Solid Oxide Fuel Cell Cathode Enhancement Via Single-step Infiltration

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Outline

- About Materials & Systems Research Inc. (MSRI)
- R&D Motivation
- Accomplishments (up to date)
- Results and Discussions
- Summary and Future Work

Materials & Systems Research Inc.

specializes in materials and electrochemical engineering for power generation and energy ge applications: fuel cells/electrolyzers, storage batteries, and thermoelectric converters.

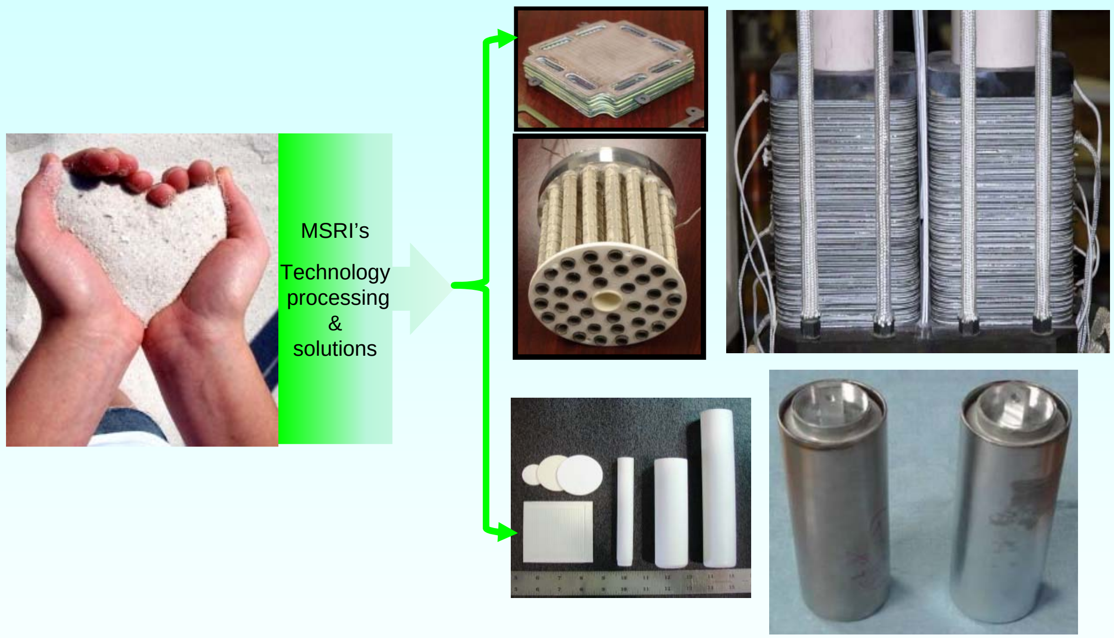
has 12 employees: 5 with PhDs in material, mechanical, chemical, & chemistry

ell/Electrolyzer

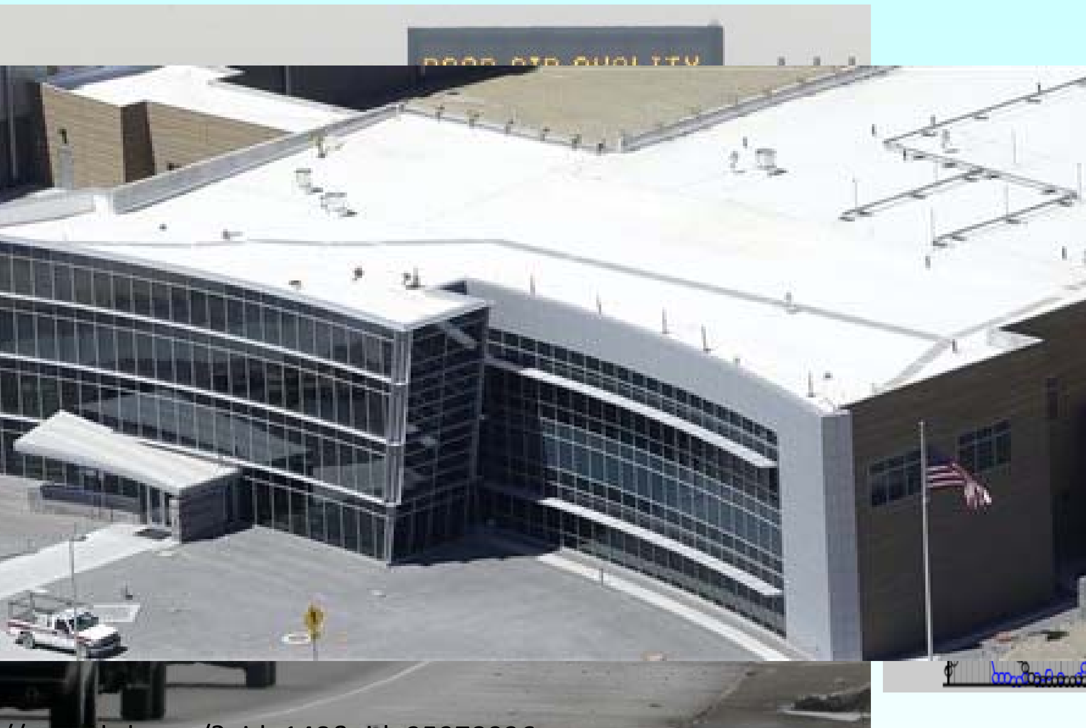
- th planar and tubular cells
- r-cell active area varying from 1 to 0 cm^2
- cks/bundles from 10 W to 4 kW

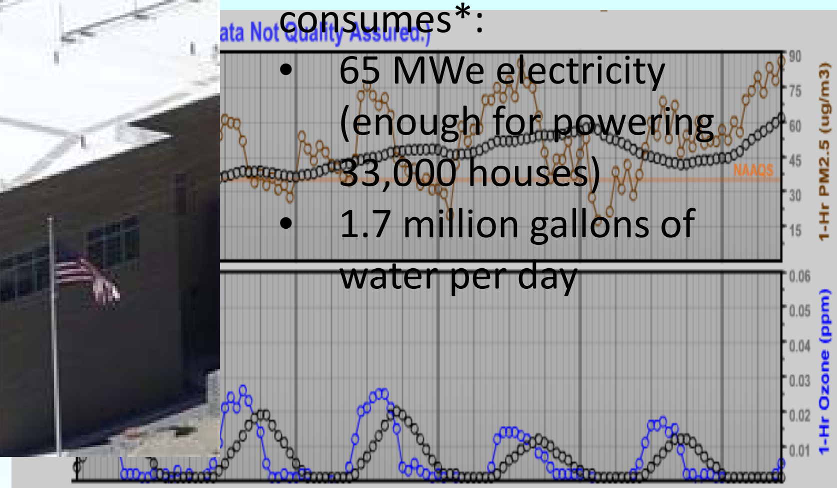
m-beta Battery

- vanced Na^+-conducting ceramic ctrolyte
- ique battery designs



Cleaner Energy





$1.7 billion cost of the NSA data center in Bluffdale, UT consumes*:

- 65 MWe electricity (enough for powering 33,000 houses)
- 1.7 million gallons of water per day

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ww.deseretnews.com/article/865571239/Winter-inversions-hitting-Utah-harder-more-frequently.html?pg=all

Solid Oxide Fuel Cell is capable of converting the chemical energy of the carbon-based fuels rectly into electricity with higher efficiencies while reducing the NO_x and SO_x emissions

- o Power generation
- o Energy storage

Motivation for Cathode Enhancement

igh power density, long-term reliability & minimal degradation are critical
success of SOFC technologies and fast market penetration

- **cost target:** stack cost < $175/kW (cathode material cost ~ 18%, or ~ $31.5/kW)
- **degradation rate:** 0.1~1% per 1000 hours operation

athode polarization losses attribute significant amount to total cell losses

athode development: High-performing cathode materials, or/and cathode
rocessing optimization

- infiltration of a nano-structured/nano-sized catalyst has been proven to be one of most effective/efficient means for cathode enhancement
- challenges
  - key parameters determining the success of infiltration process, including adaptability to the pre-established cathode backbones, precursor solution concentration, surfactant, wetting agent, evenness of catalyst distribution along cathode backbones
  - simplicity
  - cost-effective
  - scalable for large cells
  - durability (stability) & process repeatability

Objective & Accomplishments

Objective: to develop and implement an advanced cathode deposition process via infiltrating a nano-catalyst(s) into pre-established cathode backbones for SOFC performance enhancement

Accomplishments:

- Engineered cathode backbone microstructures for an efficient single-step infiltration
- Developed and implemented a single-step VPIT process for infiltrating a nano-sized catalyst into pre-established cathode backbones with per-cell active area varying from 2 cm^2 to 100 cm^2
- Developed a 2^{nd} generation of an infiltration apparatus for large cell applications
- Successfully increased the catalyst loading level to 2~2.5 mg/cm^2 on both button-sized cells and 10 cm x 10 cm cells via the single-step VPIT process
- Improved cell performance more than 60% after catalyst infiltration
- Developed a viable strategy to mitigate cell degradation and was validated over accumulated 25,000 cell-hour tests
- Successfully demonstrated cell degradation rates < 3%/1khrs over 5,700 hrs tests

Single-step Infiltration Concept

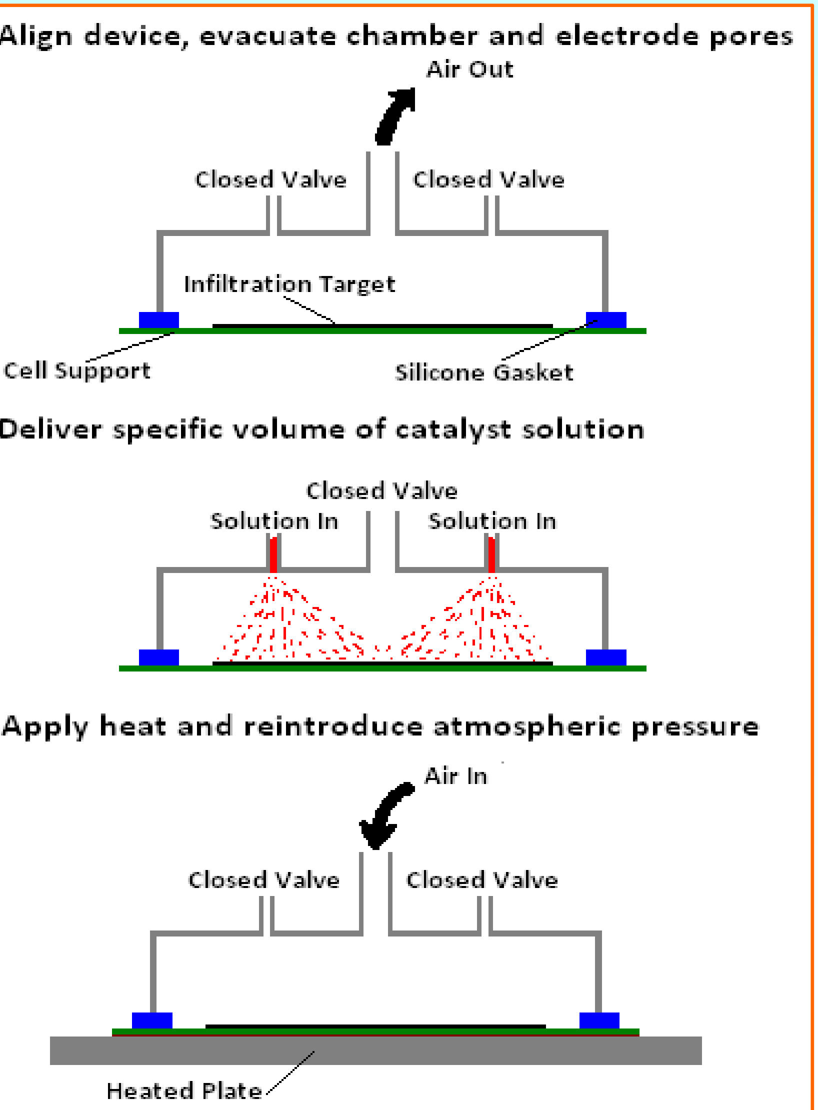


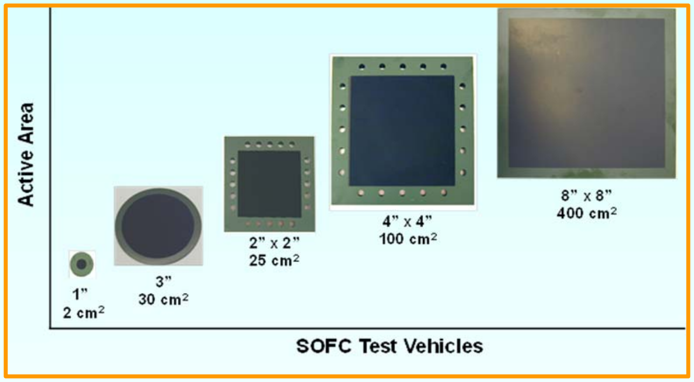
Diagram of the single-step Vacuum-Pressure-Infiltration-Thermal Treatment (VPIT) technique, involving:

