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

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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 ~300 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

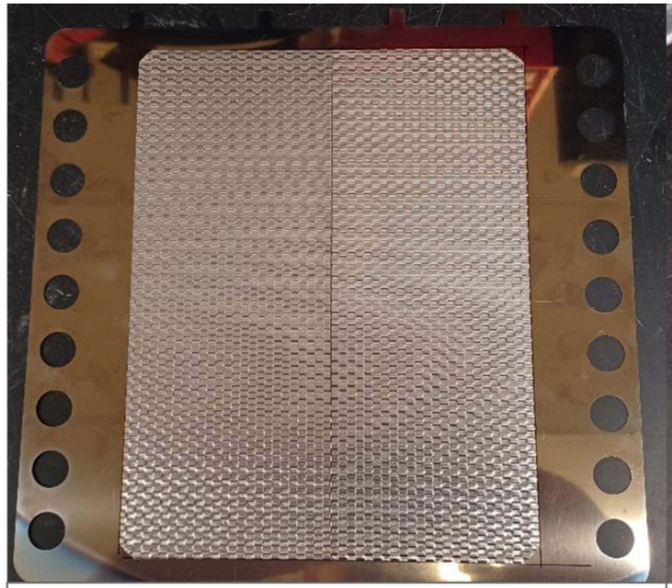
Approach

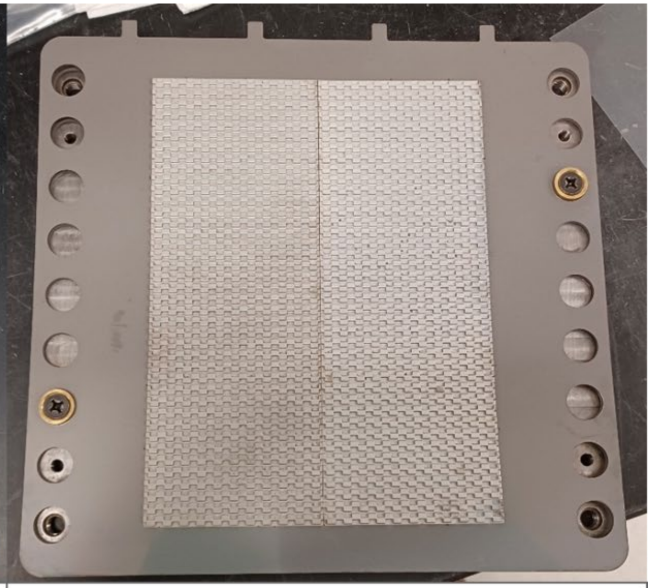
- Develop process to fabricate ~300 cm^2 active area cells using state-of-art materials
- Fabricate repeat units (cell, metal frames, and interconnects)
- Fabricate manifolds, load frames and stack current collectors
- Assemble several short 2-5 cell stacks and perform short shakedown and acceptance 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

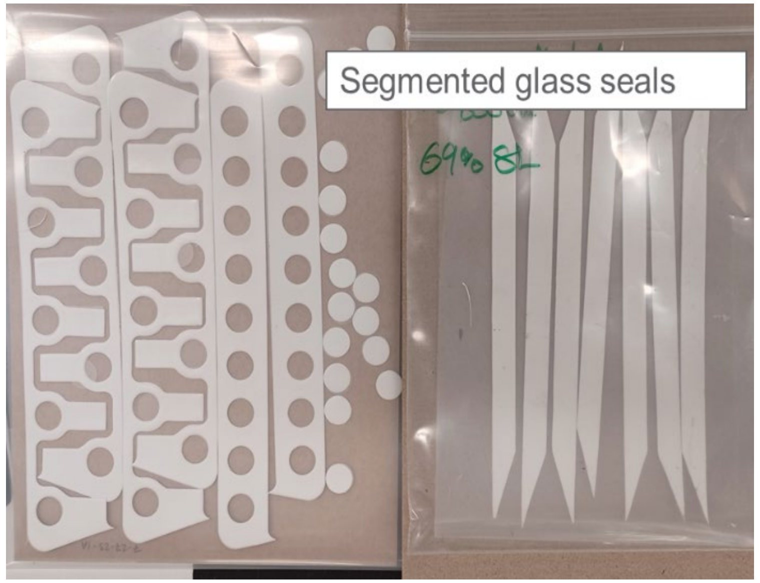
Cell Production of Different Sizes Established

- ❑ 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


Welded corrugated Ni Sheet

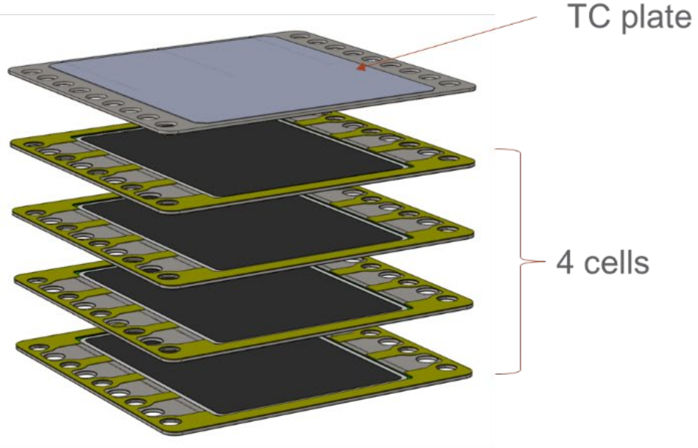

Welded corrugated Co coated Sheet



- 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 cm² Active Area Cells

- Produced multiple well-sealed cassettes with large 300 cm^2 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^2 active area cells

