

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



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

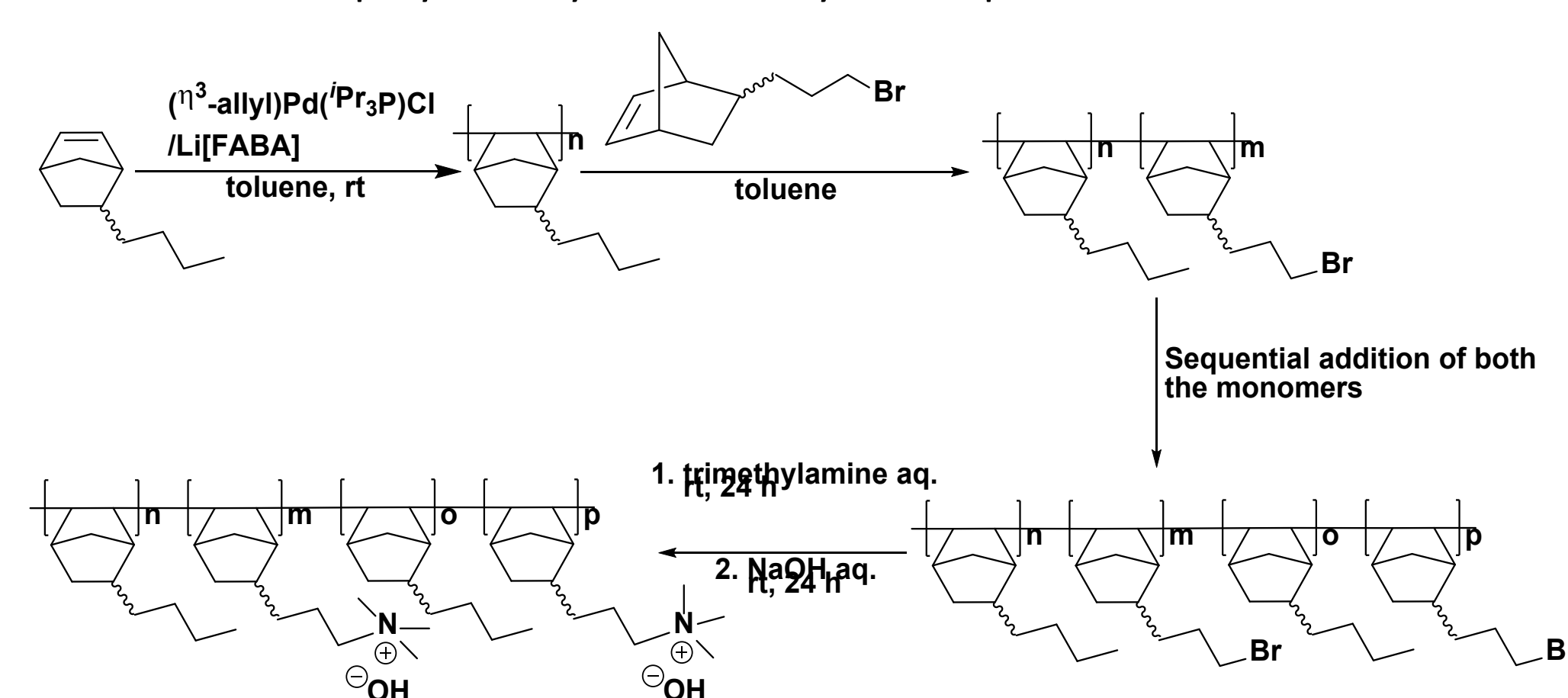
- High T_g (350 °C), higher device T
- Thin, reinforced membrane

