



DOE Hydrogen and Fuel Cell Office  
2024 Annual Merit Review and Peer Evaluation Meeting

May 7, 2024

# Low-Cost Large Area SOEC Stack for Hydrogen and Chemicals Production

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**Project ID # FE006**

DOE FECM Project Award 77108

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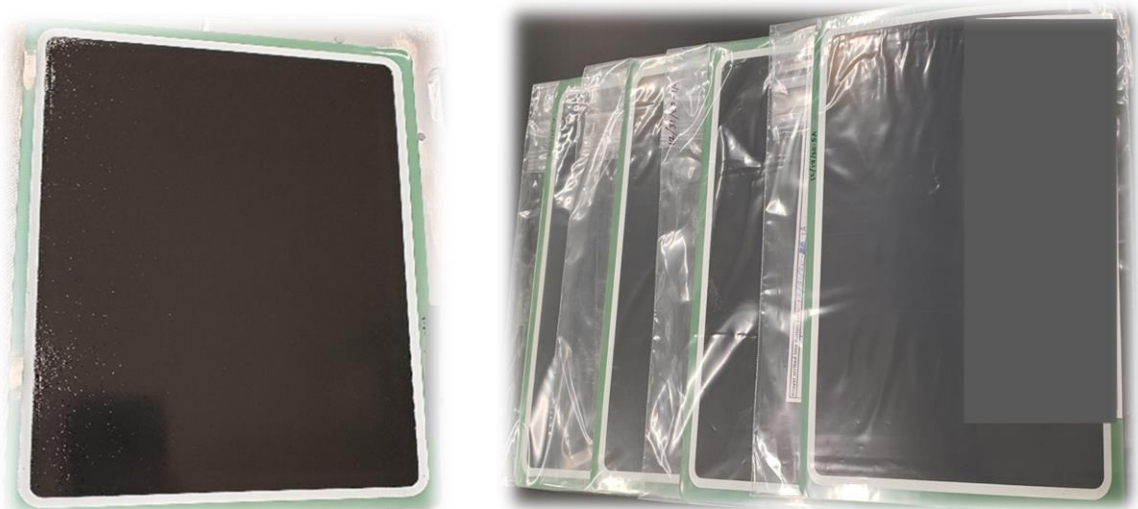
# **OBJECTIVE: Develop and Build an Efficient 5 kW Solid Oxide Electrolyzer and Demonstrate Operation Under Simulated, but Commercially Relevant Conditions**

- Design and construct cells with  $\sim 300 \text{ cm}^2$  active area
- Validate performance in short stacks
- Develop and employ optimized materials to provide the best possible combination of performance, lifetime and cost
- Model the performance of the cells and stack to include consideration of gas flow rates, cell and stack potential, current density, temperature/temperature distributions, and fuel utilization
- Produce and demonstrate an operation of a stack in the electrolysis mode under realistic conditions for, at least, 500 hours
- Demonstrate a stack degradation rate of less than 0.4%/1000 hours

# Approach

- Develop process to fabricate ~300 cm<sup>2</sup> active area cells using state-of-art materials
- Fabricate repeat units (cell, metal frames, and interconnects)
- Fabricate manifolds, load frames and stack current collectors
- Assemble several short 2-5 cell stacks and perform short shakedown and acceptance tests
- Perform short duration parametric tests as well as at least one long-term durability test over 1000 hours to obtain realistic steam utilization and hydrogen production rates as functions of operated voltage/current
- Perform post-mortem characterization using SEM, TEM and other tools, as needed
- Complete stack design validation using 2D and 3D modeling as well as structural modeling for reliability validation

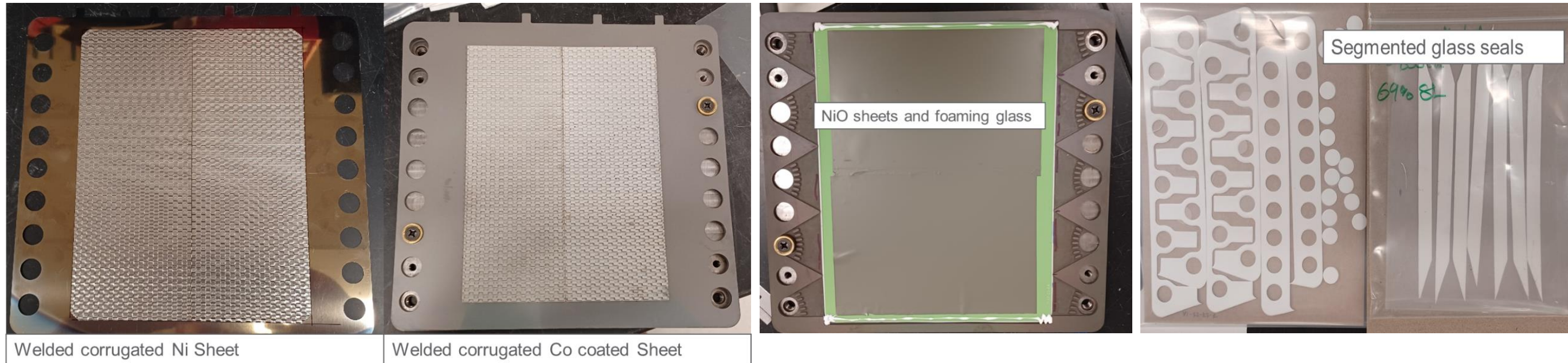
# Cell Production of Different Sizes Established



- ❑ Ni-YSZ electrode-supported planar cells have been selected as standard reference cells
- ❑ Developed a batch fabrication process to minimize the variance between separate cells
- ❑ Initiated the development of QA/QC procedures
- ❑ Successfully produced large cells to reduce stack part count, the number of interfaces in stack, and cost



# Cassette Assembly

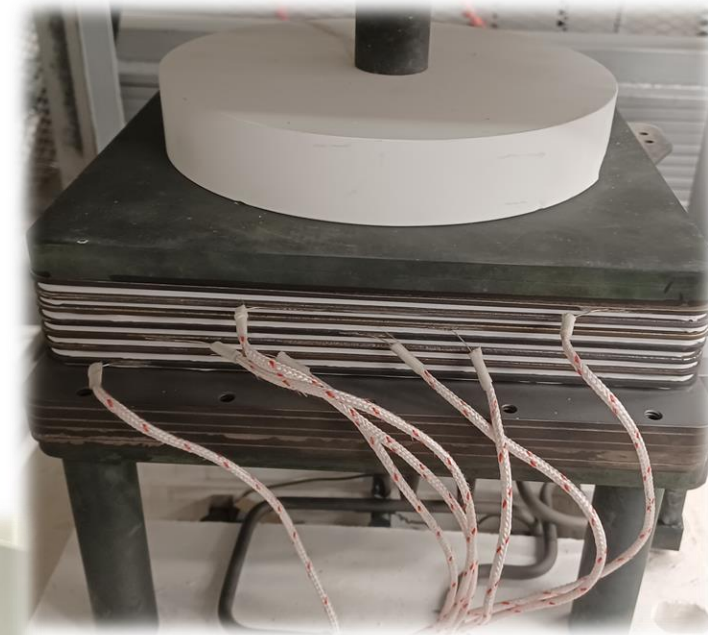
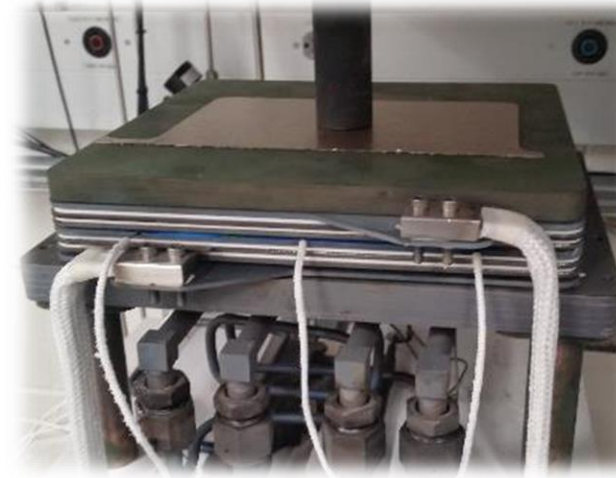
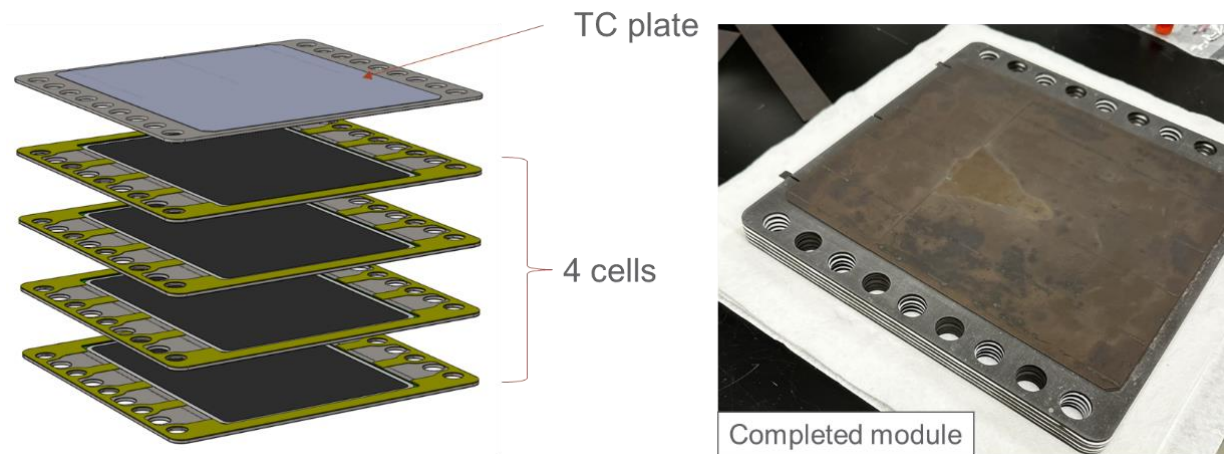


