H2NEW Hydrogen from Next-generation Electrolyzers of Water

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DOE Hydrogen Program
2023 Annual Merit Review and Peer Evaluation Meeting

H2NEW HTE: Durability and AST Development

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Project ID # P196E

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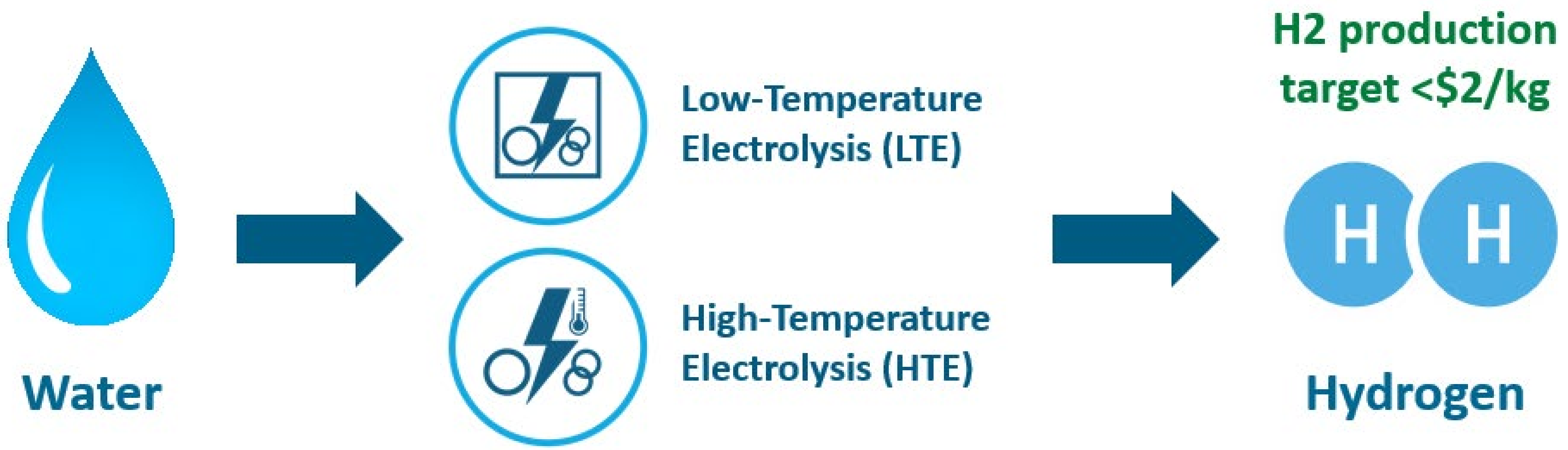
NREL Transforming ENERGY · INL Idaho National Laboratory · Argonne National Laboratory · Berkeley Lab Bringing Science Solutions to the World · Lawrence Livermore National Laboratory · Los Alamos National Laboratory EST. 1943 · National Energy Technology Laboratory · Oak Ridge National Laboratory · Pacific Northwest National Laboratory

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

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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 FY22
- FY23 DOE Funding: $4.05M

Partners

INL, PNNL, LBNL, LLNL, NREL, NETL

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

HTE Electrolyzer Stack Goals by 2025	
Capital Cost	$100/kW
Electrical Efficiency (LHV)	98% at 1.5 A/cm^2
Lifetime	60,000 hr

Approach: Experimental Investigation to AST

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- Fabricate identical cells using well known state-of-art materials
- Define standard experimental conditions, including temperature, gas compositions, current/voltage, to obtaining a baseline
- Initiate testing under standard operations to determine potential degradations
- Identify the number of test repeats to establish confidence
- Determine degradation mechanisms via extensive post-test characterization; compare findings to known from SOFC and SOEC literature
- Identify potential stressors for Accelerated Stress Testing (AST)
- 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:
Established Multiple Size Cell Production for H2NEW Partners

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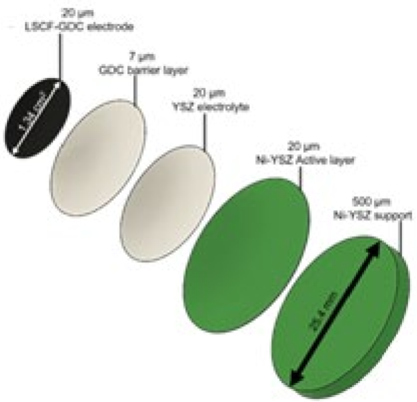
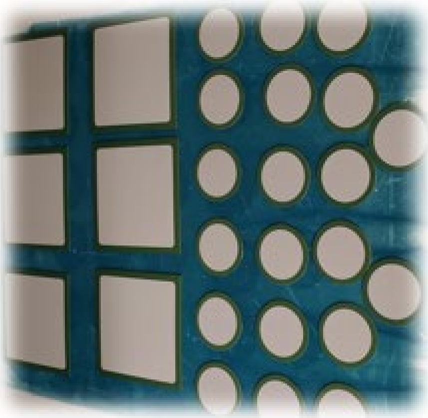
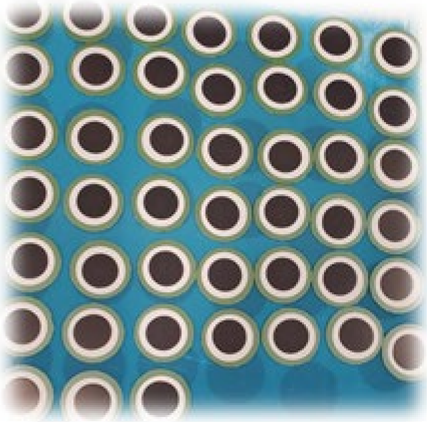
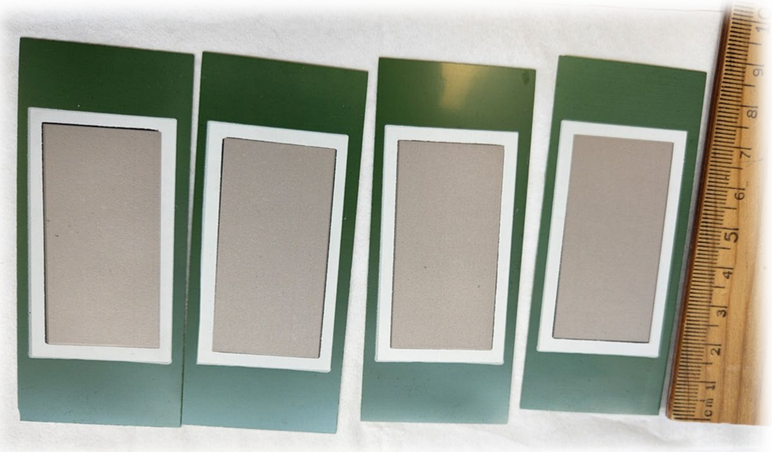
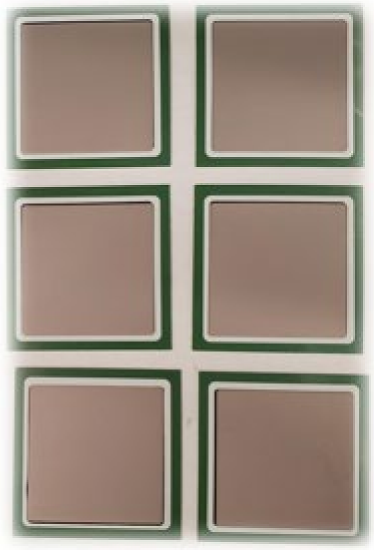
- Consortium labs use <u>identical</u> cells for testing, performance validation, and characterization
- Ni-YSZ electrode-supported cells in 4 different formats:
  - 2.5 cm diameter (1-5 cm^2 active area) cells
  - 1-5 cm^2 symmetric cells
  - 4 x 9 cm cells (13 cm^2 active area)
  - 5 x 5 cm cells (16 cm^2 active area)
- A batch fabrication process was developed to minimize the variance between separate cells











Technical Accomplishments:
Achieved Excellent Production Quality Control and Consistent Testing