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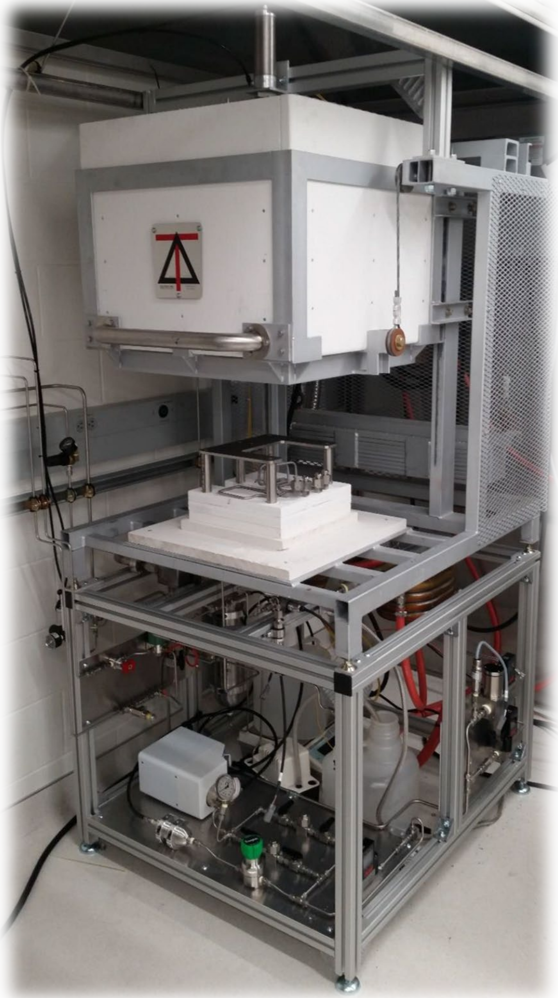
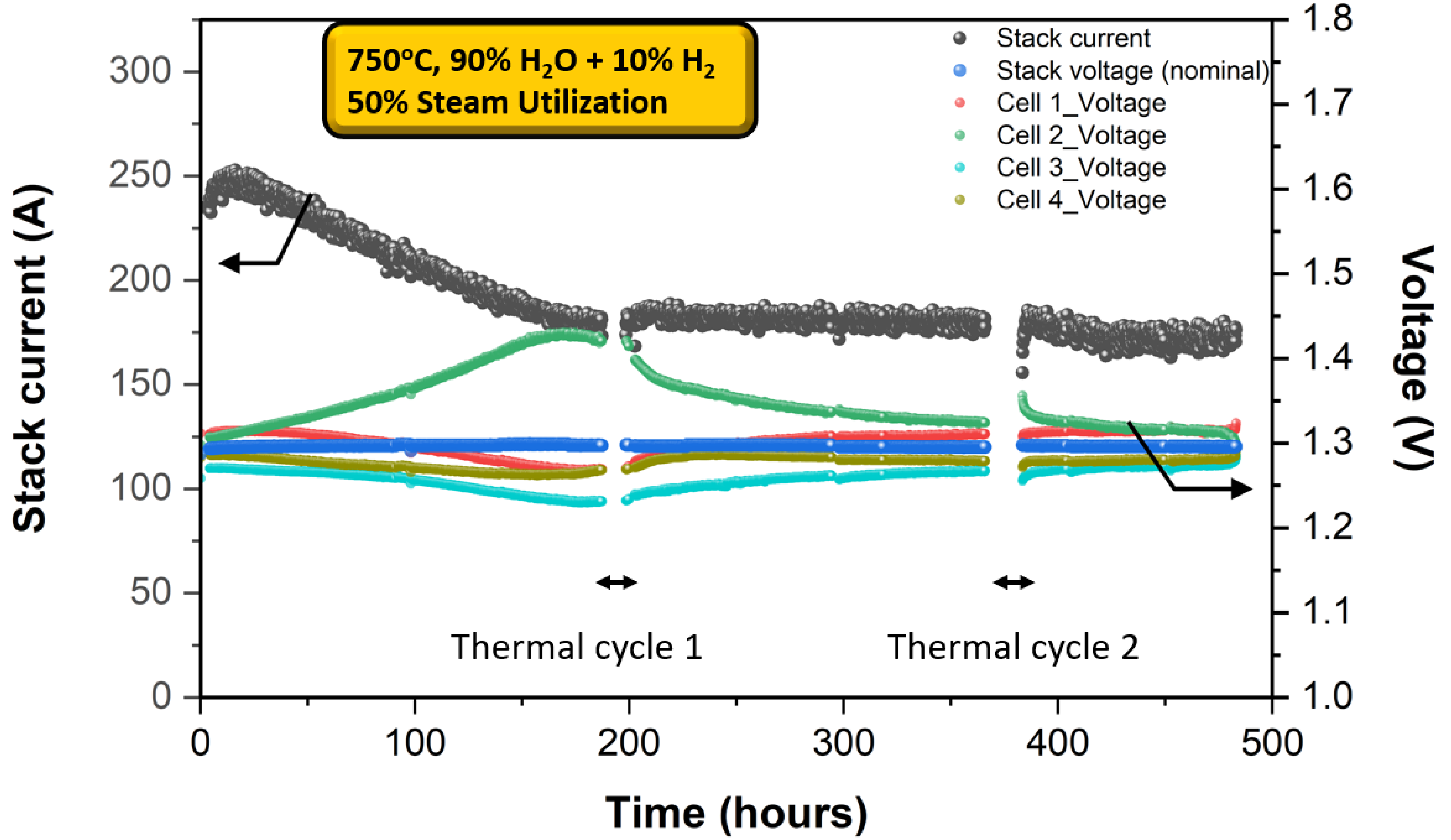
Three 1-5 kW Stack Test Platforms



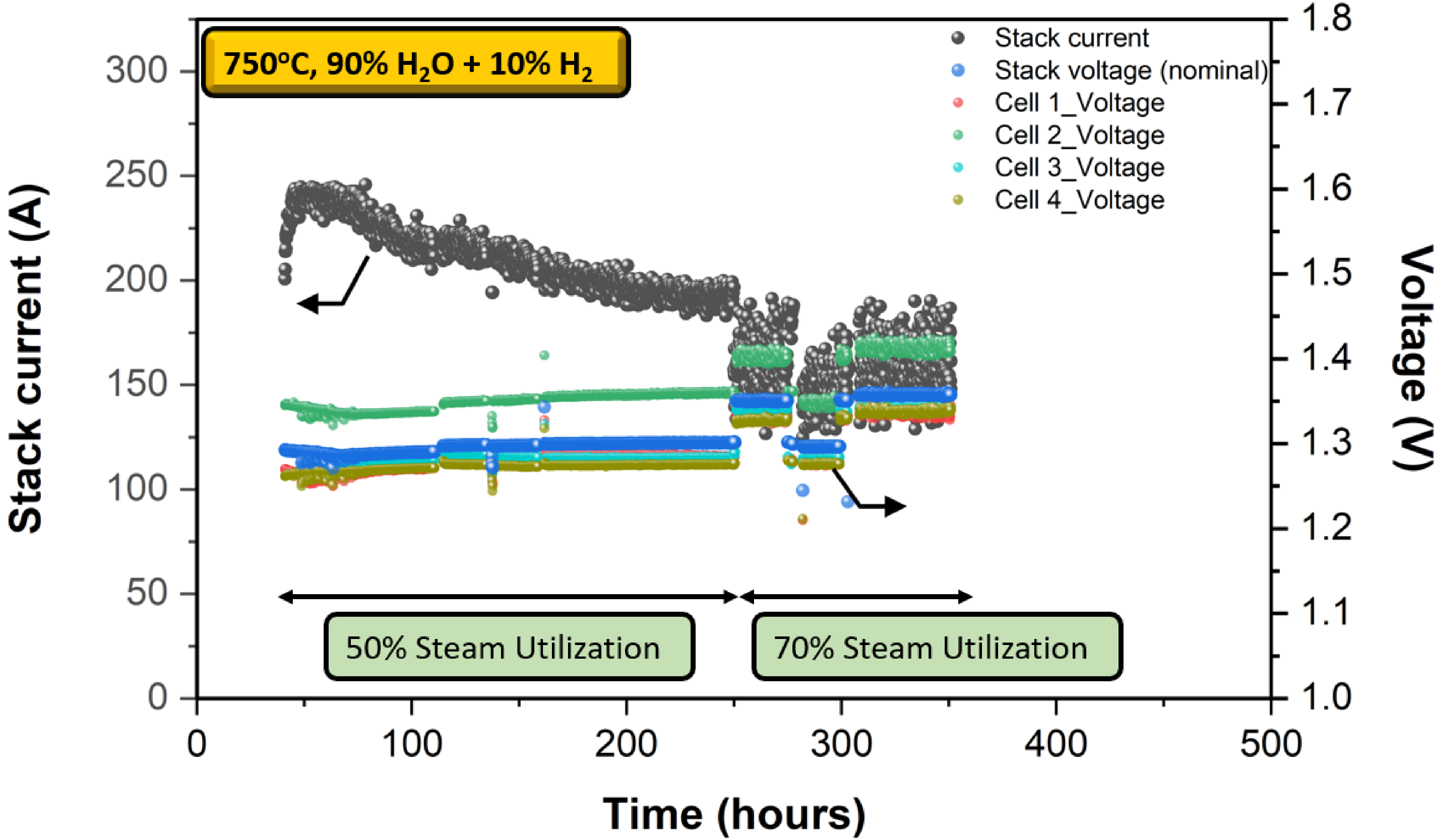
- Each includes heat exchanger, recycle loop, compact microchannel vaporizer, gas controls and automated stack control system

