

Benchmarking Advanced Water Splitting Technologies: Best Practices in Materials Characterization

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HydroGEN LTE Questionnaire (Distributed May 2018) Summary of Responses 37 Responses as of November 6, 2018

Background and motivation: We aim to develop standards for benchmarking performance, so comparisons between devices from different research groups can be made in future. In addition to device-specific optimal operating conditions, a community-accepted benchmarking tests developed through this exercise are strongly encouraged to include in publication.

A questionnaire was sent to EMN project leads, National Lab Node Leads, Industry, academic and international experts in the Spring of 2018. The goal of this effort was to collect broad feedback across the water splitting community with a specific target of obtaining at least a 50% response rate from EMN Level 1 Node Leads and Project PI's.

As part of the questionnaire, respondents were asked if they wished to provide feedback to the proposed test framework. Access to the draft framework documents was provided for those interested and they will be able to add comments/edits. Following the collection of feedback, the framework will be reviewed and updated.

The following table illustrates the feedback received to date (November 2018). See attached summary report for detailed feedback.

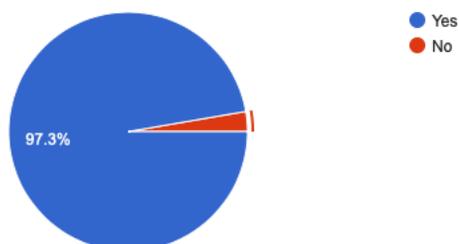
| Affiliation | Sent | Response Rec'd | % Response Rate |
|--------------------|------|----------------|-----------------|
| EMN | 21 | 17 | 81% |
| Domestic (Non EMN) | 33 | 9 | 27% |
| International | 16 | 11 | 69% |
| Total | 70 | 37 | 53% |

Summary of LTE Questionnaire Responses

What standard conditions should we use to benchmark devices for Low Temperature PEM and/or AEM water splitting?

1) Do you think reporting the performance of devices at standard conditions, in addition to "favored" testing conditions, would be useful?

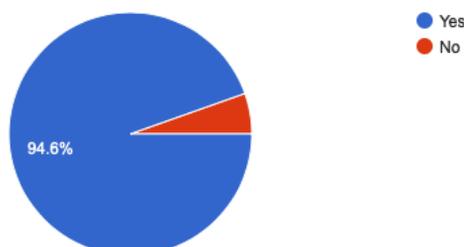
37 responses



- Strong agreement that standard conditions would be useful

2) Would a standardized cell hardware design be useful?

37 responses



Strong agreement that standardized cell hardware would be useful

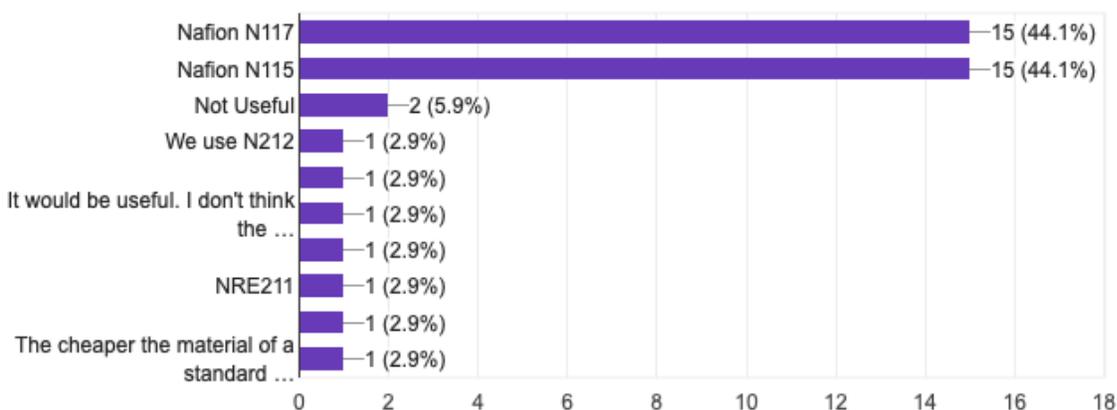
3) Comments and questions that we missed regarding benchmarking conditions?:

- There was a strong consensus that a detailed set of benchmarking conditions would be beneficial for LTE. In addition to standardized test hardware, it is critical to ensure consistency between test labs through clear test protocols and the use of round robin testing.

What Standard Materials Would be the Most Useful?

1) Would standard PEM membranes be useful for testing catalysts? If yes, which would be most useful?

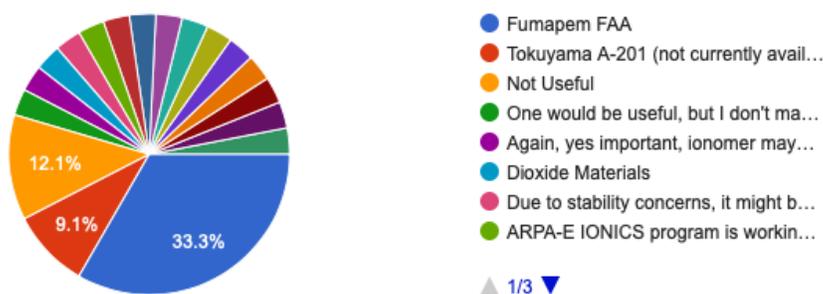
34 responses



- Nafion membrane is preferred for PEM (thickness is TBD)

2) Would standard AEM Membranes be useful for testing catalysts? If yes, which would be most useful?