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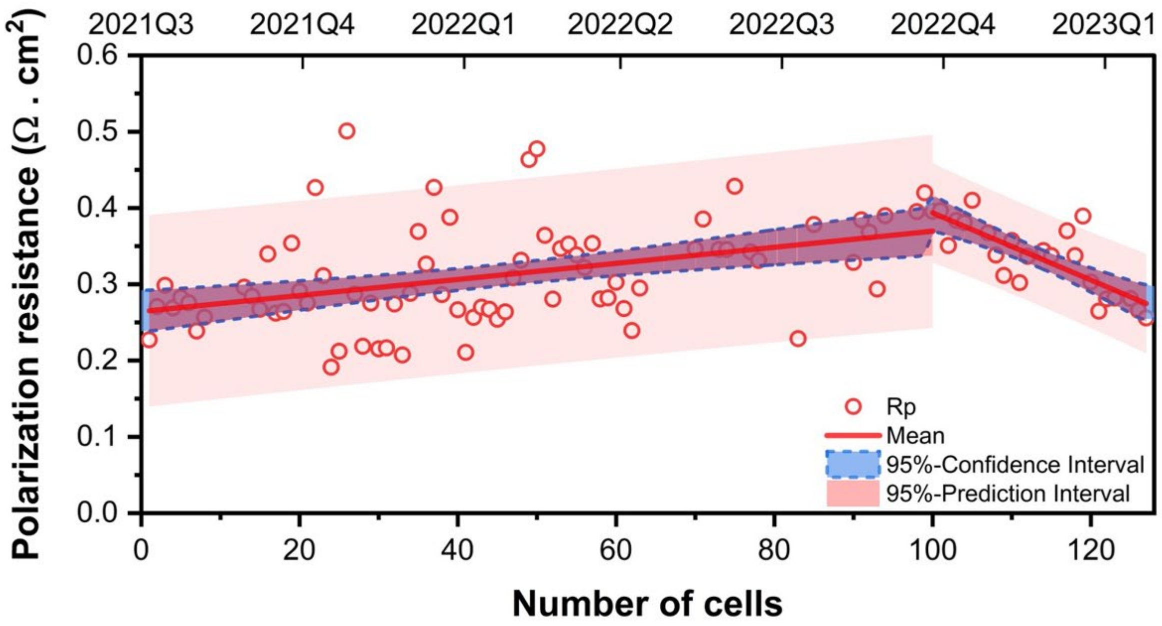
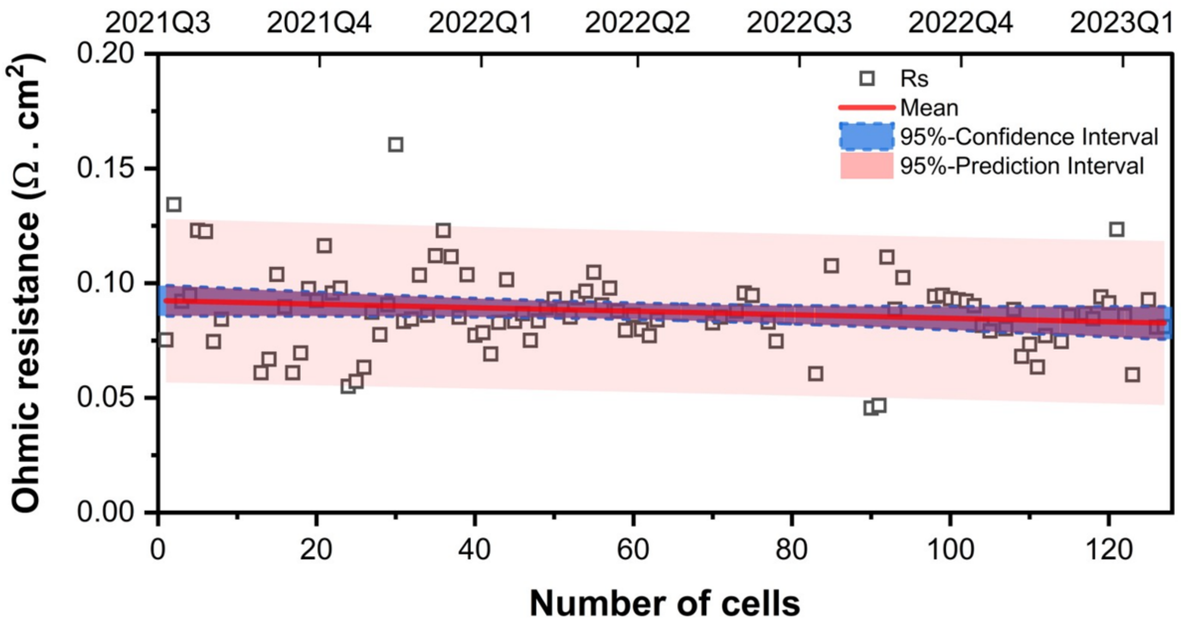
Cell performance reproducibility at PNNL

130 different cells tested over period of 20 months using "standard" conditions: 750ºC, 1.3V, 50% H_2O

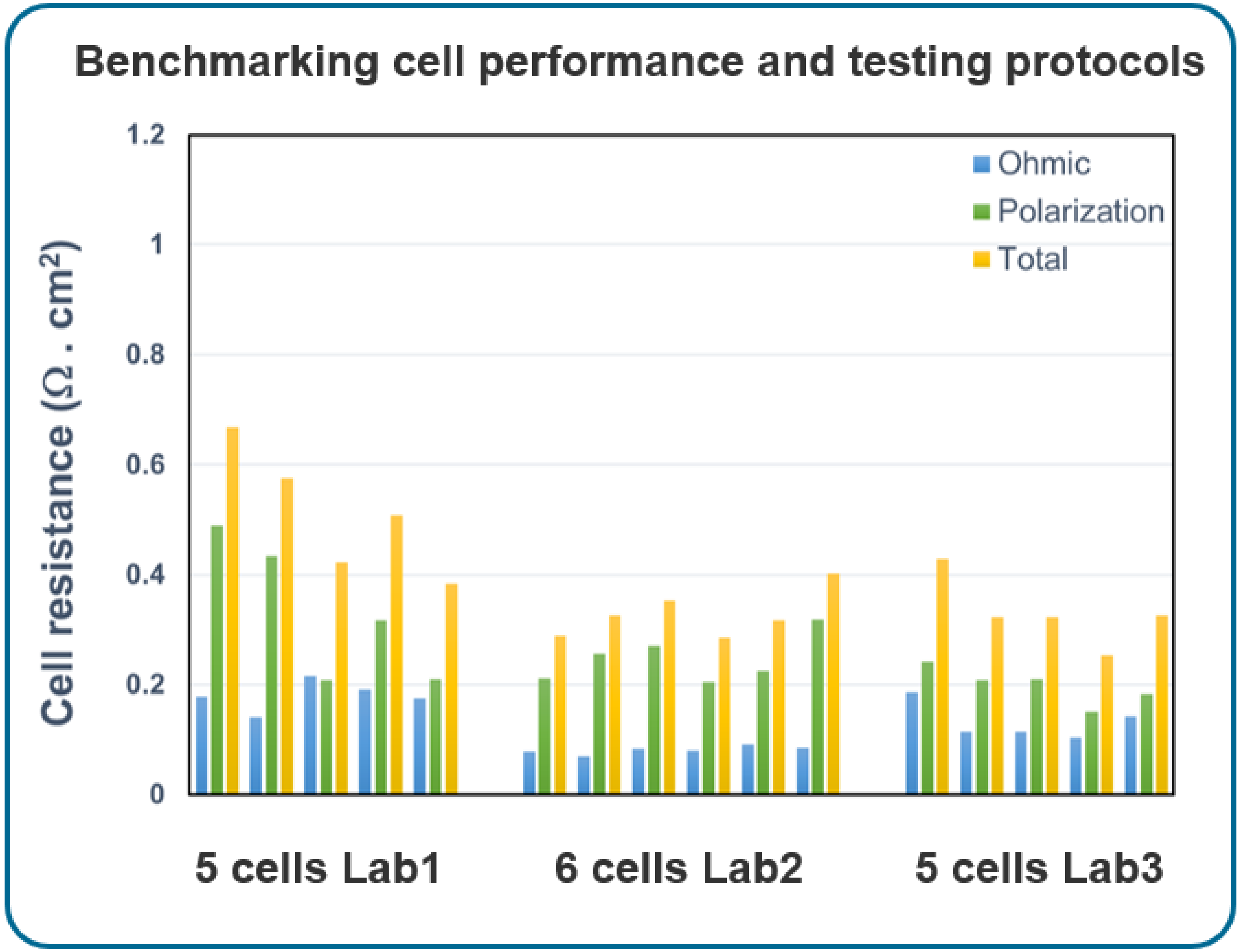




Automation of several fabrication steps and tighter test protocols improved polarization resistance