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

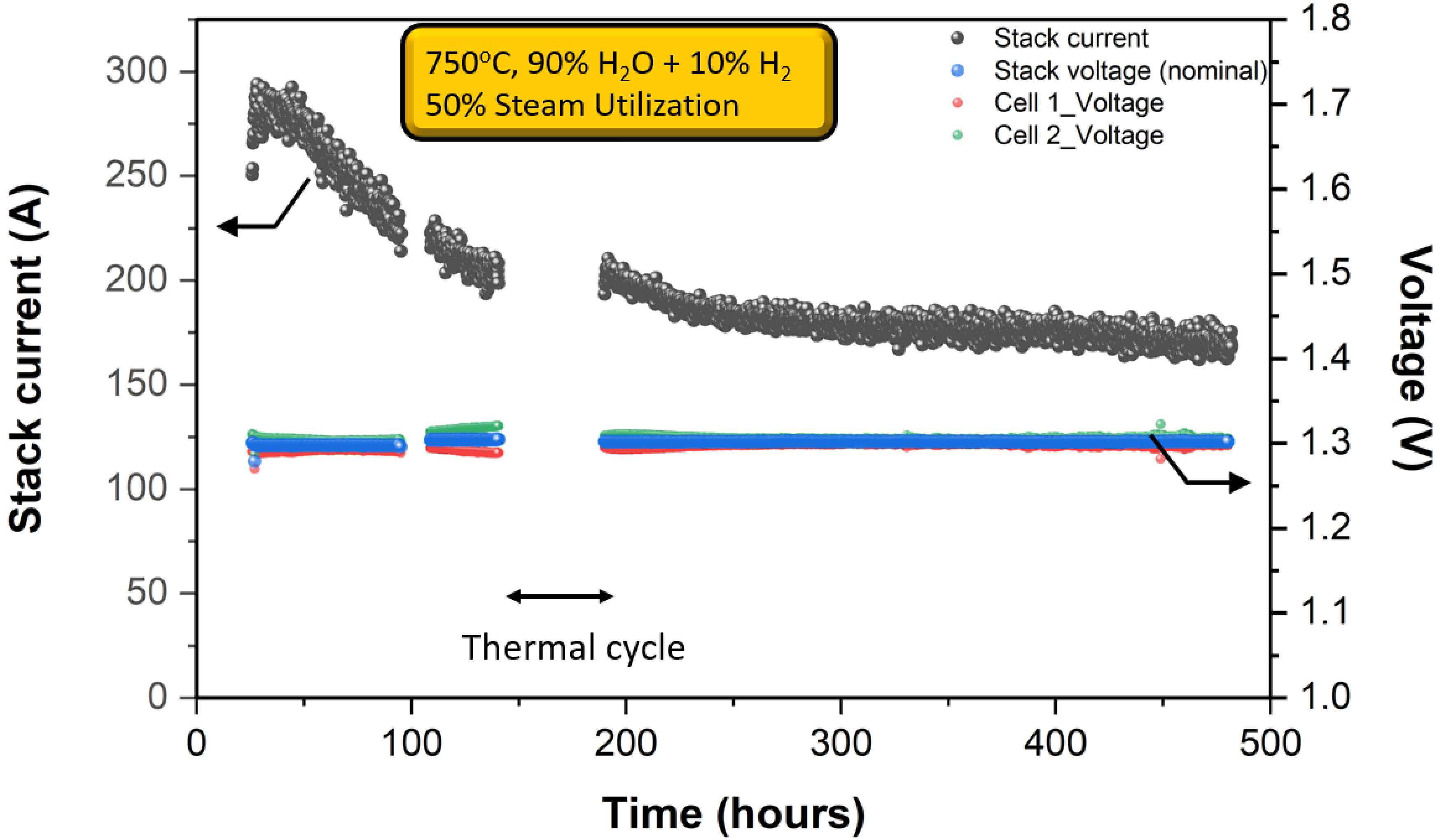


- 4 cells yield up to 1.3 kW stacks
- Maximum operation time was 500 hours
- Completed multiple thermal cycles