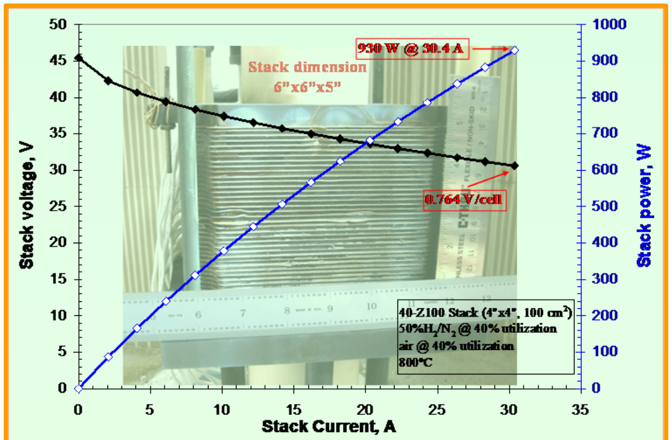
- Initial vacuum step to remove air entrapped inside the cathode backbones
- precipitation of a nitrate solution into the porous cathode backbones
- and immediately followed pressurization
- gelation/decomposition at a proper rate/temperature
- Calcination at elevated T ~850ºC
    - Precursor concentration effects on performance, e.g. $(Sm,Sr)CoO_3$, or SSC
    - Repeatability/durability
    - Scaling up

Anode-supported SOFC Fabrication

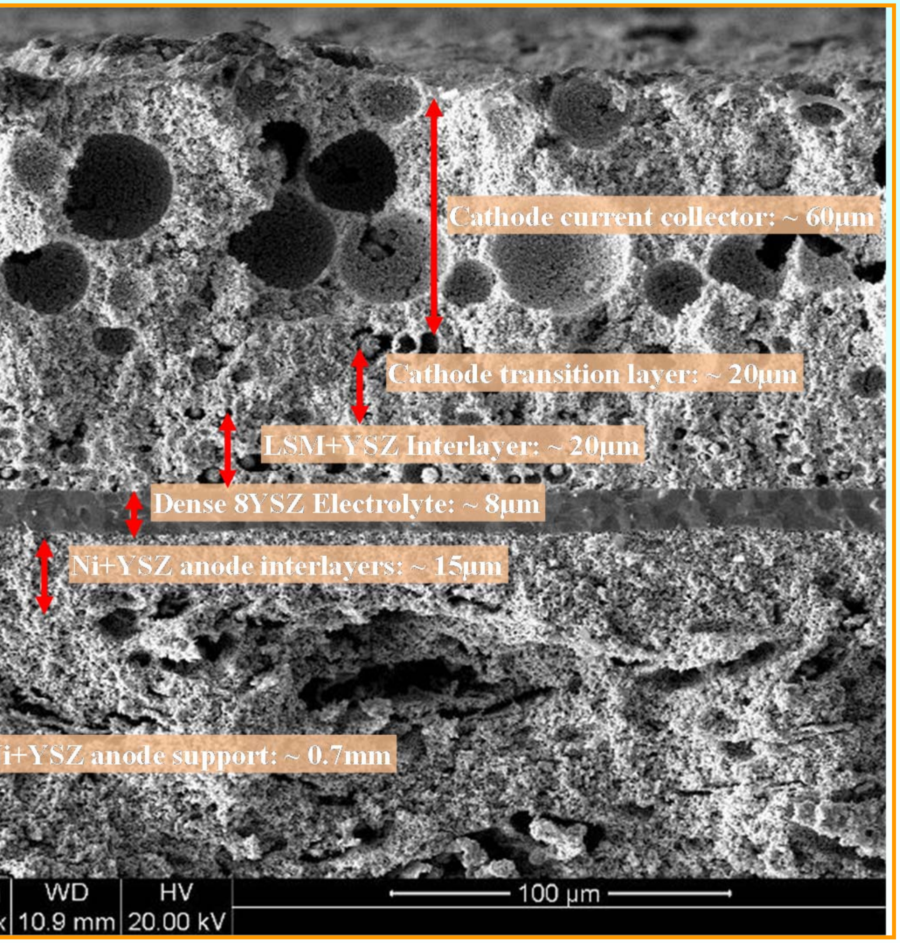
aseline cell fabrication for infiltration studies

- MSRI's standard cell fabrication process involves sequential steps: starting from powder mixing/milling → anode tape casting → cell shaping by laser cutting → bisquing → AIL & electrolyte layer application → sintering → CIL/CTL/CCL deposition by screen-printing & firing.





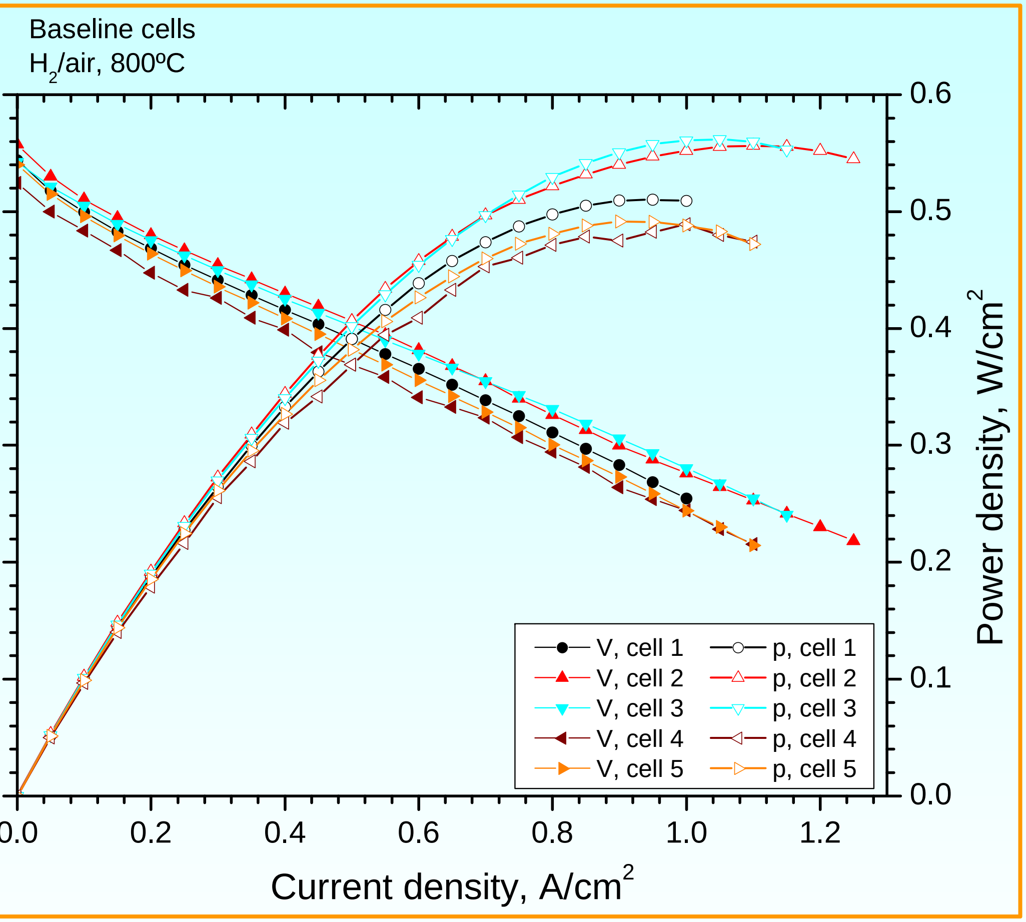
Cell Construction and Test



SEM micrograph of a base cell (MSRI standard cell)

