
Dr. Katherine Ayers
Proton OnSite/Nel Hydrogen
May 20, 2020

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Project Overview

Benchmarking Advanced Water Splitting Technologies

**PI:** Kathy Ayers, Proton OnSite (LTE)

**Co-PIs:** Ellen B. Stechel, ASU (STCH); Olga Marina, PNNL (HTE); CX Xiang, Caltech (PEC)

**Consultant:** Karl Gross

**Project Vision**
A cohesive R&D community working together; interacting with the EMN to define targets, best practices, gaps, and priorities; aggregating and disseminating knowledge; accelerated innovation and deployment of advanced water splitting technologies.

**Project Impact**
Development of a community-based living roadmap across technologies to assist in maintaining a balanced DOE portfolio.
Project Motivation

Team of subject matter experts assembled for each sub-area to engage with each sub-community

Consultant from a similar effort in hydrogen storage added to convey lessons learned

Barriers

Lack of consensus regarding testing protocol/standards

Large diversity of information to compile and develop recommendations from

Different TRLs for different technologies

Proposed Targets

<table>
<thead>
<tr>
<th>Metric</th>
<th>State of the Art</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey for priorities</td>
<td>N/A</td>
<td>High % response and opportunity for dialogue</td>
</tr>
<tr>
<td>Metrics</td>
<td>$/kW, $/kg</td>
<td>Component level parameters; system considerations</td>
</tr>
<tr>
<td>Node assessment</td>
<td>N/A</td>
<td>Identification of gaps and strengths</td>
</tr>
</tbody>
</table>

Partnerships

EMN Nodes, National Labs
Seedling Projects and other Universities
Advanced Water Splitting Industry
Related International Organizations
Project Goals & Approach

Inputs:
- DOE Project Management
- Questionnaire
- Workshops
- Community Participants

Primary Organization Tool:
(Living Document)

2B Project Team

Project Frameworks

Deliverables:
- Newsletter
- Protocols
- Node Capabilities
- Roadmaps
- Standard Materials

Success Metrics

Steering Committee
Approach - Innovation

- Develop a framework of protocols/standards for testing performance of materials, components, devices, and systems
- Facilitate acceptance of community-wide technology
- Establish an annual project meeting to share learnings and develop recommendations within and across technology areas
- Assess capabilities and identify gaps for development of advanced water splitting technologies
- Promote acceptance of protocols and methodologies including cost and performance assessments and database comparisons
- Assemble roadmaps to further development of each technology pathway
## Approach- Budget Period 2 Project Tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>Timing</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>G/NG 1: BP 1 Go/No Go</td>
<td>Apr ‘19</td>
<td>Passed</td>
</tr>
<tr>
<td>3. Protocol Definition</td>
<td>Apr ‘19 – Dec ‘20</td>
<td>Continue developing new bench scale testing protocols for each water splitting pathway</td>
</tr>
<tr>
<td>4. Protocol Verification &amp; Revision</td>
<td>Apr ‘19 – Feb ‘21</td>
<td>Verify procedures and configurations have been sufficiently defined for reproducible results based on feedback from Year 2 workshop.</td>
</tr>
<tr>
<td>5. Program Management</td>
<td>Apr ‘19 – Feb ‘21</td>
<td>Ensure protocols and Best Practices are developed in accordance with broader EMN guidelines</td>
</tr>
</tbody>
</table>
Relevance & Impact

Standardized Test Methods and Benchmarks

– Decrease development cycle times through common comparison
– Allow for direct comparisons of materials and water splitting technologies
– Revisions to draft test protocols with feedback from EMN and International experts
– Released finalized version of protocols and prioritized plans for validation
– Initiation of new protocol drafts

Community Engagement and Outreach

– Annual workshop with international participation
– Technical publications
– Presentations at scientific conferences
– Introduced protocols at HydroGEN FY19 FOA Project Kickoff Meeting and Review