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

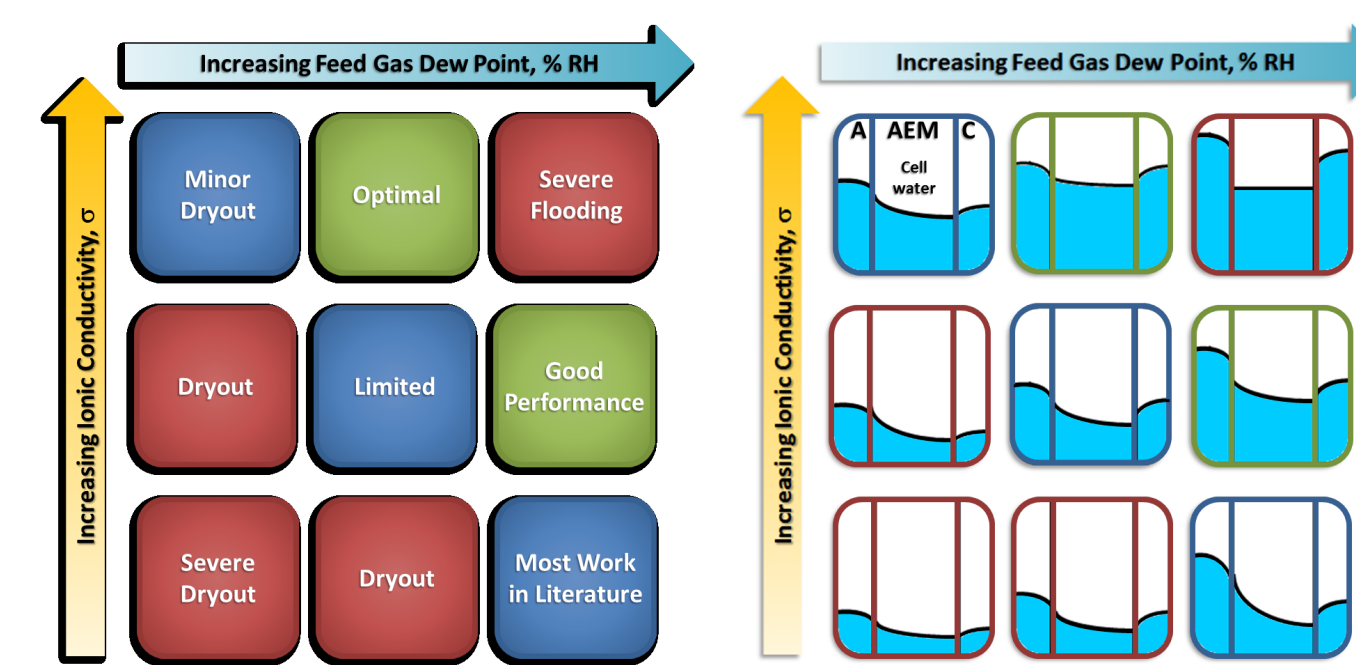
University Partners

ELECTRODE DESIGN AND OPERATIONAL CONDITIONS



Using ionomers and AEMs from Georgia Tech with catalysts provided by Pajarito Powder

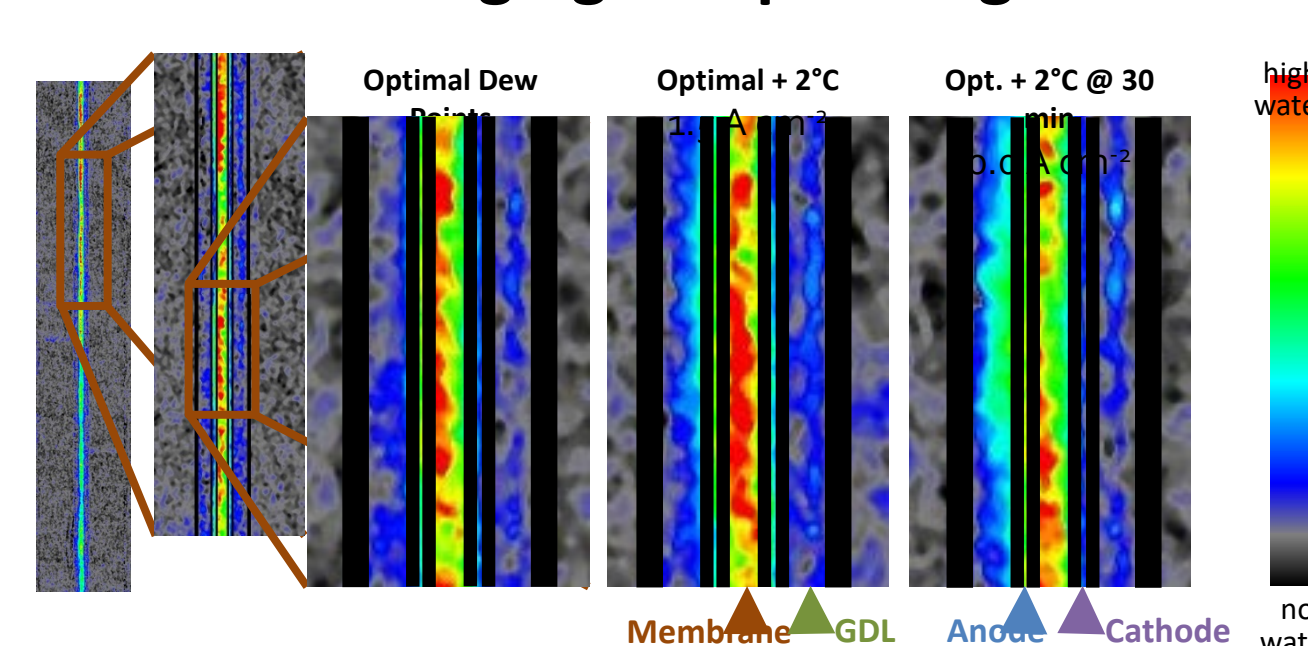
- Provide a standard baseline MEA configuration and production method
- Develop a design of experiments matrix for the relative amounts of ionomer:catalyst:PTFE in each electrode
- Understand and optimize water balance in LTE configuration