- In this study, all cells were constructed with:
  - Ni-YSZ anode support (~0.7 mm)
  - YSZ-based electrolyte (8 μm)
  - **LSM-based cathode system**, consisting of LSM+YSZ as CIL, LSM+LSCF as CTL, and LSCF as CCCL
- Per-cell active area:
  - Button cell: 2 cm^2
  - Single cell: 100 cm^2
- Test conditions:
  - Either H_2 or a diluted H_2 as the fuel
  - Low fuel utilization for button cells
  - Controlled utilization for single cells, typically 40% ~ 60%
  - **Cell temperature** fixed @ 800ºC

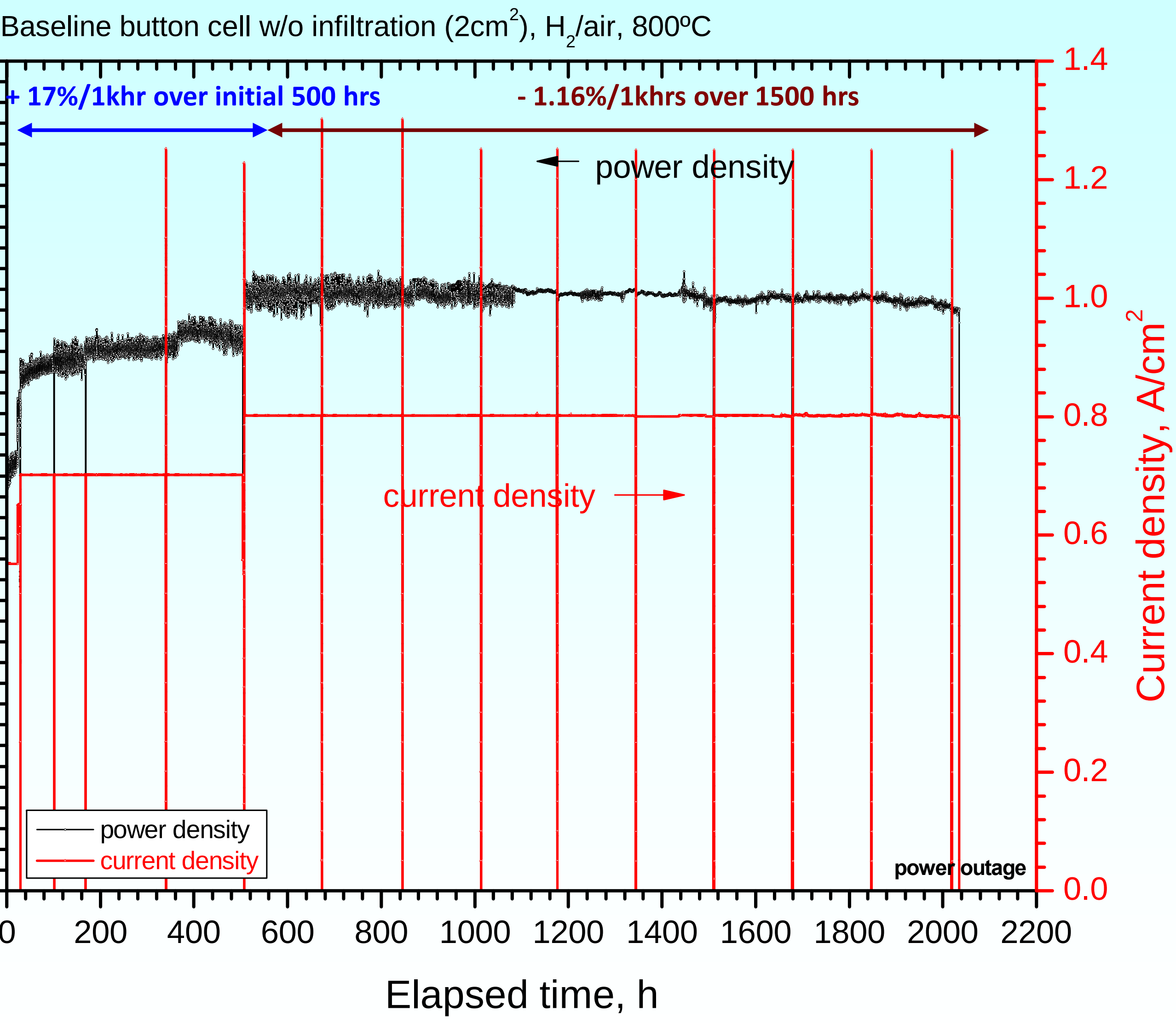
Baseline Cell (LSM-based) Tests



- Button cell baseline tests (w/o catalyst infiltration) for repeatability
- Typical power density: 0.4~0.5 W/cm^2 @ 0.7V; 0.5~0.56 W/cm^2 at peak

ne cell No.	Peak power density W/cm^2	Power density at 0.7V W/cm^2	ASR Ωcm^2
1	0.51	0.45	0.53
2	0.557	0.5	0.506
3	0.562	0.502	0.487
4	0.489	0.4	0.515
5	0.492	0.43	0.548

