HydroGEN
Advanced Water Splitting Materials

Advanced Water-Splitting Technology Pathways Benchmarking & Protocols Workshop

Breakout Session Summaries
Low Temperature Electrolysis (LTE)

March 2 – 3, 2021

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LTE Breakout Sessions

Session ID	Topic	Lead
LTE-1	LTE Technology Roadmap Review & Discussion- Catalysts	Shannon Boettcher (Univ of Oregon)
LTE-2	Technology Roadmap Review & Discussion- Porous Transport Layer (PTL) Tech	Nemanja Danilovic (LBNL)
LTE-3	Techno-Economic Analysis - LTE	Brian James (Strategic Analysis, Inc)
LTE-5	LTE Cell Test Methods & Reference Cell	Marcelo Carmo (Juelich)
LTE-7	Technology Roadmap Review & Discussion - Membranes	Andrew Motz (Nel Hydrogen)

Session Summary

Session ID: LTE-1

Title: LTE discussion - Catalysts

Summary of discussion

1. Catalysts for PEM and AEM
2. Ionomer needs in catalyst layer
3. How to distinguish catalyst and ionomer contributions to performance in catalyst/ionomer layer
4. Understanding H^+/OH^- concentration control within catalyst/ionomer layer

Consensus and/or dissenting opinions

1. Consensus – Ir and Pt catalysts work for PEM. Direction should be toward lower loadings rather than non-PGM in acid
2. Dissenting opinions – should AEM be compared to PEM or liquid alkaline?

Key Take-Aways

1. Better catalyst dispersion is key to achieving lower loadings
2. The durability of Ir in PEM systems with lower loadings (< 1 mg cm^{-2}) needs to be understood in MEA configuration
3. Need to close gap between AEM performance and durability

Action Items

Session Attendee List

Session ID: LTE-1

Title: LTE discussion - Catalysts

Name	Affiliation
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Tomek Bednarek	
Carolin Klose	
Lillian Hensleigh	
Earl Wagener	Tetramer

Session Summary

Session ID: LTE-2

Title: Porous Transport Layer (PTL) Tech Roadmap

Summary

- Commercially available materials include Bekaert (fiber), Mott (sinter) serve as baseline
  - Performance differences and optimal structures have not been determined. This is what we have based on filtration industry
  - We still don' tknow what the optimal structure might be wrt thickness, porosity, particle size etc
  - The interface between PTL/CL must be thoroughly interrogated
- Materials needed to advance PTLs:
  - Need to have similar performance and durability, mechanical properties, Changes away from Ti PTL materials need to consideration durability, cost to upscale and coating lifetime if applicable
  - Need to understand how low in PGM coating and uniformity can go or replace with PGM-free if equivalent performance and durability
  - For coatings how long does it take to apply and what is the cost of the process in addition to PGM content cost
- The mechanical properties of PTLs are important to withstand compressive forces acting on it and its land/channel support. Need to define the mechanical failure mode and then testing to find the metric to assess.
- The corrosion testing in aqueous environments is more aggressive than in the MEA based on local environment measurements (pH and V)
- MPLs are common in fuel cells but have not been optimized for electrolyzers, nor is there consensus on their ultimate need.
  - MPLs may prove useful for stability of PTLs if thinner PTLs are used
  - They may hinder oxygen removal and water flow too much.

Consensus/Dissenting

- Academia desires more specific design parameters from industry to lead investigation into new/different materials and requirements of the materials in service conditions with proprietary cells
- Researchers could/should create benchmark tests that would measure fundamental properties that are of interest to industry.
  - Mechanical properties
  - Corrosion assessment of coatings
  - Coating uniformity requirements and specs
- More information is still needed in regard to the usefulness of MPLs for electrolysis.
  - Wrt to two phase flow and catalyst layer electronic conductivity, as well as swelling of the membrane/ionomer into PTL

Key Take-aways

- When investigating new materials, the function of the material, durability and cost at scale-up need to be considered.
- We don't know what the ideal PTL structure is that we would want to scale in production (beyond current baseline)
- The mechanical properties of PTLs is just as important as it's other functions as a cell component.
- The usefulness of MPLs is still questionable.
- Differential pressure electrolyzer and un-pressurized system will have different PTL needs