Achieved 70% Steam Utilization Using 1.3 kW Stacks with Large Cell Area

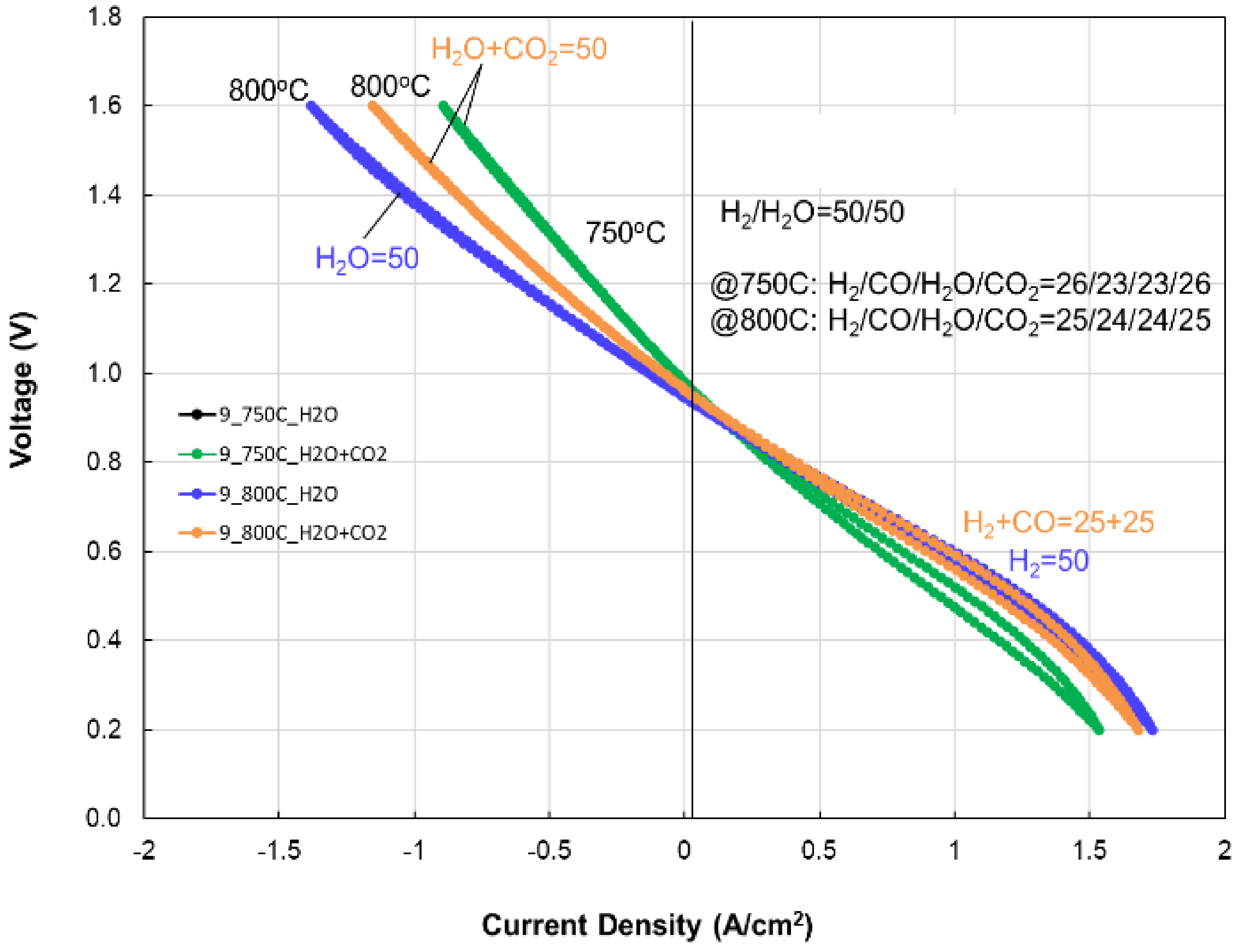


Improved Current Density by Improving Electrical Contacts



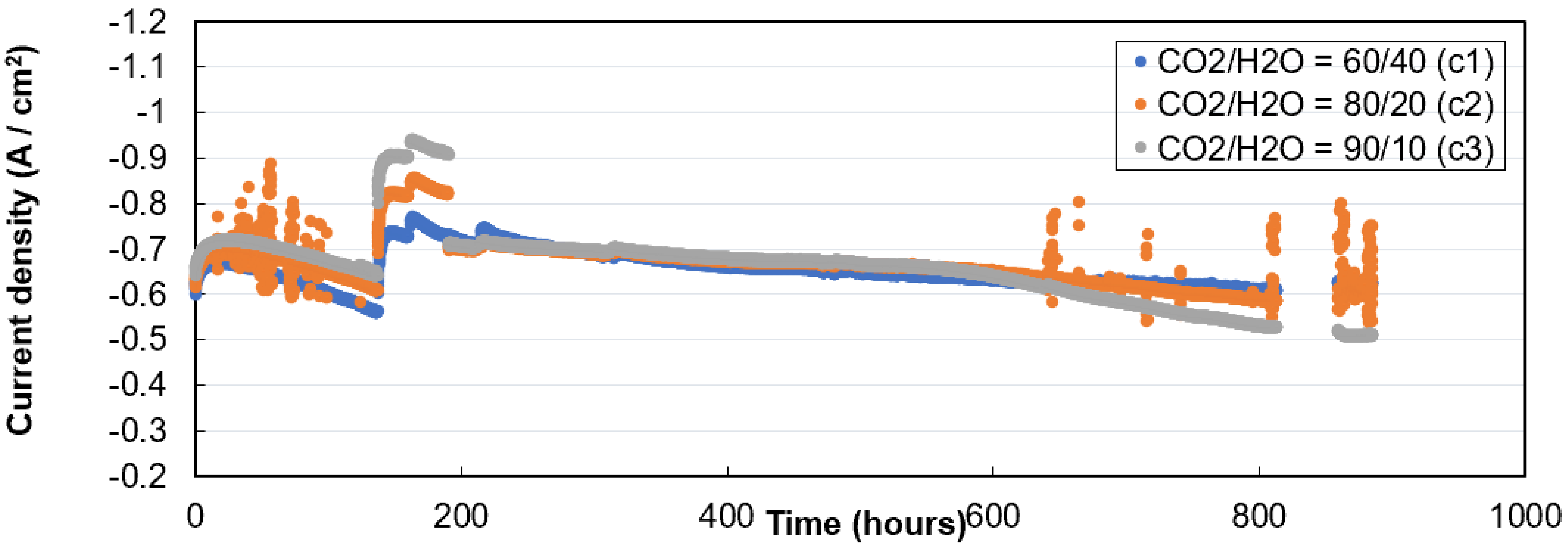
- Modified sealing procedure to obtain the electrical contact at lower temperature, below typical sintering temperature
- Achieved initial 1 A/cm^2 in 90% steam at 50% steam utilization
- In a 2-cell stack, the steam utilization was 40-50%, lower than in 4-cell stacks, because vaporizer was not designed 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.

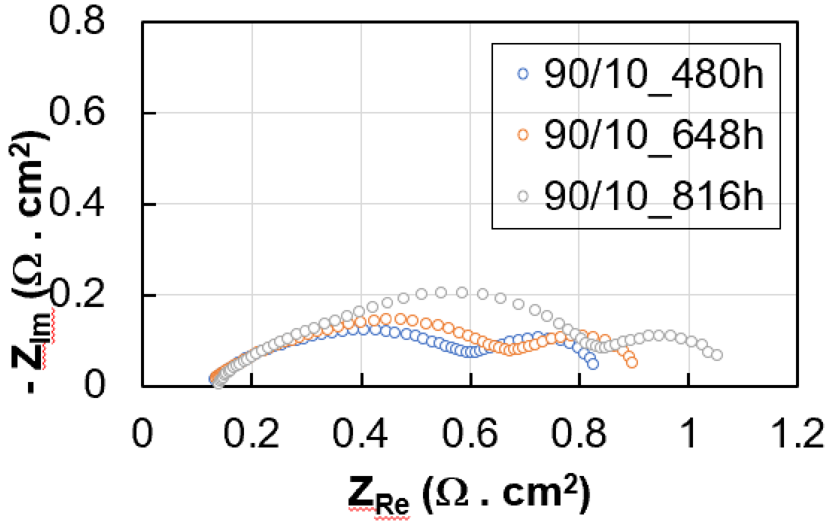
Demonstrated Cell Reversibility in the Presence of High CO_2 Concentrations

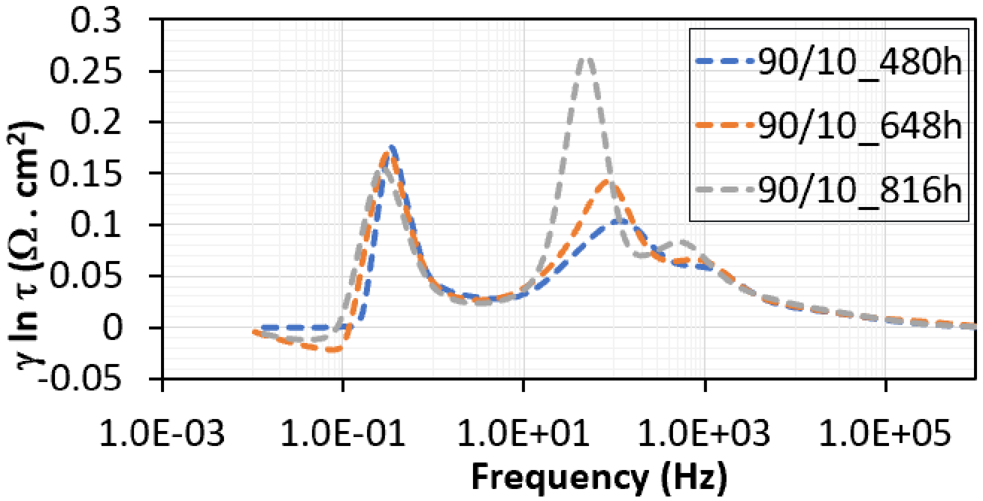


- Assessed cell stability in different CO_2-H_2O compositions with CO_2 varied from 25 to 95%
- Demonstrated syngas production and reversibility of cell operation

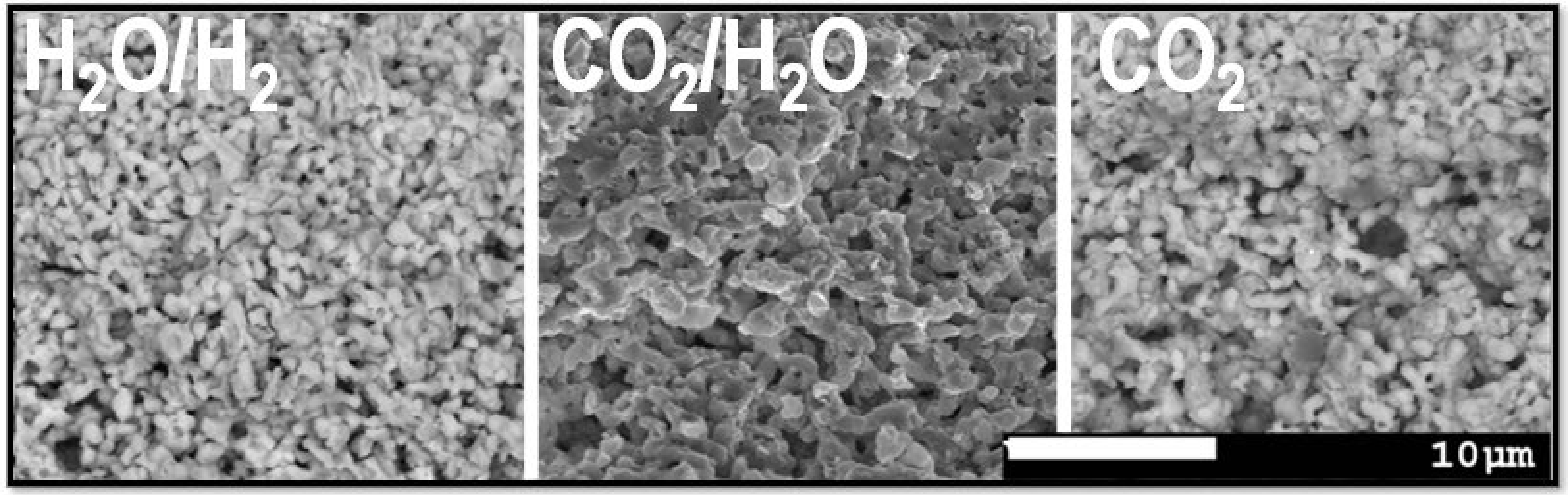
Higher CO_2 Concentrations Lead to Increased Degradation in Long-Term Tests