Ohmic resistance is consistently low

Technical Accomplishments: Significantly Improved Interlab Reproductivity by Developing SOP



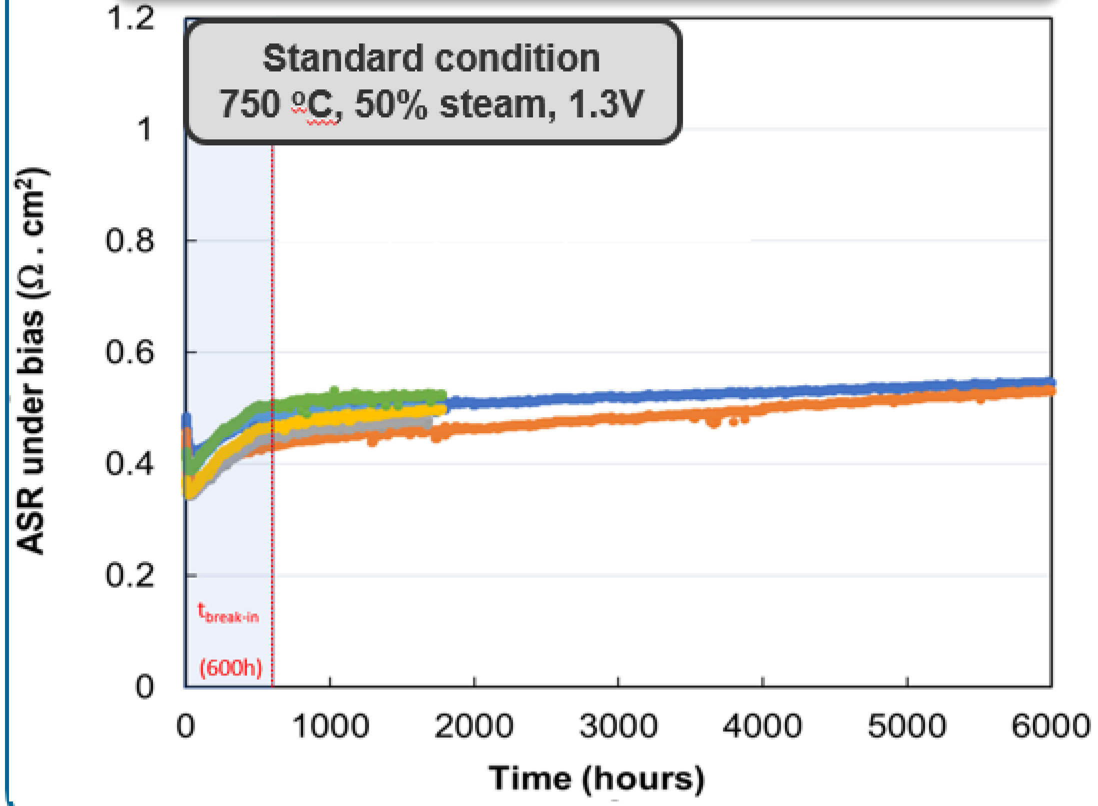
	Intra Lab Reproducibility			
	Ave. Ohmic R (Ω.cm²)	Std. Error (Ω.cm²)	Ave. Polarization R (Ω.cm²)	Std. Error (Ω.cm²)
LBNL	0.180	0.024 (13%)	0.331	0.115 (35%)
PNNL	0.081	0.007 (8%)	0.248	0.039 (16%)
INL	0.132	0.030 (23%)	0.198	0.031 (16%)
	Inter Lab Reproducibility			
LBNL + PNNL + INL	0.128	0.046 (36%)	0.258	0.088 (34%)

- Observed substantial performance variances between the labs in early testing rounds
- Significantly improved interlab reproductivity by developing standard operating procedures

Technical Accomplishments:
Improved Test Methodology to Achieve Button Cell Degradation Rate ~0.1%/khr

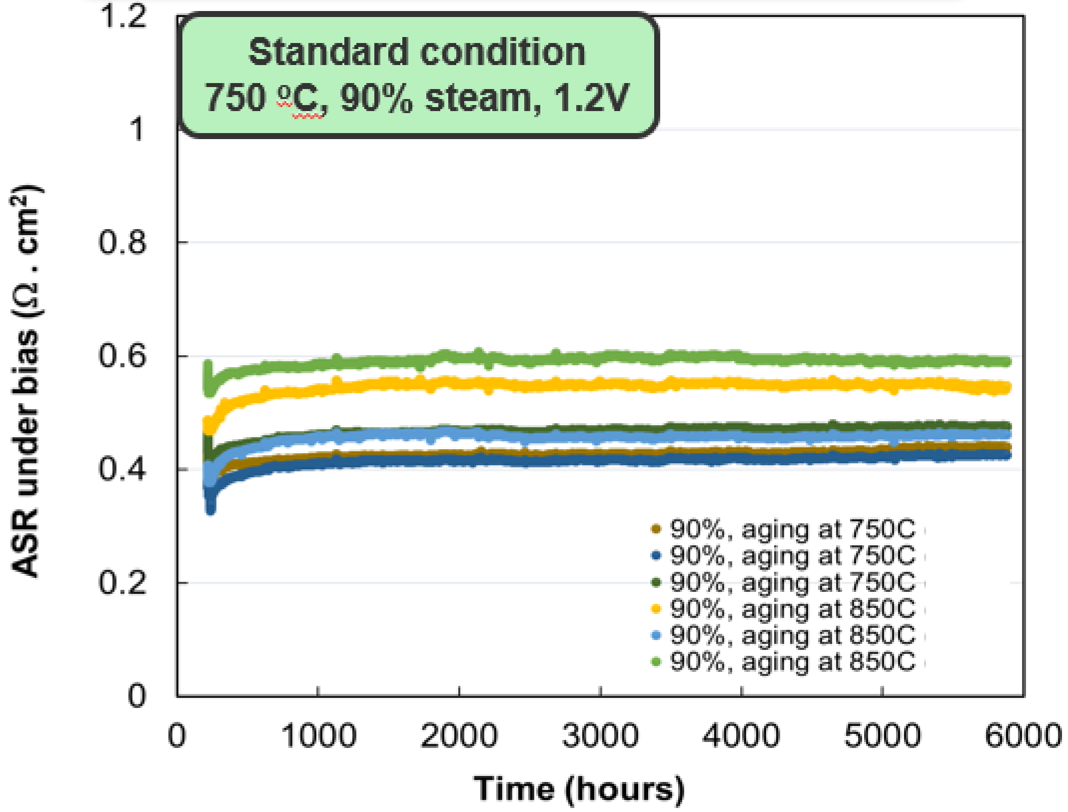
Initial long-term stability FY22 (Completed)

- Degradation rate: **~ 4% / khrs**
- Completed post-mortem characterizations to identify degradation mechanisms



Long-term stability in FY23 (On-going)

- Degradation rate: ~ **0.1% / khrs**
- Next goal: Optimize cell performance; demonstrate long-term operation using 16 cm^2 cells



Technical Accomplishments:
Extremely High Steam Concentrations Accelerate Degradation Rate