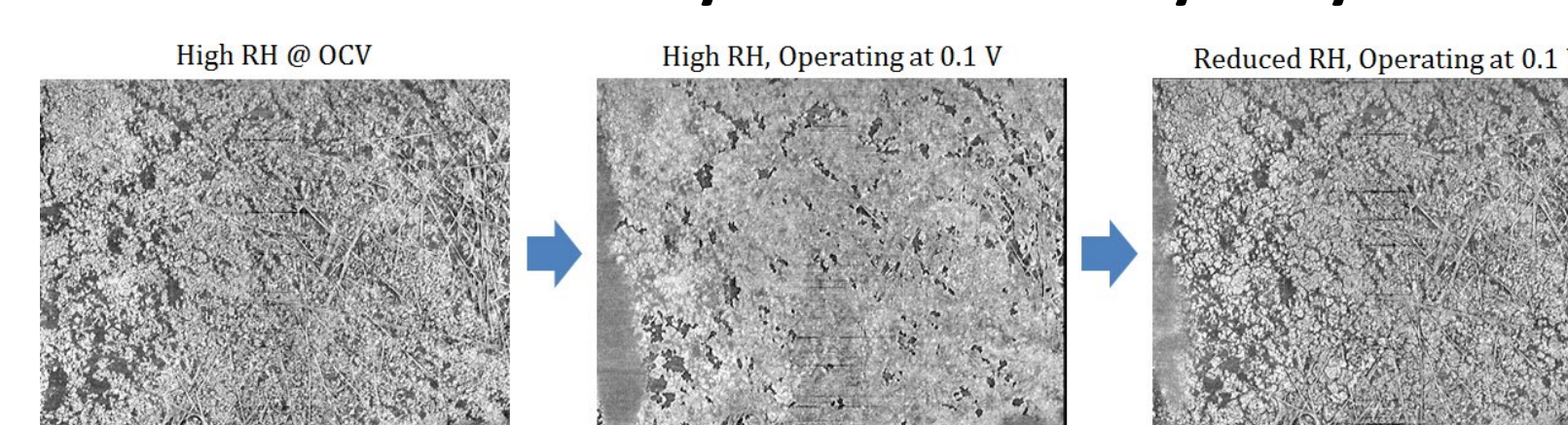
Importance of water balance in AEMFCs

- Essential for achieving extremely high peak power densities in fuel cell mode (3.5 W/cm²)
- 6 H₂O molecule swing (per reacting O₂) between the Anode and Cathode
- 3x more than PEMFC
- Even more severe when considering electro-osmotic drag (up to 38 H₂O/O₂)

Neutron Imaging of Operating AEMFCs



Water sensitivity in anode catalyst layer



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

Polymer	Cross-linker %	OH Conductivity (mS/cm)		IEC, meq/g	IEC, meq/g	σ /IEC	Ionic ASR (Ohm-cm ²)	%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

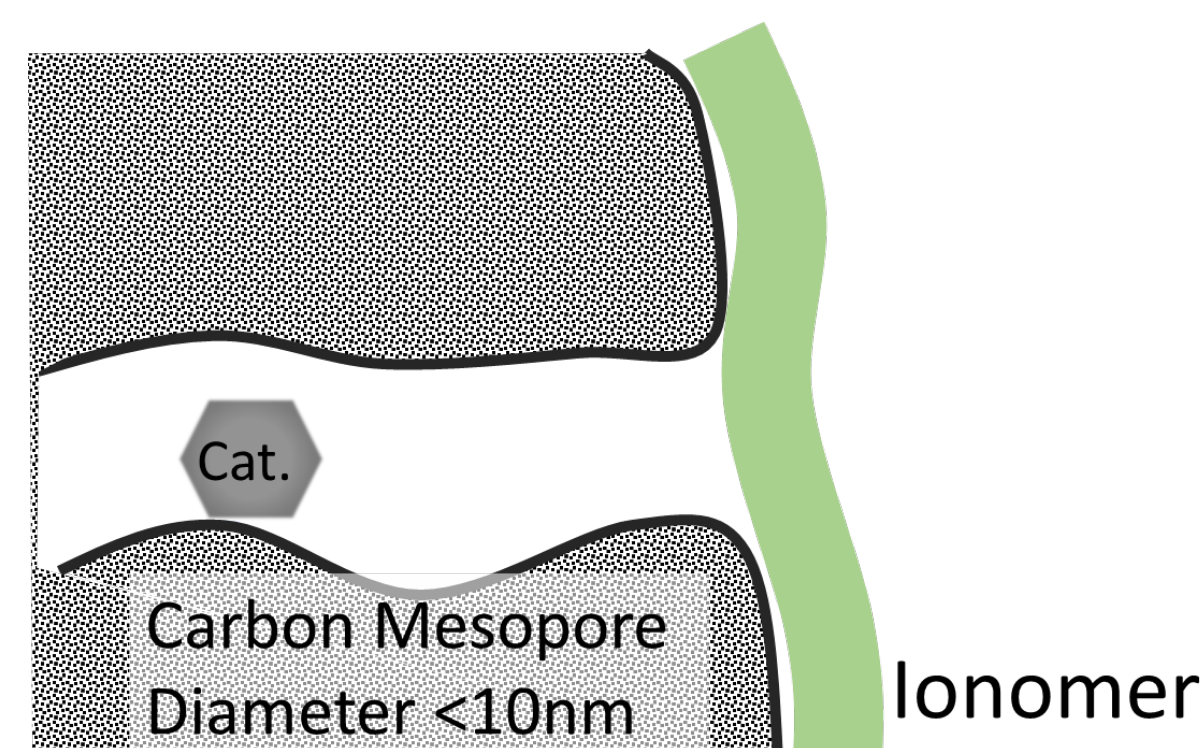
- IEC values approaching 4 meq/g can be made and used without significant penalties: (i) mobility or (ii) water uptake.
- % Water uptake must be viewed considering hydration number and mobility. Free vs bound water must be optimized for efficient electrolysis