Test Protocol Table of Contents

1. Procedures
   a. Scope and Applicability
   b. Summary of Method
   c. Definitions
   d. Health & Safety Warning
   e. Cautions
   f. Interferences
   g. Personnel Qualifications / Responsibilities
   h. Equipment and Supplies
   i. Step by Step Procedure
      • Instrument or Method Calibration and Standardization
      • Sample Collection
      • Sample Handling and Preservation
      • Sample Preparation and Analysis
      • Troubleshooting
      • Data Acquisition, Calculations & Data Reduction Requirements
   j. Data and Records Management

2. Quality Control and Quality Assurance Section

3. General Notes

4. Reference Section
Accomplishments- Budget Period 1 Go/No Go

• A review of Budget Period 1 activity was held on May 22, 2019

• Approved to proceed with Budget Period 2 which focuses on:
  – Finalizing and adding to the draft protocols, and verifying and validating the protocols.
  – Publicize the location of the protocols and encourage feedback from the broader water splitting community.
  – Assessment of relevant operating conditions for each technology.
  – Feedback on the existing protocols were reviewed at the community wide workshop in the fall of 2019.
  – Development of accelerated test protocols to assess known degradation mechanisms. (Year 3)
  – A plan and recommendations for round robin testing to verify and validate the protocols (Year 3)
<table>
<thead>
<tr>
<th>Milestone #</th>
<th>Project Milestones</th>
<th>Task Completion Date (Project Quarter)</th>
<th>Type</th>
<th>Original Planned</th>
<th>Revised Planned</th>
<th>Actual</th>
<th>Percent Complete</th>
<th>Progress Notes</th>
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</thead>
<tbody>
<tr>
<td>G/NG 1</td>
<td>Draft bench scale protocols published, definitions and notations agreed on, and metrics recommended. Draft Roadmap framework for each technology area completed.</td>
<td>Go/No-Go</td>
<td>Type</td>
<td>3/31/2019</td>
<td></td>
<td>04/19/2019</td>
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<tr>
<td>3.1</td>
<td>Assessment of relevant operational conditions for field use completed.</td>
<td>Milestone</td>
<td>Type</td>
<td>6/30/2019</td>
<td>9/30/2019</td>
<td>9/30/2019</td>
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<tr>
<td>3.2</td>
<td>Recommended accelerated testing protocol including how the protocols address known degradation mechanisms defined.</td>
<td>Milestone</td>
<td>Type</td>
<td>3/31/2020</td>
<td>6/30/2020</td>
<td></td>
<td>0%</td>
<td>Not started.</td>
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<tr>
<td>3.3.1</td>
<td>Gap assessment on capabilities within EMN / R&amp;D community for field simulations and long term reliability testing completed.</td>
<td>Milestone</td>
<td>Type</td>
<td>12/31/2019</td>
<td>3/31/2020</td>
<td></td>
<td>100%</td>
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<td>3.3.2</td>
<td>Field test sites and requirements for subscale testing within EMN and expert sites established/recommended.</td>
<td>Milestone</td>
<td>Type</td>
<td>6/30/2020</td>
<td>9/30/2020</td>
<td></td>
<td>0%</td>
<td>Not started.</td>
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<tr>
<td>4.2</td>
<td>Year 2 workshop solicited bench scale protocol feedback and solicited recommendations for extensions/modifications.</td>
<td>Milestone</td>
<td>Type</td>
<td>9/30/2019</td>
<td>10/30/2019</td>
<td></td>
<td>100%</td>
<td></td>
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<tr>
<td>End of Project Goal</td>
<td>Year 3 workshop presented subscale protocol recommendations, progress against metrics, updated technical roadmap with engagement from subject matter experts and R&amp;D community.</td>
<td>N/A</td>
<td>Type</td>
<td>9/30/2020</td>
<td>10/31/2020</td>
<td></td>
<td>0%</td>
<td>Not started.</td>
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</tbody>
</table>
Accomplishments- Test Protocols For Workshop 2 Review

Test Protocol Development Process

- Materials level test protocols were prioritized
- Future protocols will include device level and accelerated testing

Thank you to our test protocol contributors!