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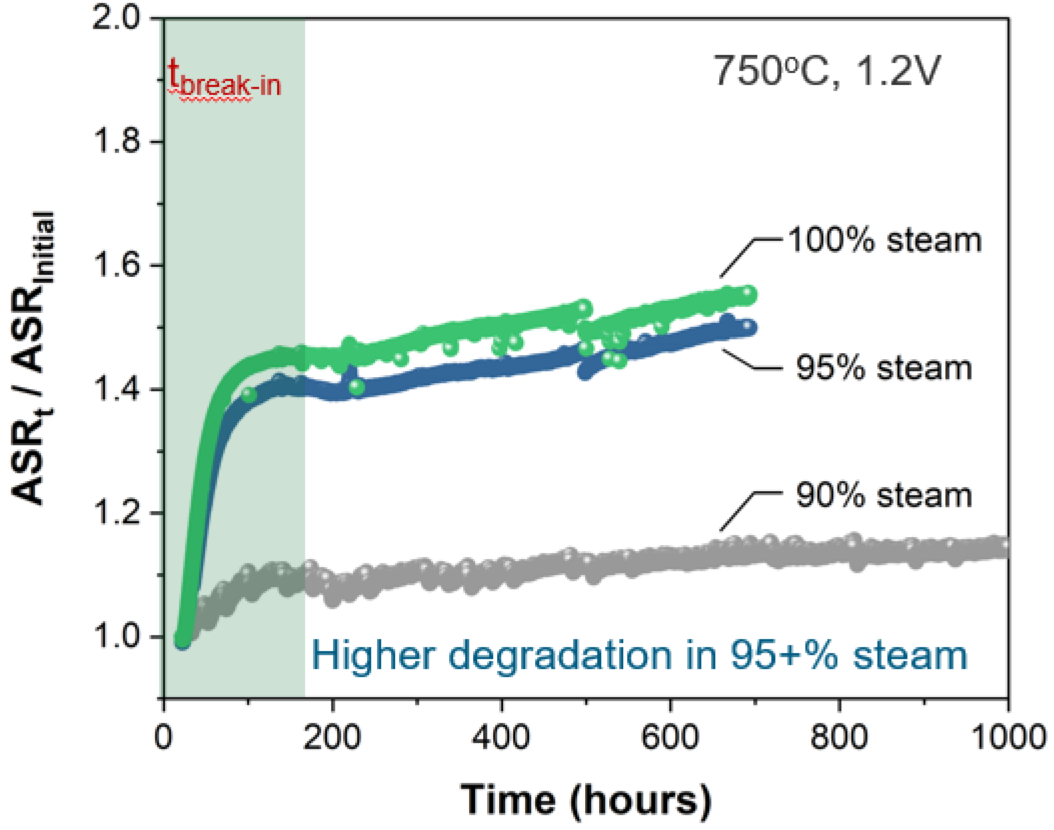
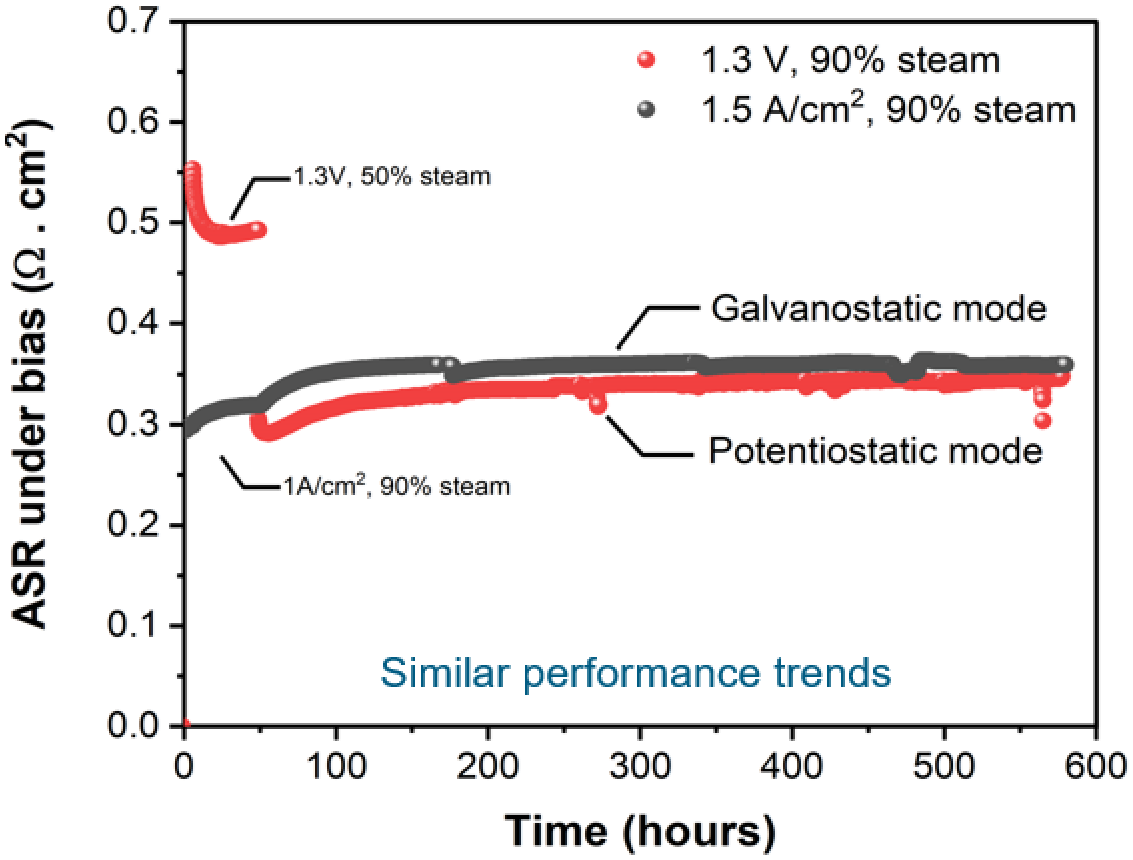
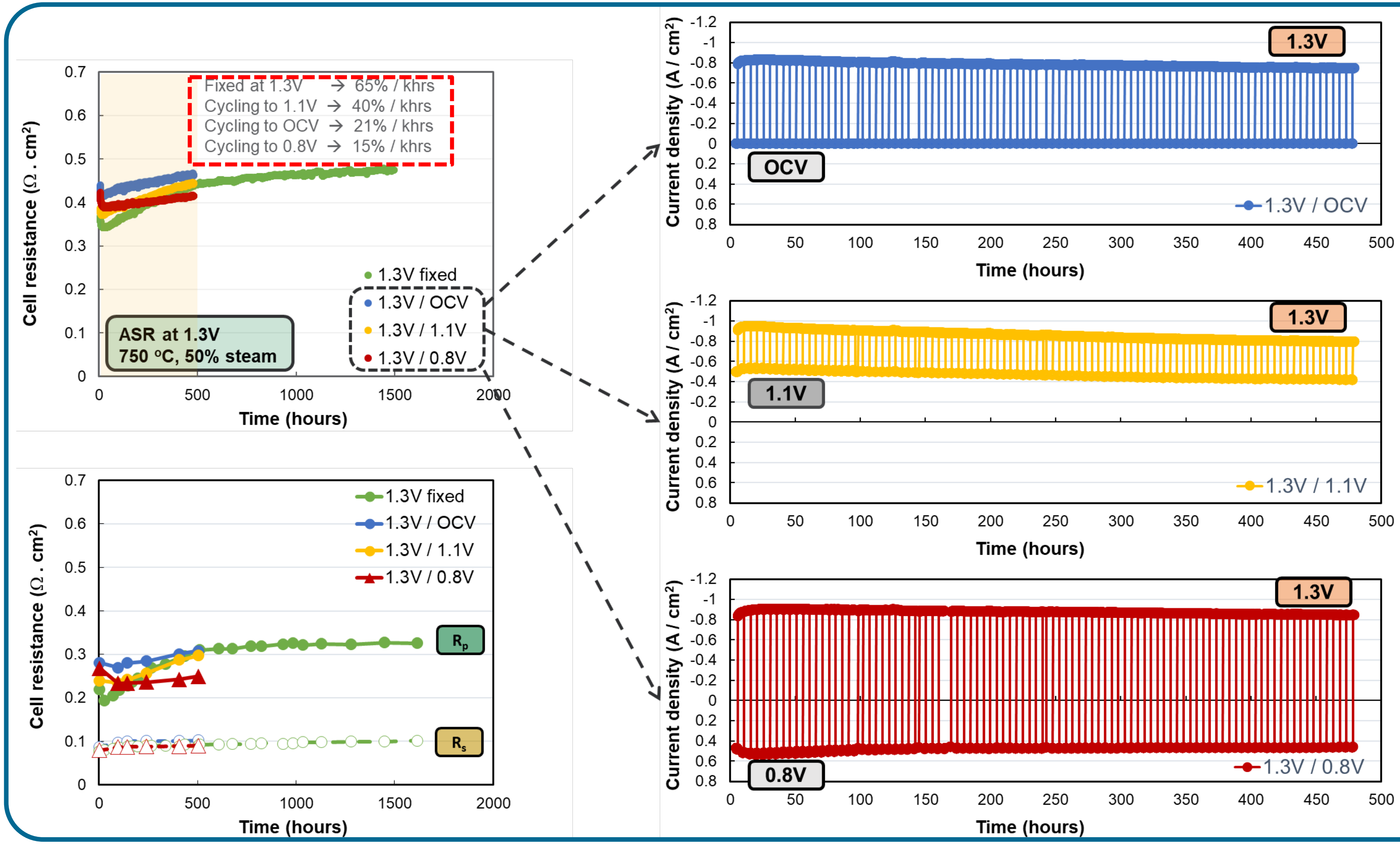
Identified pH_2O as stressor to shorten initial break-in period