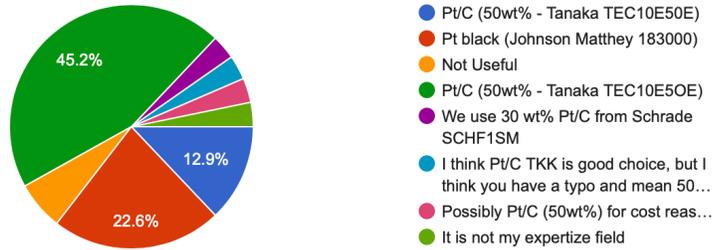
33 responses



- The lack of a commercially available AEM membrane resulted in a wide range of responses. Fumatech Fumapem FAA was the only near-term viable option.

3) Would you find any of these catalysts useful as a standard? 3a) PEM: Hydrogen Evolution Reaction

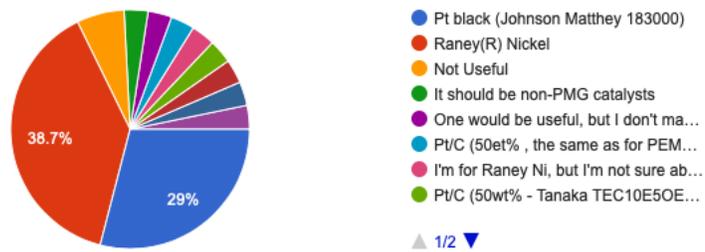
31 responses



- Pt/C (50 weight % Tanaka TEC10E50E) was preferred for PEM HER catalyst

3.b) AEM: Hydrogen Evolution Reaction

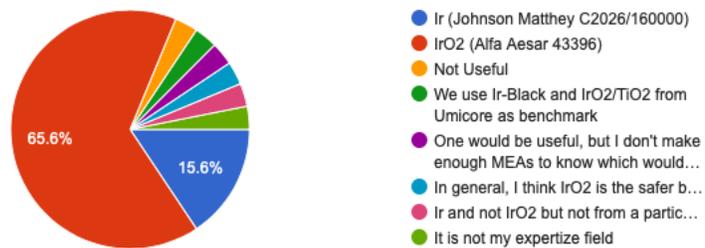
31 responses



- Raney Nickel was preferred for AEM HER catalyst

3.c) PEM: Oxygen Evolution Reaction

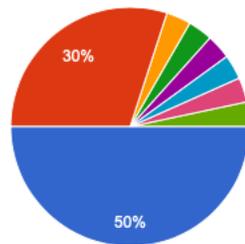
32 responses



- IrO₂ was preferred for PEM OER catalyst

3.d) AEM: Oxygen Evolution Reaction

30 responses

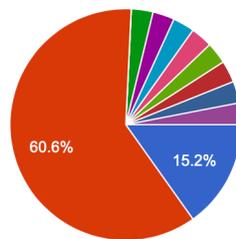


- IrO₂ (Alfa Aesar 43396)
- Raney (R) Nickel
- Not Useful
- It should be non-PMG catalysts
- One would be useful, but I don't make enough MEAs to know which would...
- I think it would be good to have one of these, but again, I'm concerned abo...
- No opinion
- It is not my expertise field

- IrO₂ was preferred for AEM OER catalyst

4) Would you find any of these GAs Diffusion Layers (GDL) useful as a standard? 4.a) Anode Side

33 responses



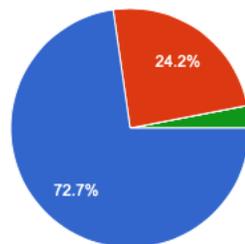
- Carbon Paper
- Porous Titanium Screen
- Not Useful
- Titanium meshes, felts and Ti sinter...
- Tendency to porous titanium screen...
- should be standardized porous Ti s...
- Anode (OER) use platinumized titanium
- A standard PTL material would gen...

▲ 1/2 ▼

- Porous Titanium Screen was preferred for the Anode GDL

4.b) Cathode Side GDL

33 responses



- Carbon Paper
- Porous Titanium Screen
- Not Useful
- Titanium screen, or sinter vs. carbon paper may depend on flow field and pressure operation or not. This needs to be answered in a wider context.

- Carbon Paper was preferred for the Cathode GDL

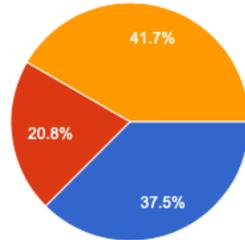
5) Comments and questions that we missed in this topic?: 13 responses

- There was general consensus in material selection. Noted that the standard PTL/GDL may be different for AEM and PEM. Interest in also standardizing bipolar plates and microporous layers.

