

Advanced Water-Splitting Technology Pathways Benchmarking & Protocols Workshop

Breakout Session Summaries *High Temperature Electrolysis (HTE)*

September 21-22, 2023

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HTE Breakout Sessions

Session ID	Topic	Lead	Note Taker
H1	Priority Research Opportunities - Materials, Components	Xingbo Liu (WVU)	Long Le (PNNL)
H2	Cell/Stack Testing Hardware and Standards	Scott Swartz (Nexceris)	Nicholas Kane (INL)
H3	HTE Protocols to be Written	Neal Sullivan (CSM)	Renaldo Springer (PNNL)
H4	Coordination of HTE Protocol Adaption	Mike Tucker (LBNL)	Kiran Adepalli (Nexceris)
H5	HTE Protocol Validation Plans	Kevin Huang (Un. of South Carolina)	Joshua Gomez (INL)

Summary of discussion

- Revise HTE Roadmap to meet DOE's goal
- Validation center can be beneficial for both industry and academia
- Degradation is still a major concern
- Need to shift research dynamic from materials development to scale-up and assembly
- Recycling of materials

Consensus and/or dissenting opinions

- Determine testing conditions: compromise between performance and stability
- What is end-of-life
- Contact and sealing are also a high-priority area
- Barrier layer is important (prevent chemical reaction and interfacial degradation)

Key Take-Aways

- Industry must provide industrial pull and leadership for the research to help academia identify real problems
- Develop systematic approaches to expand R&D to large-scale cell assembly/testing and understanding stack issues
- Lack of independent suppliers for reference cells/stacks/equipment for benchmarking baseline conditions

Action Items

- Identify supply chains for reliable sources for reference materials and reference cells
- Foster the culture of reporting unsuccessful experiments, failed tests, and the number of reproduced data points
- Include air/steam quality data
- Update Roadmap

Session Attendee List

Session ID: H1

Title: Priority Research Opportunities

Name	Affiliation	Name	Affiliation
Xingbo Liu	WVU	Hanping Ding	Oklahoma Univ.
Long Le	PNNL	Joshua Gomez	INL
Olga Marina	PNNL	Wei Wu	INL
Kevin Huang	USC	Renaldo Springer	PNNL
Xinfang Jin	UML	Juliia Kukula	ASU
Neal Sullivan	CSM	Tyler Hafen	OxEon
Chuangcheng Duan	KSU		
Zheyn Luo	Caltech		
Nicholas Kane	INL		
Kiran Adepalli	Nexceris		
Scott Swartz	Nexceris		
Xiao-Dong Zhou	UCONN		

Summary of discussion

Data/results variations come from:

- Potentiostatic vs galvanostatic mode
- Different test locations (different labs)
- Steam generation differences
- Oxygen electrode size or full cell size used to determine the area
- People will cheat a protocol if it makes their data look better – protocols need enforced by program managers
- PV sent around black box to calibrate lab setups
- Calibration procedures needed for EIS, furnace temps, dummy cells
- Materials research on button cells or finished stacks w/o fundamental research
- Need large area cells to bridge gap

Consensus and/or dissenting opinions

- Large variety in cell fixtures, protocols
- More work is needed to bridge button cells to stacks – testing large area planar cells

Key Take-Aways

- Currently no universal test fixtures, stack components available
- Need defined cell size and cell/electrode ratio
- Contact layer is very important but unresolved

Action Items

Needed Protocols:

- H2 Production Rate
- Cell/Stack Leak Test
- ECR (Electrical Conductivity Relaxation)
- Good protocol for 5cm x 5cm Cells (review Nexceris')
- Steam Generation Protocol

Session Attendee List

Session ID: H2
Title: Cell/Stack Testing Hardware and Standards

Name	Affiliation	Name	Affiliation
Olga Marina	PNNL	Hanping Ding	Oklahoma Univ.
Scott Swartz	Nexceris	Joshua Gomez	INL
Renaldo Springer	PNNL	Kiran Adepalli	Nexceris
Kevin Huang	USC	Zheyin Luo	Caltech
Xinfang Jin	UML	Xiao-Dong Zhou	UCONN
Phill Parilla	NREL	Tyler Hafen	OxEon
James Vickers	DOE	Xingbo Liu	WVU
David Ginley	NREL	Long Le	PNNL
Chuangcheng Duan	KSU	Neal Sullivan	CSM
Wei Wu	INL		

Summary

- HTE protocols are of great need when it comes to intra-laboratory comparison
- Consultation and collaboration with industry would be extremely valuable when drafting new protocols
- The development of a national lab testing hub would be of great value for validation and collaboration with academia and industrial developers
- Define / adopt stack-level metrics