Confirmed interchangeability of potentiostatic and galvanostatic modes of operation

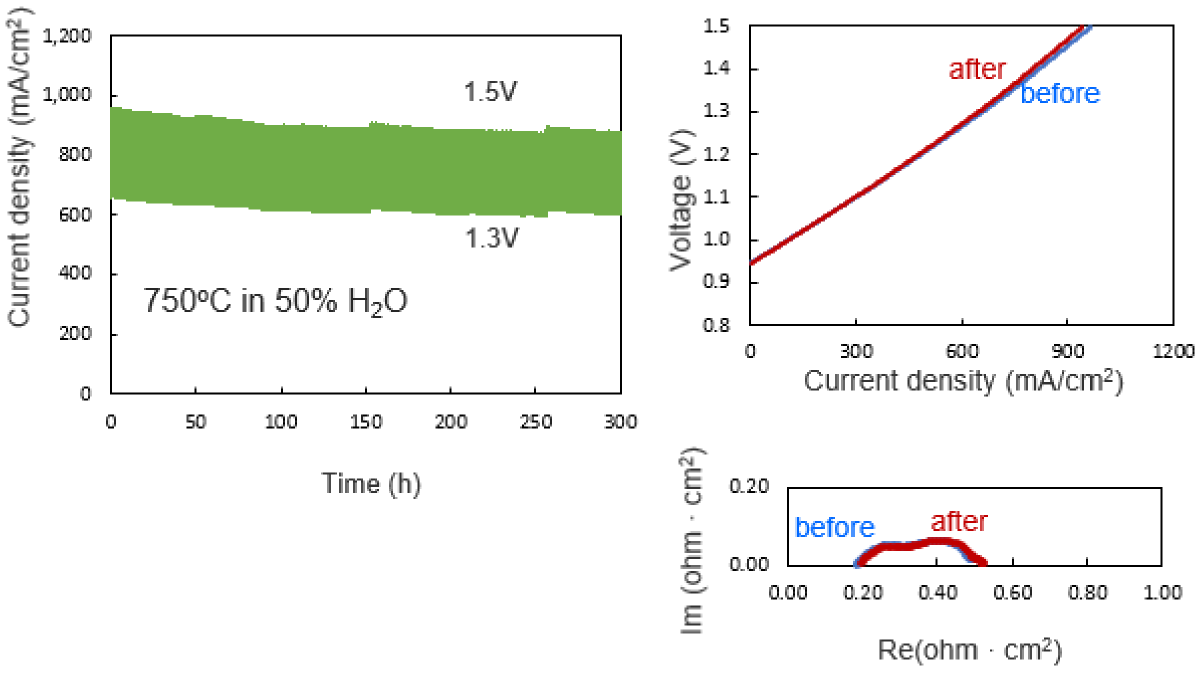


Technical Accomplishments:
Voltage Cycling Suppresses SOEC Degradation

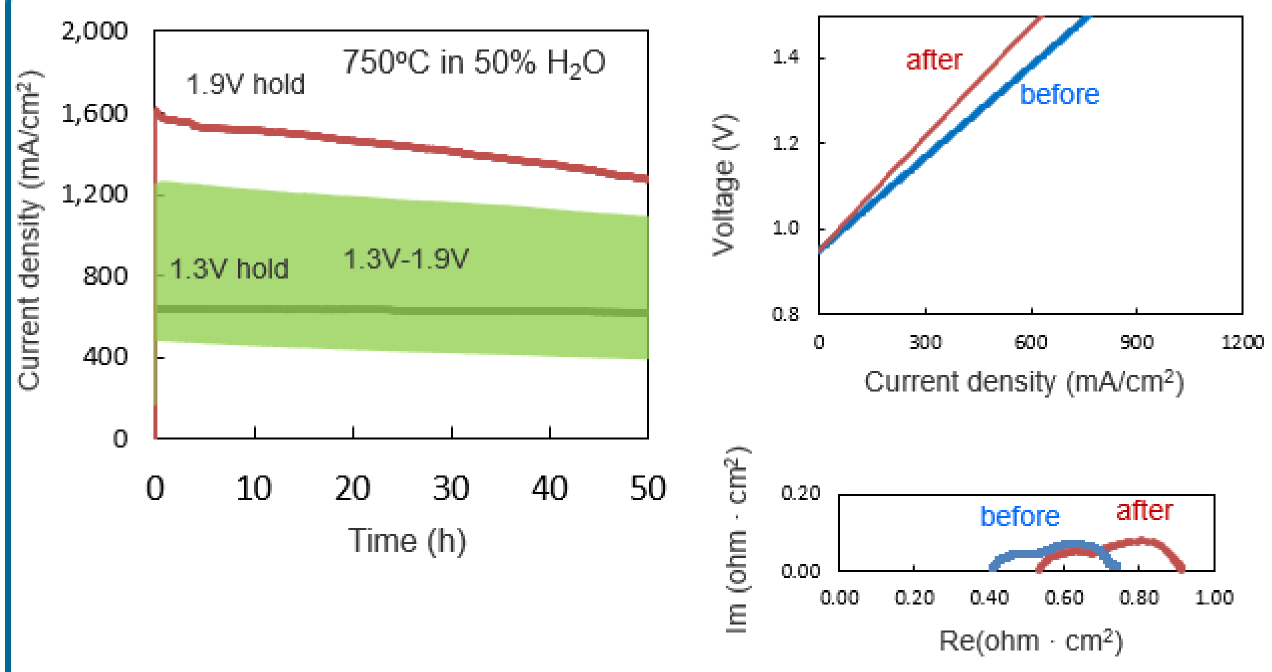


- Cycling from 1.3 Volt to OCV or to voltage below 1.3 V reduces degradation
- Cycling from SOEC to SOFC mode reduces degradation

Technical Accomplishments: Cycling to 1.9V Increases Degradation (AST)