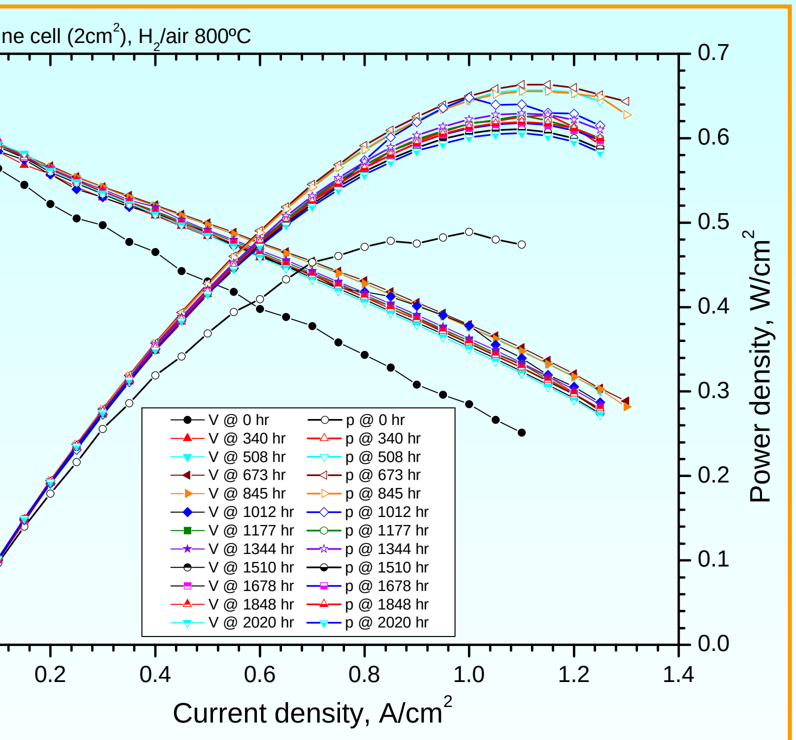
Baseline Cell Long-term Tests

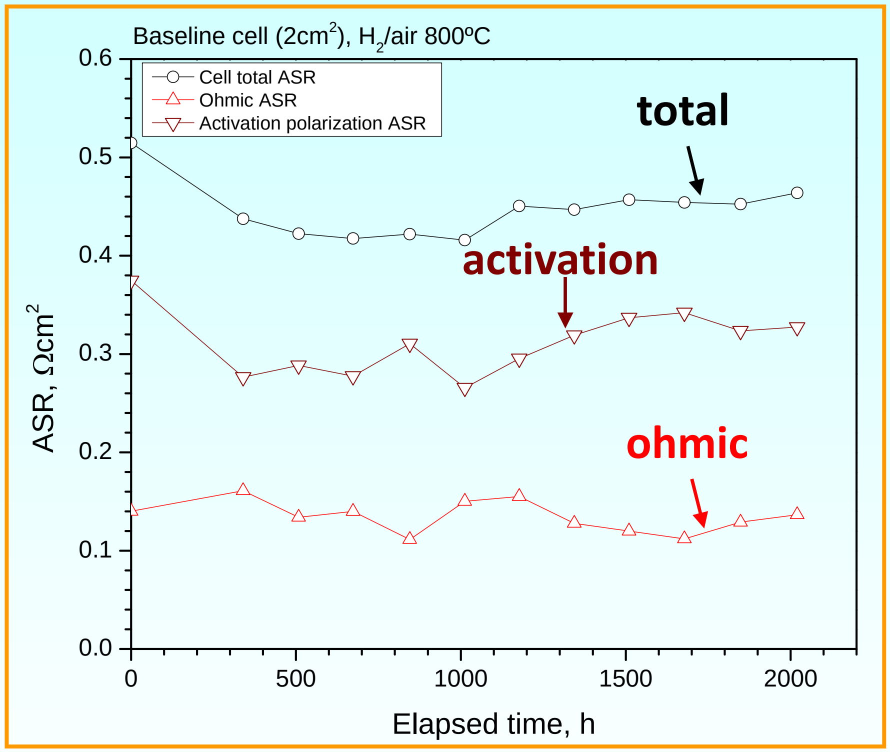


- Tested over 2000 hrs
- current density increased from 0.7 A/cm^2 to 0.8 A/cm^2 after the initial 500 hrs test
- Cell power density increased by 17%/1khrs during the initial 500 hours
- Cell degradation rate @ -1.16%/1khrs over the last 1500 hrs

aseline Cell Performance Characterization

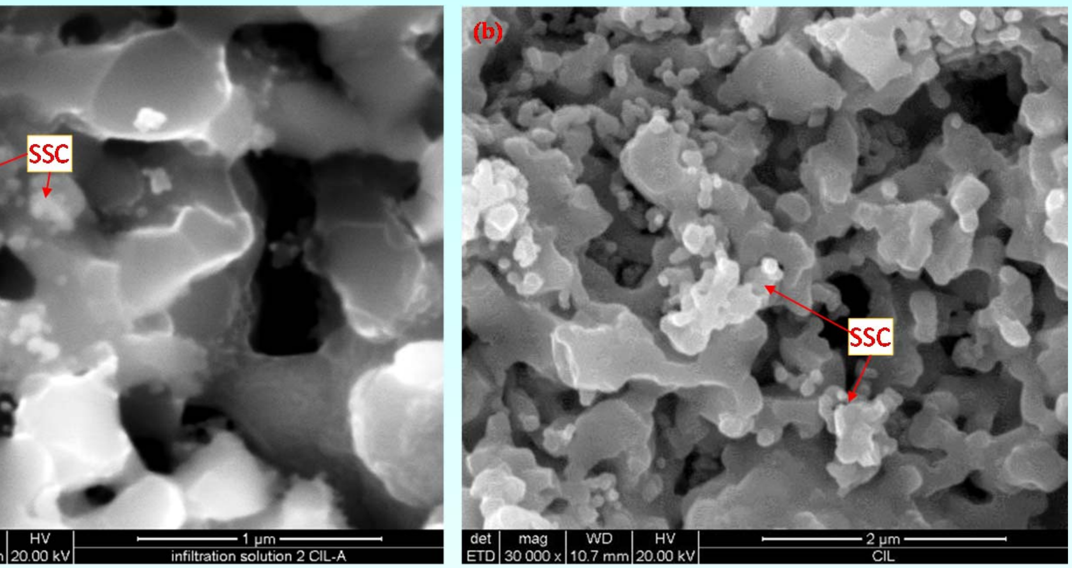
VI tests & EIS measurement at scheduled time (weekly)