Consensus and/or dissenting opinions

- A standard cell size and choice of current collector material for button cell testing needs to be established and agreed upon.
- Leak testing protocols need to be established
- Steam delivery protocol must also be established
- New protocols should not be overly policed but rather a tool for benchmarking as lack of infrastructure must be considered
- Protocols to be tested should encourage transparency

Key Take-Aways

- Standardize measurement of hydrogen production and how it is reported
- Standardize the size of both HE and OE for the button cell size and materials used for the current collector
- Create a protocol for leak testing for button cells, and quality of H₂ and O₂ products
- Collaboration between national labs and industry partners will provide great insight into structuring testing protocols
- Encourage the DOE to sponsor university grants for cell validation at national laboratories
- Expand perspective beyond button cell to stack
- Establish “standard cell” of known performance for validation of test stands worldwide

Action Items

- Structure a unanimous (round robin) session with national labs involved in HTE technology development to determine their recommendations towards button cell size and material of choice
- Work with DOE to encourage funding behind standardized university cell testing at national labs for validation
- Craft stack-level performance metrics and first-draft protocol
- When reviewing manuscripts, press authors to cite Frontiers papers regarding protocols
- Market “standard” cell for validating test stands ⁷

Session Action Item Assignments

Session ID: H3

Title: HTE Protocols to be Written

Name	Affiliation	Action Item	Target Due Date
Dr. Long Q. Le	PNNL	Market “standard” cell of known performance for validating test stands around the world	Sept 21, 2024
All	All	When reviewing manuscripts, press authors to cite Frontiers papers regarding protocols	Sept 21, 2024
All	All	Encourage DOE funding for cell testing at national labs for performance validation	Sept 21, 2024
	All	When reviewing manuscripts, press authors to document steam-delivery protocol	Sept 21, 2024
	All	When reviewing manuscripts, press authors to document current collection materials & fabrication protocols	Sept 21, 2024
	All	When reviewing manuscripts, press authors to document leak-testing protocols	Sept 21, 2024
Dr. Joshua Gomez	INL	Craft stack-level performance metrics and first-draft testing protocol	Sept 21, 2024
Dr. Olga Marina	PNNL	Develop national lab testing hub to validate cell performance	Sept 21, 2024
Dr. Olga Marina	PNNL	Structure round-robin session with national labs to define standard cell size and materials	Sept 21, 2024

Session Attendee List

Session ID: H3

Title: HTE Protocols to be Written

Name	Affiliation	Name	Affiliation
Olga Marina	PNNL	Hanping Ding	Oklahoma Univ.
Scott Swartz	Nexceris	Joshua Gomez	INL
Renaldo Springer	PNNL	Kiran Adepalli	Nexceris
Kevin Huang	USC	Zheyu Luo	Caltech
Xinfang Jin	UML	Xiao-Dong Zhou	UCONN
Tyler Hafen	OxEon	Neal Sullivan	CSM
Xingbo Liu	WVU	Nicholas Kane	INL
Long Le	PNNL		
Chuangcheng Duan	KSU		
Wei Wu	INL		

Session Summary

Session ID: H4

Title: Protocols Adoption

Summary

1. Adoption of protocols is important and the team discussed the topic with guidelines based on Dissemination, Acceptance, Utilization and Lessons Learned
2. It was identified dissemination is possible by creating a community group, sharing protocol information in manuscripts and presentations, actively updating, communicating and round-robin type tests
3. Acceptance of the protocols can be accomplished by validated tests on standards, educating and encouraging and being role-models
4. Utilization can be achieved by websites, hubs, including DOE, journals, universities to accept and possibly require protocols as part of their process
5. We need to share lessons learned, end result of using protocols, changes or deviations from definitions, make the document hub a living document with opportunity to comment and provide feedback

Consensus and/or dissenting opinions

1. Validate the protocols and accept widely.
2. But: who or which lab will validate the protocols?
3. Get funding for Round Robin type tests
4. Who will be included in this activity, DOE, DOD, ARPA-E, California energy?
5. Deposit papers/protocols in ArXiv – opensource with doi, make the work accessible whether it is good or bad result
6. We need standard samples (from company or national labs) for validation
7. Who will initiate it manufacturer or the labs?
8. Can data hubs be accessible internationally?

Key Take-Aways

1. Have an updated SOP and calibration / standards test procedure.
2. Use website, social media, conferences, training videos for young generation
3. Protocols as living document, reviewed and updated at cadence
4. Increase visibility of the protocol and benefit, this will encourage newcomers and veterans to adopt
5. Create a data hub and provide access to labs
6. Include journal editors to provide guidelines to reviewers to adopt certain protocols for comparing data
7. Set a workshop either at major conferences or satellite workshop to exchange and educate good practices and protocols
8. DOE like EIE set minimum protocol requirement on proposals, there needs to be an incentive (funding or benefit) for universities to adopt or change years of practice.

