HydroGEN
Advanced Water Splitting Materials

Advanced Water-Splitting Technology Pathways Benchmarking & Protocols Workshop

Breakout Session Summaries
High Temperature Electrolysis (HTE)

March 2 – 3, 2021

This presentation does not contain any proprietary, confidential, or otherwise restricted information

nel number one by nature™ | ASU Arizona State University | Caltech | PNNL

HTE Breakout Sessions

Session ID	Topic	Lead
HTE-2	HTE Roadmap	Jamie Holladay (PNNL)
HTE-3	HTE Techno-Economic Analysis	Brian Murphy (Strategic Analysis)
HTE-4	Standard Cell and Test Methods	Dong Ding (INL)
HTE-6	Stack Testing Protocols	Neal Sullivan (CO School of Mines)
HTE-7	Performance/Durability Test Protocols	Xingbo Liu (WVU)

Session Summary

Session ID: HTE-2

Title: HTE Roadmap

- Summary of discussion
  - Proton conducting materials may require their own roadmap
  - Thermal cycling for proton conducting needs test protocol
  - Degradation of button cells is better understood than degradation of full cells. Stack degradation needs lots of study. Stacks are a challenge since there is a lot of business sensitive information
  - LCA and TEA needed
  - System development is important and needs to be added

- Consensus and/or dissenting opinions
- Dissenting opinion on good cell sizes. Majority thought that larger cell size would decrease costs.
- Reversible operation and testing is important
- Consensus that electronic leakage and faradaic efficiency need to be quantified
- Pressurized operation (<7bar) has benefits

- Key Take-Aways
  - Degradation for cells and stacks needs additional understanding
    - Generic stack to studies degradation would be useful
  - Proton conducting has enough challenges that a separate roadmap is needed
  - Dynamic operation is important
  - LCA and TEAs are needed to understand value proposition
  - Efficiency needs to be considered in the roadmap

- Action Items
  - Add systems development
  - Develop similar roadmap for proton conducting
  - TEA and LCA are needed.
  - Standard dynamic cycling test protocol is needed
  - Add pressurized operation testing

Session Attendee List

Session ID: HTE-2

Title: HTE Roadmap

Name	Affiliation
Meilin Liu	Georgia Tech
Colin Gore	Redox
Tadashi Ogitsu	LBNL
Ann Call	Un. of Sheffield, UK
Mark Williams	Keylogic
Scott Swartz	Nexceris
Jamie Holladay	PNNL
Olga A Marina	PNNL
Marie-Laure Fontaine	SINTEF, Norway
Ryan O'Hayre	CSM
Srikanth Gopalan	BU
Gary Groenewold	INL
Rachael Rothman	Un. of Sheffield, UK
Ned Stetson	DOE

Session Attendee List

Session ID: HTE-2

Title: HTE Roadmap

Name	Affiliation
David Peterson	DOE
Sruthi Kattamanchi	Shell India Market
Michael Tucker	LBNL
Brian Murphy	Strategic Analysis
Kevin Huang	Un. of South California
Nguyen Minh	UC-SD
Will Gibbons	DOE
Richard Boardman	INL
Joseph Barton	FuelCell Energy
Neal Sullivan	CSM
Kerry Meinhardt	PNNL
Tianli Zhu	Raytheon
John Pietras	Saint Gobain
Dong Ding	INL

Session Attendee List

Session ID: HTE-2

Title: HTE Roadmap

Name	Affiliation
Xinfang Jin	UMass, Lowell
Bob Bell	NREL
Joseph Hartvigsen	OxEon
Wenyuan Li	WVU
Julie Mougin	CEA, France
Sachin Gaikwad	Shell India Market
Jennie Huya-Kouadio	Strategic Analysis
Ryan O'Hayre	CSM
Sridevi	Shell India Market
Zachary Clifford	Rutgers University
Karl Gross	H2 Technology Consulting
Huyen Dinh	NREL

Session Summary

Session ID: HTE-3

Title: HTE TEA Review

Summary of discussion

- Operating at 7¢/kWh does not make sense, would operate under lower electricity prices (wind/PV can be < 2¢/kWh).
- Does not make sense to operate at low capacity factors (20% for curtailed wind for example)
- Inverter, compressors, and purification equipment are high cost BOP components => can reduce cost by operating at higher pressures
- 700C is inflection point on creep and temp for using lower price alloys and SS materials for BOP

Consensus and/or dissenting opinions

- All agree should move toward larger cell area and automation in manufacturing line
- Dissenting: Moving to lower operating temperatures (<700C) can reduce material/component costs

Key Take-Aways

- Electricity price is location and source specific.
- Increasing stack size reduces labor and manifolding cost
- When increasing cell size, need to consider shrinkability, camber, lower yield due to defects, and max current take-off
- Inventive system designs contribute to lower cost of H_2 (increased oper. pressure, lower oper. temperature)
- Tradeoff between stack operating temp (efficiency) and BOP material costs

Action Items

- Define minimum stack size and number of units needed to achieve lowest cost (knee in curve)
- Optimization of time varying electricity pricing and capital utilization factor
- Impact on H2 cost with trade-off of stack life and stack cost
- Determine market affect on cost/price of electrolyzers

Session Attendee List

Session ID: HTE-3

Title: HTE TEA Review

Name	Affiliation
Xinfang Jin	UMass, Lowell
Olga Marina	PNNL
Ann Call	Un. of Sheffield, UK
David Peterson	DOE
Gary Groeneworld	INL
Joseph Barton	FuelCell Energy
Rachael Rothman	Un. of Sheffield, UK
Dong Ding	INL
Richard Boardman	INL
Mike Tucker	LBNL
Colin Gore	Redox
Bob Bell	NREL
Huyen Dinh	NREL
Jamie Holladay	PNNL
Joseph Hartvigsen	OxEon Energy
Julie Mougin	CEA, France
Mark Williams	Keylogic