- Window frame: 430 SS, Al coated (sputtering)
- Air side contact: 444 SS, Co coated (electroplating)
- Hydrogen side contact: metal Ni, uncoated



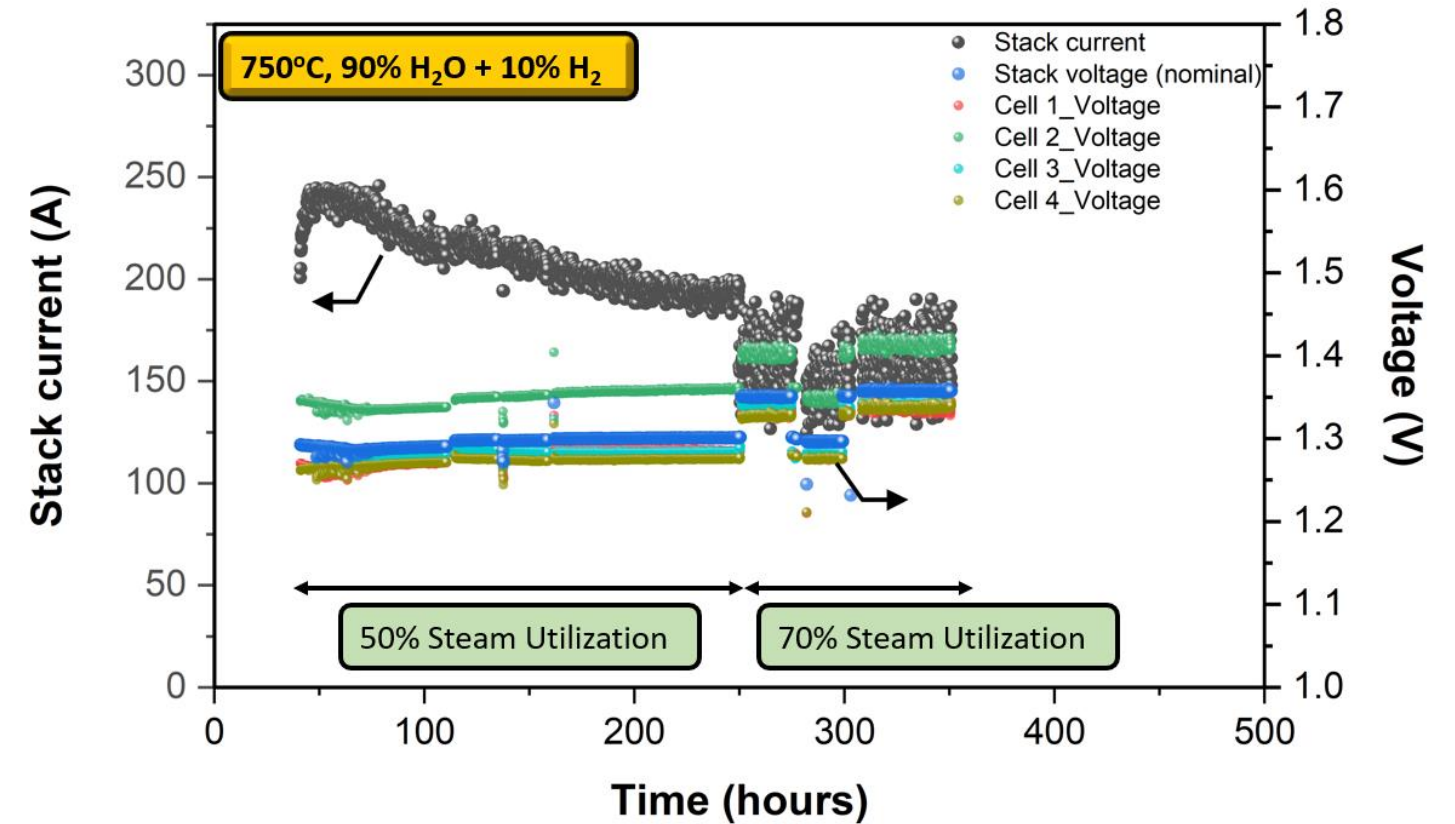
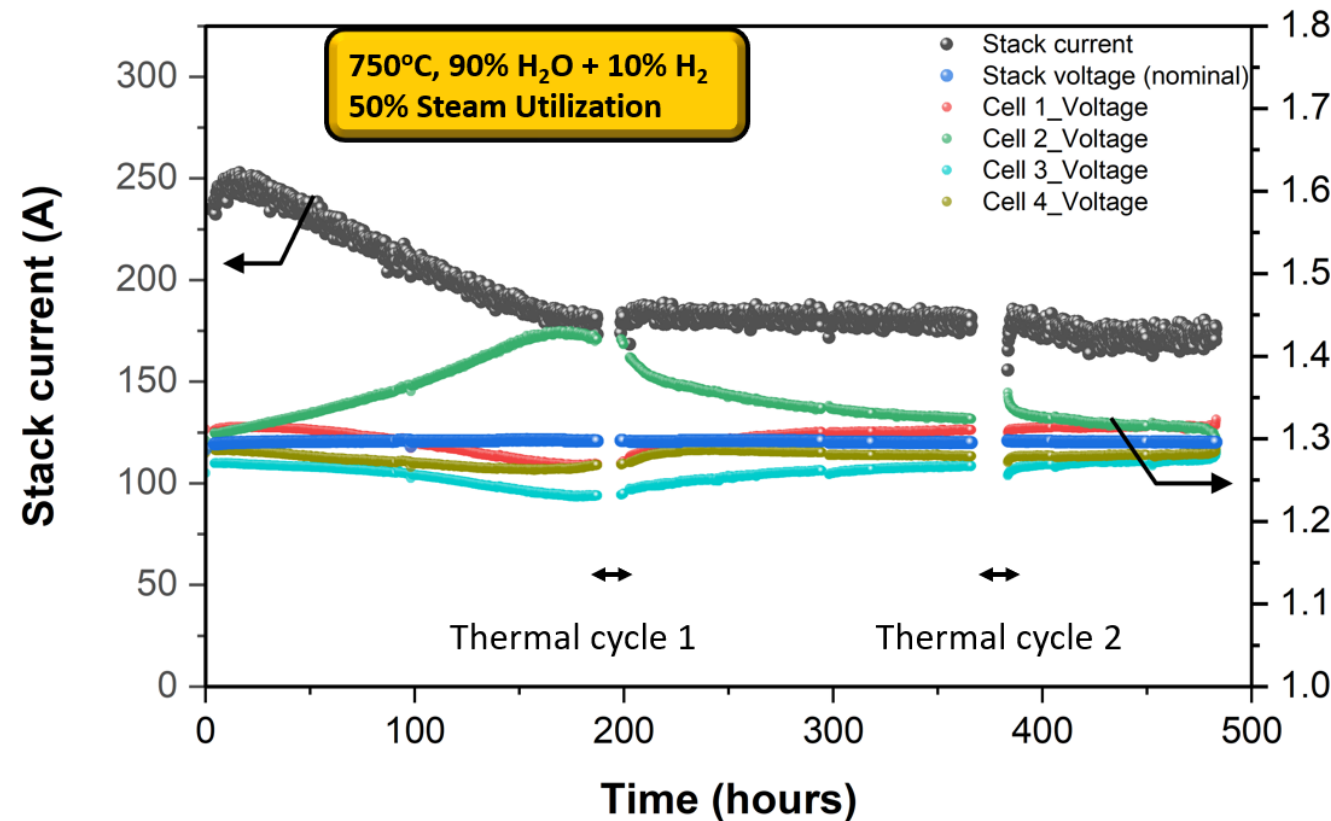
# Stack Assembly and Testing Using 300 cm<sup>2</sup> Active Area Cells