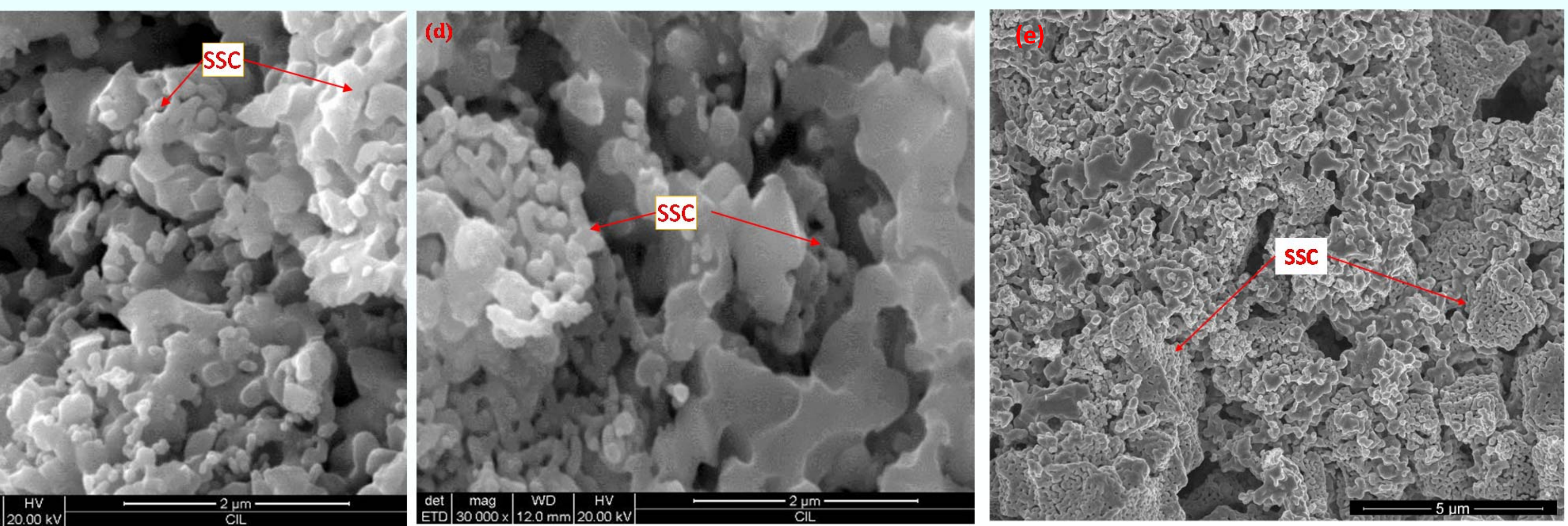
tivation polarization losses were much higher than Ohmic losses

ecursor Concentration Effects on Loading along CIL



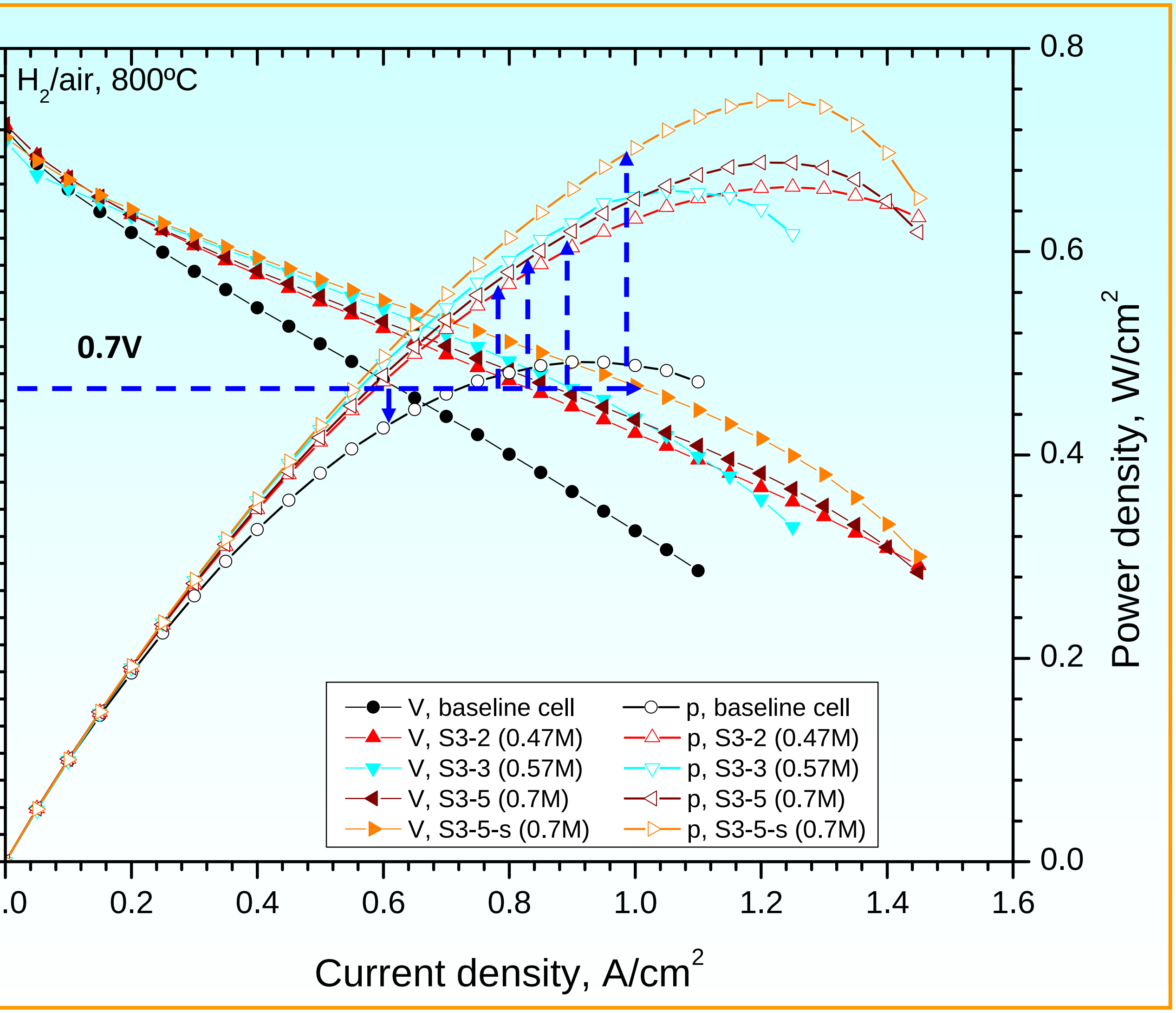
SSC concentrations: (a) 0.25 M, (b) 0.47 M, (c) 0.57 M, (d) 0.7 M, (e) 0.76M

SSC loading was increased from 1 mg/cm^2 to 2~2.5 mg/cm^2 for both button cells (2 cm^2) and large cells (100 cm^2) after the single-step VPIT process