Session Attendee List

Session ID: HTE-3

Title: HTE TEA Review

Name	Affiliation
Meilin Liu	Georgia Tech
Michael Tucker	LBNL
Neal Sullivan	Colorado School of Mines
Nguyen Minh	UC-SD
Rachael Rothman	Un. of Sheffield, UK
Sachin Gaikwad	Shell India Market
Srikanth Gopalan	Shell India Market
Scott Swartz	Nexceris
Tadashi Ogitsu	LBNL
Tianli Zhu	Raytheon
Will Gibbons	DOE

Session Summary

Session ID: HTE-4

Title: Standard Cell & Test Methods

Summary of discussion

- Recap of standard cell and methods
- Confusion exist about what the standard cell is and what it is needed.
- Standard cell and reference cell
- Value of round robin test
- Button cells vs 5x5 cells
- Test and cell specs (e.g. assemble, cure, active areas, steam concentration, etc)

Consensus and/or dissenting opinions

- There is still uncertainty and hesitation to accept the standard cell/reference cell;
- Controlling steam at high concentration with relevant tests (H_2 production rate, leakage) is challenging
- Need to specify the active area for a given cell when comparing the performance
- Repeatable measurements of cell performance is necessary

Key Take-Aways

- Reference and standard cell are equally important;
- Round robin test is necessary and useful
- Button cells and large cells are equally important for p-SOEC.

Action Items

- Need to contribute spreading the word and talking about the importance of standard cell and test methods.
- Need to develop standard measurement approaches for H_2 production rate, especially at small scales.
- Need to identify the cell provider(s) who can sell the standard cells/reference cells

Session Summary

Session ID: HTE-5

Title: Stack testing protocols

- Summary of discussion
  - Balance details of metrics with concerns of developers
  - Consider gross stack properties
    - H2 production rate / kg stack
    - Efficiency
    - Degradation
  - Define an "easy" test condition

- Consensus and/or dissenting opinions
  - Where is "Tipping point" in info-vs-IP decision making?
  - Protocols need boundaries (no "unit-cell" stacks)
  - Potentially costly endeavor

- Key Take-Aways
  - Suffer less information to gain commercial participation
  - Clearly define operating point
  - Avoid overly restrictive protocols
  - Develop metrics that developers are willing to publish
  - Third party testing & dissemination

- Action Items
  - Participants note that only developers build stacks
  - Developers rarely publish results
  - Stack benchmarking would need third party testing

Session Attendee List

Session ID: HTE-5

Title: Stack testing protocols

Name	Affiliation
Neal Sullivan - Chair	Colorado School of Mines
Olga Marina	PNNL
Mark Williams	Keylogic
Will Gibbons	DOE
Srikanth Gopalan	Boston University
Joseph Barton	FuelCell Energy
Tianli Zhu	UTRC
Kevin Huang	University of South Carolina
Dong Ding	INL
Colin Gore	Redox
Ann Call	Un. of Sheffield, UK
Xinfang Jin	UMass Lowell
Xingbo Liu	WVU
John Pietras	Saint Gobain

Session Attendee List

Session ID: HTE-5

Title: Stack testing protocols

Name	Affiliation
David Peterson	DOE
Michael Tucker	LBNL
Long Le	CSM
Tadashi Ogitsu	LBNL
Julie Mougin	CEA, France

Session Summary

Session ID: HTE-7

Title: HTE Performance / Durability

- Summary of discussion
  - Differentiate o-SOEC v. p-SOEC goals
  - Evaluate utility of experimental parameters and metrics, including temp, pressure, steam conc, I-V, electrochemical (EIS)
  - H_2 production rate (under what condition), steam utilization
  - Efficiencies are very important

- Consensus and/or dissenting opinions
- p-SOEC: 550C, 1.4 V, at least 20% H_2O in air vs. 5%H2 in Ar
- o-SOEC: 750C, 1.3V at H_2O/H_2 = 1 or 4 vs. air
- EIS tests should be with overpotential
- At least 500 hours

- Key Take-Aways
- Tests should be at relevant conditions
- "Accelerated tests" should be based on known mechanisms (needs more investigations)
- Baselines needs to be established (well-characterized cell/stack)

- Action Items
- Establish the baseline with well-characterized cell/stack, understand the kinetics of each degradation mechanism, then start "accelerated tests"

Session Attendee List

Session ID: HTE-7

Title: HTE Performance / Durability

Name	Affiliation
Xingbo Liu	WVU
Kevin Huang	Un. of South Carolina
Joseph Barton	FuelCell Energy
Olga A Marina	PNNL
Gary Groenewold	INL
Will Gibbons	DOE
Ann Call	Un. of Sheffield, UK
Colin Gore	Redox
David Peterson	DOE
Jamie Holladay	PNNL
John Pietras	Saint Gobain
Karl Gross	H2 Technology Consulting
Long Le	Colorado School of Mines
Mark Williams	Keylogic

Session Attendee List

Session ID: HTE-7

Title: HTE Performance / Durability

Name	Affiliation
Michael Tucker	LBNL
Ryan O'Hayre	CSM
Srikanth Gopalan	BU
Sridevi Govindarajan	Shell India Market
Zachary Clifford	Rutgers University
Sachin Gaikwad	Shell India Market
Xinfang Jin	UMass, Lowell
Rob Bell	NREL
Dong Ding	INL
Shaun Alia	NREL
Nguyen Minh	UC-SD
Tianli Zhu	Raytheon