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OPERATIONAL EVALUATION AND SCALE-UP

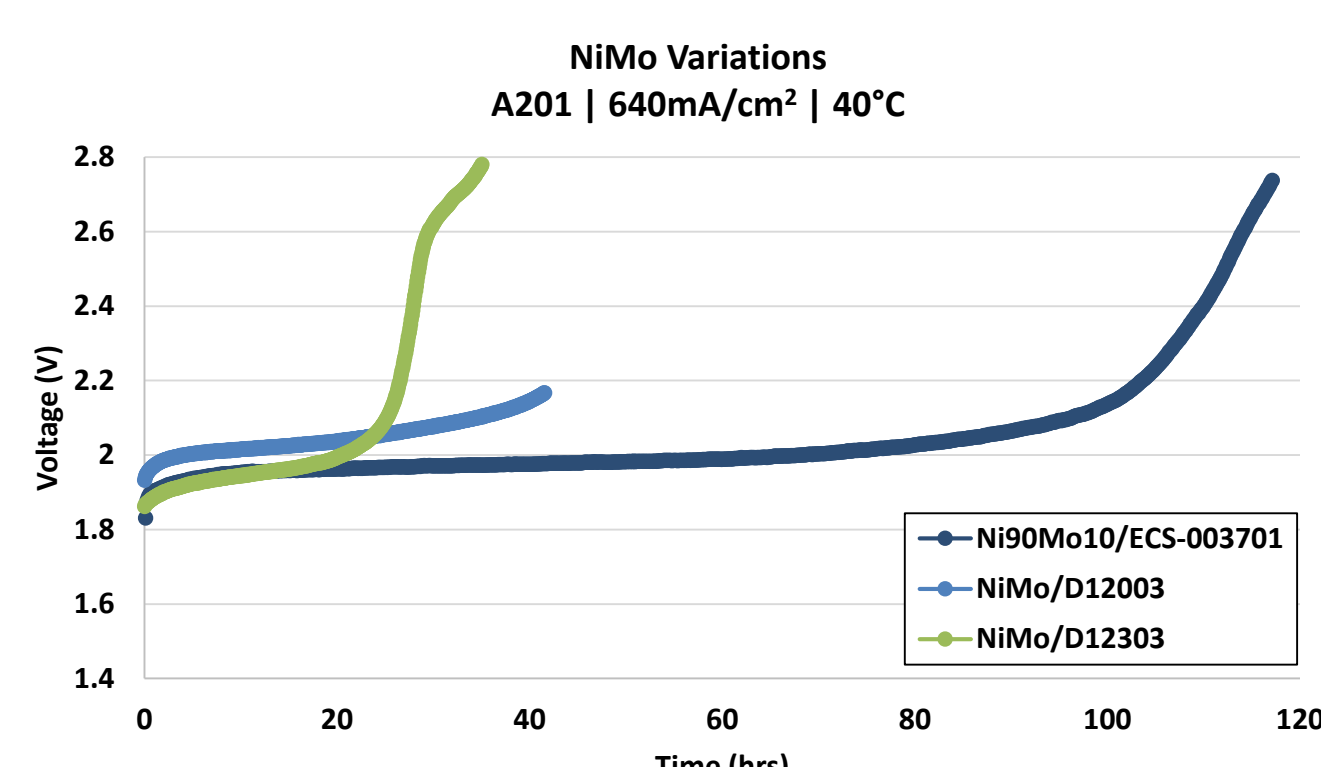