Authors: LTE
Shaun Alia
Chulsung Bae
Chris Capuano
Nem Danilovic
Kelly Meeks
Sarah Park
Alexey Serov
Hui Xu

HTE
John Hardy
Jeff Stevenson
Yeong-Shyung Chou
Fengyu Shen
Dong Ding
Ani Kulkarni

PEC
James Young
Todd Deutsch
Adam Weber
Nem Danilovic
Charles Dismukes
Shu Hu
Burt Simpson
Jason Cooper
Dave Palm

STCH
Andrea Ambrosini
Bob Bell
Eric Coker
Dave Ginley
Chris Muhich
Anthony McDaniel
Michael Sanders
Jonathan Scheffe

And expert reviews/workshop input from many national and international researchers
Accomplishments- Test Protocols For Workshop 2 Review

- 36 test protocols were drafted, reviewed and prioritized for validation
- 40 additional protocols in drafting process

### LTE

<table>
<thead>
<tr>
<th>Number</th>
<th>Protocol</th>
<th>Component</th>
<th>Validation Priority</th>
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<tbody>
<tr>
<td>LTE-P-8</td>
<td>Gas Permeability</td>
<td>AEM/PEM</td>
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<tr>
<td>LTE-P-9</td>
<td>Chemical Stability</td>
<td>AEM</td>
<td>1</td>
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<tr>
<td>LTE-P-10</td>
<td>RDE</td>
<td>PGM</td>
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<tr>
<td>LTE-P-20</td>
<td>Water Uptake Measurement</td>
<td>PEM/AEM</td>
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<tr>
<td>LTE-P-3</td>
<td>Ion Exchange Capacity</td>
<td>PEM</td>
<td>2</td>
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<tr>
<td>LTE-P-5</td>
<td>Thermal Stability</td>
<td>PEM</td>
<td>2</td>
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<tr>
<td>LTE-P-5</td>
<td>Conductivity</td>
<td>AEM</td>
<td>2</td>
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<tr>
<td>LTE-P-7</td>
<td>Ion Exchange Capacity</td>
<td>AEM</td>
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<tr>
<td>LTE-P-14</td>
<td>Electronic conductivity</td>
<td>Non-PGM</td>
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<tr>
<td>LTE-P-1</td>
<td>Compressibility</td>
<td>GDL</td>
<td>3</td>
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<tr>
<td>LTE-P-19</td>
<td>LTE Definitions and Notations</td>
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### HTE

<table>
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<td>HTE-P-01</td>
<td>Measurement of Bulk Conductivity</td>
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<tr>
<td>HTE-P-02</td>
<td>Ion Conductivity/Transference Numbers</td>
<td>Electrolyte</td>
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<tr>
<td>HTE-P-03</td>
<td>Mixed Ion Conductivity</td>
<td>Electrolyte</td>
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<td>HTE-P-07</td>
<td>Leak Test</td>
<td>Cell/Stack</td>
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<td>HTE-P-09</td>
<td>Cell Performance Steady-State</td>
<td>Cell</td>
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<tr>
<td>HTE-P-05</td>
<td>Linear Thermal Expansion</td>
<td>Electrolyte</td>
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<tr>
<td>HTE-P-10</td>
<td>Polarization Resistance</td>
<td>Electrode</td>
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<tr>
<td>HTE-P-04</td>
<td>Density Measurement</td>
<td>Electrolyte</td>
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<tr>
<td>HTE-P-13</td>
<td>Metal-Supported Cell Test</td>
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<tr>
<td>HTE-P-14</td>
<td>Bonding Strength</td>
<td>Contact Layer</td>
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### PEC