- Produced multiple well-sealed cassettes with large 300 cm<sup>2</sup> active area electrode-supported SOEC cells
- Assembled and tested 16 short stacks of different sizes, ranging from 250 W to 1 kW



**1 kW SOEC stacks  
with 300 cm<sup>2</sup> active  
area cells**

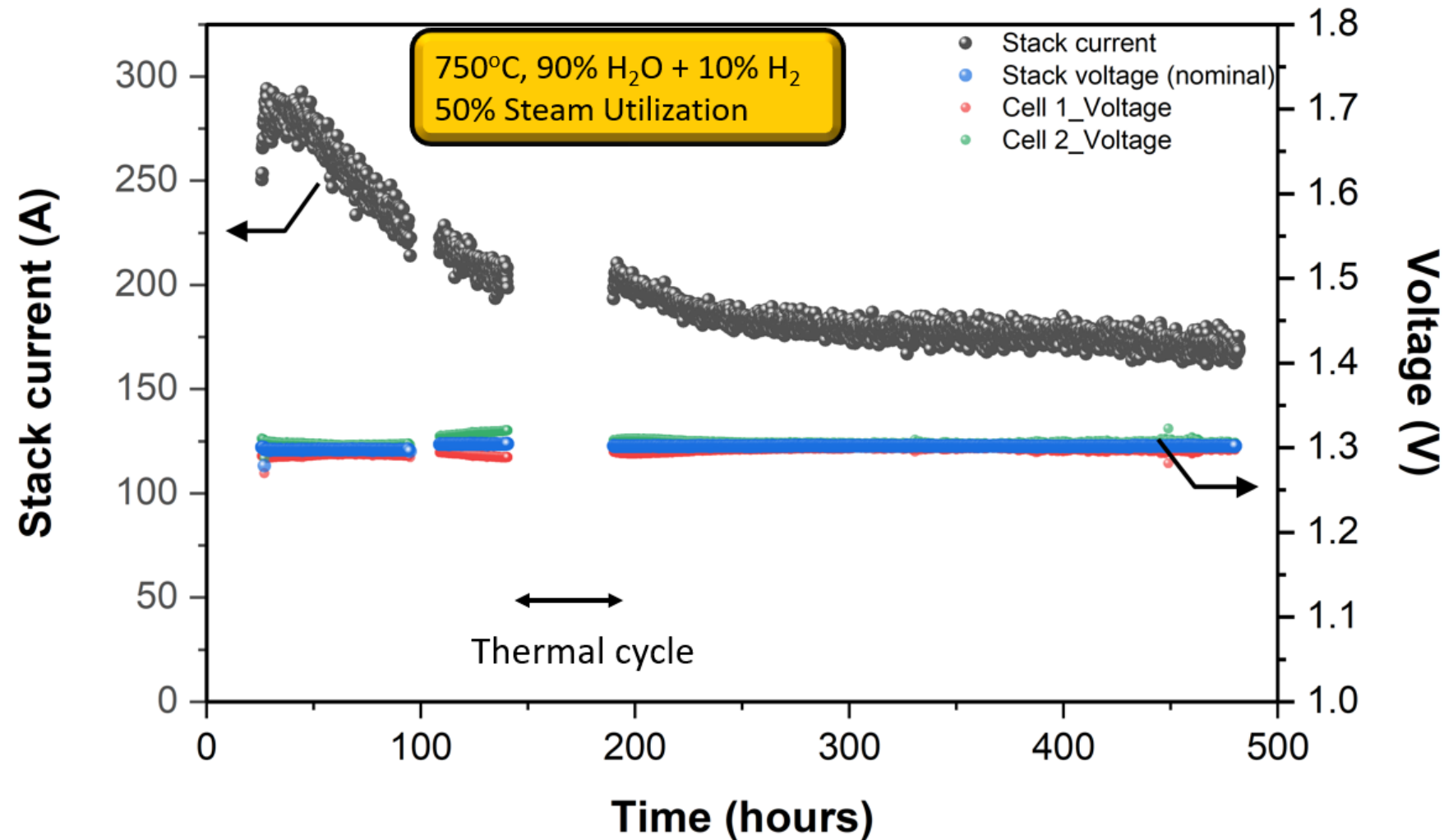
# Achieved 500 hours of Testing 1.3 kW Stacks with Large Cell Area



- 4 cells yield 1 kW stacks
- Maximum operation time was 500 hours
- Completed multiple thermal cycles
- Achieved 70% Steam Utilization Using 1.3 kW Stacks with Large Cell Area



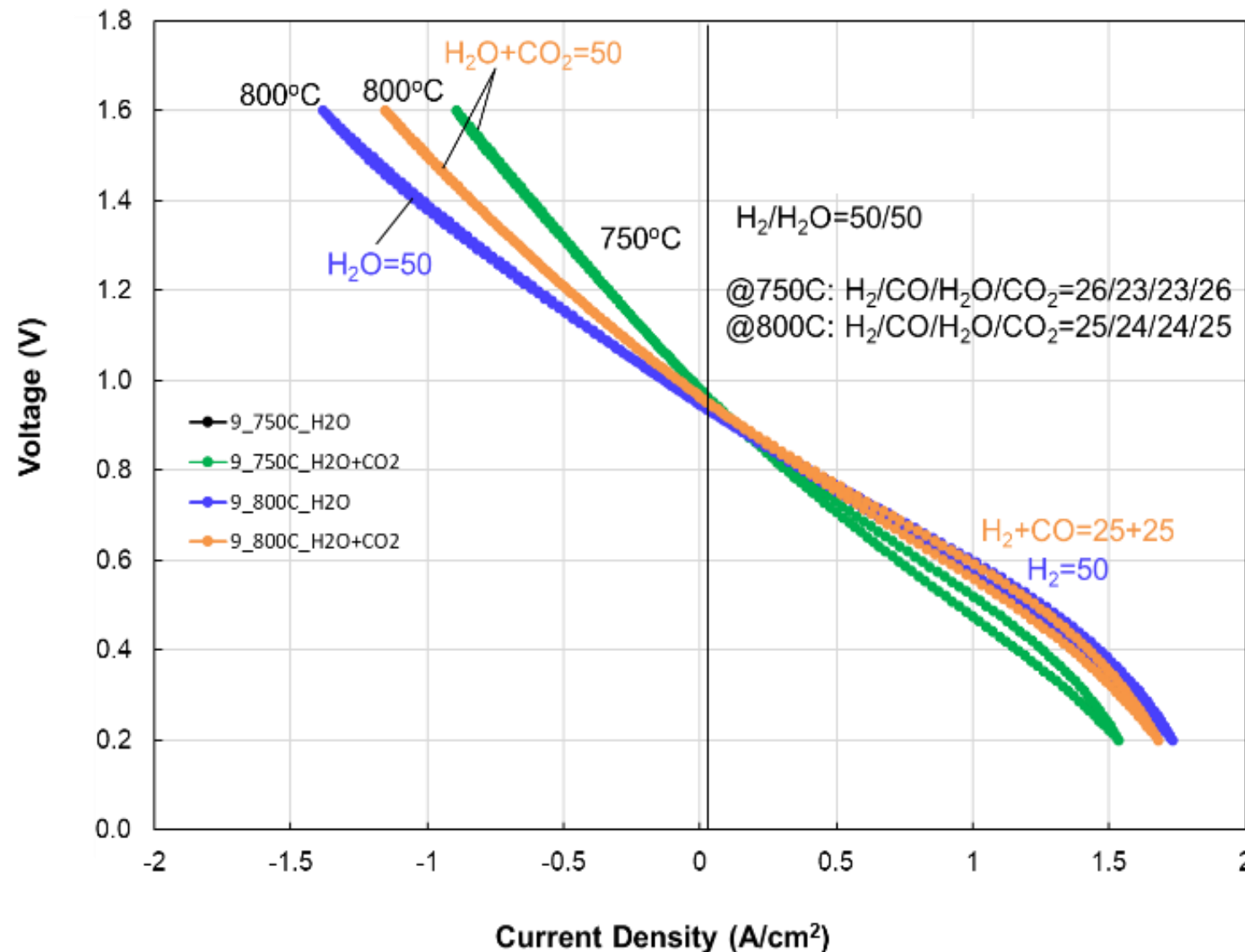
# Improved Current Density by Improving Electrical Contacts