PGM AND PGM-FREE CATALYST DEVELOPMENT

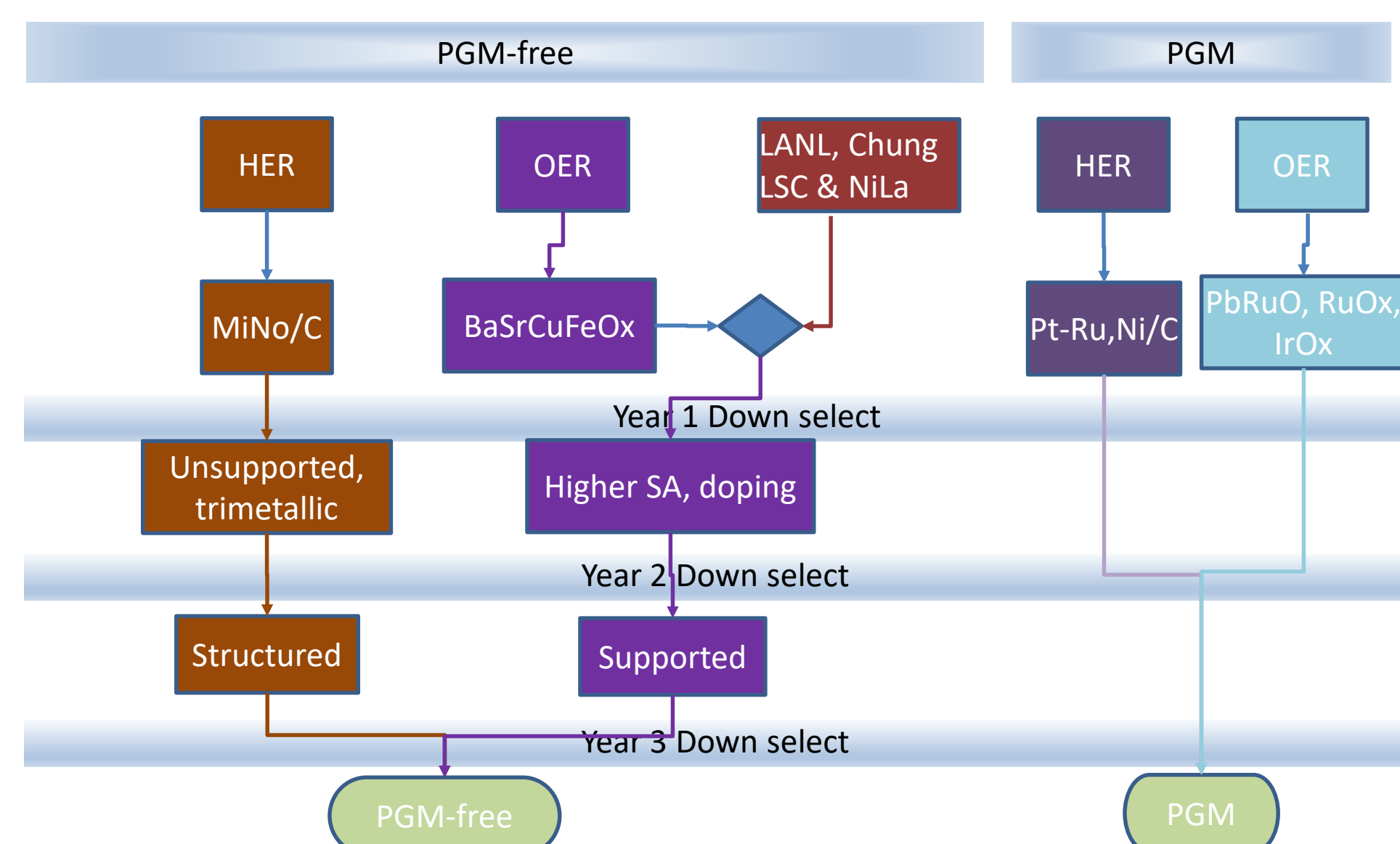


Mesoporous Support Concept