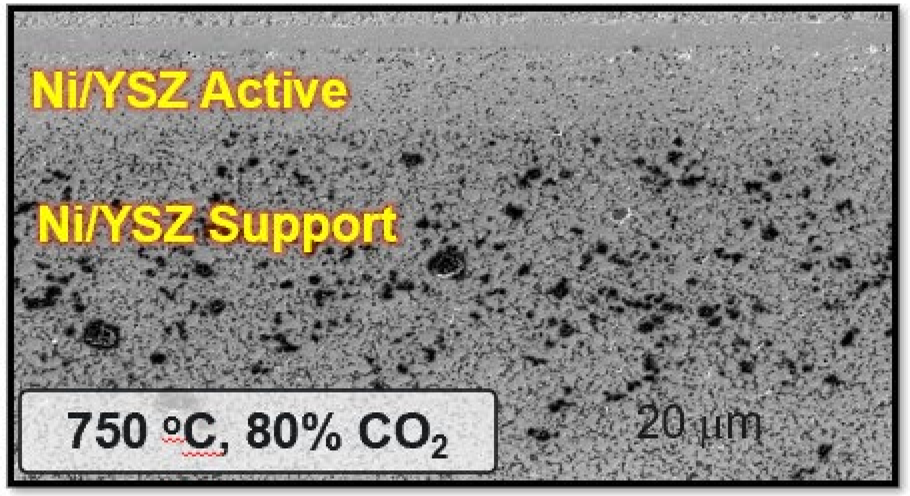


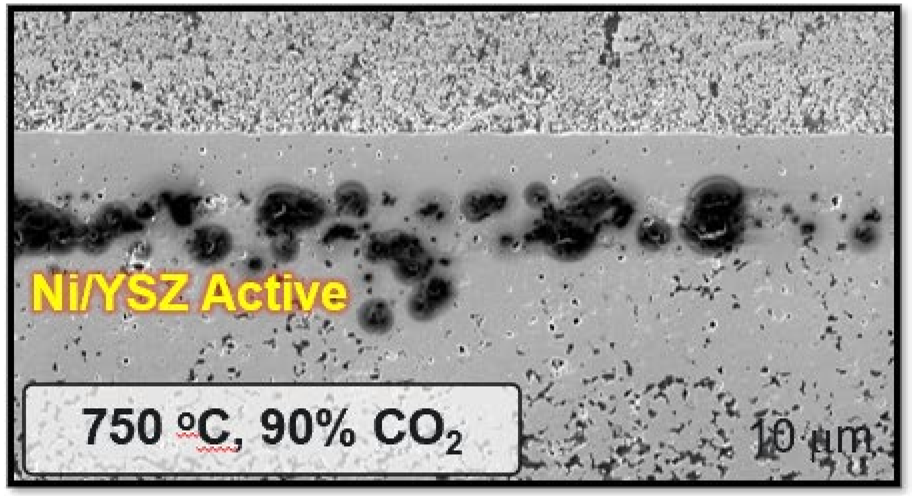




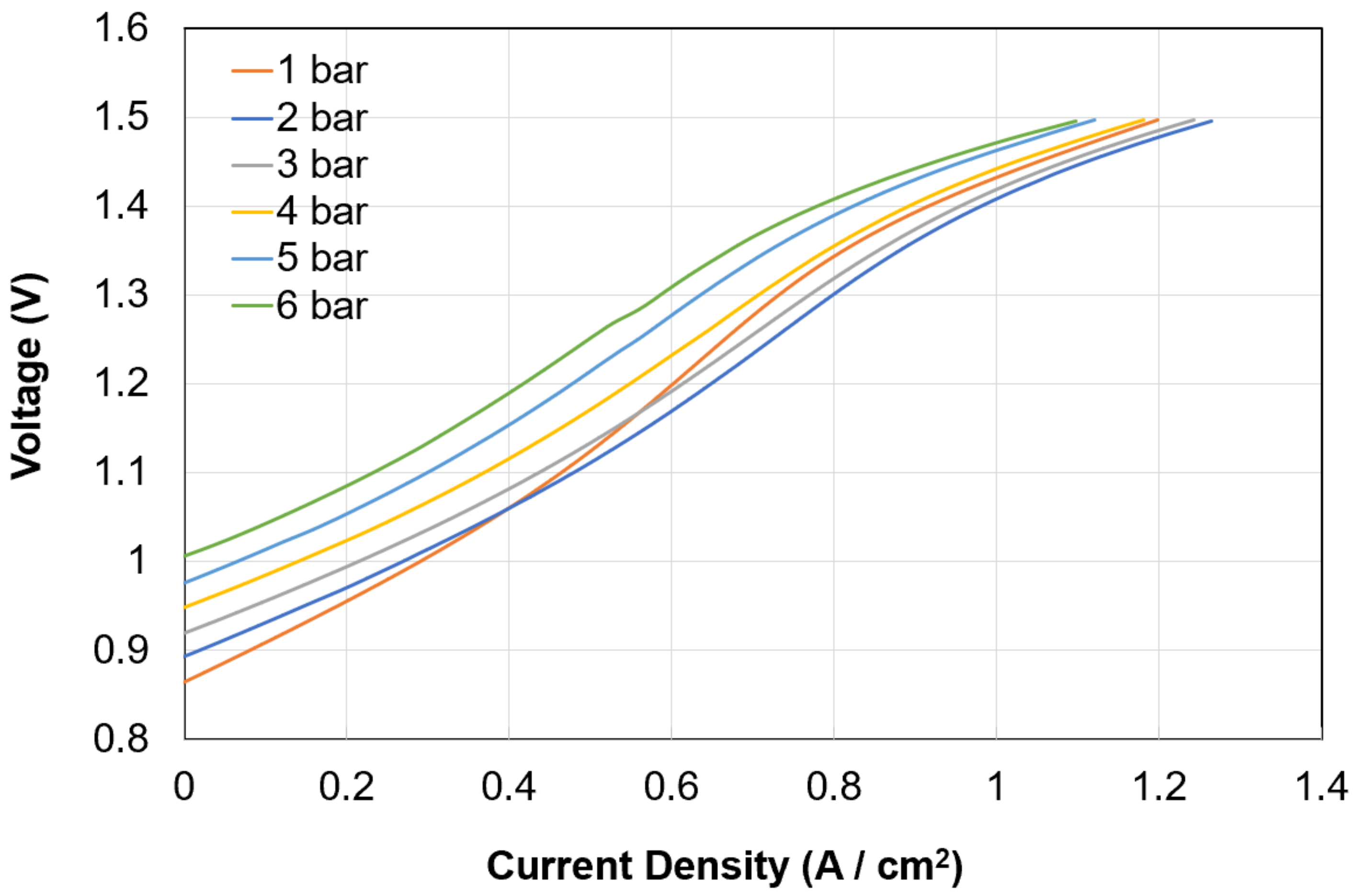
After 1000 hr, Coking was Observed at High CO_2