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<td>PEC-P-1</td>
<td>Photoelectrodes preparation</td>
<td>Photoelectrode</td>
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<tr>
<td>PEC-P-2</td>
<td>Illumination calibrations</td>
<td>Device</td>
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<tr>
<td>PEC-P-3</td>
<td>Tandem light absorber IPCE</td>
<td>Photoelectrode</td>
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<tr>
<td>PEC-P-5</td>
<td>Product crossovers</td>
<td>Transport</td>
<td>1</td>
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<tr>
<td>PEC-P-7</td>
<td>Interfacial band energetics</td>
<td>Protective layer</td>
<td>2</td>
</tr>
<tr>
<td>PEC-P-8</td>
<td>Membrane separators conductivity</td>
<td>Membrane electrolyte</td>
<td>2</td>
</tr>
<tr>
<td>PEC-P-9</td>
<td>Outdoor, on-sun measurements</td>
<td>Device</td>
<td>1</td>
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<tr>
<td>PEC-P-10</td>
<td>PEC device fabrication/integration and scale up</td>
<td>Device</td>
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<tr>
<td>PEC-P-0</td>
<td>Comparison Metrics and Terms for PEC Water Splitting</td>
<td>General</td>
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### STCH

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<th>Number</th>
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<th>Component</th>
<th>Validation Priority</th>
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<tbody>
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<td>STCH-P-1</td>
<td>Metrics, Units, Definitions</td>
<td>General</td>
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<td>STCH-P-2</td>
<td>Ceria Standard And Material Specs</td>
<td>Materials</td>
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<td>STCH-P-4</td>
<td>Detailed Thermodynamics Screen</td>
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<td>STCH-P-8</td>
<td>Detailed Kinetics Screen</td>
<td>Materials</td>
<td>2</td>
</tr>
<tr>
<td>STCH-P-10</td>
<td>Durability Level 1 Screen</td>
<td>Materials</td>
<td>2</td>
</tr>
</tbody>
</table>
Accomplishments- Assessment of Relevant Operational Conditions for Field Use

- Past work on system durability and relevant operational conditions was analyzed
- Themes will be used as a basis for development of field relevant protocols

$/\text{kgH}_2$ vs HTE Operating Conditions

![Example LTE Load Profile](image)

![Example PEC Load Profile](image)

Energy Environ. Sci., 2013, 6, 3605-3618

STCH Cycle


Two temperatures and two pressures
Accomplishments- Annual Project Meeting

A community wide workshop was held on October 29 - 30, 2019 at Arizona State University, Scottsdale campus.

**Workshop Objectives:**
- Summarize progress over past year and plan for year two outcomes
- Review, refine, identify, and resolve issues regarding test protocols
- Review, refine, identify, and resolve issues regarding technology roadmaps
- Identify, leverage, and align related international efforts
- Identify opportunities to best utilize the database capability

**Representative Outputs:**
- Revisions to protocols and identification of new protocols to be written
- Updates recommended for technology roadmaps
- Engagement of international community in harmonization of protocols
- Strategies established for verifying protocols
HydroGEN: Advanced Water Splitting Materials

