Low Cost, Large Area SOEC Stack for H_2 and Chemicals

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R&D to Reduce Stack Cost and Improve Durability

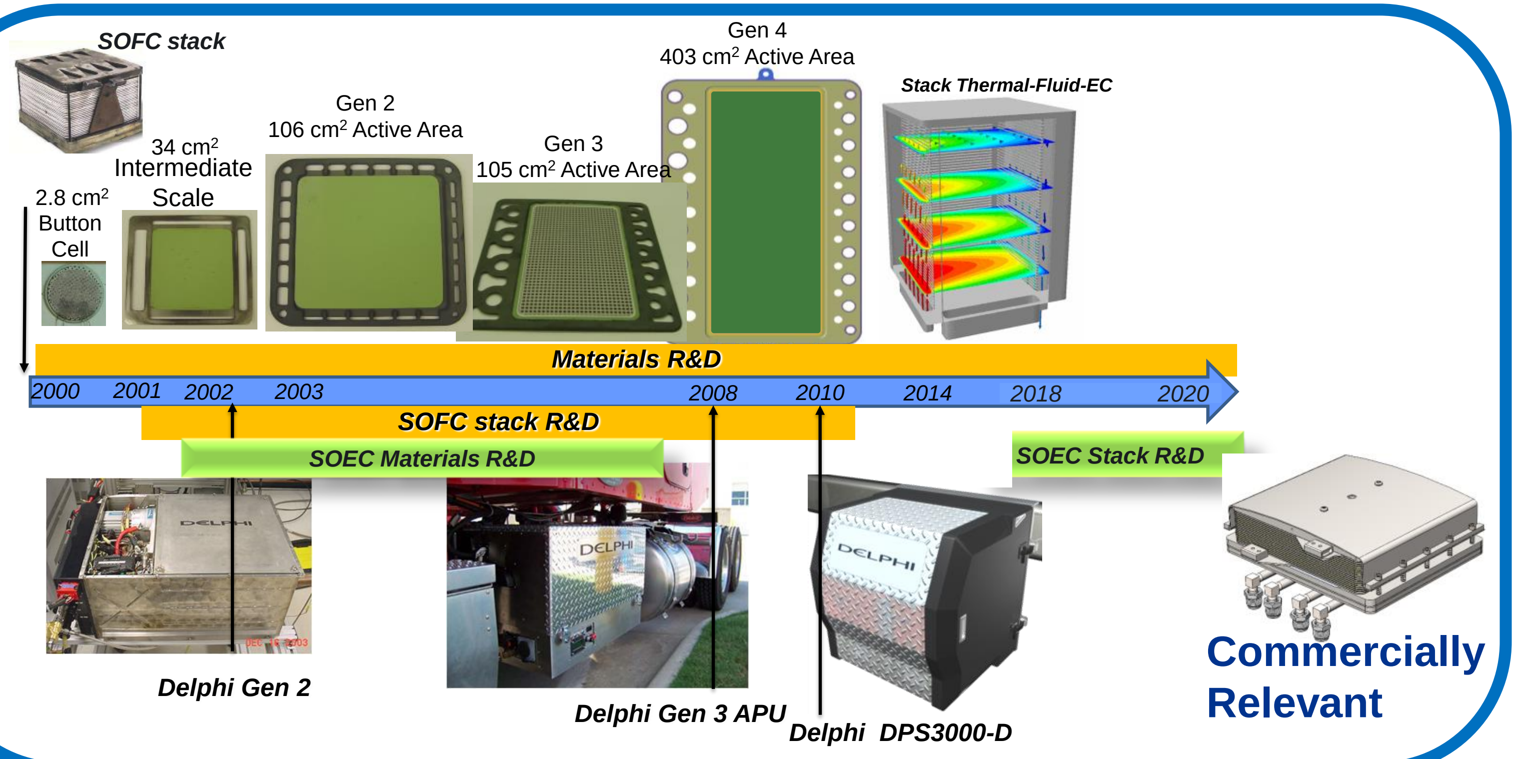
Technical Barriers and Gaps

HTE stack performance and durability remains understudied due to industry proprietary R&D:

- Stack durability is rarely reported
- Cost at scale is not known
- Commercially relevant repeat units are not available

DOE Targets

HTE Electrolyzer Stack Goals by 2025	
Capital Cost	\$100/kW
Electrical Efficiency (LHV)	98% at 1.5 A/cm²
Lifetime	60,000 hr



PNNL has established cells/stacks fabricating and modeling capabilities and expertise from multiple DOE SOFC R&D programs and private investments

