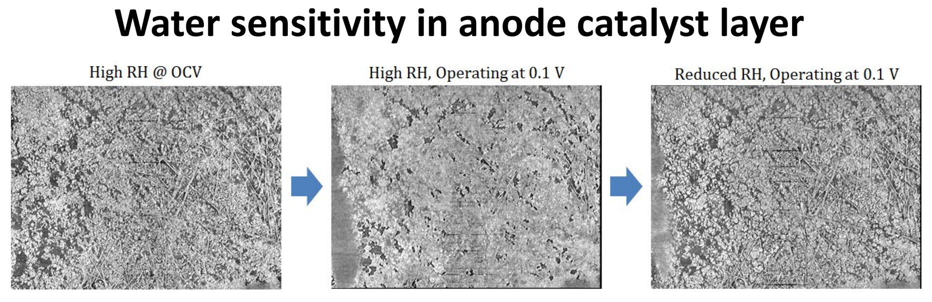


Importance of water balance in AEMFCs
- Essential for achieving extremely high peak power densities in fuel cell mode (3.5 W/cm²)
- 6 H_2O molecule swing (per reacting O_2) between the Anode and Cathode
  - 3x more than PEMFC
  - Even more sever when considering electro-osmotic drag (up to 38 H_2O/O_2)

Neutron Imaging of Operating AEMFCs



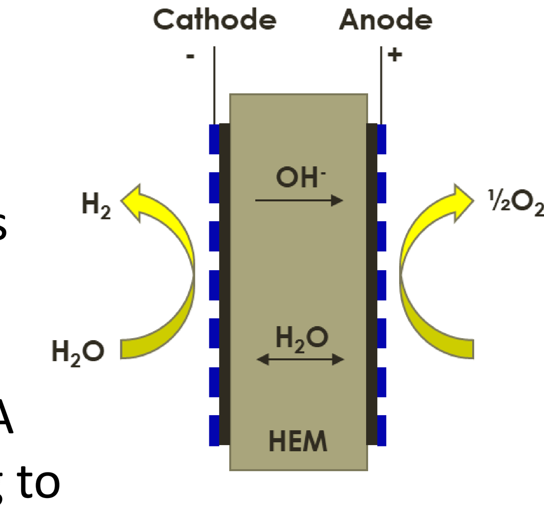
Water sensitivity in anode catalyst layer



Omasta, Mustain et al, *Energy Environ. Sci*, **11** (2018), 551-558

Project Goals

1. In-situ membrane performance and stability
2. PGM-free catalysts performance and stability
3. Ionomers and MEA fabrication leading to high-performance, durable alkaline LTE systems
4. Understanding AEM performance fundamentals and addressing pure-water operation
5. Performance optimization and demonstrating long-term stability



Metrics

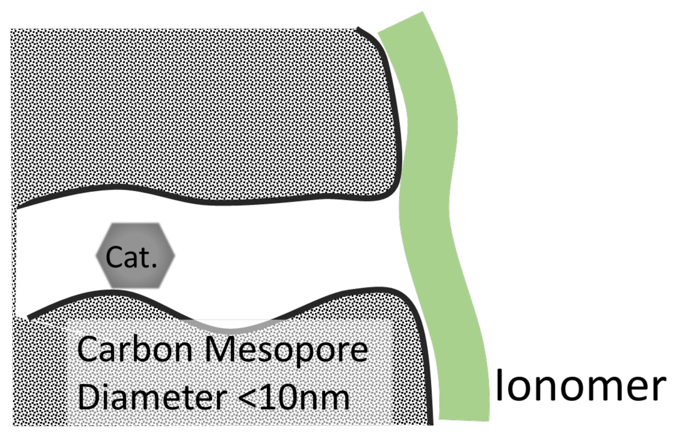
Performance:
43 kWh/kg-H_2
(i.e. 1.6 V electrolysis at 100% coulombic efficiency),