Cycling 1.3V-1.5V: No Change in Degradation



Cycling 1.3V-1.9V: Increased Degradation

SEM analyses to be performed

Technical Accomplishments: Demonstrate Dynamic Cycling of HTE

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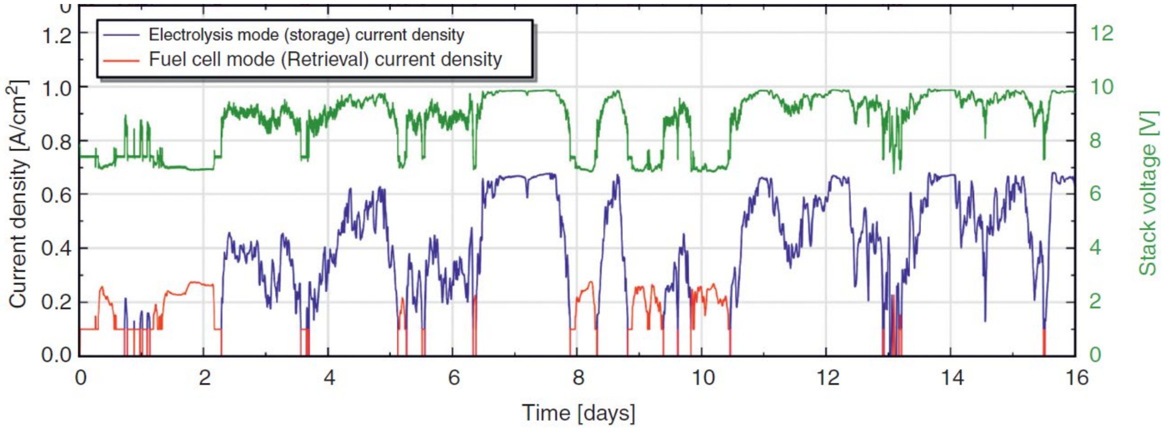
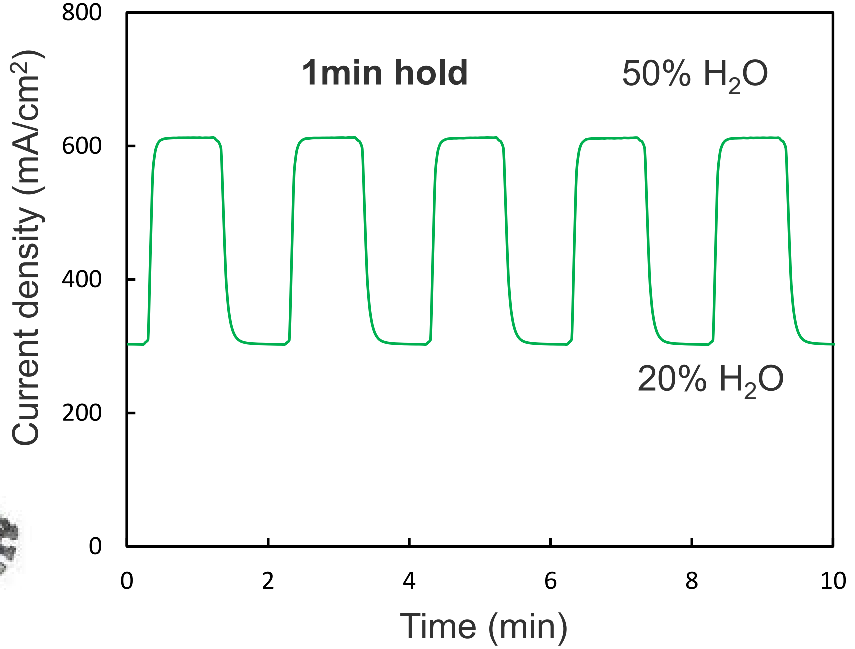
Anticipated HTE operation is highly dynamic



C. Graves, J.V.T. Høgh, K. Agersted, X. Sun, M. Chen et al., July 2014, Department of Energy Conversion & Storage, Technical University of Denmark

Capability development

Switching valve for rapid automatic control of gas composition

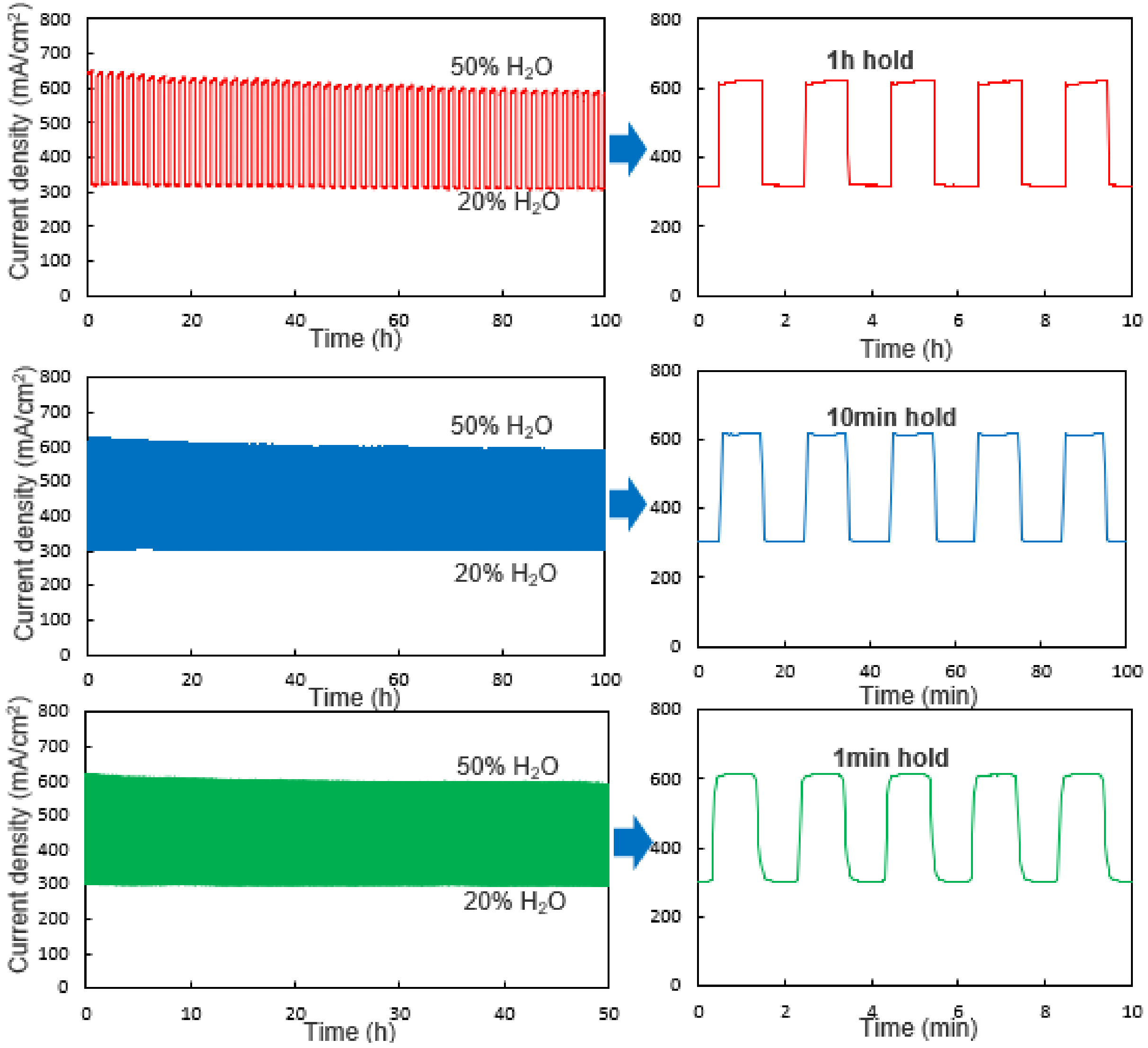


Demonstrate cell operation dynamic conditions by:

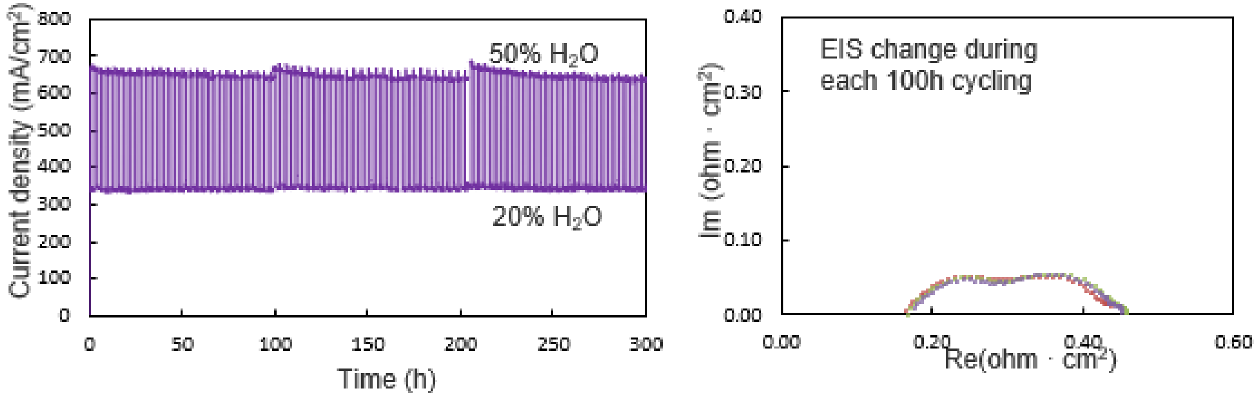
- Voltage cycling 1.3 to (1.5-1.9) V
- Steam content cycling (3-20%) to (50-75%)
- Steam frequency cycling (1min-2h) hold

