Advanced Water-Splitting Technology Pathways Benchmarking & Protocols Workshop

Breakout Session Summaries
Low Temperature Electrolysis (LTE)

May 3 – 4, 2022

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LTE Breakout Sessions

Session ID	Topic	Lead
L1-A	Priority Research Opportunities - Membrane, Catalyst	Andrew Motz (Nel Hydrogen)
L1-B	Priority Research Opportunities - Components, Stack	Guido Bender (NREL)
L2-A	LTE (PEMs) Protocols Published to Date and Plans for Validation	Huyen Dinh (NREL)
L2-B	LTE (AWEs and KOH-AEMs) Protocols Published to Date and Plans for Validation	Paul Kempler (U of Oregon)
L4-A	LTE (PEMWEs) Protocols to be Written	Mukund Mukundan (LANL)
L4-B	LTE (AWEs inc. KOH-AEM) Protocols to be Written	Shannon Boettcher (U of Oregon)
L5-A	AEMWEs vs. AWEs (electrocatalysis + polymer chemistry under KOH)	Baar Zulevi (Pajarito Powder)
L5-B	PEMFCs x PEMWEs (synergy towards URFCs)	Chris Capuano (Nel)
L6-A	Wrap-up/Action Item Assignment: LTE Membrane, Catalysts	Ahmet Kusoglu (LBNL)
L6-B	Wrap-up/Action Item Assignment: LTE Components, Stacks	Brian Pivovar (NREL)

Session Summary

Session ID: L1-A
Title: Priority Research Opportunities: Membranes, Catalyst

- Summary of discussion

1. Membrane: What membrane should be used as standard reference for PEMWE?
2. Membrane: What are priority improvements needed for AEMs?
3. Catalyst: High value approaches to maximize Ir usage?
4. Catalyst: OER catalysts for AEMWEs

- Consensus and/or dissenting opinions

1. Nafion 115 is leading, 113 would be ideal but isn't as available

3. Two promising categories to explore: 1) oxidative- and acid-stable, electronically-conductive support; 2) advanced architectures; target loading 0.4 mg with performance at 2 A cm-2

- Key Take-Aways

1. See consensus 1; still need to try and push toward thinner PEM
2. Need a membrane (AEM) capable of operation in both supporting electrolyte and pure water; needs to sustain 1 A cm-2 for 500h at HydroGEN durability goal; availability and consistency is higher priority over performance (to an extent);
3. See consensus 3; Pt supports may be more viable as Pt costs decrease relative to Ir
4. In supporting electrolyte there are many options, pure water is limiting system; need sufficient electrical conductivity without degrading anode ionomer; is dynamic nature of Ni and Fe systems inherently limiting for MEA geometry? Co3O4 works well in DI – how to address geopolitical concerns?

Session Summary

Research priorities for components and stacks:

- O_2 side:
  - coatings (low PGM or alternatives),
  - (BOP) contamination during assembly and operation
- H_2 side:
  - hydrogen embrittlement & material choices
- System:
  - (Intermittent) Operating modes - influence on materials, service periods for large plants and overall lifetime
- Reference cell/stack (pressurized operation) is needed

- Overall Consensus on topics from summary
- Discussion about importance of cell voltage monitoring systems
  - Useful for research
  - too costly and not required for field operation

- Understanding how next generation green hydrogen systems are operated is important because operating modes and parameters impact material choice and prize, lifetime and performance

Session Summary

Session ID: L2-A
Title: LTE (PEMs) Published Protocols To-Date & Plans for Validation

- Discussed briefly the 4 LTE protocols that have been submitted or published in Frontiers in Energy journal
- Validation is important & needed to accelerate technology and harmonization
- Discussed who should do the protocol validation, in what timeline, and the drivers for participating in the validation

- Should involve multiple parties, including international institutions
- Start with national labs and industry who have the expertise, equipment, and funding to do this, then expand to universities & other entities
- Need to choose standard materials that are available, reproducible, and may not be the best performing
- Prioritize protocols based on simplicity of protocol, alignment with R&D needs, has existing equipment & expertise to carry out the test in multiple institutions

- Validation success means data from multiple entities are reproducible, accurate (with error bars), relevant, and adopted by the community
- Protocols need to be disseminated quickly so that people can start validate it, help refine it, and adopt it.
- Protocols shouldn't be static. There can be multiple versions but there must be a central control of the versions.
- Publications & citations help widen reach & adoption

- Publish standard protocols
- Prioritize the protocol to validate
- Funding is needed to validate protocols
- Form teams to perform protocol validation and round robin testing
- Create video tutorials for simple procedures (can have wide reach)
- Create hands-on training &/or workshops for complex protocols
- Create validation center to validate promising new materials (labs have very specifics controls like lab environment)

Session Summary

Session ID: L2-B
Title: AWEs and KOH-AEMs: Protocols Published to Date and Plans for Validation Technology

Two protocols discussed for measuring (1) the ion exchange capacity and (2) the alkaline stability of anion exchange membranes, within the context of AWE and KOH-AEMs

AgBr (or Cl) precipitation used for IEC measurement

1 M KOH at 80 C used for stability measurement

Consensus:

- 1 M KOH is a *starting point* for stability in KOH-AEMs and AWE… higher pH and temperature (>80C) needed
- IEC measurement is standard and appropriate

Dissenting:

Some performing in plane measurements in addition to through plane measurements for conductivity of AEM. Most believe not necessary.

