Energy Materials Network
U.S. Department of Energy

HydroGEN
Advanced Water Splitting Materials

Advanced Water-Splitting Technology Pathways Benchmarking & Protocols Workshop

Breakout Session Summaries
High Temperature Electrolysis

October 24-15, 2018

PROTON ON SITE · Arizona State University · Caltech · Pacific Northwest National Laboratory

HTE Breakout Sessions

Breakout Session #	Session ID	Technology	Topic	Lead
2	H2-A	HTE	Electrolytes: Oxygen and Proton Conductors	Mike Tucker (LBNL)
3	H3-A	HTE	Electrode Activity & Stability	Joseph Barton (FuelCell Energy)
4	H4-A	HTE	Cell Test Protocols	Mark Williams (AECOM)
5	H5-A	HTE	In situ Methods for Degradation Studies	Xingbo Liu (WVU)
6	H6-A	HTE	Stack Testing Protocols	James O'Brien (INL)

Session Summary

Session ID: H2-A
Title: Solid Electrolytes

Summary of discussion

- Lots of different test protocols discussed: materials compositions, cell designs, quality of standard cell fabrication (must be extreme), humidification method, steam conversion, constant current vs voltage.
- PCEC - Faradaic efficiency is often not reported or measured. Important!
- “Standard” cells with same material can be very different.
- Important to measure steam concentration, steam utilisation and if steam-starved (not just give pH_2O,%).
- Electrolyte materials test matrix - Techniques used in combination to find properties

Consensus and/or dissenting opinions

- Important to have benchmark cell and benchmark test. The benchmark results should be obtained in the same test rig.

Key Take-Aways

- Benchmark cell - would be very useful. Ability to buy (from a single manufacturer to ensure consistency) and test in own rig. Cell should come with validation curve and standard test protocol and should have values for all characterisation parameters reported.
- Standard electrolyte material that has to use with own electrode materials - not useful due to materials compatibility issues. BUT option of buying electrolyte from benchmark cell, so can test own electrodes
- Proton vs oxide ion conducting – need separate benchmark (different test apparatus, gas supply, etc)

Action Items

- Oxide ion conducting - 8YSZ as benchmark
- Proton conducting - no benchmark composition at the moment but something that should be worked towards as a priority

Session Summary

Session ID: H3-A
Title: Electrode Activity/Stability

Summary of discussion

- Electrode development is core R&D
- Electrolyte-supported cells with 8YSZ as benchmark; Ni-YSZ is standard fuel electrode; leverage on SOFC expertise and materials
- Air electrode often limits performance; discussed LSM, LSM/YSZ and LSCF. Chose LSCF for benchmarking
- Current collectors – avoid Pt, use Au or perovskite; purchase cell with current collectors and wires
- Symmetrical cell is okay for benchmarking: would be great to have a reference electrode, but likely will introduce additional error

Key Take-Aways

- Many factors are important for electrode standard: accurate raw material composition, fabrication steps, microstructure, particle size, thickness, sintering temperature, porosity: would rather purchase from a manufacturer with a high quality control (>1000 cells for statistical analysis)
- Cell pre-conditioning is as important as testing and will be benchmarked
- Comparison should be performance driven: H2 production (measure by current and by GC)
- Standardizing test and operation condition are critical

Consensus and/or dissenting opinions

- Benchmarking will promote innovation: how to beat (good) benchmarking cell
- All agreed to participate in Round Robin validation
- Accelerating tests are not possible at the moment, as cell is exposed to extreme conditions

Action Items

- How to make Round Robin tests a reality: who pays for validation
- How do we accelerate commercialization: need demonstration (just like SOFCs)