- 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

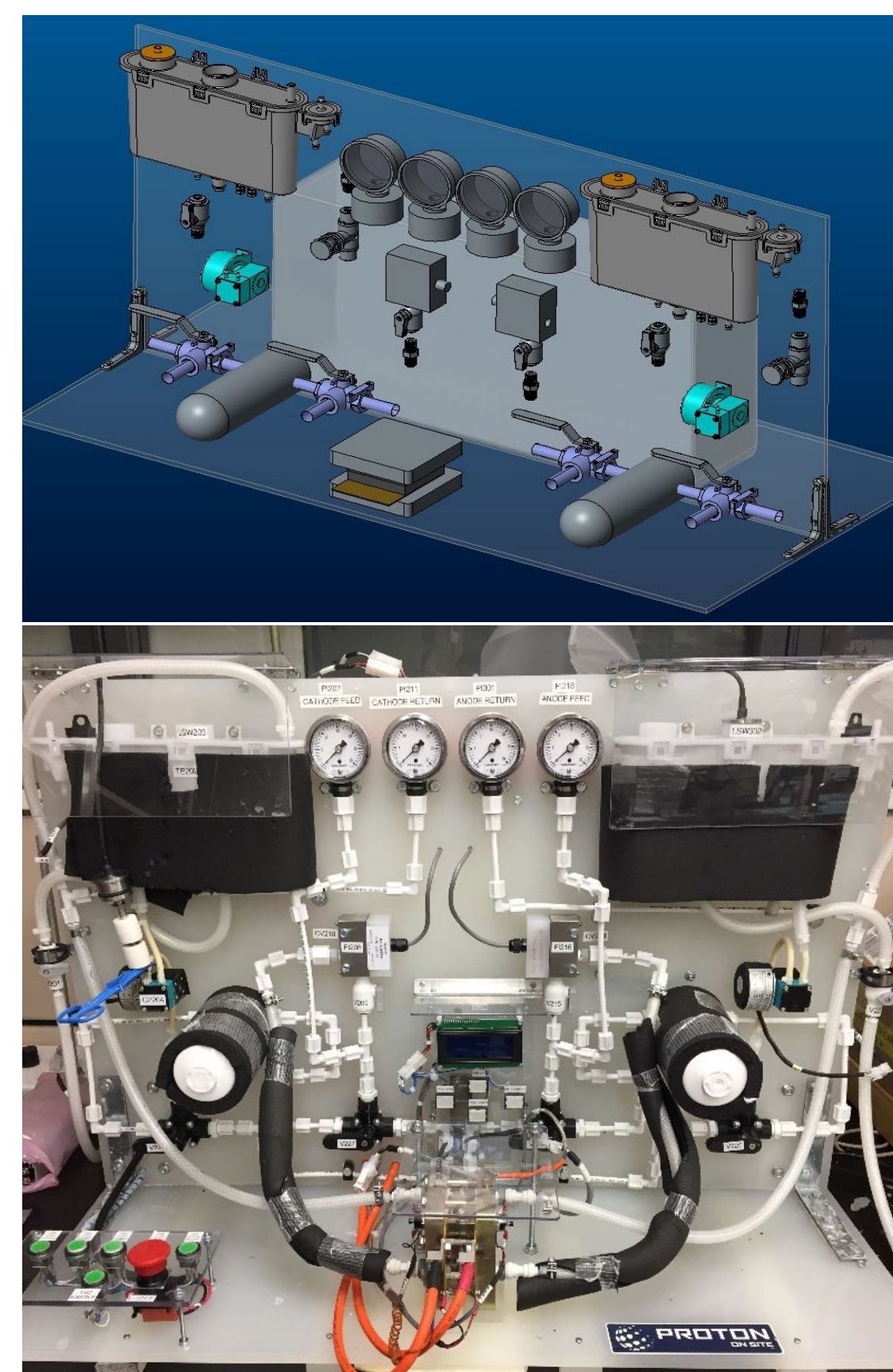


Oxygen Evolution Reaction (OER)