- Modified sealing procedure to obtain the electrical contact at lower temperature, below typical sintering temperature
- Achieved initial 1 A/cm<sup>2</sup> in 90% steam at 50% steam utilization
- In a 2-cell stack, the steam utilization was 40-50%, lower than in 4-cell stacks, because vaporizer was not designed for small stacks
- The stack was successfully thermally cycled with no increase in leak rate and the stack returned to the same power. Thermally cycled again then ran for <500 hrs in total and cooled.

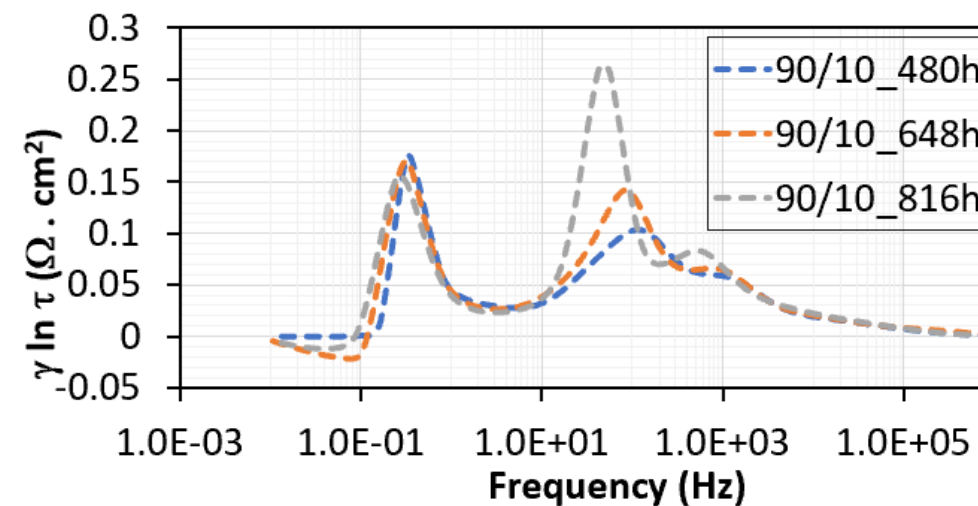
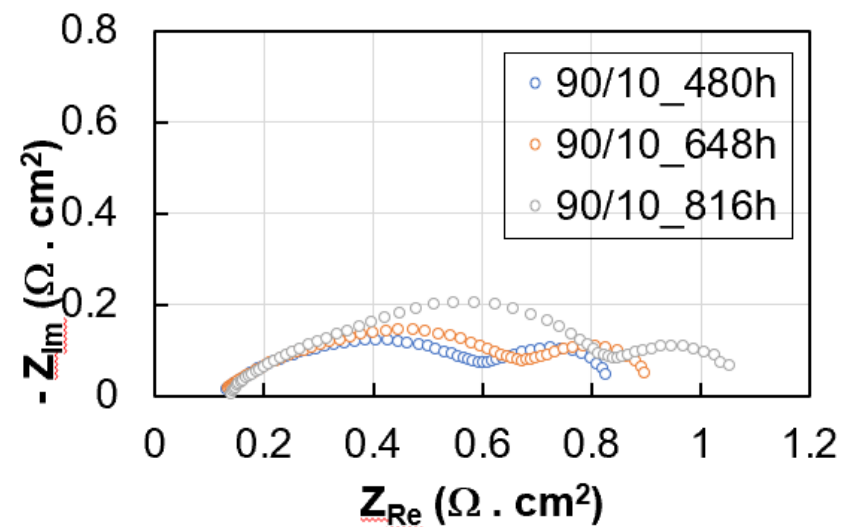
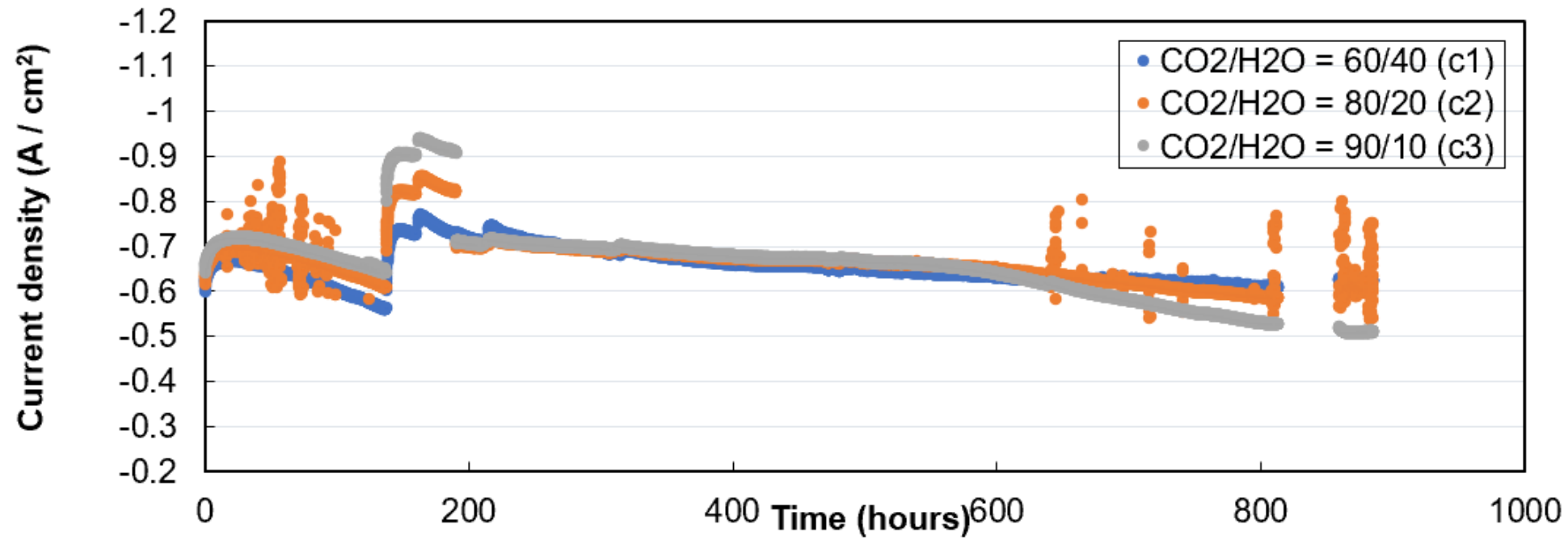