Session Summary

Session ID: H4-A
Title: Cell Test Protocols

Summary of discussion

- Economics: commercialize technology and H2@Scale program
- Leverage as much on the SOFC technology
- Cell will be electrolyte-supported, with Ni-YSZ fuel electrode and LSM or LSCF air electrode; don't bring new materials in benchmarking as it adds new problems
- Testing protocols:
  - is cell size important? Report active electrode area.
  - Discussion on Thermal Management (at >5x5 cell size, heat transport and steam utilization become important).
  - Startup Procedure: Ni reduction step may have significant implications on future cell performance, Open Circuit Voltage to monitor for stability (overnight suggested)
  - Test as SOFC and switch to SOEC
  - What parameters to report? - Current @ constant V, H2 produced (GC), Steam Utilization, Periodic IV curves with reversal into Fuel Cell mode, AC Impedance

Consensus and/or dissenting opinions

- All agreed on the importance of the Benchmark test.
- Our future protocols will be "recommendations", not requirements
- Agreed that thermal management should be ignored in single cell testing.

Key Take-Aways

- Thermal management should be ignored for single cell testing
- Should test @ 800 C and for at least 100 hours
- Ni/YSZ fuel electrode with YSZ electrolyte and GDC blocking layer with LSCF material set chosen for Benchmark test

Action Items

- Prepare GoogleDoc spreadsheet where we can share our Testing Protocols.
- Pursue project for Benchmark cell production/distribution of cells
- H2@Scale webinar on HydroGEN

Session Summary

Session ID: H5-A
Title: In situ Methods

Summary of discussion

- Current focus has been performance driven
- 2 types of degradations: reversible (e.g., ion accumulation) and irreversible (phase separation/formation, microstructure change, mass transport, oxidation species, diffusion)
- Should we operate cell @constant current and monitor voltage or at @constant voltage and monitor current, or it does not matter.
- Faradaic efficiency and energy balance should be calculated
- Not possible to carefully measure H_2 production rate on small O^{2-} conducting cells, but possible on large cells and on any PCEC.
- EIS at a bias current or voltage; deconvolution EIS data; equivalent circuit model
- Should we report ASR degradation rate, rather than V or I. Determine how ASR is calculated.
- Acceleration/stress tests could be misleading

Consensus and/or dissenting opinions

- Higher efficiency in HTE than in LTE
- Higher degradation is seen in SOEC mode than in SOFC mode
- Majority agrees degradation should be measured under either constant current or constant voltage conditions. Minority thinks it should be measured under constant current only.

Key Take-Aways

- In-situ techniques are important to understand fundamental mechanisms and should be part of the consortium.
- EIS should be done under bias/operation conditions
- Nat Lab Nodes can provide capabilities each project cannot afford, such as high pressure, in-operando, scale-up button cell etc.

Action Items

- Sharing the data to help computational modelers to predict life-time
- Revisit the topic later

Session Summary

Session ID: H6-A
Title: Stack Test Protocols

Summary of Discussion

Stack testing introduces additional complications that are not considered when doing button-cell or single-cell testing:

- The repeat unit includes an oxygen-side flow field, oxygen electrode, electrolyte, steam/hydrogen electrode, steam/ hydrogen flow field, and interconnect/separator plate.
- There may be additional flow field/ interconnect coatings and contact layers.
- The stack may be internally or externally manifolded.
- Stack sealing and differential expansion must be considered.
- Stacks often require mechanical compression.
- The heat-up procedure is critically important.

Consensus and/or dissenting opinions

- Stack testing represents a fundamentally more difficult test regime compared to button cell testing.
- Additional considerations include stack operating conditions such as current density, per-cell voltage, steam utilization, constant current or constant voltage operation, hydrogen inlet flow rate, hydrogen recycle, and heat recuperation.

Key Take-Aways

- Large-scale stack testing requires big investment and is done mostly for demonstration purpose, not for R&D
- Short stack testing is most appropriate for the HydroGEN EMN Program
- A standard stack should be developed for testing at multiple locations

Action Items

- Develop standard (reference) short stack and associated test protocols
- Identify funding for the joint effort