Accomplishments - Annual Project Meeting

Breakout Sessions

<table>
<thead>
<tr>
<th>Session #</th>
<th>Session ID</th>
<th>Technology</th>
<th>Topic</th>
<th>Lead</th>
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<tr>
<td>1</td>
<td>H1-A</td>
<td>HTE</td>
<td>HTE Technology Roadmap Review &amp; Discussion - Materials, Components</td>
<td>Olga Martin</td>
</tr>
<tr>
<td>1</td>
<td>H1-B</td>
<td>HTE</td>
<td>HTE Technology Roadmap Review &amp; Discussion - Devices, Testing</td>
<td>Mark Williams</td>
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<tr>
<td>1</td>
<td>L1-A</td>
<td>LTE</td>
<td>LTE Technology Roadmap Review &amp; Discussion - Membrane, Catalyst</td>
<td>Chris Casapiano</td>
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<tr>
<td>1</td>
<td>L1-B</td>
<td>LTE</td>
<td>LTE Technology Roadmap Review &amp; Discussion - Components, Stack</td>
<td>George Roberts</td>
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<tr>
<td>1</td>
<td>P1-A</td>
<td>PEC</td>
<td>PEC Technology Roadmap Review &amp; Discussion - Materials</td>
<td>Koel van de Krol</td>
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<td>1</td>
<td>P1-B</td>
<td>PEC</td>
<td>PEC Technology Roadmap Review &amp; Discussion - Devices</td>
<td>Francesca Haukensvik</td>
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<tr>
<td>1</td>
<td>S1-A</td>
<td>STCH</td>
<td>STCH Technology Roadmap Review &amp; Discussion - Materials</td>
<td>Andrea Ambrosini</td>
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<tr>
<td>1</td>
<td>S1-B</td>
<td>STCH</td>
<td>STCH Metrics - Units and Operating Boundaries (Protocols)</td>
<td>Chris Mullich</td>
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<tr>
<td>2</td>
<td>H2-A</td>
<td>HTE</td>
<td>Best Methods and Practices for Characterizing NiOx Materials</td>
<td>Joseph Berton</td>
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<tr>
<td>2</td>
<td>H2-B</td>
<td>HTE</td>
<td>Best Methods and Practices for Characterizing Fuel Cells</td>
<td>Dang Biao</td>
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<td>2</td>
<td>L2-A</td>
<td>LTE</td>
<td>PEM Membrane, HER, Thermal Stability, Water</td>
<td>Chulung Bae</td>
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<td>2</td>
<td>L2-B</td>
<td>LTE</td>
<td>AEM Membrane: Conductivity, Gas Permeability, Cell Stability</td>
<td>Yushan Yan</td>
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<td>2</td>
<td>P2-A</td>
<td>PEC</td>
<td>PEM Light Absorption and Photocatalysis - Photocatalysis &amp; Texts</td>
<td>Nicolas Gauffard</td>
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<td>2</td>
<td>P2-B</td>
<td>PEC</td>
<td>PEM Cathodes and Electrolyte Requirements - Texts</td>
<td>Adam Wober</td>
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<td>2</td>
<td>S2-A</td>
<td>STCH</td>
<td>STCH Technology Roadmap Review &amp; Discussion - Stack &amp; Systems</td>
<td>Ivan Ermakova</td>
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<td>2</td>
<td>S2-B</td>
<td>STCH</td>
<td>STCH Stack, Interfaces (Protocols)</td>
<td>Jonathan Scheffer</td>
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<tr>
<td>3</td>
<td>C3-A</td>
<td>Cross Cutting</td>
<td>Hybrid Thermodynamic Pathways: Electrochemical step</td>
<td>Hector Colan-Mercado</td>
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<tr>
<td>3</td>
<td>C3-B</td>
<td>Cross Cutting</td>
<td>Cross Cutting and PGM Catalysts</td>
<td>Shannon Bechtler</td>
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<tr>
<td>3</td>
<td>C3-C</td>
<td>Cross Cutting</td>
<td>PEM Nanocatalyst, Membrane Requirements &amp; Texts</td>
<td>Chris Topping</td>
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<tr>
<td>3</td>
<td>C3-D</td>
<td>Cross Cutting</td>
<td>Cross Cutting: Support Environment Development (calibration, null measurements, etc.)</td>
<td>Karl Gross</td>
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<tr>
<td>3</td>
<td>C3-F</td>
<td>Cross Cutting</td>
<td>Cross Cutting: Functionalization of Catalysts, Protocols and Readings</td>
<td>Ivan Ermakova</td>
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<tr>
<td>4</td>
<td>H4-A</td>
<td>HTE</td>
<td>Water Management - Protocols, Validation</td>
<td>Jim O'Brien</td>
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<td>4</td>
<td>H4-B</td>
<td>HTE</td>
<td>Water Management - Operating Conditions and Boundaries</td>
<td>Jorgou Olmazegian</td>
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<td>4</td>
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<td>LTE</td>
<td>PEM Catalysis, RDE</td>
<td>Marcelo Cermilo</td>
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<td>4</td>
<td>L4-B</td>
<td>LTE</td>
<td>Non-PEM Catalysis: Electrocatalysis</td>
<td>Guido Benders</td>
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<tr>
<td>4</td>
<td>P4-A</td>
<td>PEC</td>
<td>PEC in the Design of Efficient and Cost-effective Electrochemical Systems</td>
<td>Shu Hu</td>
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<tr>
<td>4</td>
<td>P4-B</td>
<td>PEC</td>
<td>PEC in the Design of Efficient and Cost-effective Electrochemical Systems</td>
<td>Shu Hu</td>
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<td>4</td>
<td>S4-A</td>
<td>STCH</td>
<td>STCH Thermodynamics (Protocol)</td>
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<td>4</td>
<td>S4-B</td>
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<td>5</td>
<td>H5-A</td>
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<td>Materials and Device Lifetime Testing Protocols</td>
<td>Xingdao Liu</td>
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<td>H5-B</td>
<td>HTE</td>
<td>Terminology and Units</td>
<td>Neal Sullivan</td>
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<td>L5-A</td>
<td>LTE</td>
<td>Porous Transport Layer (PTL) - Characterization Protocols</td>
<td>Neer Domitoiu</td>
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<td>5</td>
<td>P5-B</td>
<td>PEC</td>
<td>PEC Device Testing Protocols, Standards and Formats</td>
<td>James Young</td>
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<td>5</td>
<td>S5-A</td>
<td>STCH</td>
<td>STCH Durability (Protocol)</td>
<td>Ivan Ermakov</td>
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<tr>
<td>5</td>
<td>S5-B</td>
<td>STCH</td>
<td>STCH Density Functional Theory</td>
<td>Tony McDaniel</td>
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<td>HTE</td>
<td>Wrap-up/Action Item Assignment: HTE Materials, Components</td>
<td>Ani Kulkarni</td>
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<td>HTE</td>
<td>Wrap-up/Action Item Assignment: HTE Cells, Stacks</td>
<td>Jamie Mulligan</td>
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<td>STCH</td>
<td>Wrap-up/Bringing it to Closure and Next Steps: STCH Active Materials</td>
<td>Tony McDaniel</td>
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<td>STCH</td>
<td>Wrap-up/Bringing it to Closure and Next Steps: STCH What's Missing</td>
<td>David Gitlow</td>
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Example Session Output: Quad Chart for Each Breakout