# Demonstrated Cell Reversibility in the Presence of High CO<sub>2</sub> Concentrations

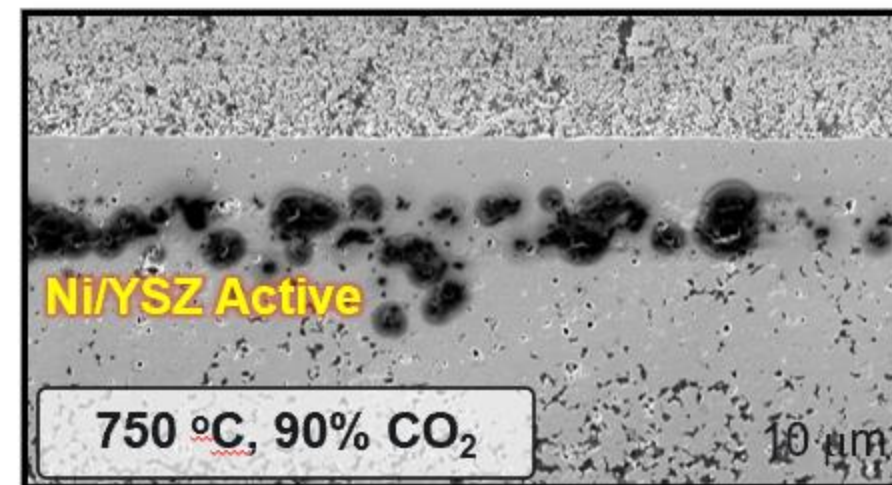
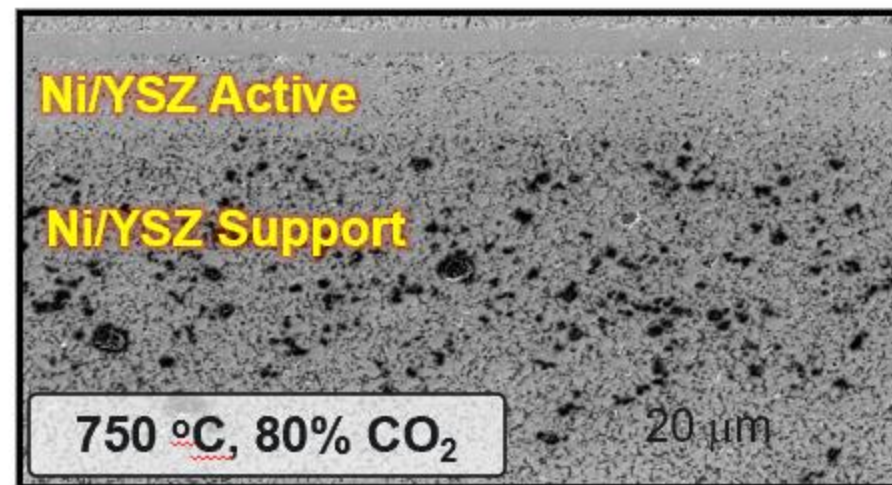
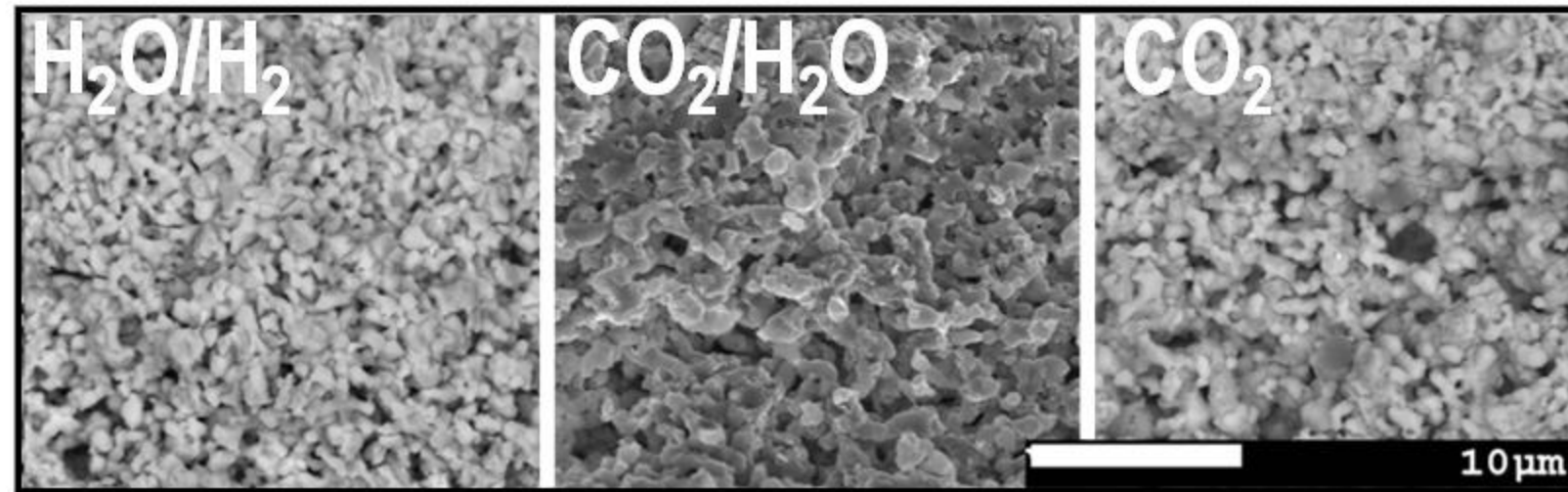


- Assessed cell stability in different CO<sub>2</sub>-H<sub>2</sub>O compositions with CO<sub>2</sub> varied from 25 to 95%
- Demonstrated syngas production and reversibility of cell operation