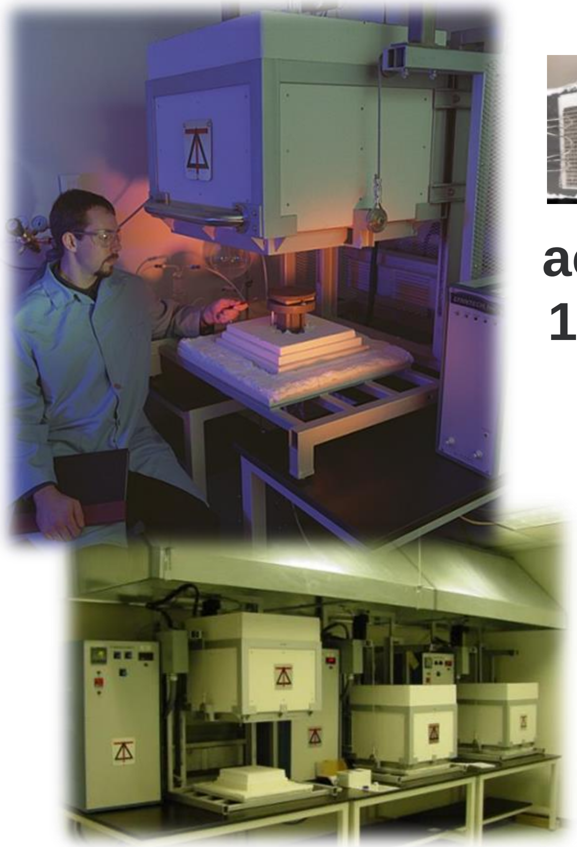
PNNL Tests Button Cells, Full Size Cells and Stacks

High throughput button cell testing (~50 cells)

active area 2-4 cm²

- I-V and EIS measurements
- pH_2O=1-99%
- Impurities

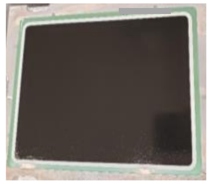
Larger size cell testing



active area 16 cm²

- Relevant steam utilizations
- Higher currents
- T gradients
- Interconnect

Short 1-5 kW stack testing



active area 300 cm²

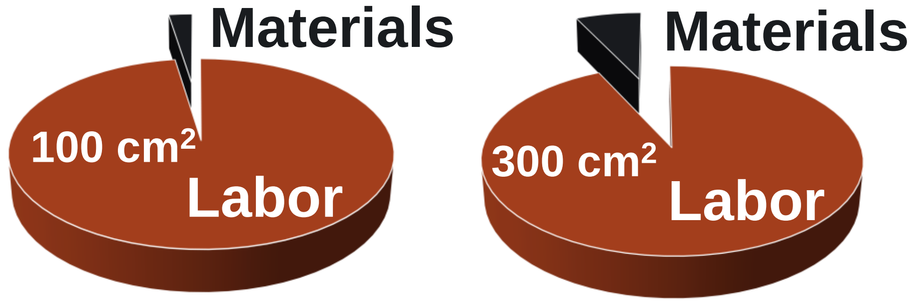
- Components
- Seals
- Steam delivery and utilization
- Heat management
- Durability

Develop and Build an Efficient 5 kW Solid Oxide Electrolyzer and Demonstrate Operation under Simulated, but Commercially Relevant Conditions

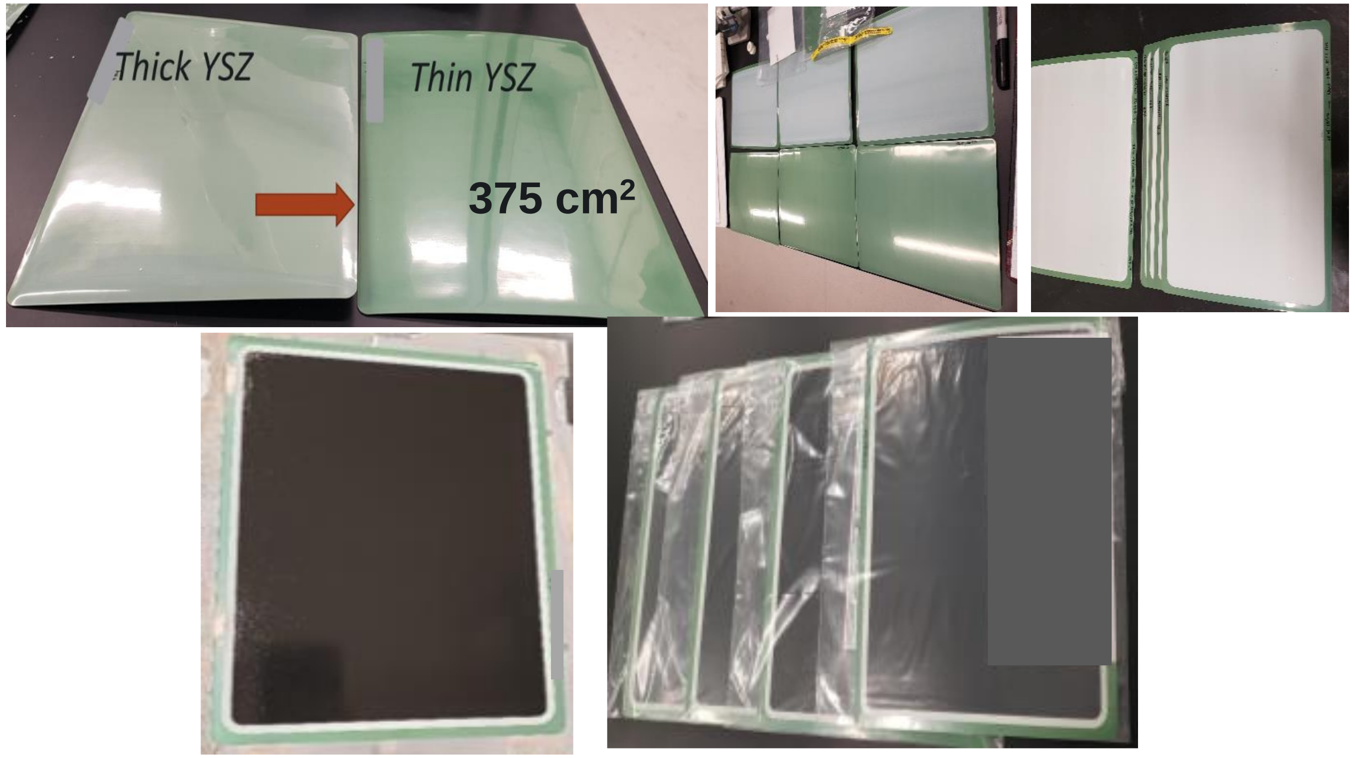
- Design electrode cassette modules of a commercially relevant size that include a large 300 cm^2 active area cell, a metal frame and channels for gas flow.
- Develop and employ optimized materials to provide the best possible combination of performance, lifetime and cost.
- Produce and demonstrate an operation of a stack under realistic conditions.