Technical Accomplishments:
Dynamic Steam Content Cycling Does Not Accelerate Degradation

Steam cycling with different frequencies

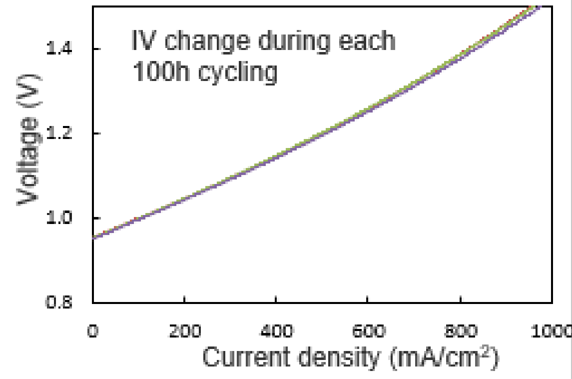


300h Steam cycling test between 20% and 50% H_2O



Completed:

- Frequency limit test (1min/10min/1h/2h hold)
- 20% to 50% H_2O, 300h test at 750ºC at 1.3V
- Preliminary test 10% to 70% H_2O



- Steam content cycling from 20% to 50% H_2O does not increase the degradation rate
- Steam cycling frequency does not impact degradation

Technical Accomplishments:
Evaluated Effect of Steam Utilization on Cell Performance and Durability

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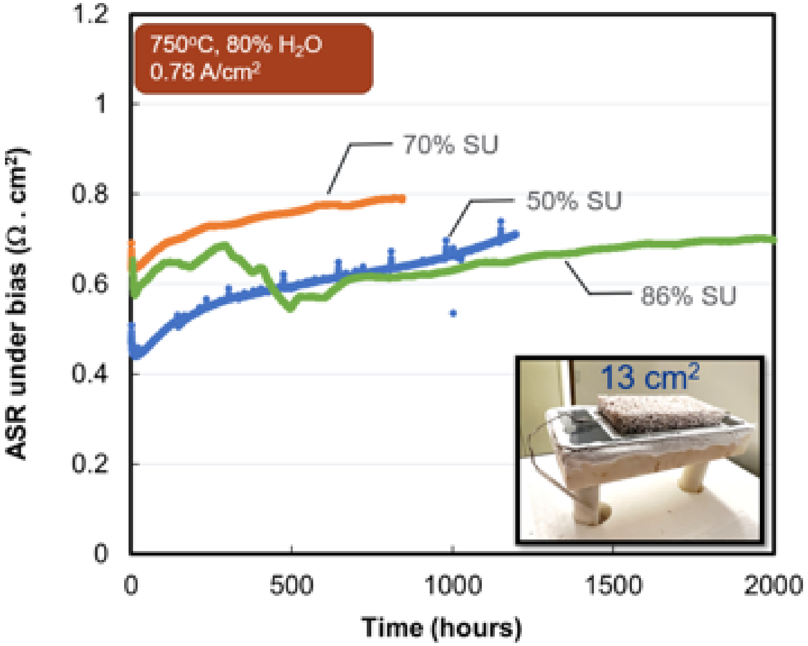
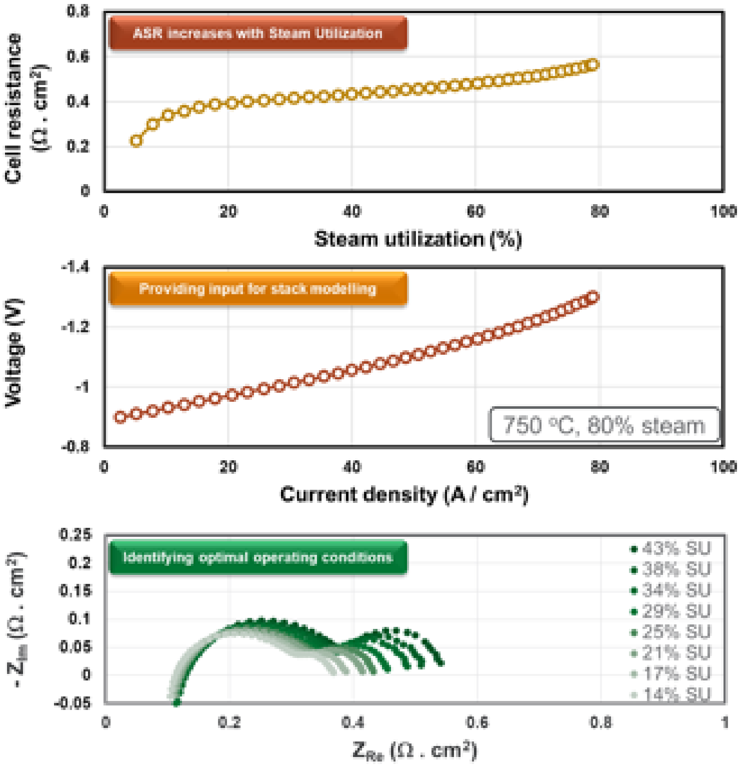
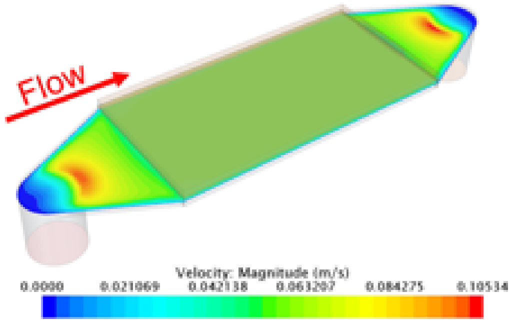
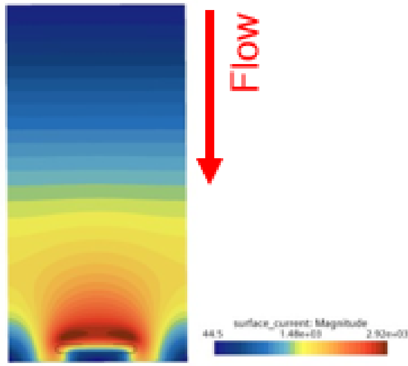