Action Items

1. Determine mechanical property test for PTL
2. Determine corrosion resistance test for PTL and coating
3. Determine two phase flow properties of PTL
4. Determine properties and limitations of PTL/CL interface
5. Determine PTL structure function relationships
6. Determine MPL sturture/function relationship
7. Find alternative PTL materials
8. Find alternative PGM-free coating materials, or minimum required PGM

Session Attendee List

Session ID: LTE-2

Title: Porous Transport Layer (PTL) Tech Roadmap

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Session Attendee List

Session ID: LTE-2

Title: Porous Transport Layer (PTL) Tech Roadmap

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Session Summary

Session ID: LTE-3

Title: LTE TEA Breakout

Summary of discussion

- Questions of current analysis
  - Are fixed oper. costs correct? (PEM should be lower than ALK)
  - Discussion of pressure, thinner membranes, and X-over
- Desire to lowering PGM usage
- Plate coatings: current options
- AEM: durability vs. capex tradeoff
  - What is voltage goal at 1A/cm2 (with Pt vs. non-PGM cathode)

Consensus and/or dissenting opinions

- For base material that will corrode, coatings need to be perfect
- Getting beyond Ir and Ti will be difficult for PEM- thrifting or supporting such materials may allow cost reduction
- May not be able to eliminate PGM. But how low is low-enough?
- Maintain PGM coatings performance while reducing loadings (and thus costs)
- 2V in oxygen rich environment is a big challenge

Key Take-Aways

- Need thinner membrane (but must watch X-over and affect on polarization curve)
- Pt is costly, but most promising to reduce rather than replace with non-PGM
  - Reduce as coating and catalyst
- Ir needs to be reduced 10x
- Decent base case but many unanswered trade-offs:
  - Durability vs. PGM loading
  - Current Density vs. CapEx vs. Efficiency
  - Cheap Electricity vs. Capacity Factor

Action Items

- Explore manufacturing development to drive down costs. (3D printing, molding, etc.)
- Try to learn-from/make-use-of solar industry lessons
- Need to understand durability:
  - impact of alternate/cheaper materials,
- Need to stabilize OER catalyst during on/off cycling (which will be more sensitive to catalyst dissolution at low loadings)

Session Attendee List

Session ID: _LTE-3

Title: LTE TEA Breakout

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Session Summary

Session ID: LTE-5

Title: LTE Cell Test Methods & Reference Cell

- **Summary of Discussion**
- MEA and CCMs
- How should MEAs/CCM be stored?
- Storage depends on the processing and the size.
- Humidity should also be considered as the membranes can/will expand with hydration and if the hydration needs to be controlled this could be a concern.
- There are some industry protocols that exist for “cleaning” MEAs after longer term storage.
- Can or should components be reused?
- Typically this is only done out of necessity.
- EIS measurements should always be taken if reusing components to evaluate the appropriateness of this process.
- Test cells need to work for both performance and degradation experiments, which might warrant research into different cell materials.
- Is there any need to further refine harmonized test protocols for pol. Curves?
- Possibly reverse steps 1 and 2 of the protocol or add a step prior to step 1.
- Step 2 should be reworded as either, optional, relevant or based on manufacturer requirements. Any processing of the membrane done by researchers, such as applying electrodes, could also affect this step.
- Better definition of the acceptable deviation in water flow, temperature and pressure is needed.
- A better definition of when operating conditions reach stability is needed.
- Temperature should be reported as inlet and outlet temperature, rather than just temperature in general.

Session Summary

Session ID: LTE-5

Title: LTE Cell Test Methods & Reference Cell

Key Take-Aways

- The importance of harmonizing:
  - Test protocols
  - Reference components and cells
  - Performance and durability data
- Create trust and allow meaningful comparability of results (apples with apples)
- Aim is to create a simple reference point for data comparison within and outside a given institution
- Current activities (interest) within:
  - DOE (2B, H2New), IEA-Annex30, EU-JRC, DOE
- Importance to keep the continuity of such initiatives and its harmonization

Consensus (C) and/or Dissenting (D) Opinions

- **C-** To adopt the earlier results/experiences within Annex30
- **C-** Further refining of defined protocols important
- **D-** Not clear how valid the information is, since technology is under constant developmemt
- **C-** Agreed that such protocols need to be re-visited after a given period
- **C-** Join forces (H2New + Annex30) to allow continuity and makes use of synergy