# Higher CO<sub>2</sub> Concentrations Lead to Increased Degradation in Long-Term Tests



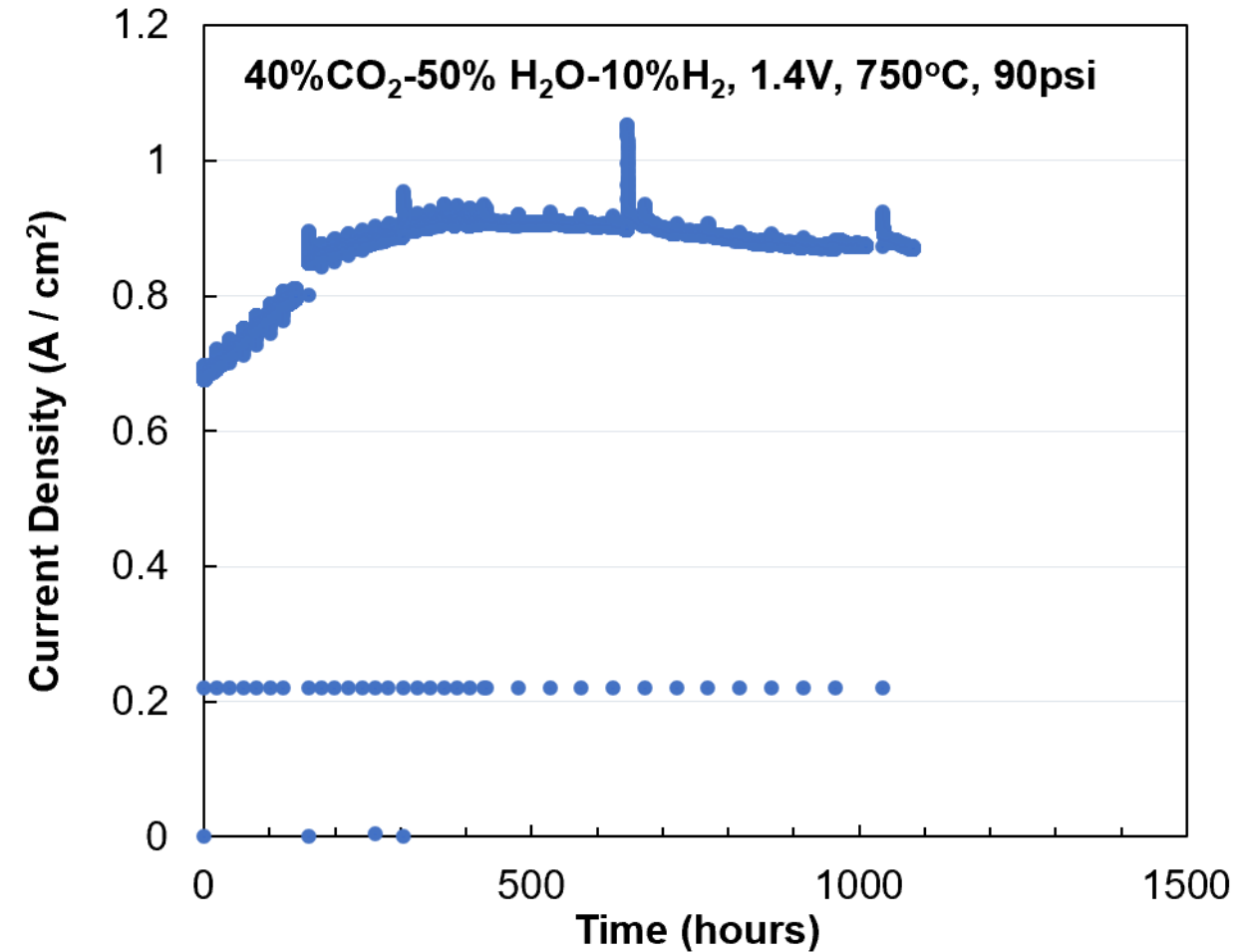
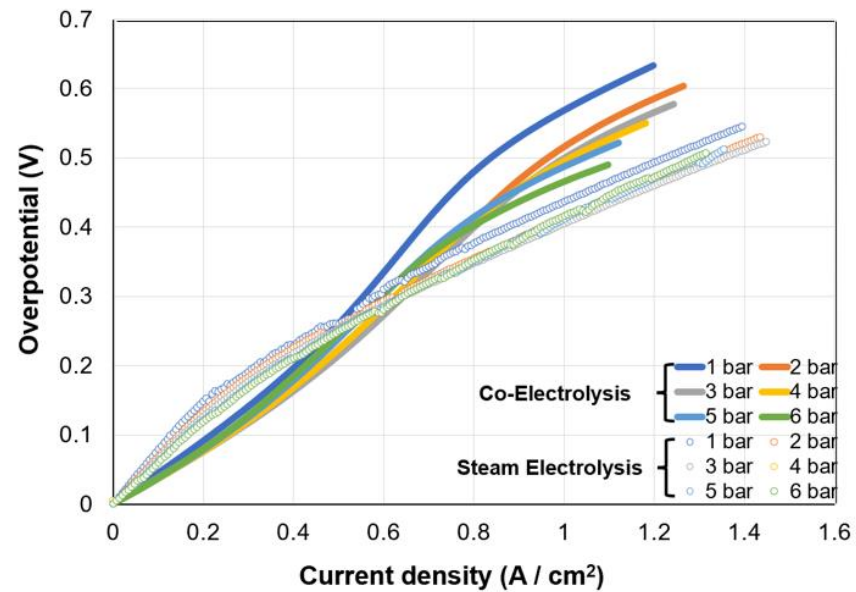
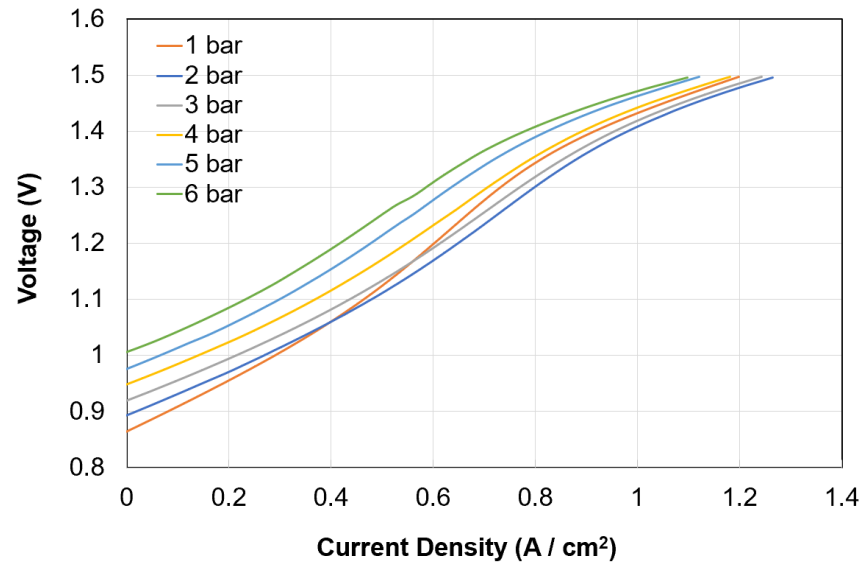
# After 1000 hr, Coking was Observed at High CO<sub>2</sub>





# Co-Electrolysis: 40%CO<sub>2</sub>-50%H<sub>2</sub>O-10%H<sub>2</sub>, 750°C

## Electrolysis: 50%H<sub>2</sub>O-50%H<sub>2</sub>, 750°C

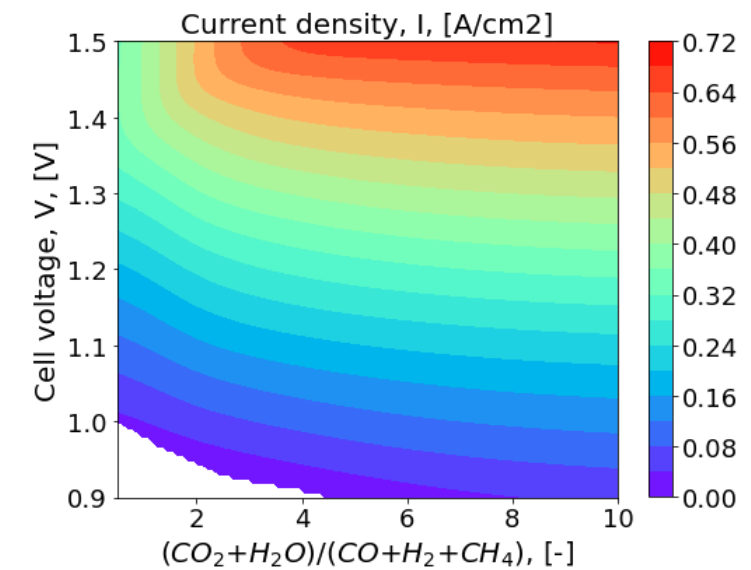
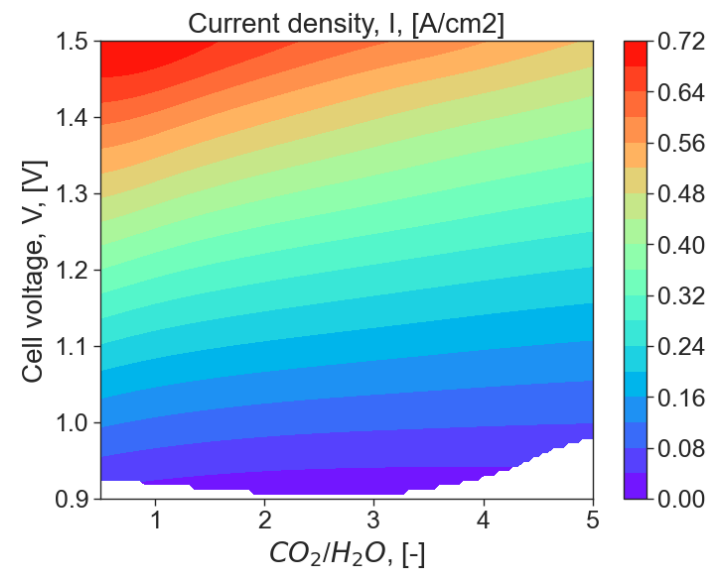
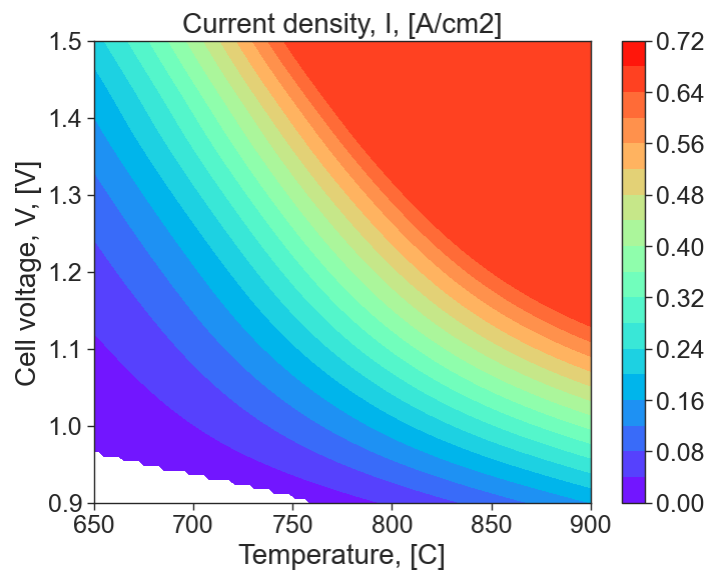