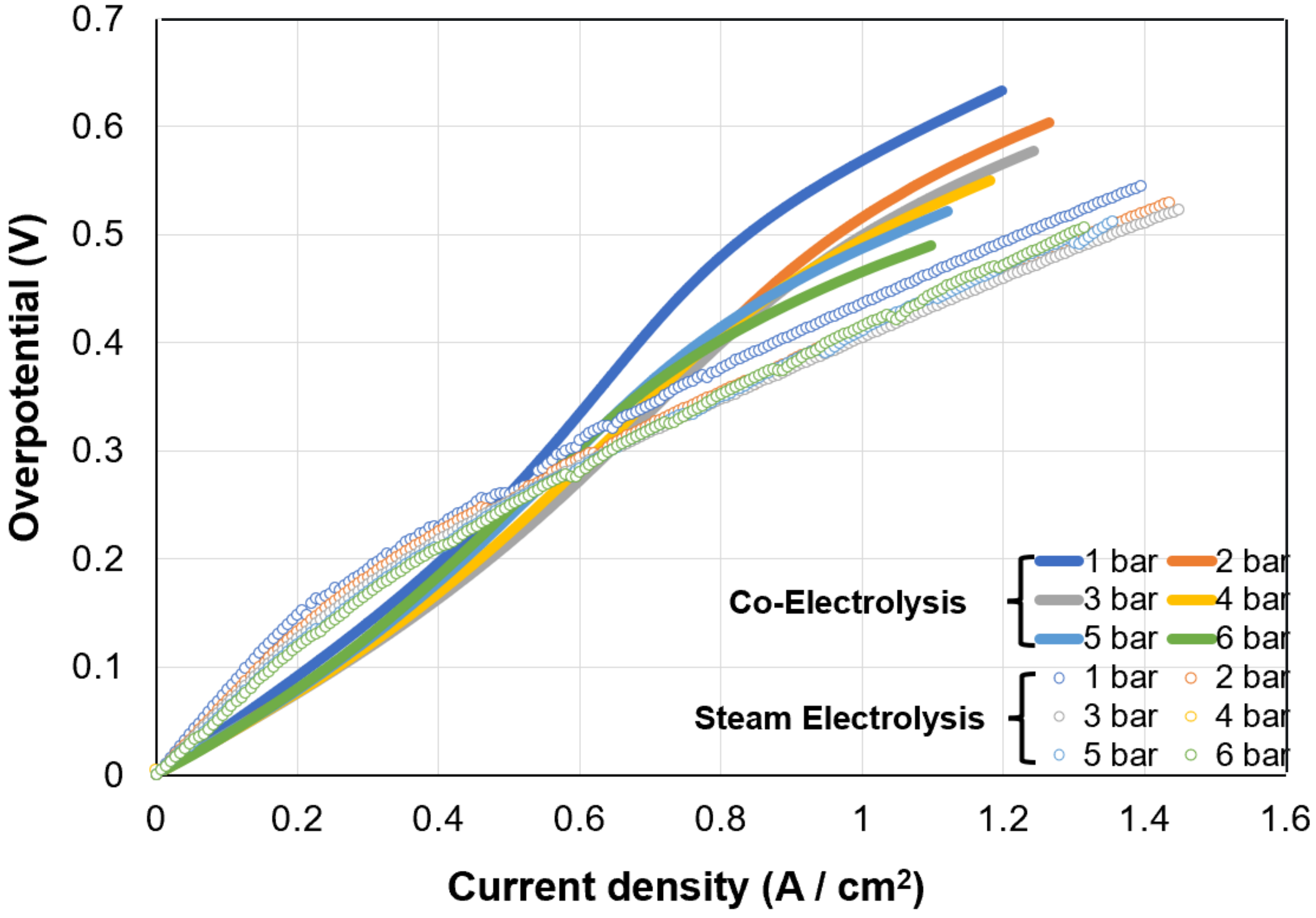






Co-Electrolysis: 40%CO_2-50%H_2O-10%H_2, 750°C
Electrolysis: 50%H_2O-50%H_2, 750°C





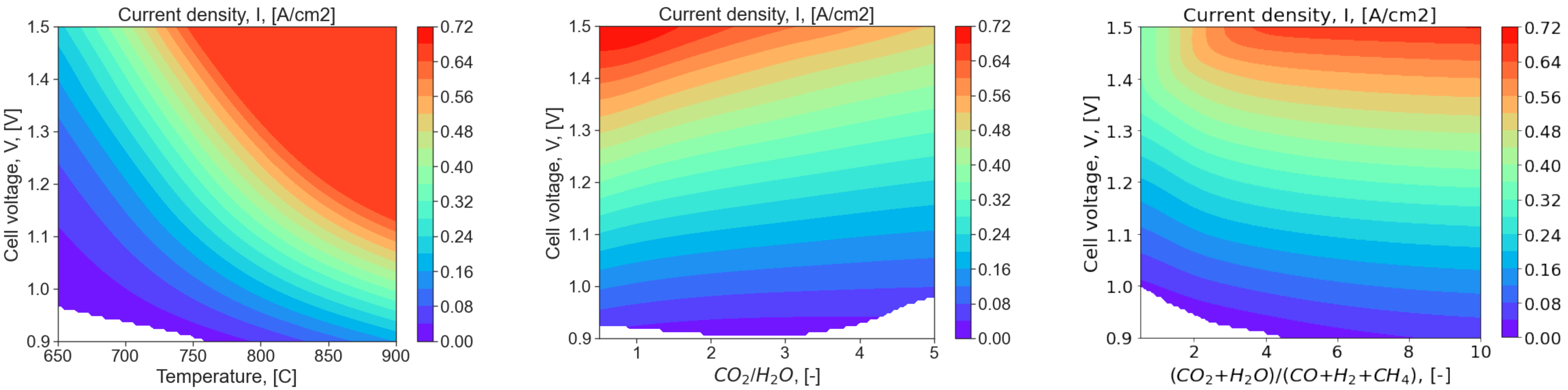
Developed Model to Predict Ideal Operating Conditions and Critical Factors for Co-Electrolysis