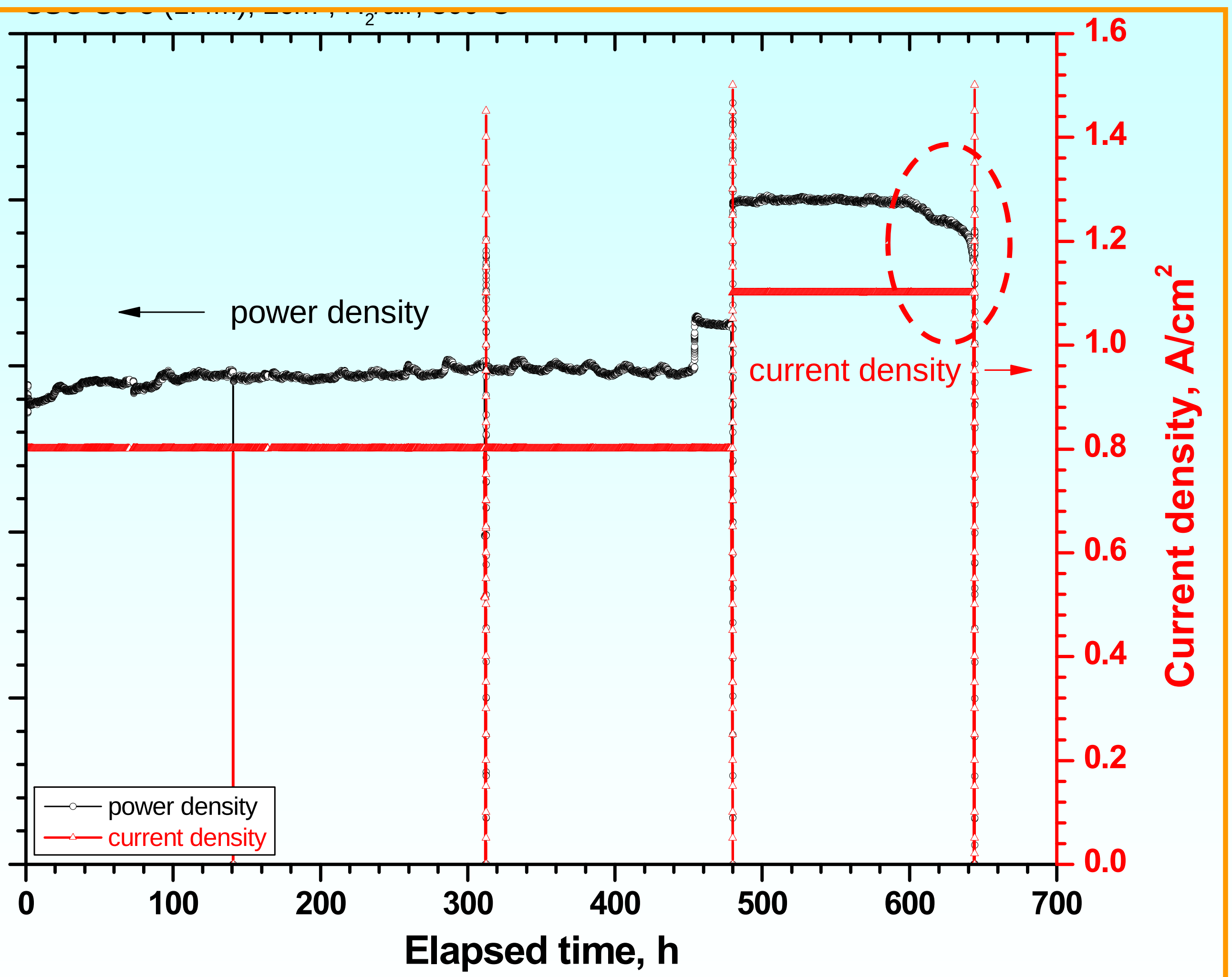
C Precursor Concentration Effects on Cell Performance

Infiltration of (Sm, Sr)CoO_3 catalyst



- Three precursor solutions with concentration varied from 0.47M 0.7M
- Power density improvement > 45% (at 0.7V)
- Cells infiltrated with 0.7M solution outperformed others

