Advanced Water-Splitting Technology Pathways Benchmarking & Protocols Workshop

Breakout Session Summaries
Cross Cutting Topics

June 11 – 12, 2024

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Cross Cutting Breakout Sessions

Session ID	Topic	Lead	Note Taker
C4-A	Addressing AWST Benchmarking A+'s: Accessibility, Acceptance, Application, Advancement, Adherence	Karl Gross (H2 Technology Consulting)	Kathy Ayers (Nel Hydrogen)
C4-B	Setting Common Metrics for LTE, HTE, PEC, STCH	Ellen Stechel (ASU)	Sarah Shulda (NREL)-
C4-C	Protocol Validation- Best Practices & Lessons Learned from LTE team	Sarah Park (LANL)	Andrew Boudreau (NREL)
C4-D	Recycling of PEM electrolyzer materials/components and a look ahead for other water splitting technologies	Shuang Ma Anderson (U of Southern Denmark)	Ai-Lin Chang (NREL)

Summary of discussion

1. ***Accessibility:*** How to make the community aware of and able to easily access benchmarking publications, measurement protocols, lessons learned, standard measurement results ….
2. ***Acceptance:*** How to best gain community wide agreement on measurement protocols and reporting.
3. ***Application:*** How to encourage community wide use of measurement protocols, validation testing, and best-practices.
4. ***Advancement:*** What are approaches to improve and accelerate benchmarking work including protocol development, protocol testing and improvement, validation testing, standards (with data sets) for testing measurement equipment, procedures, and analysis….
5. ***Adherence:*** How to best address adherence to accepted best-practices and the validity of exciting new results.

Consensus and/or dissenting opinions

1. ***Accessibility:***
   - Can we connect to AICHE e.g. For help with maintenance.
   - Email the links to the group that posts all standard protocols?
2. ***Acceptance:***
   - Feedback mechanism to project/writers - could be website based
   - Should the protocols have a template log sheet? To ensure the relevant info is collected.
3. ***Application:***
   - Technical committee connected to ASTM.
4. ***Advancement:***
   - Safety is a key topic to consider especially for low TRL areas - how do we integrate this philosophy
5. ***Adherence:***
   - Can EPRI help with international representation?

Key Take-Aways

1. ***Accessibility:*** Protocols hard to find and not easily accessible.
   - "Marketing" needed - maybe newsletter?
2. ***Acceptance:*** There needs to be a way for users to provide feedback on issues with or improvements to protocols they use.
3. ***Application:*** Again, without knowledge of the existence of these protocols they will not be used.
   - Parallel to codes and standards - these are updated online.
4. ***Advancement:***
   - Need to pitch the long view to academia - faster training of grad students means more papers
   - Getting journals to publish round robins and professors to value doing the work
   - EPA analogy where labs are certified for validation
5. ***Adherence:***
   - Better ways of referencing - shows up as an author in a citation - maybe put "cite as"

Action Items

1. ***Accessibility:***
   - Create a website for these protocols - who would maintain?
   - Create an email list to receive all new updated protocols.
2. ***Acceptance:***
   - How to connect to IEA and other orgs to ensure synergy.
3. ***Application:***
   - Another kickoff with new projects including Benchmarking team.
   - Need a reference results/data for each type of measurement.
4. ***Advancement:***
   - Leverage National Labs for repository materials (e.g. roll to roll).
5. ***Adherence:***
   - Leverage H2New for LTE/HTE - use as example for others.
   - Reporting results of use of a standard as internal validation motivates the use of protocols and standards.
   - Round robin testing where possible.

Session Attendee List

Session ID: C4-A
Title: Addressing AWST Benchmarking A+'s: Accessibility, Acceptance, Application, Advancement, Adherence

Name	Affiliation
Elias Pomeroy	DOE
Nick Kane	INL
Seraphim Belko	PNNL
Balasubramanian Lakshmanan	Versogen
Siari Sosa	Southern California Gas
Xiaohan Ma	Yale
Katherine Ayers	Nel Hydrogen
Karl Gross	H2 Technology Consulting LLC

Session Summary

Session ID: C4-B
Title: Setting Common Metrics for LTE, HTE, PEC, STCH

Summary of discussion

- Current metrics are specific to technologies and not relevant across different technologies.
- Goal: Establish a common set of metrics (4-5) applicable to all pathways.
- Motivation: Aid DOE and customers in understanding pros and cons, drive towards a dollar/kg metric, and demonstrate the value of diverse pathways.
- Specific metrics discussed:
  - H2 metrics: Low and high pressure, low and high purity (e.g., 99.999% vs. 99.6% purity, 30 bar vs. atmospheric pressure).
  - Energy input comparison: kWh/kg with consideration for technology differences.
  - Power density: Mass footprint and volume considerations, conversion factors for reporting.

Consensus/Dissenting Opinions

Consensus:

- Common H_2 metrics for purity and pressure levels.
- Bar chart for showing solar, electricity, and heat inputs
- Power density to be reported with clear conversion factors (ΔG^0, HHV, LHV).

Dissenting Opinions:

- kWh input comparison may unfairly disadvantage solar technologies when compared to electricity-based technologies.
- Debate on how to fairly compare exergy between solar and electricity-based technologies.

Key Take-Aways

- Establishing common metrics is crucial for cross-technology evaluation.
- Agreed upon metrics for hydrogen purity and pressure levels.
- Use kWh/kg for energy input with clear understanding of its limitations.
- Importance of reporting power density with explicit conversion factors.
- Need for a visual representation (e.g., bar chart) for energy input comparisons.