Identifying Pathways to Lower Stack Cost: Large Format Cells

Increasing cell size does not increase cost



Cell Production Established



Impact:

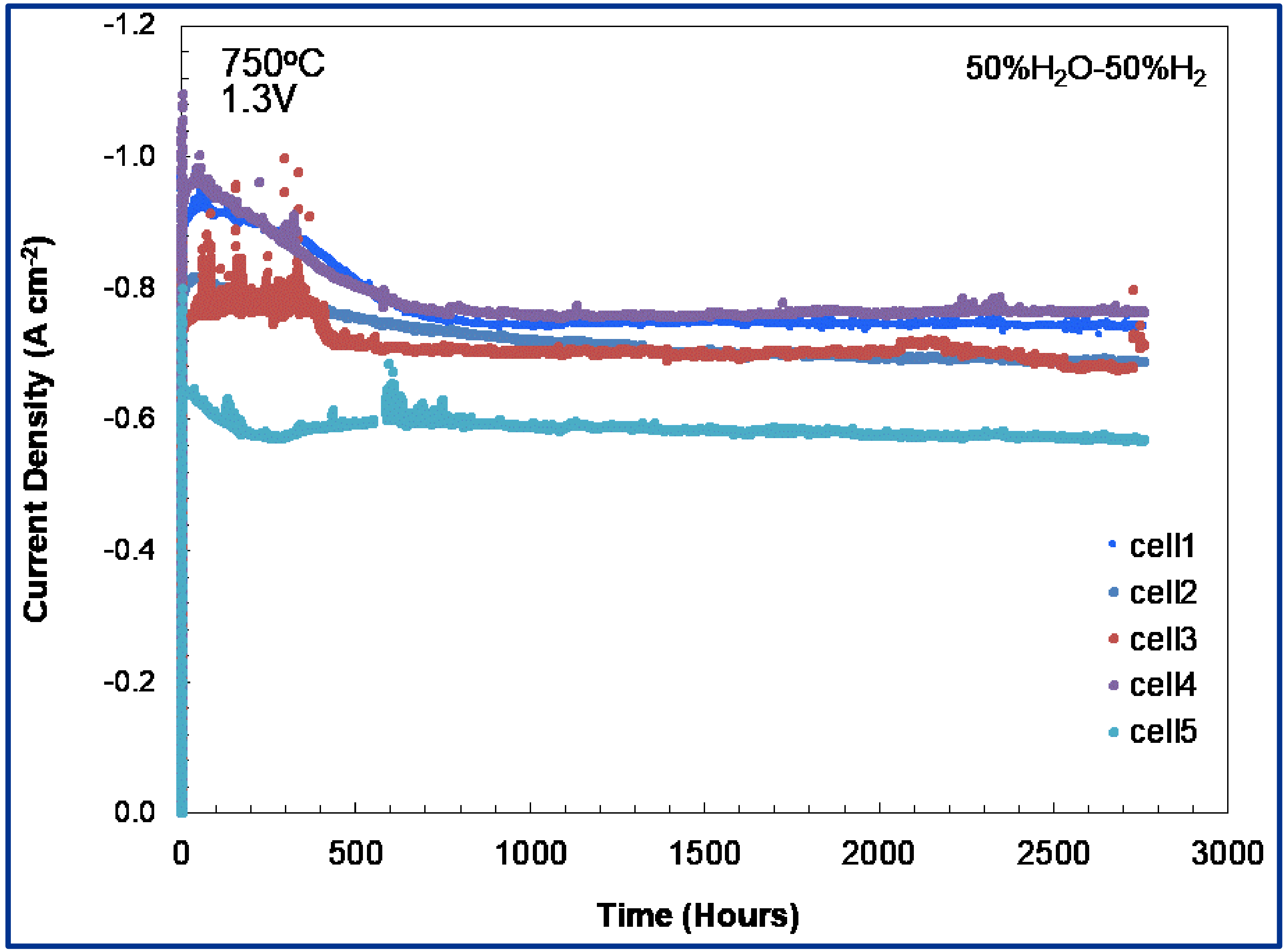
- Reduced number of all parts by a factor of 3
- Reduced number of interfaces, thus failures/degradations

Difficulty:

- Materials properties
- Equipment size
- Variability in materials sources, different materials purity

- Successfully produced large cells
- Decreased YSZ thickness to reduce firing steps, cost and improve the performance
- Oxygen electrode is being optimized
- Initiated QA/QC