- 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



Using a standard test cell, Nel will collect nitrogen permeation measurements

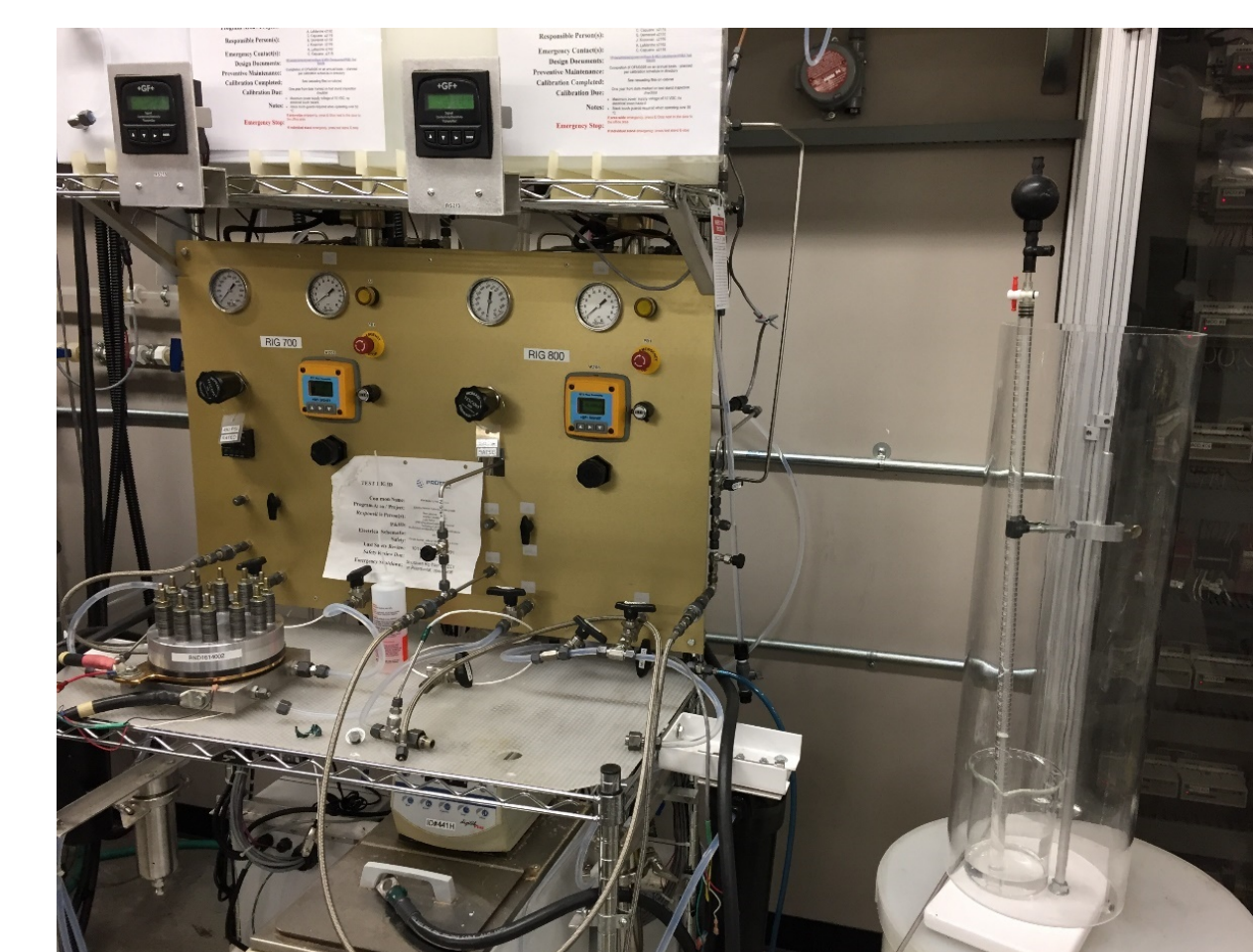
- Incremental measurements in 1-2 bar steps
- Non-linear response indicates a leak

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

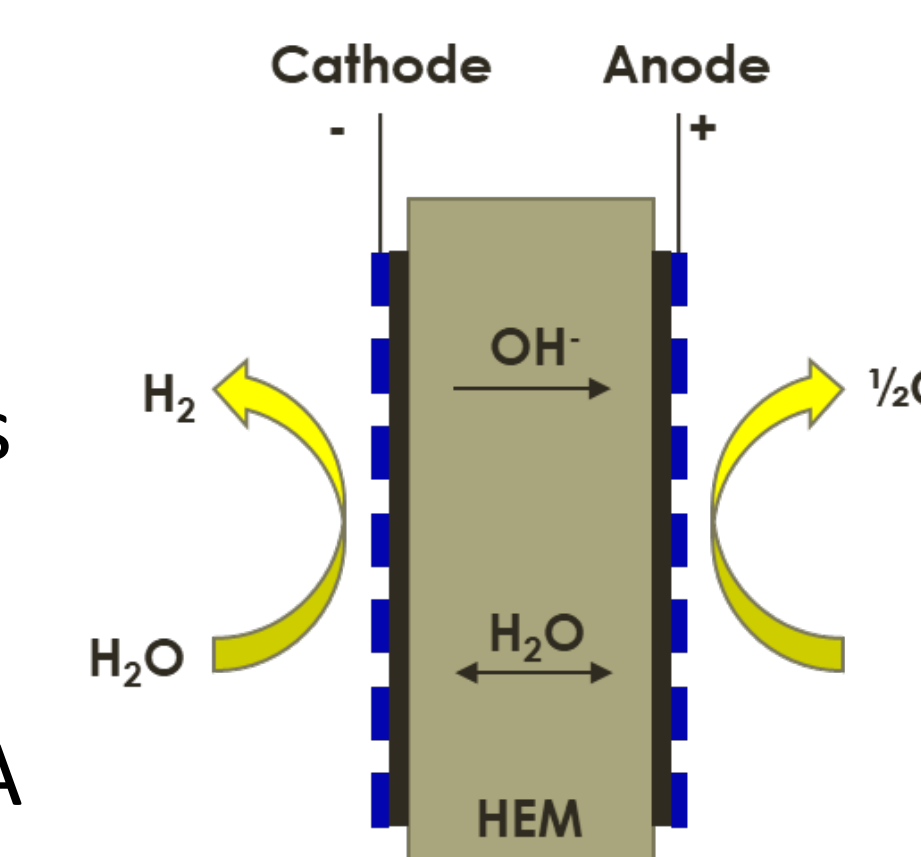
Test stand available purely for AEM tests