Session Summary

Summary of discussion
Focused on the variety of applications DFT is applied to for STCH research, including high throughput screening and structural prediction.

The benefit of community discussion of best practices was affirmed. Also discussed whether creating a DFT protocol was feasible and/or useful.

Key Take-Aways
- There are a variety of uses for DFT in the STCH community.
- Will likely find it difficult to find consensus on many issues.
- Better to inform and guide as opposed to stipulate.
- Recognized the need for continued group discussion.

Action Items
- Determine if other technologies are interested in a cross cutting meeting talking about how DFT is used in HydroGEN before next workshop.
- Have regular online meetings to discuss best practices in STCH DFT.
- Begin working on a suggested protocol/best practices discussion.

Consensus and/or dissenting opinions
- No consensus on whether DFT protocols are needed or would be useful (do not want to specify exact equipment or method).
- No consensus on whether Peer review is sufficient.
- Difficulty in determining a “right answer” when it comes to tradeoffs between chemical accuracy and high throughput.
- Hard to enforce standards on wider community; people working in this field do not provide sufficient details when reporting results.
- Accuracy need to be to be effective (or convincing) for screening (0.1-4% errors <0.25 kcal/mol absolute? to claim it is a good candidate to split water).
- Clear metrics needed for DFT and DFT methodology, accuracy, etc.
- Magnetic ordering, is it important at high temperature.
Collaboration- Effectiveness

• Approach: Engage subject matter experts, FCTO staff, HydroGEN Steering Committee, and community in dialogue for each pathway
  – Engage broad community in development of standards, protocols, and priorities through annual workshop and regular communication
  – Encourage collaborative best practices development efforts
  – Leverage the international community to utilize existing protocols and develop a common set of protocols for use worldwide
Collaboration- Effectiveness