# Developed Model to Predict Ideal Operating Conditions and Critical Factors for Co-Electrolysis

- The deep neural network (DNN) was applied to construct the reduced order models (ROM) for co-SOEC
- The DNN based ROM provides higher prediction accuracy than the conventional regression approaches
- DNN-ROM helps on understanding the response of the cell performance to the operating conditions
  - Previously developed SOFC-MP solver were utilized as the input models
  - Assuming quasi-two-dimensional, three major reactions involved
    - Steam electrolysis  $2H_2O \rightarrow 2H_2 + O_2$  *endothermic*
    - RWGS  $CO_2 + H_2 \leftrightarrow CO + H_2O$  *endothermic*
    - methanation  $3H_2 + CO_2 \leftrightarrow CH_4 + H_2O$  *exothermic*
  - A few of operating parameters are considered essential in this study:
    - ✓ external voltage V
    - ✓ fuel ratio:  $(CO_2+H_2O)/(CO+H_2+CH_4)$
    - ✓  $CO_2/H_2O$  ratio,
    - ✓ operating temperature T
    - ✓ fuel flow rate / air flow rate

# Critical Factors in co-SOEC Performance

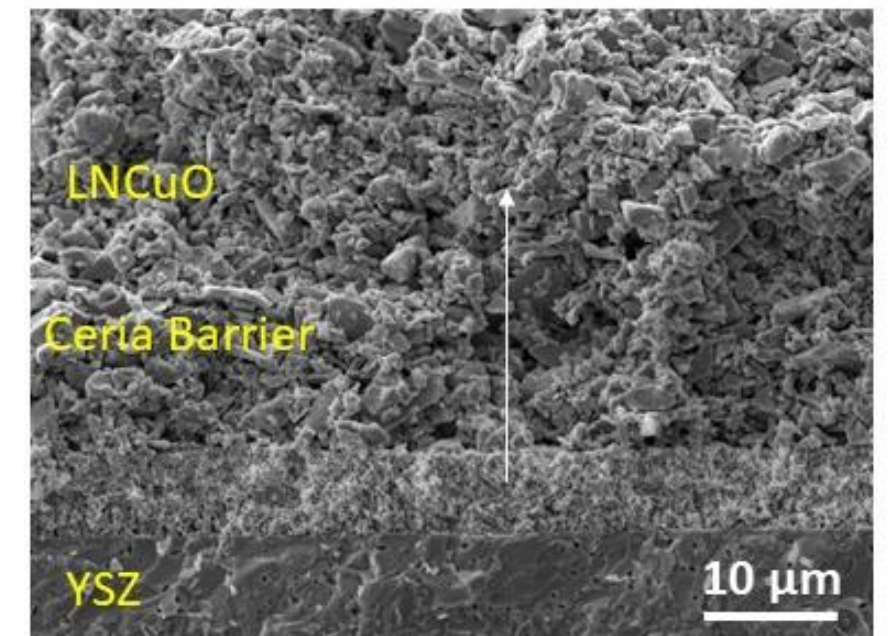
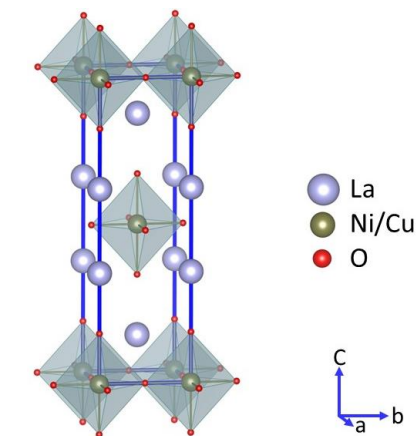
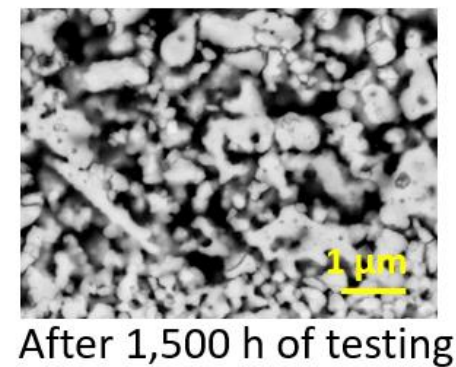
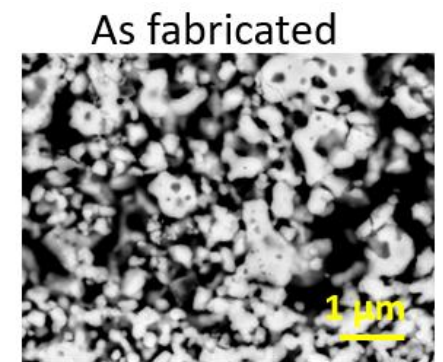
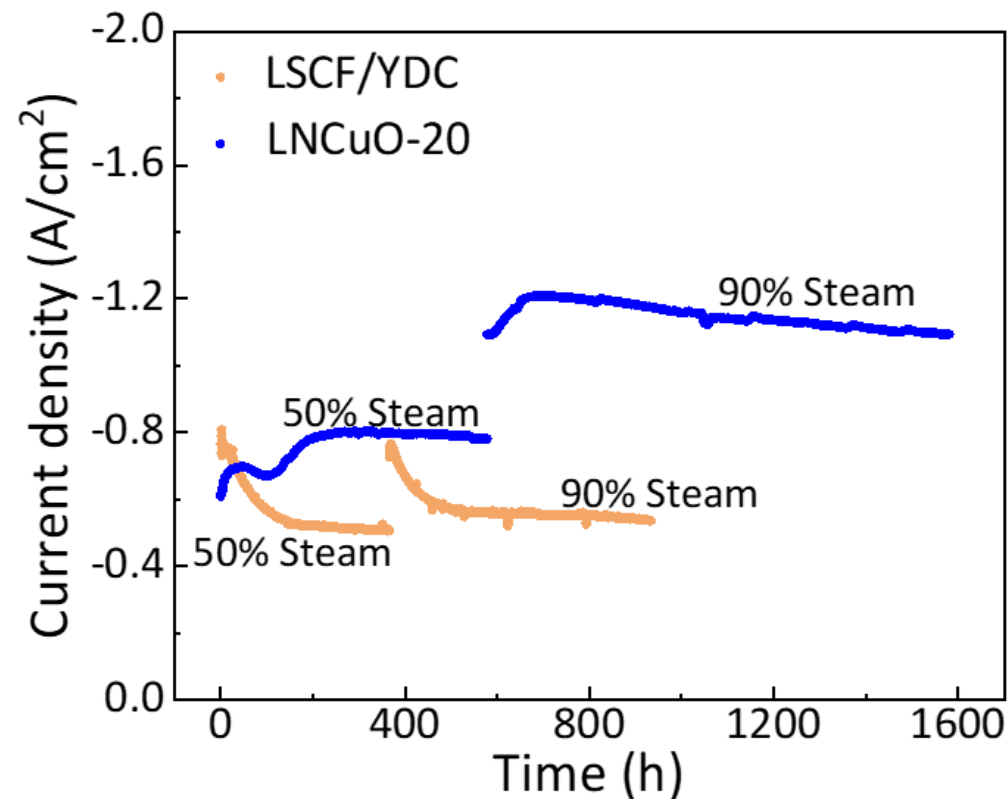
- Explore operation margin and production rate for button cells:
  - baseline condition:  $V=1.2V$ ,  $(CO_2+H_2O)/(CO+H_2+CH_4)=4$ ,  $CO_2/H_2O=2$ ,  $T=750\text{ }^\circ\text{C}$
- For higher  $CO_2$  consumption:
  - increase cell voltage and temperature, which also enhances production rate
  - increase  $CO_2/H_2O$  ratio
  - maintain sufficient fuel ratio to suppress methane production