- 1 M KOH is not alkaline enough to validate polymer stability for KOH-AEM or AWE applications
- 5M is closer to device conditions for KOH-AEM + AWE
- We need protocols that are effective at “breaking” materials being tested
- Conductivity measurements should specify inert gas purge
- Oxidizing environment necessary for pure water AEM stability (not discussed today)

- Validation of alkaline stability measurements (inclusive of IEC) will be led by U. Oregon M.S. electrochemistry students… NREL agreed (in principle) to participate in validation
- We will recruit relevant AEM manufacturers to participate (none present in breakout)
- Target will be a round robin testing publication of commercially available AEM materials across more aggressive pH + temperature, next year

Session Summary

- Discussion of current protocols, harmonization efforts, cell conditioning, common material sets and advanced diagnostics to monitor cell health

- Catalyst dissolution is not a problem during normal operation
- Membrane mechanical failure is key failure mechanism to focus in

- There is a need for durability protocols that represent real world degradation mechanisms.
- There is a need for advanced diagnostics that can monitor the state of health of a cell

- Work towards a protocol that can evaluate Membrane mechanical failure
- Work towards a protocol that can capture catalyst degradation during shutdown and start up.

Session Summary

- Goal: increase data transparency, create operating guidelines for the field.
- How to set
  - Protocol
  - Targets and roadmap
  - Baseline and guideline

- All topics had consensus among all participants.

- DI guidelines need to be set
  - Break in procedures
  - Demonstration of data accuracy (Short checks)
- Guidelines for supporting electrolyte should be the same as in DI water but more aggressive.

- Documents must be written to develop a multigroup base line
- Determine targets for DI and supporting electrolyte
- Guidelines to allow the introduction of new work must be developed.

Session Summary

Session ID: L5-A

Title: AEMWE vs AWE

- Are degradation mechanisms similar across DI, 0.1-7M KOH, Carbonate?
- What are differences between DI, “supported” and alkaline operations?
- What are critical components?
- Are existing protocols sufficient?

- Community discussions were largely in agreement, few if any dissentions. Discussion was open rather than controversial
- Assumption on similarity in systems is unproven
- Use of carbonate versus KOH was discussed
- What are key issues? Stability, cross over, mechanical

- Systems containing KOH may have similar degradation mechanisms
  - 0.1-1M AEMWE , 5-7 for AWE
  - Compatibility issues unknown
- Protocols for AEMWE are relevant but need to be refined
- Additional protocols needed
  - Mechanical properties of membranes
  - Ionomer properties
  - Separator properties

- Determine operating conditions for technologies
- Examine existing protocols and how to change for different technologies
- U Oregon to suggest separator properties needs

Session Summary

- Likely some protocols can translate between FC and WE
- Switching protocols/parameters need to be established for both component and device testing
- Need for standardization of duration and power for each mode of operation
- Understanding degradation effects on membrane resulting from switching effects

- All topics were in agreement

- Common approach to determining roundtrip efficiency is not available
- Understanding end-use application will help to determine what test protocols would look like
  - Duration and power in each mode
  - When to operate each mode
- What break-in procedure (conditioning) needs to be applied before test
- FC and WE use different methods
- Bi-functional catalyst is the biggest gate to enabling technology

- Identify what components from the FC and WE can be translated to URFC
  - Which components need development for this integrated device
- Identify how test systems can be made available

Session Summary

What do we need to consider for components and stacks in the AEM space? Topics covered:

- PTL and bipolar plate development needs; compatibility with supporting electrolyte
- Potential for recombination layers?
- Operation method (wet/wet vs wet dry; water vs supporting electrolyte)
- Need for reclaiming catalysts?

- There is a need for standardization but materials aren't developed enough for an agreed reference
- For non-PGM anodes reclaiming catalysts is not necessary; may be worth exploring for cathode if Pt remains standard

- Gas crossover through AEM needs to be understood
  - Recombination catalysts may be a solution but effect on efficiency needs investigation
- PTLs and Bipolar plates; effect of supporting electrolyte – still big blank space that needs understanding
- DI water vs KOH – what are the technology development timelines for each?

- Need a standardized test cell specific for AEM/alkaline environment
  - Should be modular to account for different GDL materials etc.
- Need standard reference AEM materials
- Glossary of terms
  - Can adapt from existing in PEM space
- Standard protocols and procedures