- Automatic data acquisition enabled
- Can supply water to both the anode and cathode
- Temperature control



Project Goals

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



Metrics

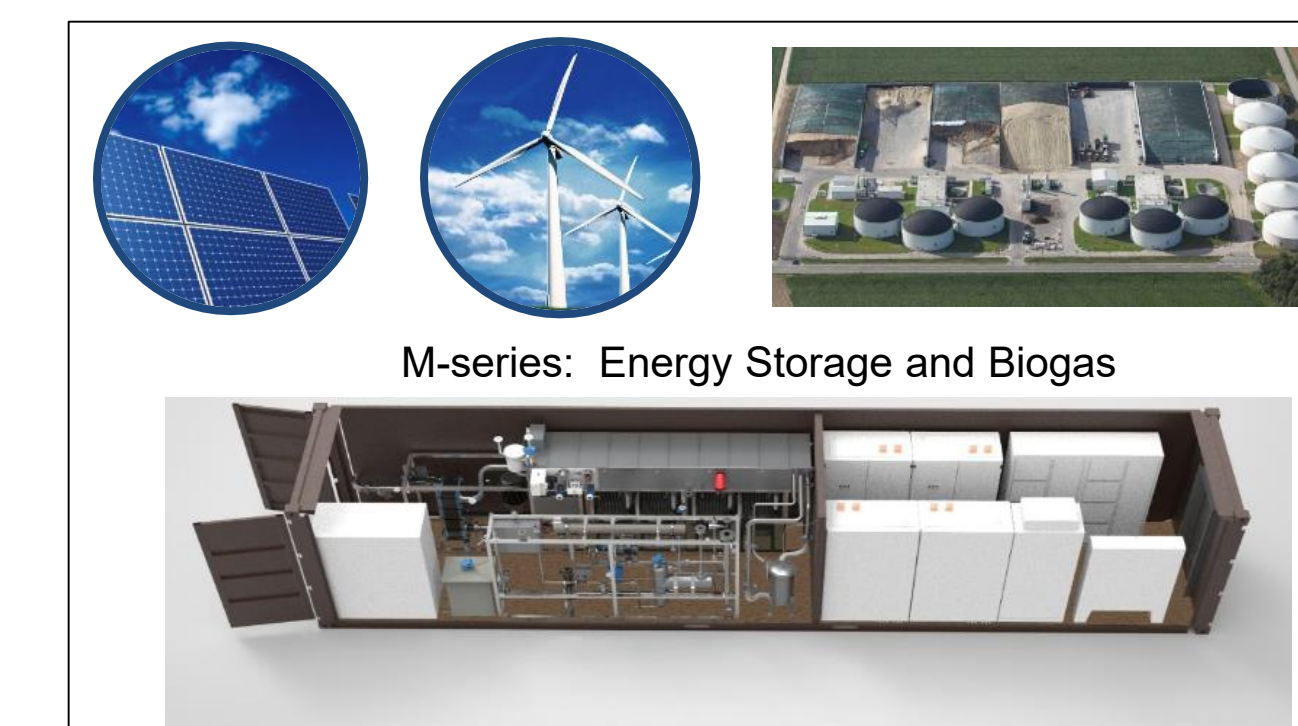
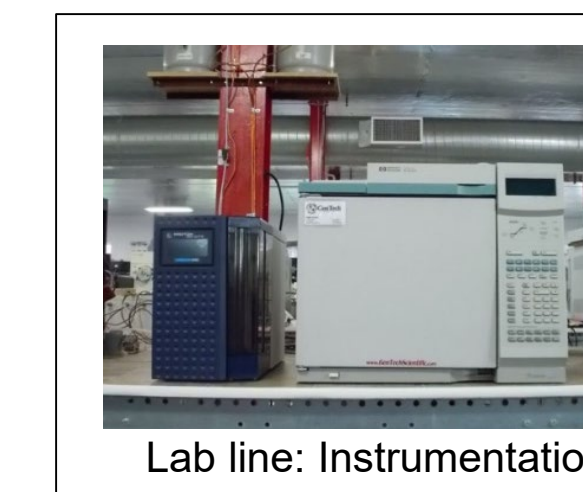
Performance:
43 kWh/kg-H₂
(i.e. 1.6 V electrolysis at 100% coulombic efficiency),

Durability:
4 mV/1000 h degradation

Cost: \$2/gge

Electrolysis Markets

Nel has scalable platforms for identified markets



Successfully maintaining sustainability and profitability