Action Items

- Continue discussion in a smaller group (clear reporting information, break-in procedure, flow, EIS)
- Intensify discussion to define the strategy to combine efforts (H2New + Annex 30, and others)
- Definition of common protocol and a reference cell for PEM electrolyzers
- Work on possible MEA alternatives as reference (challenges with ordering E300 from Greenerity)
- Long-term testing and eventually ASTs
- Brainstorm the possibility to start a harmonization of AEM electrolyzers
- List of key names and contact points

Session Attendee List

Session ID: LTE-5

Title: LTE Cell Test Methods & Reference Cell

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Session ID: LTE-5

Title: LTE Cell Test Methods & Reference Cell

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Session Summary PEMWE

Session ID: LTE-7
Title: Technology Roadmap Review & Discussion- Membranes

Summary of discussion

Durability

- Compression and tension in polymers are different processes and have different failure modes
- During testing need to take into account: active area is under different pressure than the area directly under the seal; pressure fluctuates during testing (can lead to membrane puncturing)
- Fluoride leaching not detected when measured at the anode, so the chemical degradation of the membrane is not confirmed. However, leached cations will likely cause damage to the membrane
- Initiative to use thinner membranes to improve cell resistance (thinner membrane = less resistive) can result in lack of durability due to poor mechanical properties. Potential solution: to use reinforced membranes. But: mechanical reinforcement can decrease conductivity
- Going below 50 µm in membrane thickness might improve performance but decrease durability

Characterization

- Tests done ex situ on dry membranes are not relevant. Ex situ tests on hydrated membranes under elevated temperatures are complicated
- H2 crossover rate is assumed to be constant at constant pressure, but some data reports suggest a dependence on current
- H2 sensors get wet during operation and cannot measure H2 levels
- Thinner membranes will result in more H2 crossover

Consensus and/or dissenting opinions

- Does the observed amount of H2 crossover presents a safety concern?
  - ✓Yes it might for thinner membranes
  - ✓No, the bigger concern is cell efficiency loss
- Should we aim for thinner membranes or stick to the current optimal thickness?
  - ✓If performance suffers from reinforcement, no point in using thinner membranes
  - ✓Reinforcement might improve mechanical properties of thinner membranes (same performance as thicker membranes but better durability)

Key Take-Aways

- To achieve performance targets, we should go as thin as possible – we need to investigate performance and durability trades of thinner membranes
  - Mechanical reinforcement trade-offs should be considered
  - 50 µm might be an optimal thickness for the membrane
- H2 permeation will become increasingly important to understand as thinner membranes are used
  - High H2 crossover leads to cell efficiency loss that has to be offset by operating at high current density
- Lack of ex situ and in situ tests for the mechanical properties of membranes (specifically compression tests)

Action Items

- Need to develop thinner, robust, electrolysis specific membranes
- Develop ex-situ testing that is representative of common failure modes
- Understand the phenomena that is causing observed increase in H2 permeation

Summary of discussion

Supporting electrolytes

- improve performance of non-PGM catalysts
- Use of highly concentrated KOH requires hazmat precautions and regular maintenance; leads to membrane degradation through OH- attack or precipitation
- K_2CO_3 is less corrosive than KOH. But: causes pH gradients in the membrane, CO_2 release, and precipitation. pH at the cathode is high even in a dilute electrolyte
- For the purpose of advancing technology might stick to using KOH if cheap H_2 can be produced
- Supporting electrolyte gets access to more active site: better catalyst utilization
- Another strategy to improve non-PGM AEMWE performance: new ionomer/membranes and GDL design
- Increasing the stack number to achieve the performance of PEMWE may not be cost-effective even though each cell stack alone is cheaper in materials than a single PEM stack

Consensus and/or dissenting opinions

- Are shunt currents an issue for the system?
  - ✓ No, system design allows to avoid them at a low cost

Key Take-Aways

- Separation of pure-water systems and systems that use supporting electrolyte: different design principles and considerations
  - Systems with supporting electrolyte are more of a near term technology
- For AEMWE with supporting electrolytes, it is preferred to use dilute electrolyte to avoid related issues
- Some membrane degradation issues might be solved by testing cathode feed
- The investigation into pH gradient in the system is desirable
- There is no AEM equivalent to Nafion in performance and durability

Action Items

- Perform a TEA analysis on Stack cost, durability, and current density (assume voltage parity with current PEM ~1.9 V) to understand the minimum requirements to achieve cost parity.

Session Attendee List

Session ID: LTE-7
Title: Technology Roadmap Review & Discussion- Membranes

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Session Attendee List

Session ID: LTE-7

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