Cells tested at 0.78 A/cm^2 at 50-86% steam utilization for 700-2,000 hours

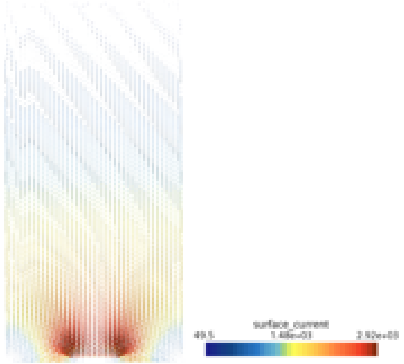




Validated uniformness of flow field at 87% steam utilization



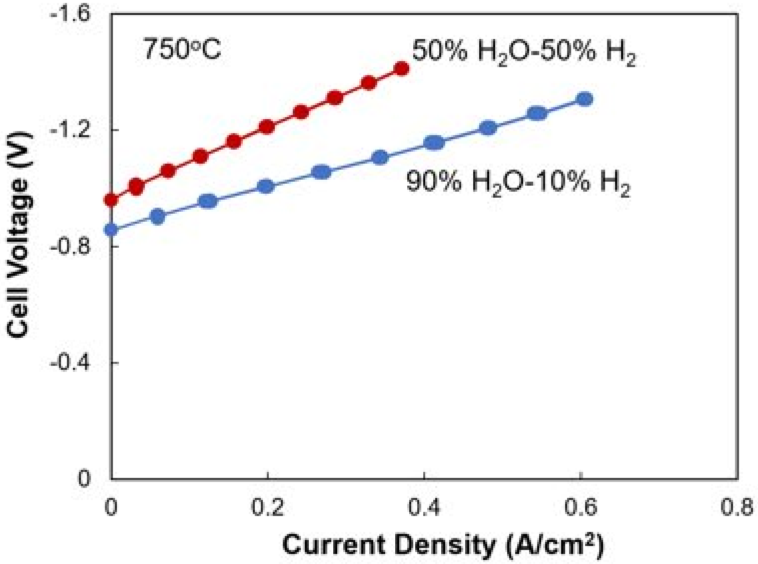
Current density distribution



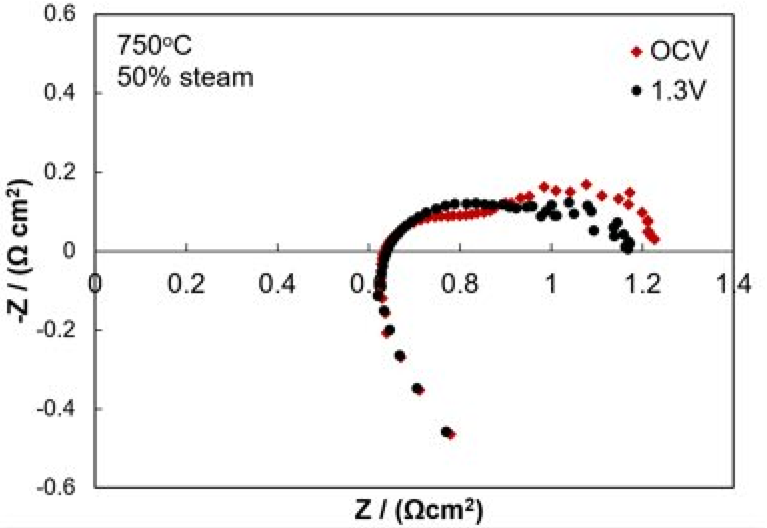
Current path in planar direction

- Provided input to modelers; initiated large cell performance modeling, current and voltage distribution, quality of flow fields and gas channels validation
- Initiated post-test microstructure SEM/EDS and TEM analyses to compare to button cells

Technical Accomplishments: Evaluate Effect of Realistic Interconnect, Coatings, and Contacts on Cell Performance and Degradation Rate



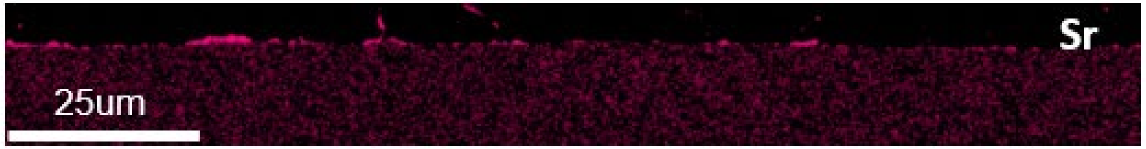
- Validated seal quality
- Validated ability to produce and deliver 50-90% steam



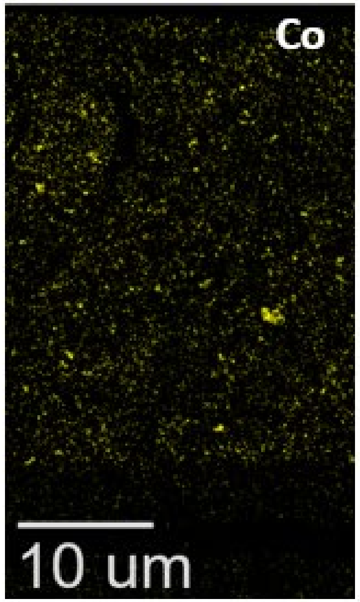
- Separated ohmic and electrodic losses
- High ohmic losses attributed to poorer contacts compared to button cells

Technical Accomplishments: Performed SEM/EDS Post-Test Cell Charterization to Elucidate Degradation Mechanisms

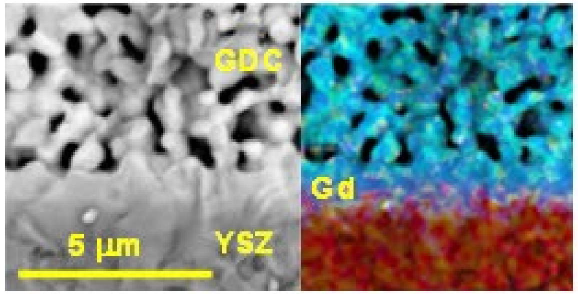
Oxygen Electrode Characterization



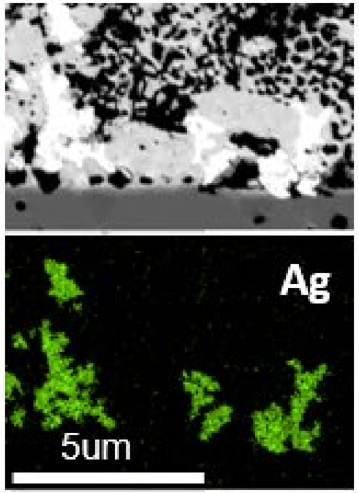
Sr surface segregation



Spinel formation increases during testing

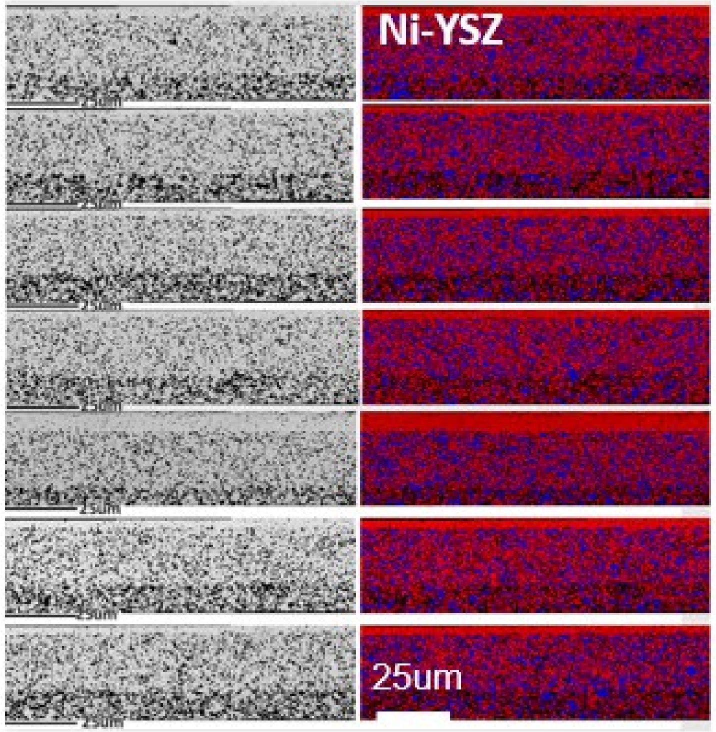


Dopant in barrier layer migrates into YSZ



Ag migration into barrier layer and YSZ

Elemental maps of Hydrogen Electrode



- No obvious Ni migration
- Ni coarsening and Ni – YSZ particle detachment observed in 90-100% steam at 750°C

Responses to Previous Year Reviewers' Comments

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- The project was not reviewed in previous years; no comments have been received

Collaboration and Coordination

Pacific Northwest National Laboratory — Materials, cell fabrication, cell testing, AST development characterization, modeling

Berkeley Lab — Cell testing, emphasis on thermal and electrical cycling

INL Idaho National Laboratory — 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

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- Cell performance needs to be improved via electrode materials R&D
- Ag contacts needs to be eliminated
- Single 10-16 cm^2 cell reproductivity and interlab comparison has not been established
- Degradation mechanisms are affected by interplay of many external factors, not only intrinsic materials properties
- Significant delays with procurement and instrument repairs delay progress

Proposed Future Work

- Cell Optimization:
  - Improve cell performance via electrode optimization
  - Implement advanced manufacturing approaches
  - Identify or develop stable contacts for all cell formats
- Accelerated Stress Tests Development using button and larger size cells:
  - Validate high steam utilization, high voltage, high current, high temperature etc as potential stressors and determine key stressors
  - Define AST protocols and initiate testing using small step change magnitude; this will be an iterative process; identify safe magnitude of accelerating without changing degradation mechanism
  - Rely on performance diagnostics and post test characterization
- Accelerated Stress Tests Development using the interconnect with coatings
- Correlate findings from different cell formats to identify most relevant to industry

Proposed future work is subject to change based on funding levels

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