Durability:
4 mV/1000 h degradation

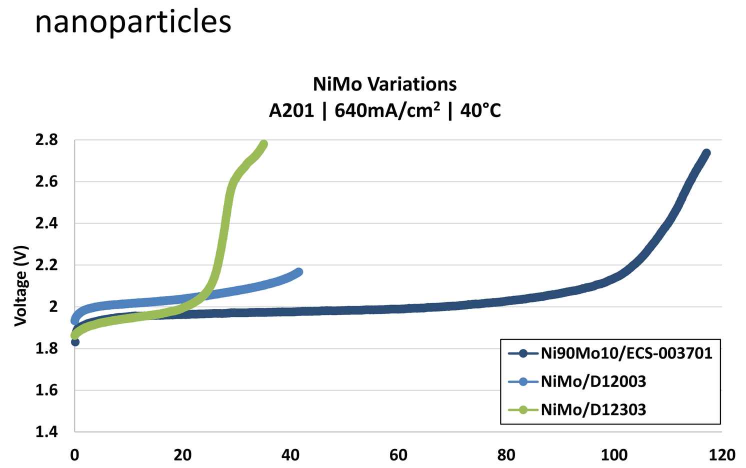
Cost: $2/gge

Industry Partners

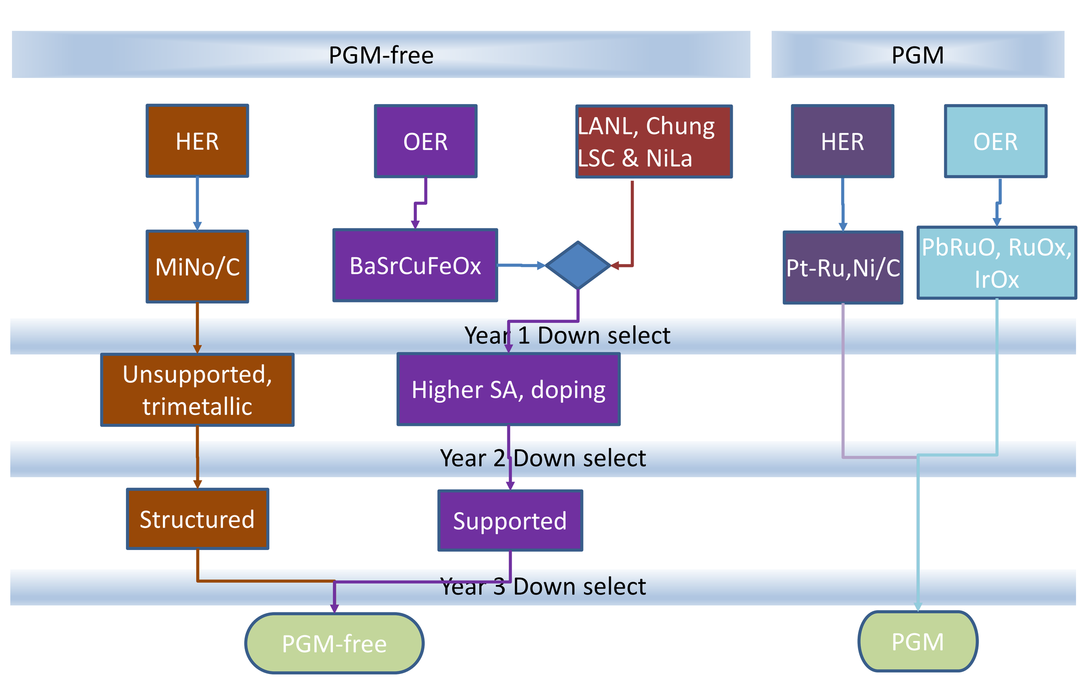
Pajarito Powder — PGM AND PGM-FREE CATALYST DEVELOPMENT



Mesoporous Support Concept
- Protect ionomer from oxidation by catalyst
- Protect catalyst from ionomer poisoning
- Enables smaller stable catalysts nanoparticles



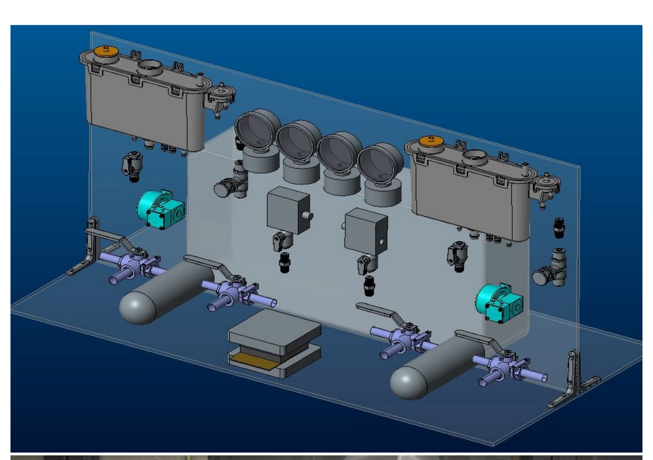
NiMo on mesoporous (6nm) support appears stabilized, possibly due to reduced ionomer interactions