Demonstrated Cell Stability in Long-Term SOEC Tests Using Multiple Repeats



- Validated electrode activity and cell performance at 750ºC using button cells fabricated in a similar fashion
- Established a baseline cell performance for 2800 hours
- Identified and eliminated the degradation mechanism responsible for the initial performance loss

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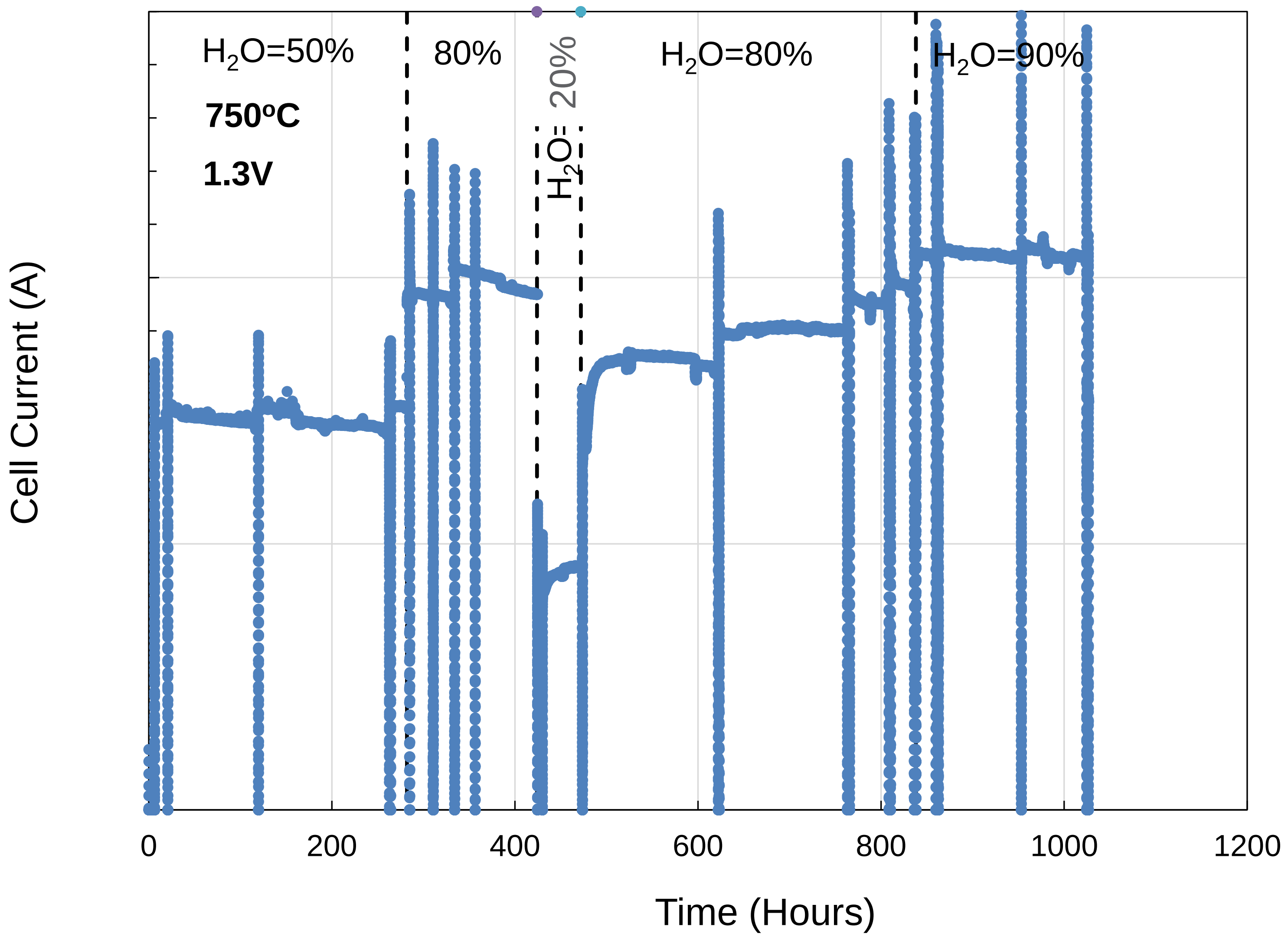
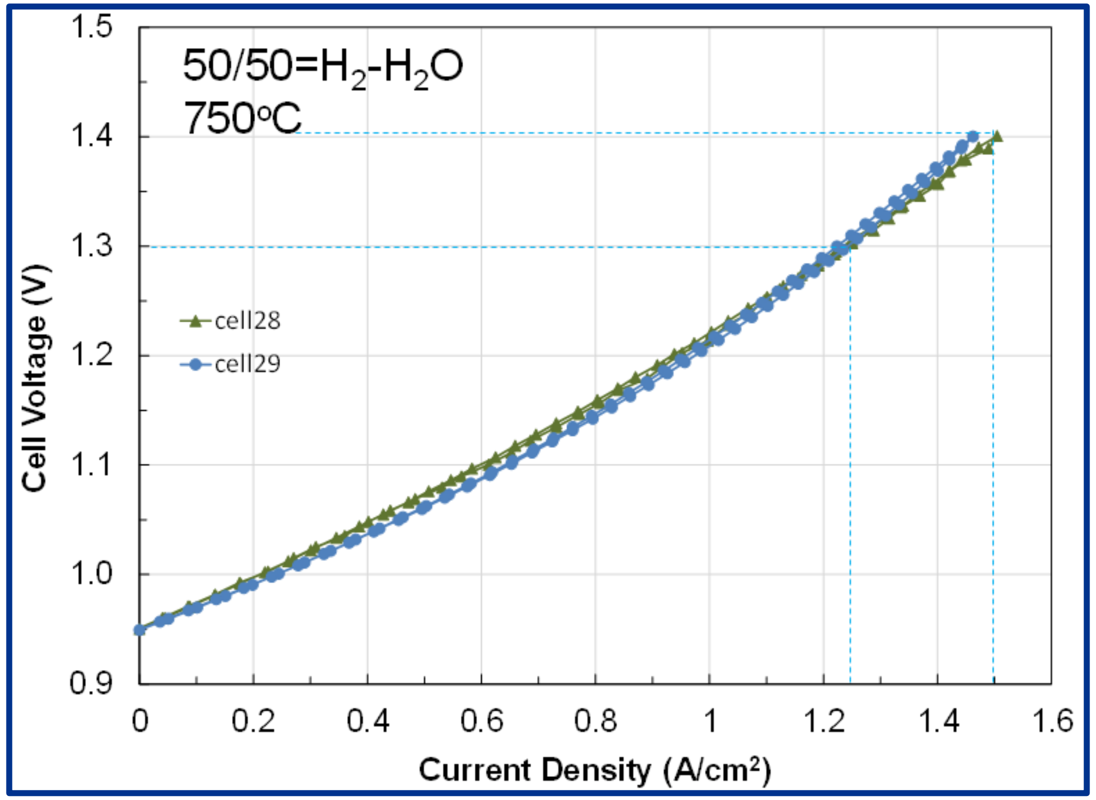
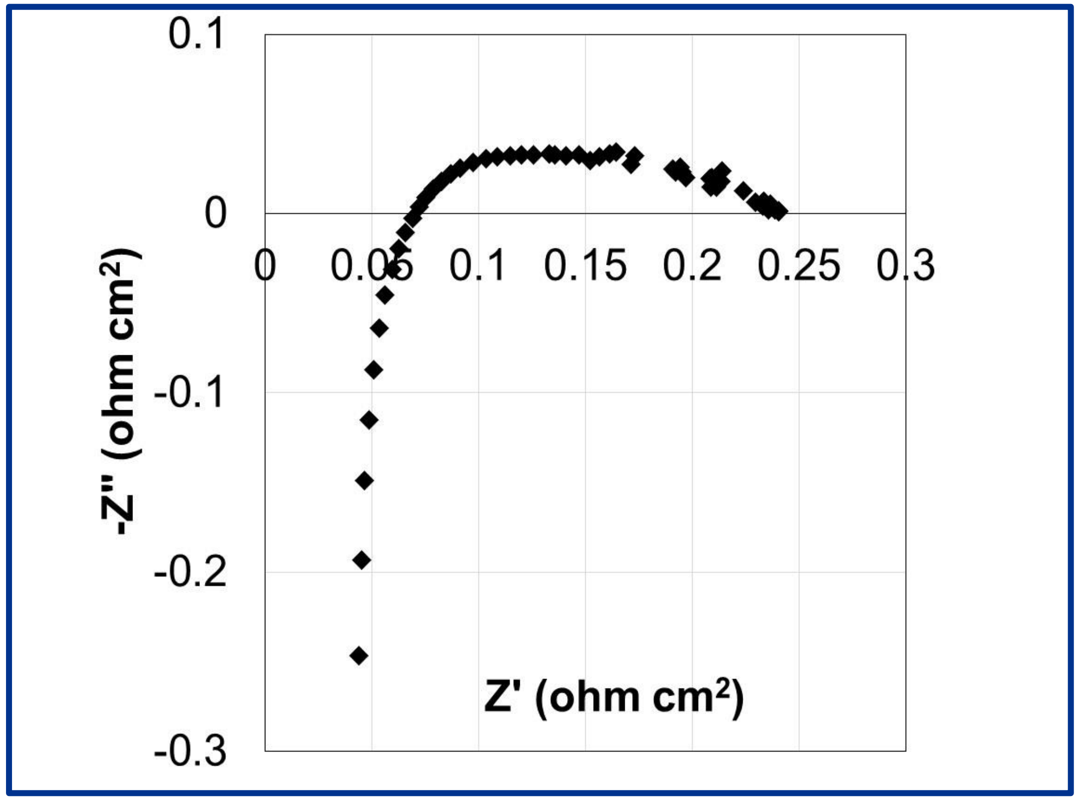
Demonstrated Cell Stability in High Steam Contents under Varied Loads