What Type of Standard Cell Hardware Would be Most Useful?

1. What cell hardware would your lab like to work with?

24 responses

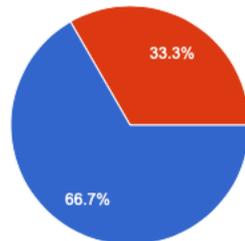


- 25cm2 cell from ISE Fraunhofer Institute https://www.ise.fraunhofer.de/content/dam/ise/en/documents/information-material/Hydrogen-Technologies/17_en_ISE_Flyer_PE...
- 50 cm2 cell from FuelCellStore <http://www.fuelcellstore.com/hydrogen-equipment/hydrogen-production-electrolyzers/electrolyzer-hardware-test-cell-square>
- 25cm2 cell from Proton OnSite

- There was not a clear consensus for standard cell hardware. Agreement that hardware needs to be readily accessible to all at a reasonable cost. Round robin testing will be required to ensure consistent results across labs

2) What is the maximum price range you would be willing to pay for a standard cell? Labs participating in Hy...t other labs could afford (choose one):

27 responses



- \$3,000 - \$5,000 (USD)
- \$5,000 - \$10,000
- More than \$10,000

- There was agreement that hardware cost should be minimized. Comments stressed the need for robust hardware that provides consistent results since labor costs and lost time can become costlier than the hardware CAPEX.

3) What is the price of the current cell your lab uses to test LTE materials and cells? Would it be useful to consider designing cells that would be a competitively priced alternative that labs outside the initiative would purchase?: 27 responses

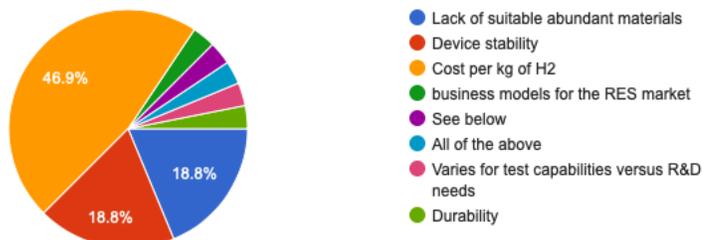
- Costs ranged from \$3,000 - \$10,000

- 4) Other hardware related topics that you would like to suggest, please list.: 14 responses
- Comments included the need to specify a standard PTL and flow field configuration. Stack build instructions must be clear to ensure consistent results. Location of measurements (i.e. temperature) must be clearly specified.

Open Questions

1) What are the most pressing needs/challenges for LTE water splitting?

32 responses



Please elaborate.: 17 responses

- Cost of hydrogen was the overarching response since it covers all aspects of material cost, efficiency and lifetime. After digging deeper, it became clear there was a need to develop a PEM stack construction that contains readily available, low cost materials capable of long term stable operation. AEM was less certain due to the lack of commercially available membranes.

2) What are the critical parameters to calculate and characterize for LTE? List parameters that should be measured during ex-situ and/or in-situ testing.: 24 responses

- Ex-Situ: Catalyst activity, surface area, morphology, membrane conductivity, gas permeability, water transport and mechanical properties
- In-Situ: Cell voltage, current density, temperature and pressure. Efficiency, and lifetime were important at the stack level.

3) How can we accelerate testing of device/component stability?: 25 responses

- Agreement that a common testing platform is important. Operating temperature, current density, water quality and voltage cycling were listed as stressors. Extensive characterization will be required to correlate acceleration factors with real world operation.

4) What techniques/instruments would be the most useful for US National Labs to develop as nodes?: 20 responses

- Comments included XAS, XPS, Raman, HRTEM and neutron imaging for characterization. Accelerated cell testing and characterization was identified as a need for in-situ testing.

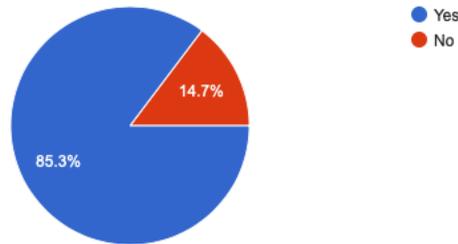
Further Input

1) Comments and/or questions that we missed regarding standards and benchmarking conditions?: 4 responses

- Coordinate with IEA activities to leverage their experience. Clear guidelines must be established for reporting test data to ensure clear comparisons between labs.

2) Would you like to review and provide feedback on the proposed Test Framework? (If yes, you will be sent a... sheet to review and provide feedback)

34 responses



- The majority of respondents were open to providing feedback on the proposed test framework.

Acronyms:

- AEM: Anion Exchange Membrane
- EMN: Energy Materials Network
- GDL: Gas Diffusion Layer
- HER: Hydrogen Evolution Reaction
- IEA: International Energy Agency
- LTE: Low Temperature Electrolysis
- OER: Oxygen Evolution Reaction
- PEM: Proton Exchange Membrane
- PTL: Porous Transport Layer

LTE Questionnaire can be found at:
<https://datahub.h2awsm.org/dataset/lte-questionnaire-summary/resource/16571300-4495-4ff1-8543-5fa1dbf00966>