Action Items

- Finalize the set of common metrics (4-5) for all pathways.
- Develop a methodology for comparing kWh input across different technologies and inputs
- Create guidelines for reporting power density with specified conversion factors.
- Design and circulate a bar chart template for visualizing energy input comparisons.
- Address unresolved issues around exergy comparisons in future discussions.

Session Attendee List

Name	Affiliation
Aadarsh	CSM
Aaron Overacker	SNL
Ari Klauser	SNL
Elias Pomeroy	DOE
Eric Coker	SNL
Flavio da Cruz	SoCalGas
Huyen Dinh	NREL
Jeremy Hartvigsen	INL
Jim Miller	ASU
Kai Outlaw-Spruell	UH
Kat Rinaldi	DOE
Keith King	SNL
Kiram Adepalli	Nexceris
Long Le	PNNL

Session Attendee List

Session ID: C4-B
Title: Setting Common Metrics for LTE, HTE, PEC, STCH

Name	Affiliation
Matt Whitman	SNL
Michael Sanders	CSM
Nick Strange (session secondary scribe)	SLAC
Sarafina Fortiner	NEL
Sarah Shulda (session primary scribe)	NREL
Sean Bishop	SNL
Tadashi Ogitsu	LLNL
Todd Deutsch	NREL
Tyra Douglas	SNL

Session Summary

Session ID: C4-C

Title: LTE protocol validation

Summary of discussion

- All validation is volunteer effort, challenging to locate labs with resources and interest to participate
- Acquiring samples can be challenging, distributing same batch of materials at the same time can be difficult and time consuming
- Accessibility has been limited for protocols, continue to promote usage and citation

Consensus and/or dissenting opinions

- Incentive needs to be provided for participating in validation as well as using the protocols
- Protocols need to be generic as possible vs. include details as much as needed
- What range of error should be tolerated using the protocols

Key Take-Aways

- To avoid bias/unintended preference, labs that did not participate the protocol writing should be validating the protocols
- It might be advised to cross-correlate samples from different companies for component characterization
- The equipment used for validation process can vary, but proper calibration for each instrument is important for reliability
- Accessibility of protocols needs to be improved

Action Items

- Identify other protocols to be validated
- Try to pair related protocols to be completed together
- Reduce how much work it takes to complete validation
- Encourage community to include testing protocols

Session Attendee List

Session ID: C4-C

Title: LTE protocol validation

Name	Affiliation	Name	Affiliation
Minkyoung Kwak	U of Oregon	Rajib Das	ACS Industries
Joel Ager	LBNL	Shujia Hou	UC Berkeley
Lily Suian	CalTech	Jong-Ho Choi	LANL
Sol A Lee	CalTech	Aaron Kaufman	U of Oregon
Mason Jang	CalTech	Grace Lindquist	Hgen
Anthony Ekennia	U of Oregon	James Vickers	DOE
Su Min Ahn	LANL	CX Xiang	Caltech
George Roberts	Nel Hydrogen	Neal Sulivan	Colorado School of Mines
Rangachary Mukundan	LBNL	Daniel Leonard	LANL
Trent Simonetti	HyAxiom	Zeyu Zhao	INL
Olga Marina	PNNL	Hanping Ding	U of Oklahoma
Sarah Park	LANL		
Andrew Boudreau	NREL		

Summary of discussion

1. What is the estimated lifetime of your H2 technology?
2. What are the major components to be considered for recycling?
3. Has the recycling been implemented for the component?
4. What is your ideal recycling form (open / closed loop) and facility (centralized / decentralized)
5. What is a significant drive for you to recycle the component (legislation, environment, economy)?
6. How will this benefit the green H2 production?

Consensus and/or dissenting opinions

1. Lifetime of various technologies are very different and not fully uniform documentation.
2. In general, all components are interested to be recycled (PEM is more urgent). The priority will probably be based on the value / criticality of the component and recycling cost.
3. IP might be a barrier for material processing.
4. General awareness and knowledge on recycling is at its early stage. Little (for PEM) or no recycling has taken place in US. More effort and attention are needed.
5. A closed loop and de-centralized facility for recycling is preferred

Key Take-Aways

1. We want Recycling rather than Green washing
2. Recycling is beneficial for H2 technologies and can stimulate market growth and sustainability.
3. For PEM, PFAS is an important factor to be considered during recycling.
4. Customized recycling process should be developed to ensure closed loop material flow.
5. H2 technology is still at its early stage with low production quantity, which might be both pro & con for recycling.
6. More political attention and legislation should be in place to intensify recycling

Action Items

1. Consider to estimate / calculate potential economic, technical and social gain from recycling of key components in “your” H2 technology.
2. Invite politician / policy maker in the discussion
3. Start to recycle

Session Attendee List

Session ID: C4-D
Title: Recycling of PEM electrolyzer materials/components and a look ahead for other water splitting technologies

Name	Affiliation
Honghao Liu	UC Irvine
Chris Topping	Tetramer
Bradley Layne	UC Irvine
Earl Wagener	Tetramer
Joel Haber	Caltech
Shaun Alia	NREL
Tyler Hafen	OxEon Energy
Emily Volk	Mines/NREL
Nick Oliveira	Nel Hydrogen
Michaela Burke Stevens	SLAC
Ethan Simonoff	SoCalGas
Melissa Kreider	NREL
Chris Coyle	PNNL
Isabela Rios Amador	Stanford University/SLAC
Duha Syar	UC Berkeley
Ai-Lin Chan	NREL
Xingbo Liu	West Virginia University
Haoran Yu	ORNL
Shuang Ma Andersen	U. Southern Denmark