- Validated cell performance in single smaller-size planar cells for 1000 hours
- Assessed cell stability in different gas compositions with H_2O varied from 20 to 90% and steam utilization 50-70%
- Performed multiple load cycling



Optimizing Fabrication Steps to Lower ASR





- Exploring multiple approaches of cell fabrication to reduce ASR
- Not changing electrode chemistry
- Long-term testing to be assessed

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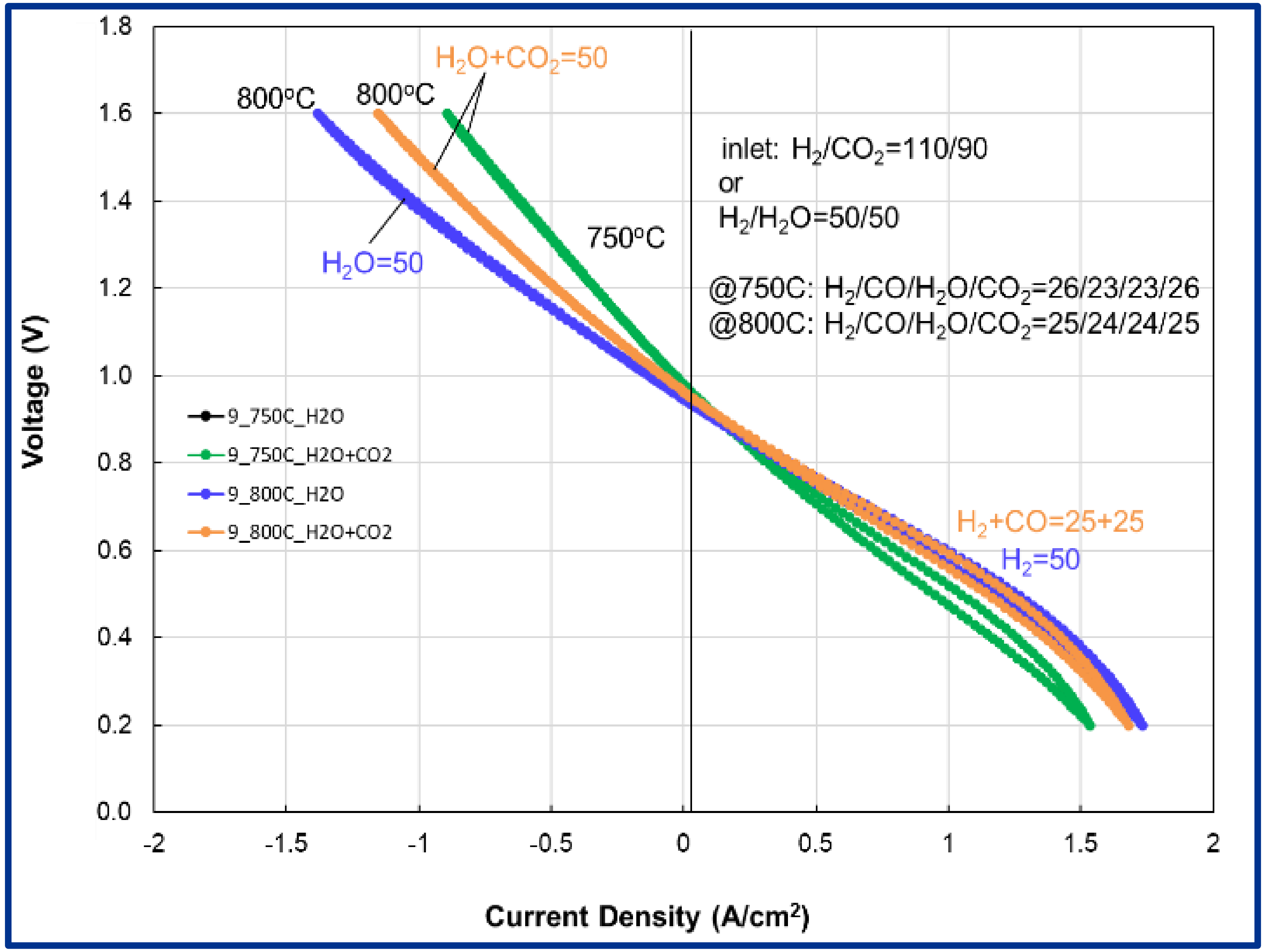
Demonstrated Cell Activity to Co-electrolyze CO_2 and H_2O to Syngas and Reversibility in the Presence of High CO_2 Concentrations



- Assessed cell stability in different CO_2-H_2O compositions with CO_2 varied from 25 to 90%

- Demonstrated syngas production and reversibility of cell operation

Modified the PNNL SOFC-MP Simulation Software to Simulation SOEC with Various Gas Species

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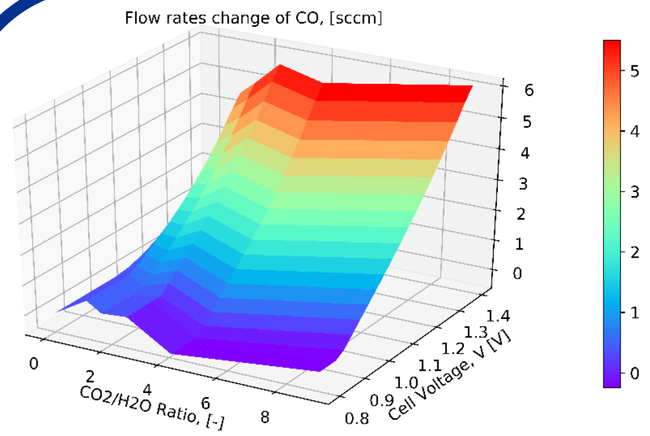
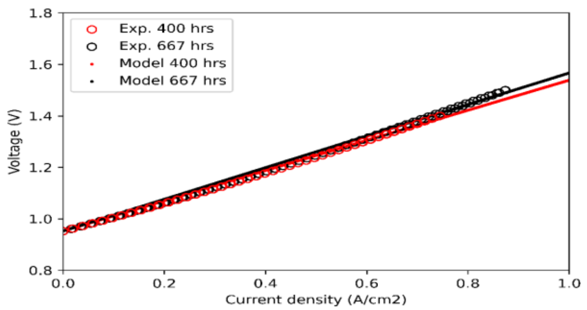
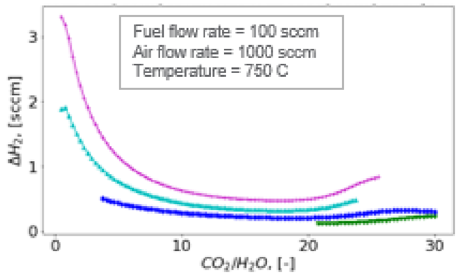