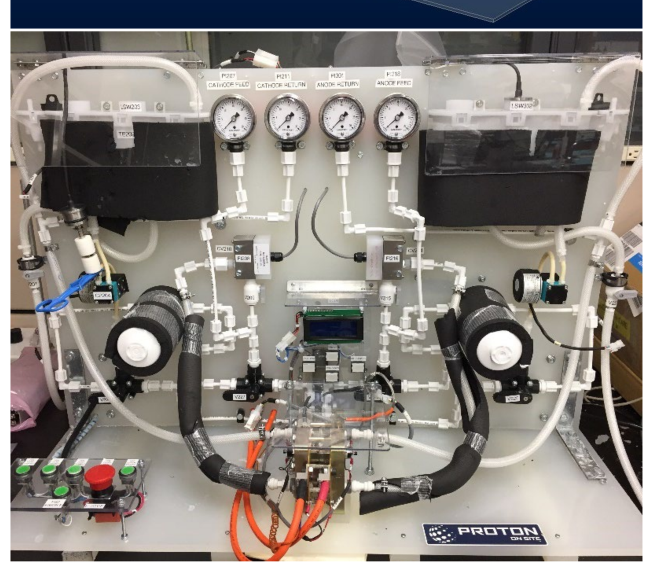


Oxygen Evolution Reaction (OER)
- PbRuOx is best OER catalyst for AEM/Alkaline
- Ni-based alloys active but stability questionable
- Oxides stable, with lower conductivity and specific performance

Hydrogen Evolution Reaction (HER)
- Pt-alloys are best HER catalysts for AEM/Alkaline
- Best for Ni-based alloys are active, stable, and can be improved
- Ni-Mo well proven
- Ni-Fe is active but unstable
- Additional improvement through composition and alloy structure (segregated, desegregated, core-shell) likely

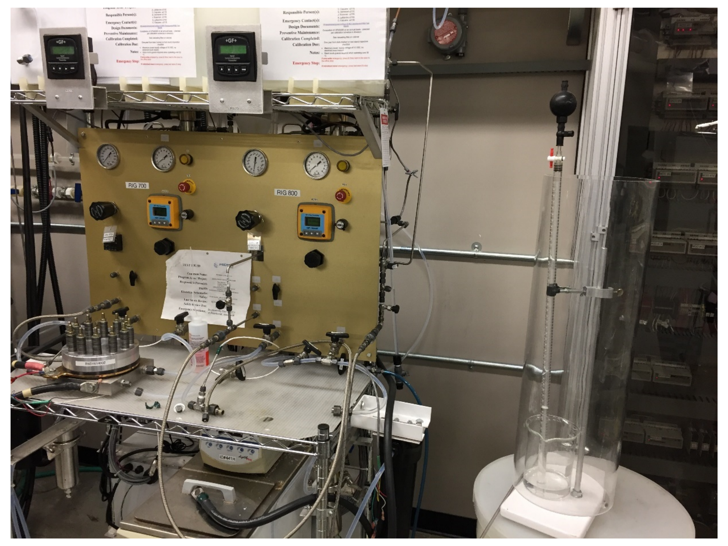
Nel — OPERATIONAL EVALUATION AND SCALE-UP





Previously evaluated numerous samples for preliminary assessment
- Operationally tested in 25cm² hardware
- Testing was performed at 50°C
- Polarization data up to 500 mA/cm²
- Steady-state testing at 500 mA/cm²

Test stand available purely for AEM tests
- Automatic data acquisition enabled
- Can supply water to both the anode and cathode
- Temperature control



Using a standard test cell, Nel will collect nitrogen permeation measurements
- Incremental measurements in 1-2 bar steps
- Non-linear response indicates a leak

Electrolysis Markets

Nel has scalable platforms for identified markets

Successfully maintaining sustainability and profitability

Georgia Institute of Technology | South Carolina | nel | PAJARITO POWDER FUEL CELL CATALYSTS