H2NEW: Hydrogen (H2) from Next-generation Electrolyzers of Water
HTE: Durability and AST Development

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Date: 4/12/2021

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Project Goals

Goal: H2NEW will address components, materials integration, and manufacturing R&D to enable manufacturable electrolyzers that meet required cost, durability, and performance targets, simultaneously, in order to enable $2/kg hydrogen.

H2NEW has a clear target of establishing and utilizing experimental, analytical, and modeling tools needed to provide the scientific understanding of electrolysis cell performance, cost, and durability tradeoffs of electrolysis systems under predicted future operating modes.
Overview

Timeline

- Project Start Date: 10/01/2020
- End: Project continuation and direction determined annually by DOE

Barriers

- Key barriers addressed
  - F. Capital Cost
  - G. System Efficiency and Electricity Cost
  - J. Renewable Electricity Generation Integration
  - K. Manufacturing

Budget

- Launching in FY21
- FY21 DOE Funding: $2.1M

Partners

ANL, INL, LBNL, LLNL, NREL, NETL, PNNL
Relevance/Impact

• H2NEW-HTE will address HTE cell and stack components performance and durability to understand degradations and enable manufacturable electrolyzers that meet required cost, durability, and performance targets, to enable $2/kg hydrogen.

• H2NEW focuses on durability and lifetime of SOEC cells and stacks

• H2NEW is a tightly focused, highly coordinated investigation harnessing extensive experimental testing, multiscale modeling and detailed materials characterization
  – National labs are ideal for this critical work – in aggregate, combination of world-class experimental, analytical, and modeling tools combined with the ability to freely share research findings.
  – The array of capability needed to understand and mitigate degradation does not exist at a single laboratory

DOE HTE Targets

<table>
<thead>
<tr>
<th>HTE Electrolyzer Stack Goals by 2025</th>
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<tbody>
<tr>
<td><strong>Capital Cost</strong></td>
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<tr>
<td>$100/kW</td>
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<tr>
<td><strong>Electrical Efficiency (LHV)</strong></td>
</tr>
<tr>
<td>98% at 1.5 A/cm²</td>
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<tr>
<td><strong>Lifetime</strong></td>
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<td>60,000 hr</td>
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Approach: Experimental Investigation to AST

- Define initial experimental conditions, including temperature, gas compositions, current/voltage
- Down select cell materials, architectures, configurations, and sizes
- Identify cell vendor/supplier
- Identify the number of test repeats to establish confidence; negotiate Round Robin tests
- Initiate testing under standard operations
- Determine degradation mechanisms via extensive post-test characterization; compare findings to know from SOFC and SOEC literature
- Identify potential stressors for Accelerated Stress Testing (AST) development
- Define AST matrix and conduct experiments using incrementally aggressive conditions
- Perform experimental validation and post-test characterization and compare results to those obtained under standard operating conditions
- Ensure active participation of HTE stakeholder advisory board that includes commercial cell developers and academia; seek feedback and guidance from experts in the field
- Develop AST protocols
Technical Accomplishments: Identified Standard Cells

- Composition identified: Ni-YSZ | YSZ | GDC | LSCF-SDC
  - Button cells initially, smaller cell area
  - Graduate to planar cells, larger cell area, 10-25 cm², for direct comparison to button cells

- Cell-related degradation previously reported:
  - Hydrogen Electrode
    - Coarsening
    - Migration
    - Si poisoning
  - Oxygen Electrode
    - SrZrO₃
    - Delamination
    - Cr, S poisoning
Technical Accomplishments: Initiated Electrochemical Testing

- INL, PNNL, and LBNL have significant suit of test stands available
- Initial screening of commercially available electrode-supported cells from FuelCellMaterials and in-house fabricated electrode-supported cells have been started
  - Commercial cells – 6 cells with LSCF electrode tested at 750°C for 600-2500 hours; 3 cells with LSM electrode tested at 800°C for 1200 hours
  - In-house made cells – 6 cells with LSCF electrode tested at 750°C for 2800 hours
  - Operating conditions: \( \text{H}_2\text{O}/\text{H}_2 = 1 \); at 1.3 Volt
  - Recorded current, temperature, OCV, I-V and EIS @ 100 h intervals
Technical Accomplishments: Performed Post-Test Characterization

- Performed post-test characterization using SEM/EDS
- Sr migration was observed through the ceria barrier layer and reaction with YSZ to form SrZrO$_3$
- LSM delamination observed in all cells tested
- Ni/YSZ did not exhibit any significant changes
Technical Accomplishments: Performed Literature Review on Dynamic Cycling

R&D SOEC testing typically at fixed conditions (V, I, T, P...)