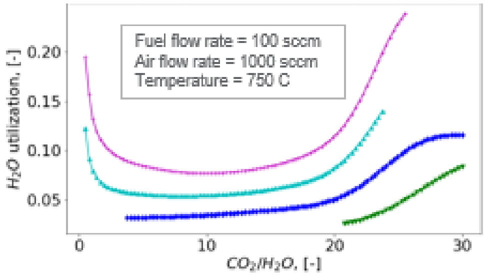
ROM Input Parameters	cell voltage	Fuel flow rate	Temperature
	CO_2/H_2O	Air flow rate	
ROM Output Parameters	ΔH_2	Current density	$(\Delta H_2+\Delta CO)$/Total Power $\Delta CO/\Delta H_2$ CO_2 utilization H_2O utilization
	ΔH_2O	Max cell temperature	
	ΔCO	Delta cell temperature	
	ΔCO_2	Outlet Fuel Temperature	
	ΔCH_4	Outlet Air Temperature	

Predict the cell electrochemistry and thermal performance

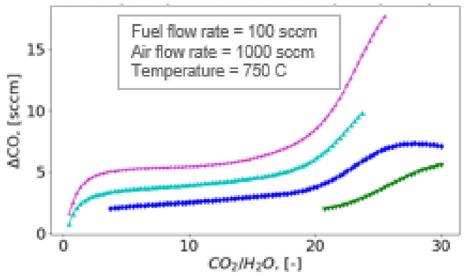
(1) ΔH_2 vs. CO_2/H_2O and voltage



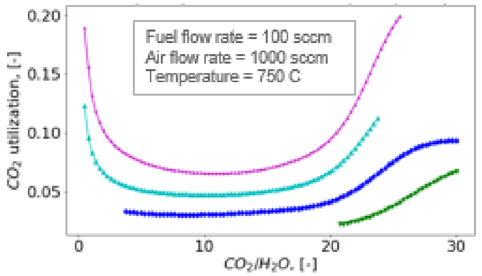
(2) H_2O utilization vs. CO_2/H_2O and voltage



(3) ΔCO vs. CO_2/H_2O and voltage



(4) CO_2 utilization vs. CO_2/H_2O and voltage

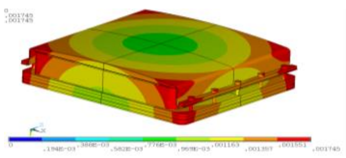


- Calibrated the model to match both SOEC performance degradation and current-voltage relationships
- Completed sensitivity study of SOEC performance with SOFC/SOEC-MP solver and reduced order model for 2-300 cm^2 cells; Completed predictive modeling for syngas production rate using varied CO_2/H_2O ratios
- Contracted the DNN-based ROMs; cell voltage, CO_2/H_2O ratio, and inlet temperature were the top input parameters that impact the cell performance the most
- Initiated long-term SOEC degradation modeling using SOx poisoning and $SrZrO_3$ formation

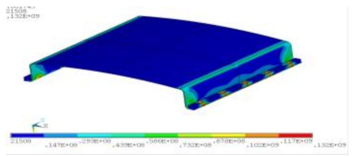
Stack Structural Integrity and Reliability Analysis Predict Low Failure Probability

- Designed stack components and validated the design using thermomechanical analysis for structural integrity to predict stack and enclosure level displacements, stresses and investigate any TEC mismatch issues

- The reliability analysis mapped potential failure probabilities concentrated locally to specific areas of the cell depending on operating voltages and operating conditions

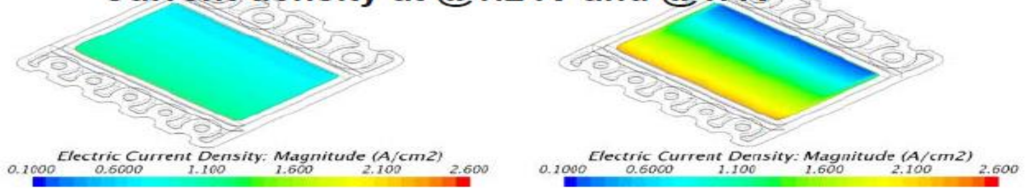


Stack overall displacements (in-plane max ~1mm)