- 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

D. Wang et al, submitted

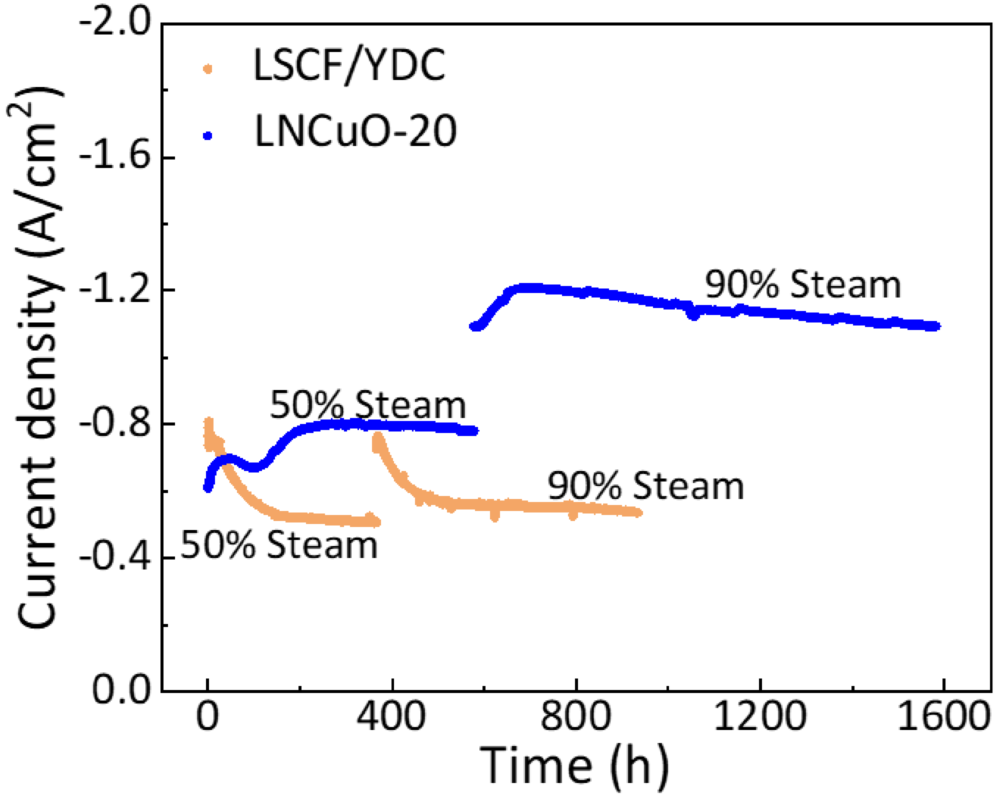
Critical Factors in co-SOEC Performance

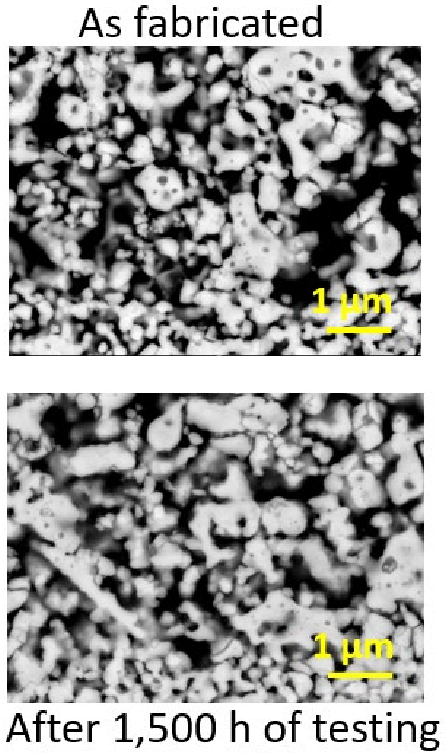
- Explore operation margin and production rate for button cells:
  - baseline condition: V=1.2V, $(CO_2+H_2O)/(CO+H_2+CH_4)=4$, $CO_2/H_2O=2$, T=750 ℃
- For higher CO_2 consumption:
  - increase cell voltage and temperature, which also enhances production rate
  - increase CO_2/H_2O ratio
  - maintain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

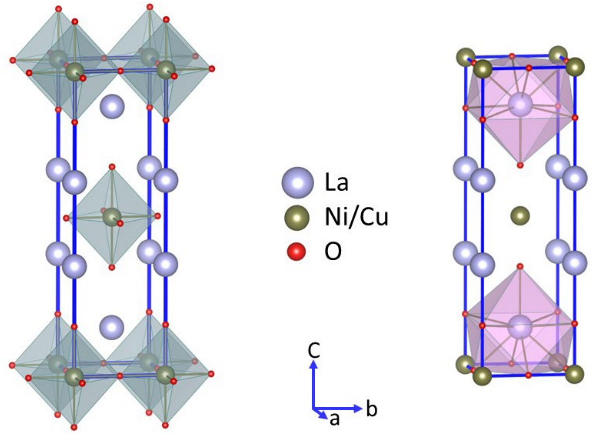


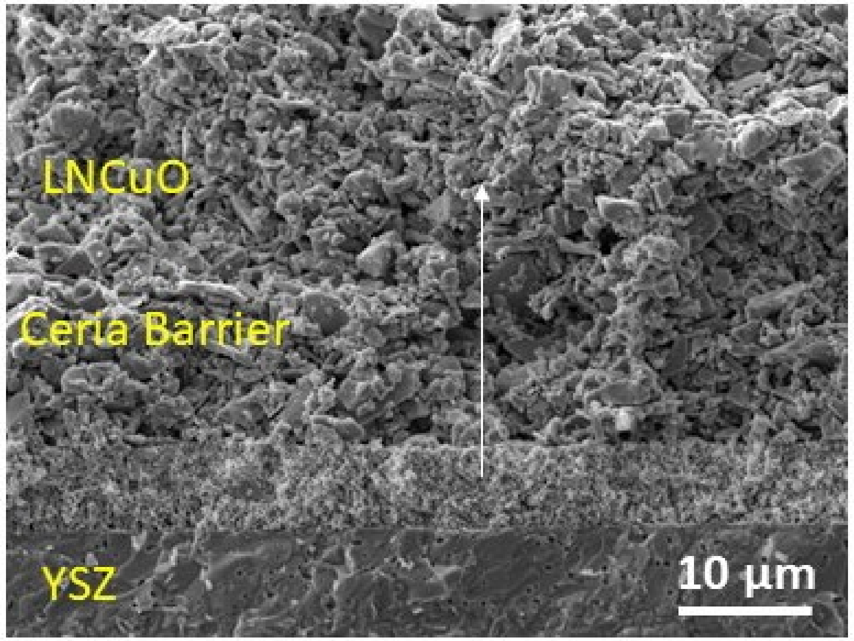
Durability Could be Improved: no Break-in Period for Cu-Doped Nickelates