Action Items

1. Make a list of HTE community and inform them at a cadence
2. A survey to send to the community
3. Active participation (lead by example) by reading, using and citing the work
4. Talk to DOE to engage protocols (add as references or requirements in FOAs)
5. Initiate round robin test to understand the baseline (currently INL, LBNL, and PNNL, broaden the participation)
6. Setup feedback mechanism, comments section to continually improve

Action Items

Session ID: H4

Title: Protocols Adoption

Name	Affiliation	Action Item	Target Due date
Olga	PNNL	A survey to send to the community	
All	ALL	Active participation and adapt to protocols	
Olga/ Richard	PNNL	Talk to DOE to engage in protocols and to enforce them (?) also approach the universities	
Tyler	Oxeon	Round robin tests on bar conductivity tests	
Olga	PNNL	Round robin test participation (beyond PNNL and INL – broader team)	
?	?	Set up feedback and comments section on the protocol website	

Session Attendee List

Session ID: H4

Title: Protocols Adoption

Name	Affiliation	Name	Affiliation
Hanping Ding	Oklahoma Univ.		
Joshua Gomez	INL		
Renaldo Springer	PNNL		
Kiran Adepalli	Nexceris		
Xinfang Jin	UML		
Tyler Hafen	OxEon		
Nguyen Minh	UC San Diego		
Long Le	PNNL		
Chuangcheng Duan	KSU		
Wei Wu	INL		
Mike Tucker	LBNL		
Xiao-Dong Zhou	UCONN		
Olga Marina	PNNL		
Scott Swartz	Nexceris		

Summary of discussion

- National Lab, University, and Industry need to be involved with protocols
- NREL has a centralized effort for validation of H₂ storage materials, which can be used as a model
- Need to have self assessment of everyone's systems
- Protocols are available to be used and stated in publications. Cite the protocols.
- Validation of protocol versus cross-lab calibration
 - Validation is to check if protocol works well. Cross-lab calibration is to verify results of a standard procedure.
 - Industry (i.e. Nexceris) can supply standard materials for cross-lab calibration

Consensus and/or dissenting opinions

- Protocols need to be published and tried in the lab
- Validation is easy for protocols already being performed

Key Take-Aways

- Need to check protocols to see if they work – can be done with current work
- Only 4 out of 19 protocols are published
- Second round of protocol publication in Frontiers in Energy Research is coming soon
- Need a standardized validation report template
- Cannot wait another year to progress – next steps after confirmation of second round of publication

Action Items

Plan for Validation:

1. Find Volunteers (Uni, NL, Industry)
2. Assign Protocols to volunteers with Timeline
3. Submission of validation reports to Benchmarking committee
4. Publication and dissemination of the reports via DOE's OSTI and NREL's database

Action Items

Session ID: H5

Title: HTE Protocol Validation Plans

ID#	Protocol	Volunteers	Target Due date
HTE-P-01	Bulk Conductivity	OxEon, INL/Wei, Caltech, KSU	
HTE-P-02	Ion Conductivity	INL, Caltech, KSU	
HTE-P-05	Linear thermal expansion	KSU, Uconn,	
HTE-P-07	Leak test	KSU	
HTE-P-09	Button Cell	Caltech, KSU, UConn, CSM, INL, LBNL	
HTE-P-10	Polarization	Caltech, KSU, UConn	
HTE-P-11	EIS	Caltech, KSU, UConn, CSM, INL, LBNL	
HTE-P-13	Metal supported cell	KSU	
HTE-P-14	Bonding strength	KSU, CSM	
HTE-P-19	ASR	OxEon, KSU, UConn	
HTE-P-22	Faradaic Efficiency	INL, KSU, WVU, CSM	
HTE-P-24	Durability	UConn	
HTE-P-23	Stack	OxEon, CSM	
HTE-P-25	Large Area Cell	UConn	
HTE-P-27	H2 production rate and purity	INL, KSU	

Session Attendee List

Session ID: H5

Title: HTE Protocols Validation Plan

Name	Affiliation	Name	Affiliation
Hanping Ding	Oklahoma Univ.	Nicholas Kane	INL
Joshua Gomez	INL	Zheyu Luo	Caltech
Renaldo Springer	PNNL	Kevin Huang	Un. of South Carolina
Kiran Adepalli	Nexceris	Neal Sullivan	CSM
Xinfang Jin	UML		
Tyler Hafen	OxEon		
Nguyen Minh	UC San Diego		
Long Le	PNNL		
Chuangcheng Duan	KSU		
Wei Wu	INL		
Karl Gross	H2TECH		
Xiao-Dong Zhou	UCONN		
Olga Marina	PNNL		
Scott Swartz	Nexceris		