BUT: anticipated operation is highly dynamic

Complete:
- Literature survey, discussion with advisory board complete
- Highest priority cycling variables: H₂/H₂O ratio, and voltage

Ongoing:
- Test standard cells under dynamic conditions
- Deliver cells to Task 7 for analysis
- Assess viability as an Accelerated Stress Test

Metal-supported SOEC, air/3% humidified hydrogen

Previous example:
Dynamic Temperature Cycling

Metal-supported SOFC (LSM/SDCN), air/3% humidified hydrogen
Technical Accomplishments: Considered Dynamic Cycling Conditions

• Literature:
  – Cycling **power** (P, V, or I) in normal range is well-studied, does not cause degradation; cycling outside normal range is not studied
  – **Steam content** cycling is not well studied, but is relevant to intermittent or variable operation
  – Small variations in **pressure, temperature, Ni reduction/oxidation** not expected to impact degradation; large variations cause catastrophic failure and so are not useful for AST
  – Most studies asked: Do SOECs tolerate cycling within normal operating regime?
    → H2NEW asks: Can cycling outside of normal operating regime be used as a relevant AST?

• Industry:

<table>
<thead>
<tr>
<th>Dynamic Variable</th>
<th>Votes from industry</th>
</tr>
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<tbody>
<tr>
<td>Steam ratio</td>
<td>5</td>
</tr>
<tr>
<td>Power (I,V)</td>
<td>4</td>
</tr>
<tr>
<td>Temperature</td>
<td>1</td>
</tr>
<tr>
<td>Redox</td>
<td>1</td>
</tr>
<tr>
<td>Pressure</td>
<td>0</td>
</tr>
</tbody>
</table>

• Summary of variables chosen for initial cycling in FY21:
  – **Steam content**: Isolation of steam content as a dynamic variable has not been reported. Therefore, it would be interesting to study its effect, both within a normal operating window (25-75%) and with excursions to off-design points (<10%, >90%). Also relevant to intermittent or variable operation.
  – **Power**: It is well-established that SOECs tolerate dynamic load within the limits of normal operation. Continuous operation at high voltage or high current density is known to cause damage. Cycling to higher power is unexplored, and may be a useful AST technique, as the cell will be stressed but the worst degradation modes expected at high power will be mitigated by cycling to lower power.
Responses to Previous Year Reviewers’ Comments

• This is a new project and has not been reviewed previously
Collaboration and Coordination

- Multi-scale modeling leveraging experience from FC, HydroGEN research
- Materials characterization, coordination, beamline interface
- Materials, cell fabrication, cell testing, AST development characterization, modeling
- Cell testing, emphasis on thermal and electrical cycling
- Cell testing, performance characterization, AST development, system integration

- This task is being performed by three labs: PNNL, INL, LBNL
- Designs and assumptions are discussed with the industrial partners, DOE and all other participating national labs
- Efficient close coordination is coordinated through by-weekly meetings
Remaining Challenges and Barriers

- Baseline cell performance under standard operating conditions will be validated at three labs
- Potential stressors for AST has not been finalized
- Preliminary AST matrix will need to be down selected
Proposed Future Work

5a. Accelerated Stress Test Development – Q1, ff.

Proposed future work is subject to change based on funding levels

- Prior research: degradation mechanisms, potential stressors
- Joint Benchmarking 2B team and AST team discussions and exchange
- Identify possible stressors
- Define AST protocols and initiate testing using small step change magnitude; this will be an iterative process
- Rely on performance diagnostics and post test characterization

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5b. Button cell testing, standard conditions - Q3

- Experimental validation: standard operating conditions
- Sufficient replicates to establish confidence
- Cell characterization: electrolysis performance during operation, in-cell diagnostics: I-V, impedance, F.E.

5b.ii. AST matrix, considering
- SOFC degradation literature
- Expertise within the SAE and HTPE team
- Results from the standard operating experiments

5b.iii. Identify key stressors accelerating degradation
- Experiments conducted using incrementally more aggressive conditions

5b.iv. Button cell experiments, AST conditions – Q3, Q4, ff.

- Cell characterization: per button cell standard experiments
- Evaluate

5b.v. Planar cell experiments, standard conditions – Q4

- Same composition as button cells: electrode-supported
  - Ni-RYSZ | YSZ | GDC | LSCF-GDC

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H2NEW: Hydrogen from Next generation Electrolyzers of Water
Summary

- H2NEW HTE is an ambitious program focused on overcoming barriers to cell and stack durability that are impediments to economic competitiveness and industrial implementation.
- Materials and component degradation mechanisms are the result of multiple, coupled phenomena derived from operating conditions.
  - A comprehensive and accurate understanding of the interplay of these phenomena does not currently exist.
  - Therefore, rationalizing, predicting, and controlling degradation currently beyond our grasp.
- The H2NEW HTE hypothesis is that a systematic, coordinated research program targeting the coupled degradation phenomena will yield refinements to composition, fabrication, and operation that will enable HTE technology to overcome current durability barriers.
- Harnessing capability at the consortium labs is well underway, and the initial operational experiments have begun.
Technical Backup and Additional Information
Technology Transfer Activities

- This analysis provides context for technology transfer across H2NEW
- No additional specific technology transfer is occurring in this task
Progress Towards DOE Targets

- This task is quantifying progress of H2NEW toward DOE’s $2/kg hydrogen production target
Publications and Presentations

• Not reported yet