- Cu-Doped Nickelates, $La_2Ni_{0.8}Cu_{0.2}O_4$, show no break-in period



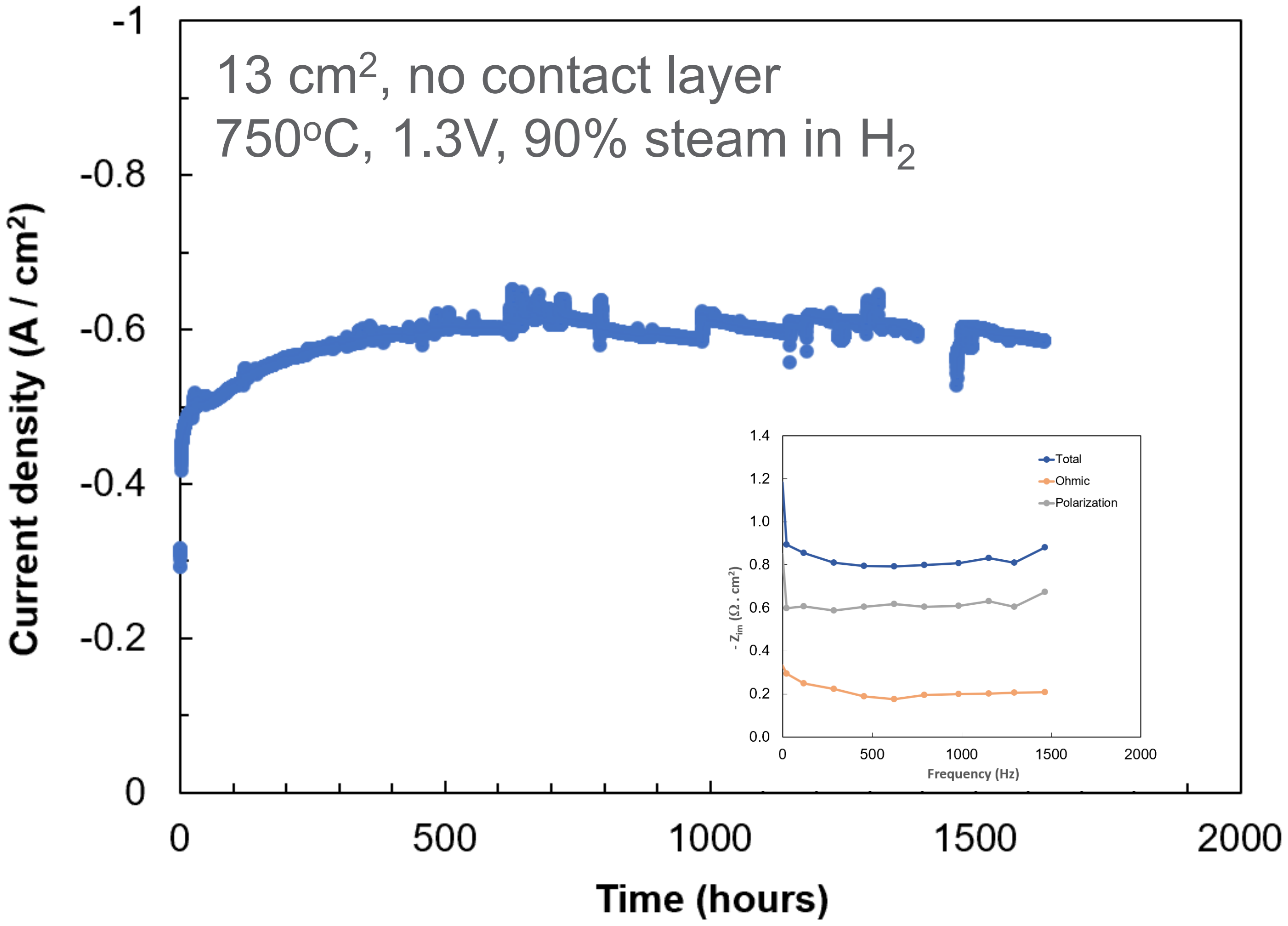


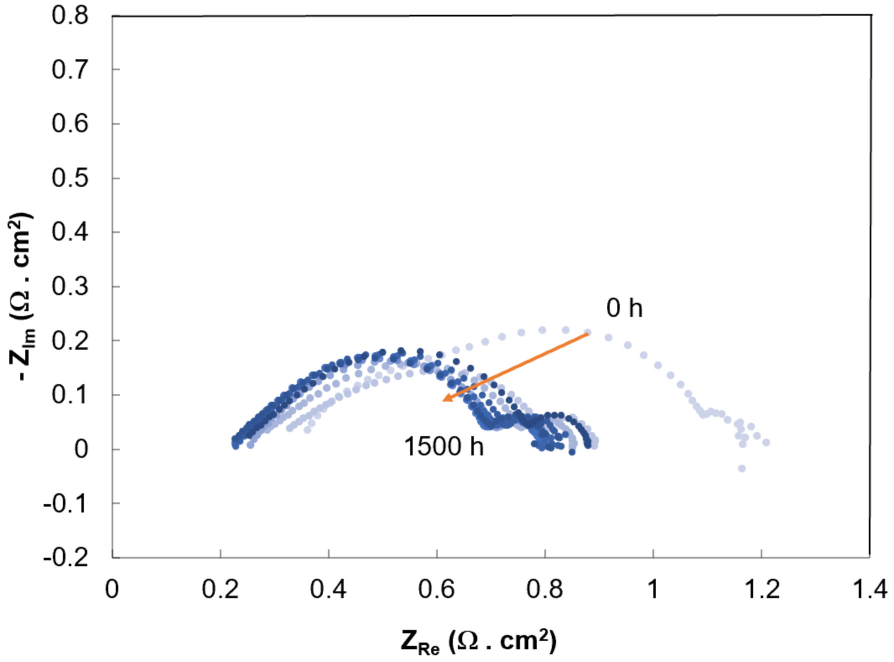


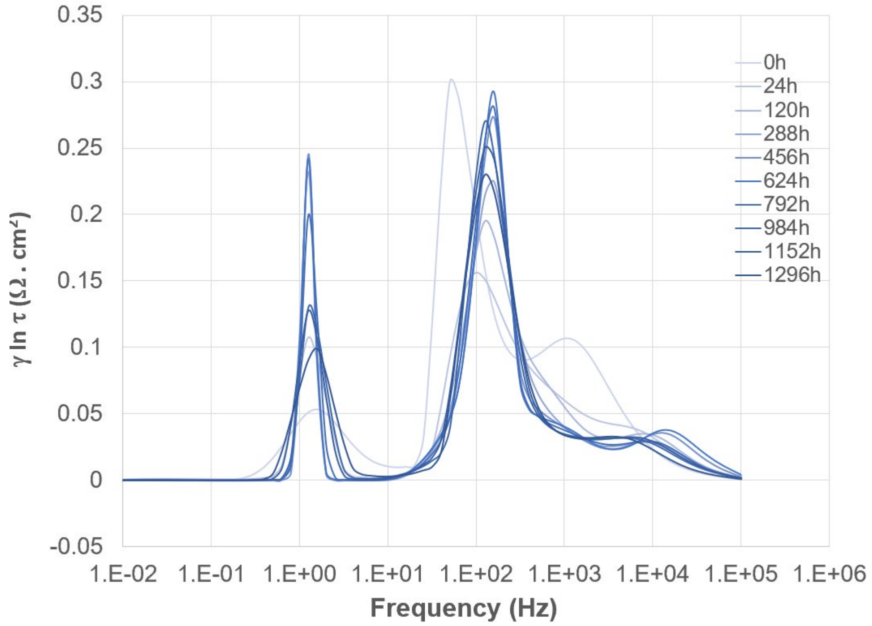


Karki et al, ECS Transactions, 111 (6) 201-209 (2023) 10.1149/11106.0201ecst

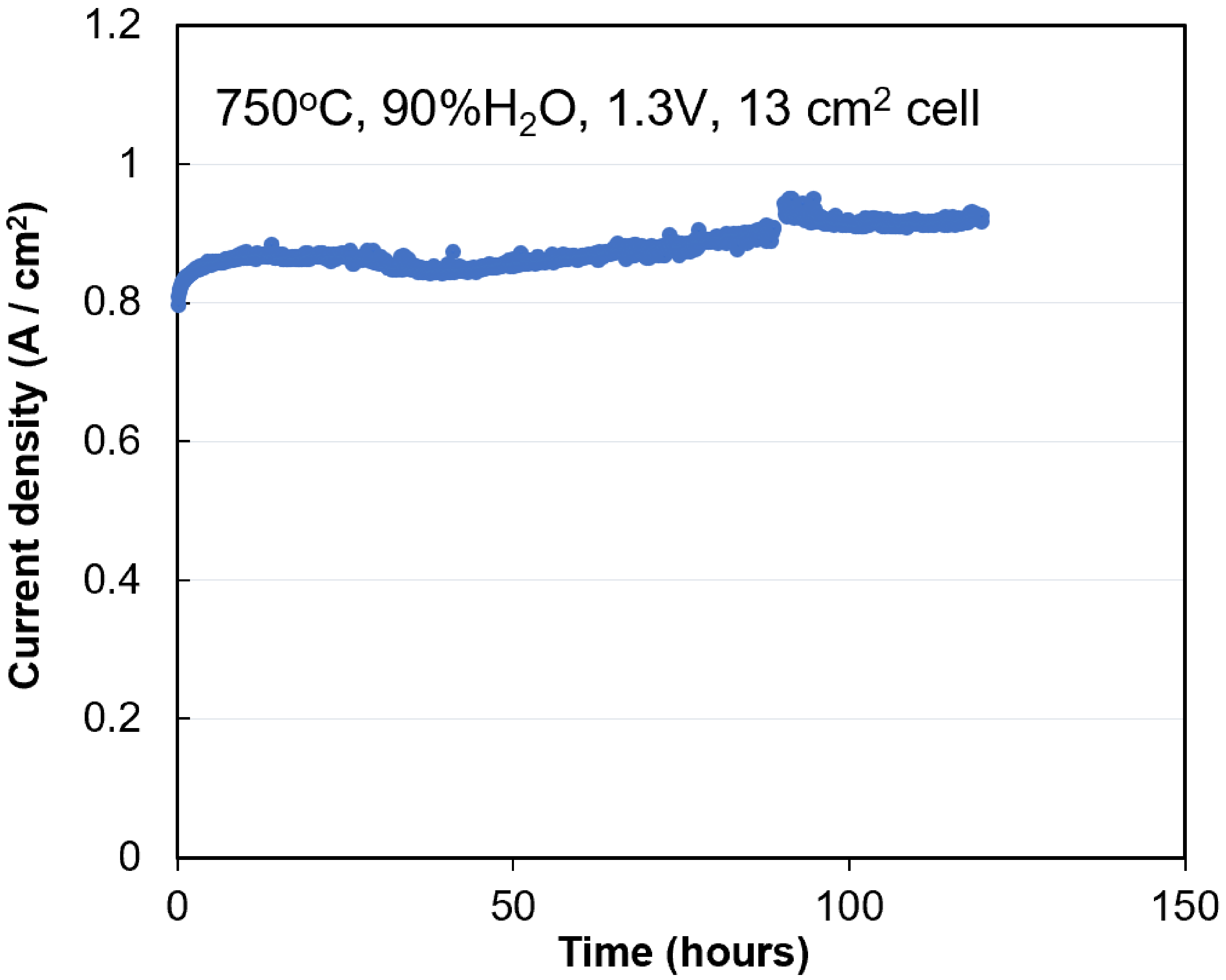
Scaleup to 13 cm^2 Single Cells







Oxygen Electrode Improvement



Summary

- Assembled and tested multiple short stacks using 300 cm^2 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 cells
- Identified a novel oxygen electrode with improved durability
- Successfully demonstrated over 1000 hr of SOEC operation on CO_2-H_2O at elevated pressures

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