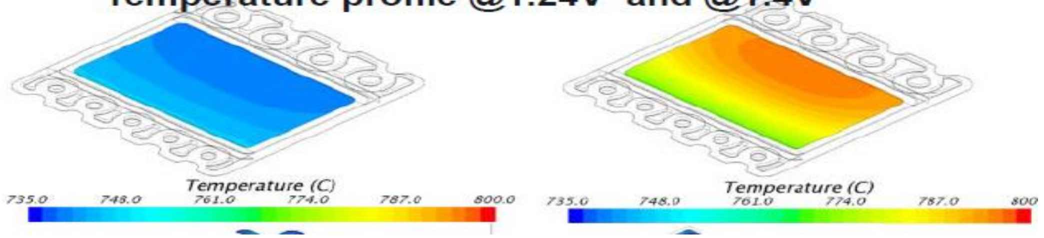


High local stresses in casing (near bolt holes)

Current density at @1.24V and @1.4V



Temperature profile @1.24V and @1.4V



Cell temperature profile

Principal stress distribution

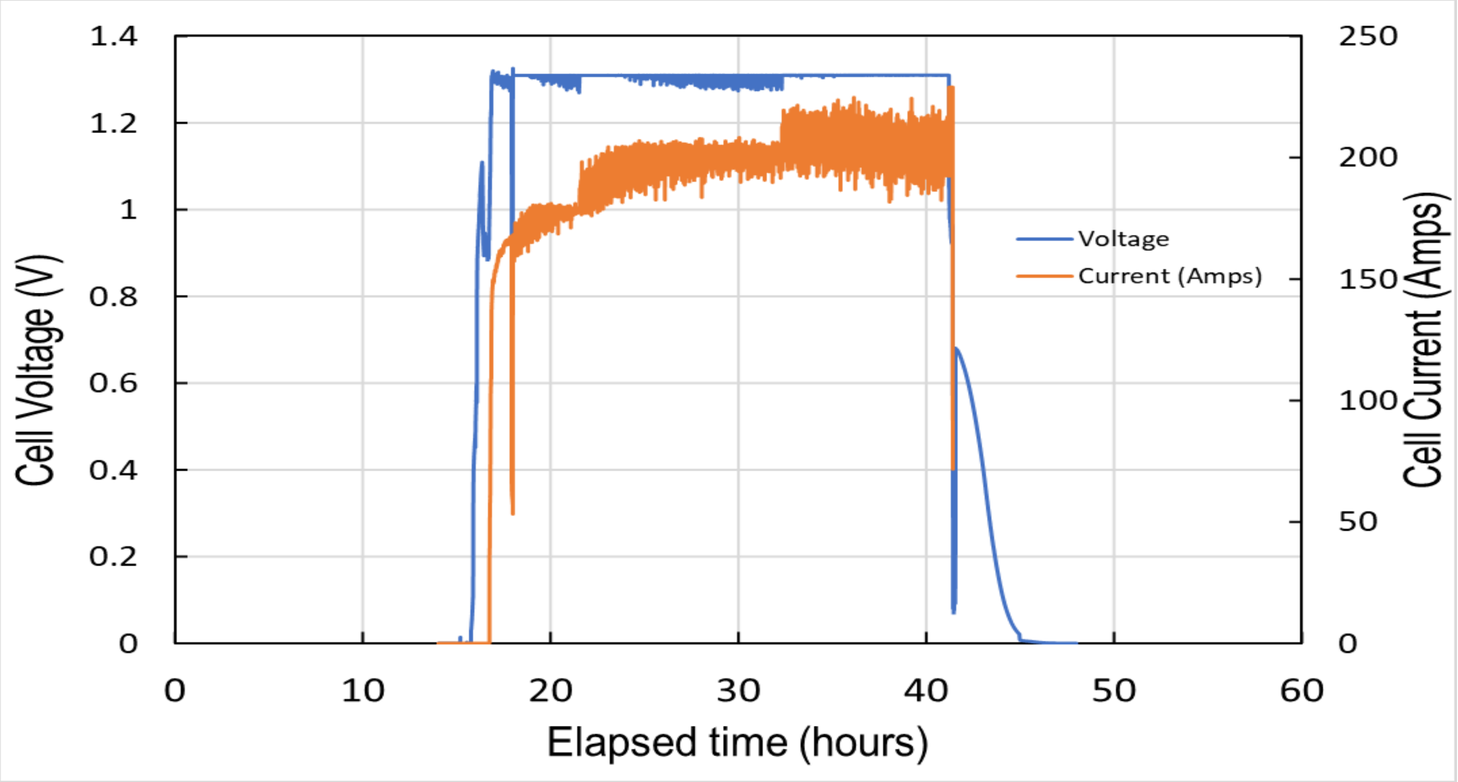
Bao et al, ECS Trans., SOFC-17

Using 300 cm^2 Active Area Cells Reduces Stack Parts by 67%

- Designed and fabricated metal cassettes
- Developed a process for sealing large cells into the metal frames
- Initiated short stack assembly and shakedown testing; addressed multiple issues
- Performed short stack baseline testing under realistic steam utilization and hydrogen production rates

Single unit stack with a 300 cm^2 active area cell

Meinhardt et al, ECS Trans., SOFC-17



Summary

- Aiming to enable DOE to develop appropriate SOEC stack cost, performance, and durability targets by linking fabrication and manufacturability to performance, degradation, and cost
- Determine actual stack efficiency at 80-90% steam utilizations
- Conduct stack performance and durability assessments
- Conduct bottom-up manufacturing cost assessment

Acknowledgements

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