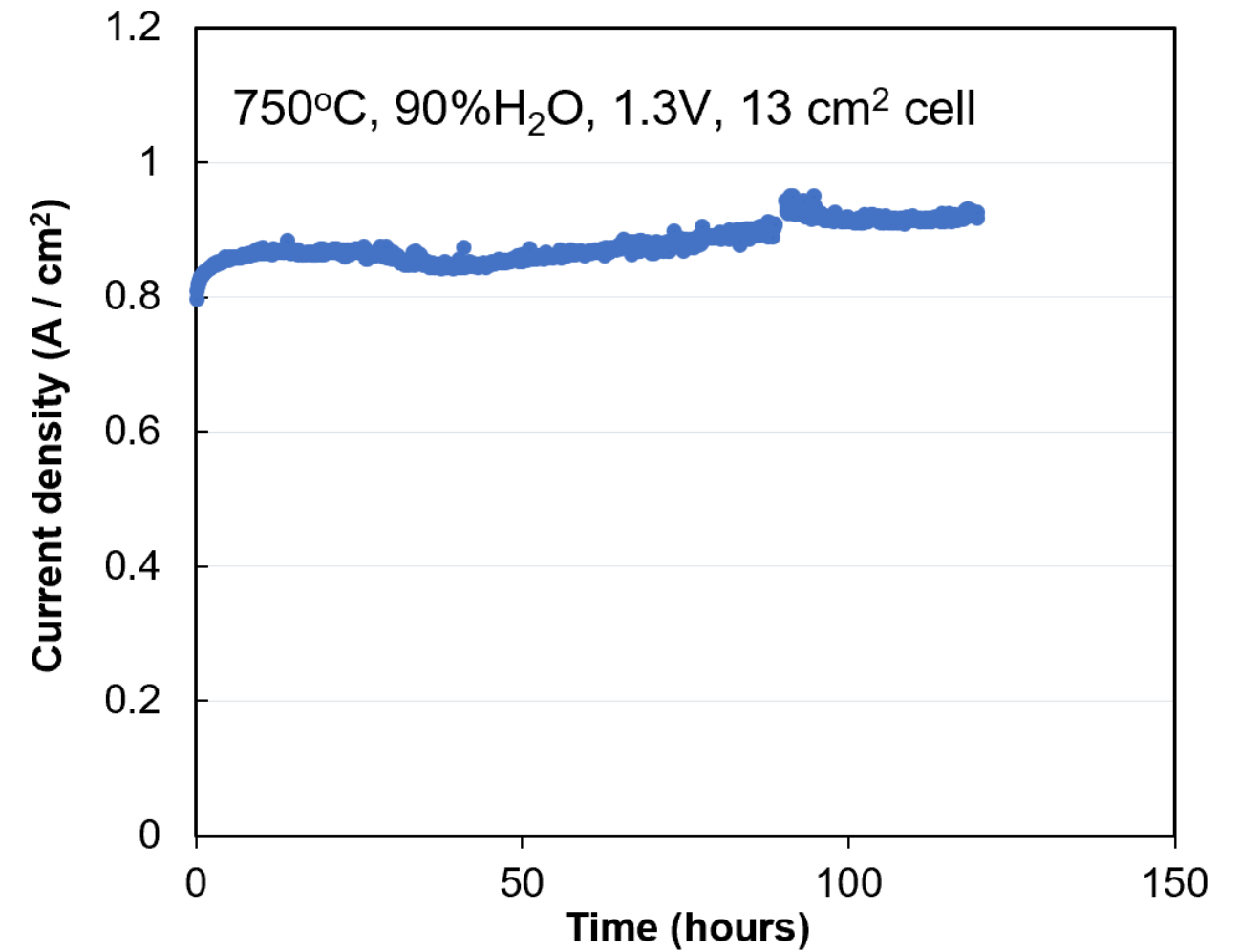
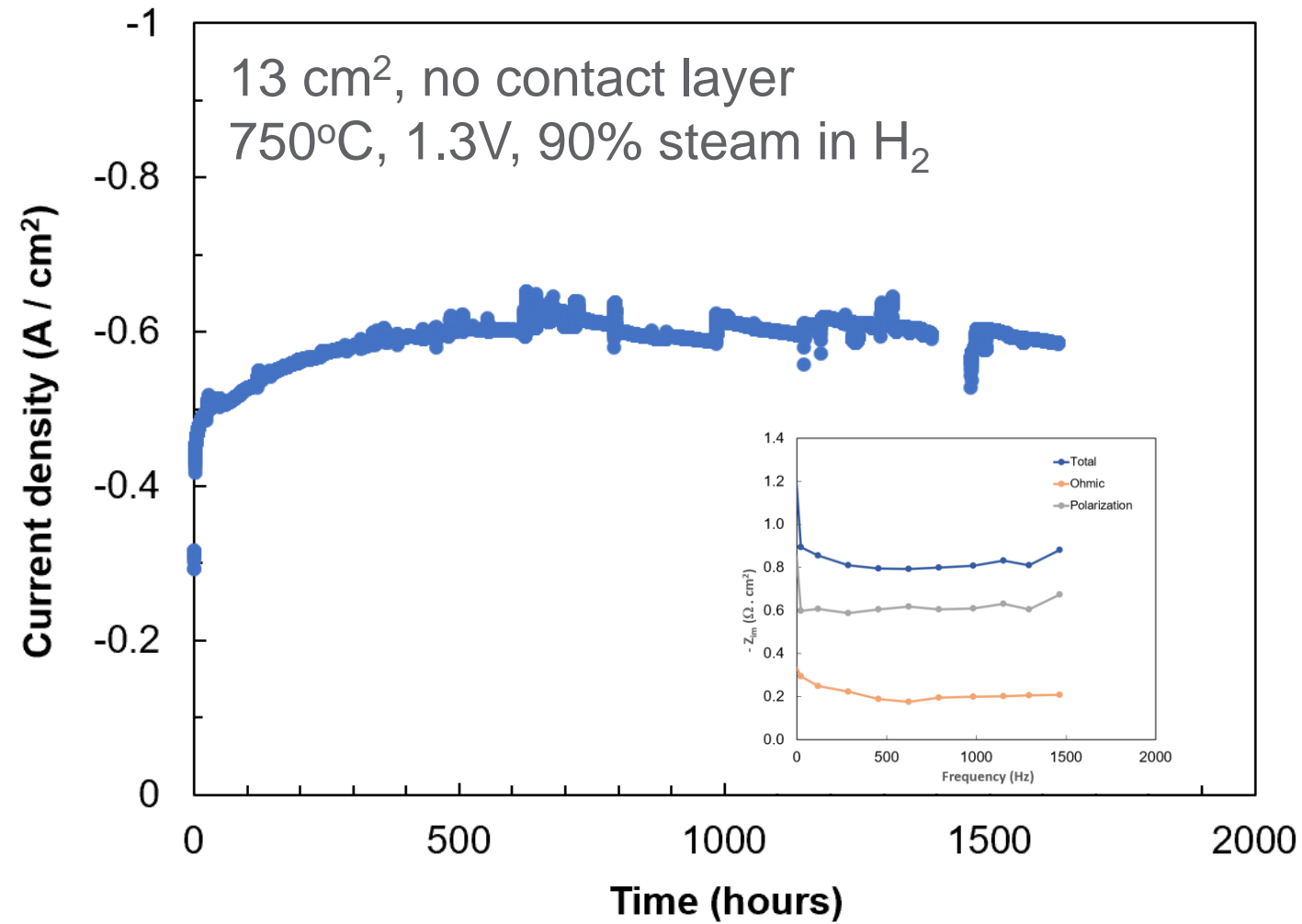
# Durability Could be Improved: no Break-in Period for Cu-Doped Nickelates

- Cu-Doped Nickelates,  $\text{La}_2\text{Ni}_{0.8}\text{Cu}_{0.2}\text{O}_4$ , show no break-in period



Karki et al, *ECS Transactions*, 111 (6) 201-209 (2023)  
10.1149/11106.0201ecst

# Scaleup to 13 cm<sup>2</sup> Single Cells



## Summary

- Assembled and tested multiple short stacks using 300 cm<sup>2</sup> cells
- Established baseline performance of 1 kW stack in 80% steam at 750°C and demonstrated 70% steam utilization
- Thermally cycled SOEC stack with large area cells
- Identified a novel oxygen electrode with improved durability
- Successfully demonstrated over 1,000 hr of SOEC operation on CO<sub>2</sub>-H<sub>2</sub>O at elevated pressures





# Acknowledgements

**Fossil Energy and Carbon Management (FECM), division of Hydrogen with Carbon Management (HCM)  
Award number is FWP-77108**

**Office of Energy Efficiency & Renewable Energy (EERE)  
Hydrogen and Fuel Cell Technologies Office (HFTO)  
Award number AOP-73526**