• Wide-ranging and collaborative effort within and beyond the HydroGEN consortium
  – LTE, HTE, STCH, and PEC technologies
  – Significant engagement from universities, national labs, and international experts
  – Feedback has been positive and enthusiastic throughout
• Workshops, newsletters, and symposia used to spread information and solicit input
• Engaging with new project teams as they start
  – Attended kickoff for latest EMN projects March 10
  – Organized breakouts by technology for initial discussion
  – Working to include protocol testing where applicable
Proposed Future Work

• Remaining project activity will focus on:
  – Bench Scale Protocol Revisions & Validation
  – Accelerated Stress Test Development
  – Identification of Testing Sites
  – Public Distribution of Protocols

<table>
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<tr>
<th>Milestone #</th>
<th>Project Milestones</th>
<th>Completion Date</th>
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<tr>
<td>3.2</td>
<td>Recommended accelerated testing protocol including defining how the protocols address known degradation mechanisms.</td>
<td>6/30/2020</td>
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<tr>
<td>3.3.2</td>
<td>Field test sites and requirements for subscale testing within EMN and expert sites established/recommended.</td>
<td>9/30/2020</td>
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<tr>
<td>End of Project</td>
<td>Year 3 workshop presented subscale protocol recommendations, progress against metrics, updated technical roadmap with engagement from subject matter experts and R&amp;D community.</td>
<td>2/28/2021</td>
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Project Summary

- **Objectives:**
  - Define targets, testing protocols, validation standards, best practices, gaps, and priorities
  - Aggregate and disseminate knowledge
  - Accelerate innovation and deployment of advanced water splitting technologies

- **Relevance & Impact:**
  - Development of standardized test methods and benchmarks
  - Supports the HydroGEN Consortium R&D model by bringing together and partnering with National Labs, Academia and Industry

- **Collaboration Effectiveness:**
  - Engagement of node subject matter experts, HydroGEN Steering Committee and broad water splitting community at annual workshop and through regular communication
  - Leverage the international community to utilize existing protocols and develop a common set of protocols for use worldwide

- **Accomplishments:**
  - Test protocol drafts were revised and new protocols were written
  - Relevant operational conditions were assessed for each of the water splitting technologies
  - A community wide workshop was held to review, develop and update test protocols and technology roadmaps

- **Future work:**
  - Continue protocol development, protocol validation and accelerated test development


High Efficiency PEM Electrolysis: Potential for H2@Scale, K. E. Ayers, C. Capuano, P. Mani, 234th ECS, Cancun, Mexico, October 2, 2018.


1) Approach to performing work:

- High Degree of Collaboration Required
  - There is considerable industry input including direct participation in the Workshop and protocol writing/reviewing, as well as engagement from research labs
  - EMN and larger community are involved in writing, editing, and reviewing protocols on a daily basis.

- International Participation
  - International experts in each technology area participated with opening presentations at the 2019 Workshop, focused on international efforts and collaboration with this project.

- Best Practices
  - The Best Practices protocols are being created and evaluated by experts in each AWS community. There will be a validation iteration by one or several experts to ensure the correctness and completeness of each protocol. These validations are currently one of the focuses of the project going forward.

- Technology Roadmaps
  - Draft roadmaps have been developed, but primary focus of efforts are currently on protocol development and validation
RESPONSE TO 2019 AMR FEEDBACK

2) Relevance/potential impact

• Need to maximize participation and input
  – Continued outreach to industry, academia, national labs and international community for development, validation and acceptance of test protocols

3) Accomplishments and Progress

• Need for publications and outreach
  – Publishing in Frontiers in Energy
  – Presentations at scientific conferences
  – Inclusion of newly developed test protocols in seedling projects
  – Working with DOE to define and develop a publicly accessible website for access to released test protocols

4) Collaboration Effectiveness

• International participation
  – Increased international participation in workshop, protocol drafting and reviewing

5) Future Work

• Protocol Dissemination
  – The future of protocol evaluation and verification is under discussion with DOE.
  – Two annual workshops have been completed. The first established the project goals, set priorities, and brought together experts in the field to participate in the development of protocols. The second, brought in the international community, provided a place and time to finalize many of the initial protocols, and to prioritize and assign responsibilities for the development of the next set of protocols.