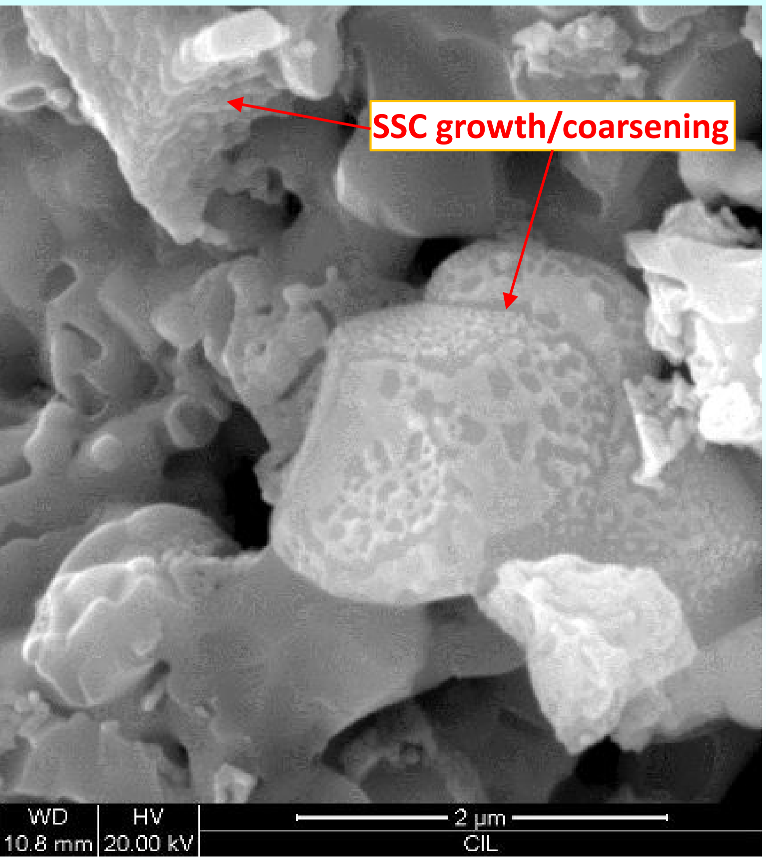
SSC-S3-5 (0.7M) Cell Long-term Test

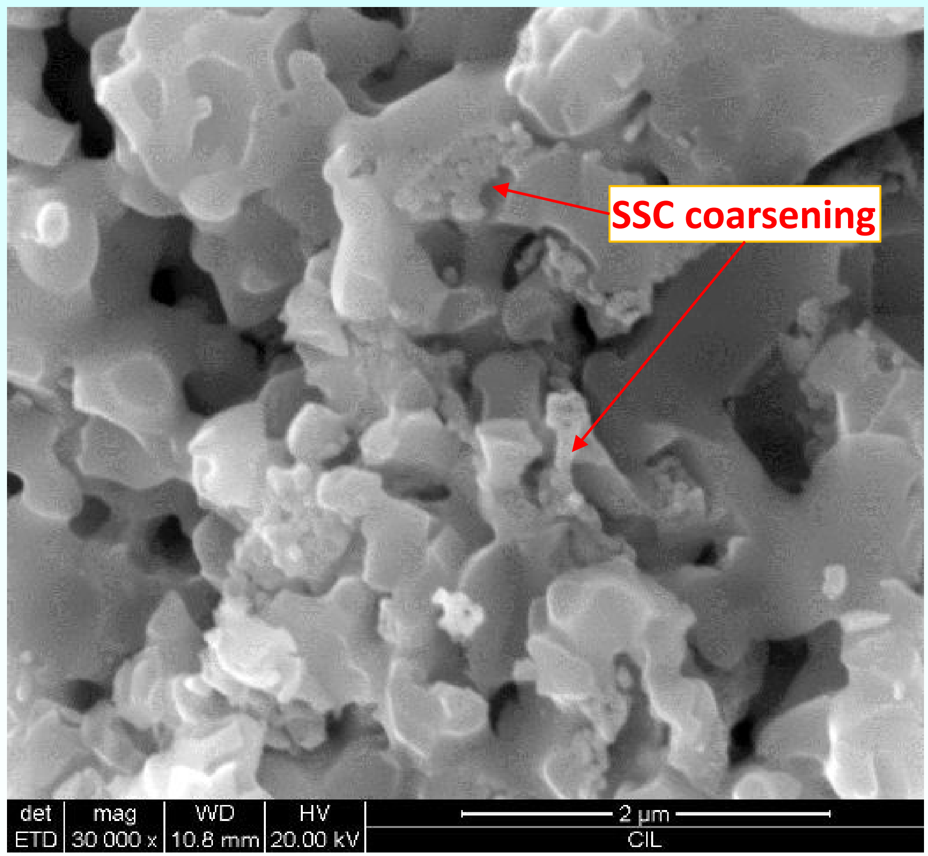


- At 0.8 A/cm², cell performance increased by 6% over 450 hrs
- Current density increased from 0.8 A/cm² to 1.1 A/cm²
- no degradation over 600 hrs
- accelerated degradation was observed during the last 50 hrs (0.72V dropped to 0.66V within 50 hrs)

Nano-catalyst Growth/Coarsening Issue

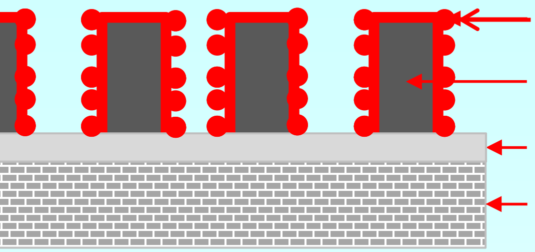
ost-test cell (SSC-S3-5 cell after 650 hrs long-term test) characterization

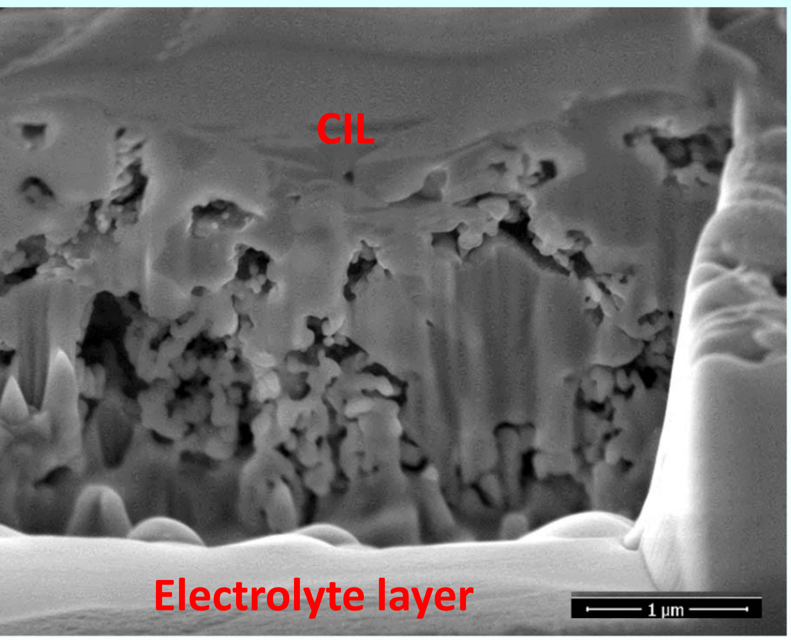


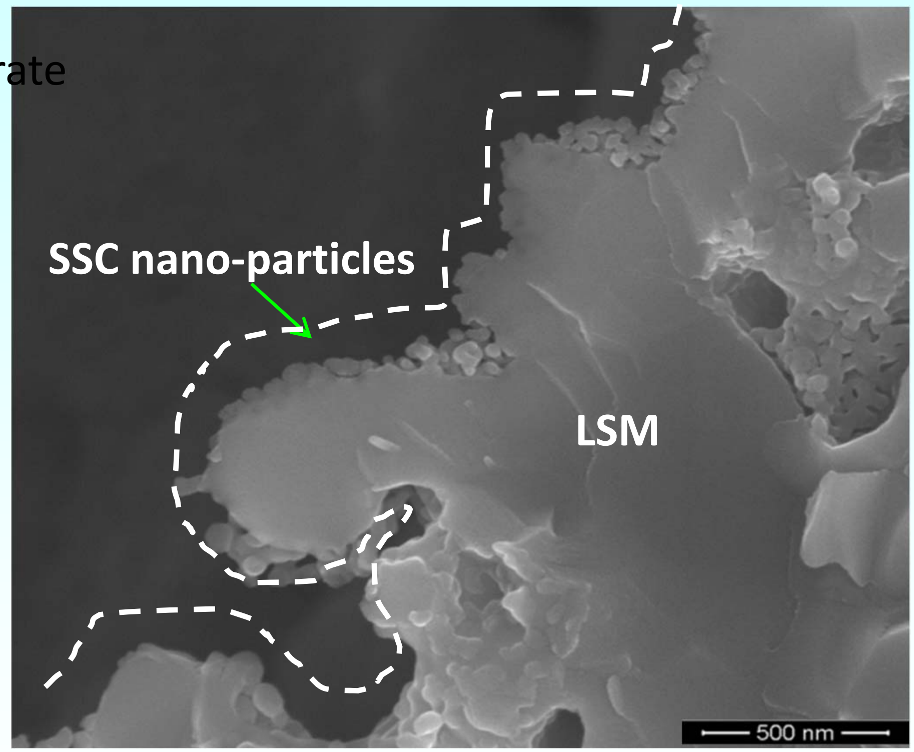


itigate Particle Growth/Coarsening Issues

"Ideal microstructures"???







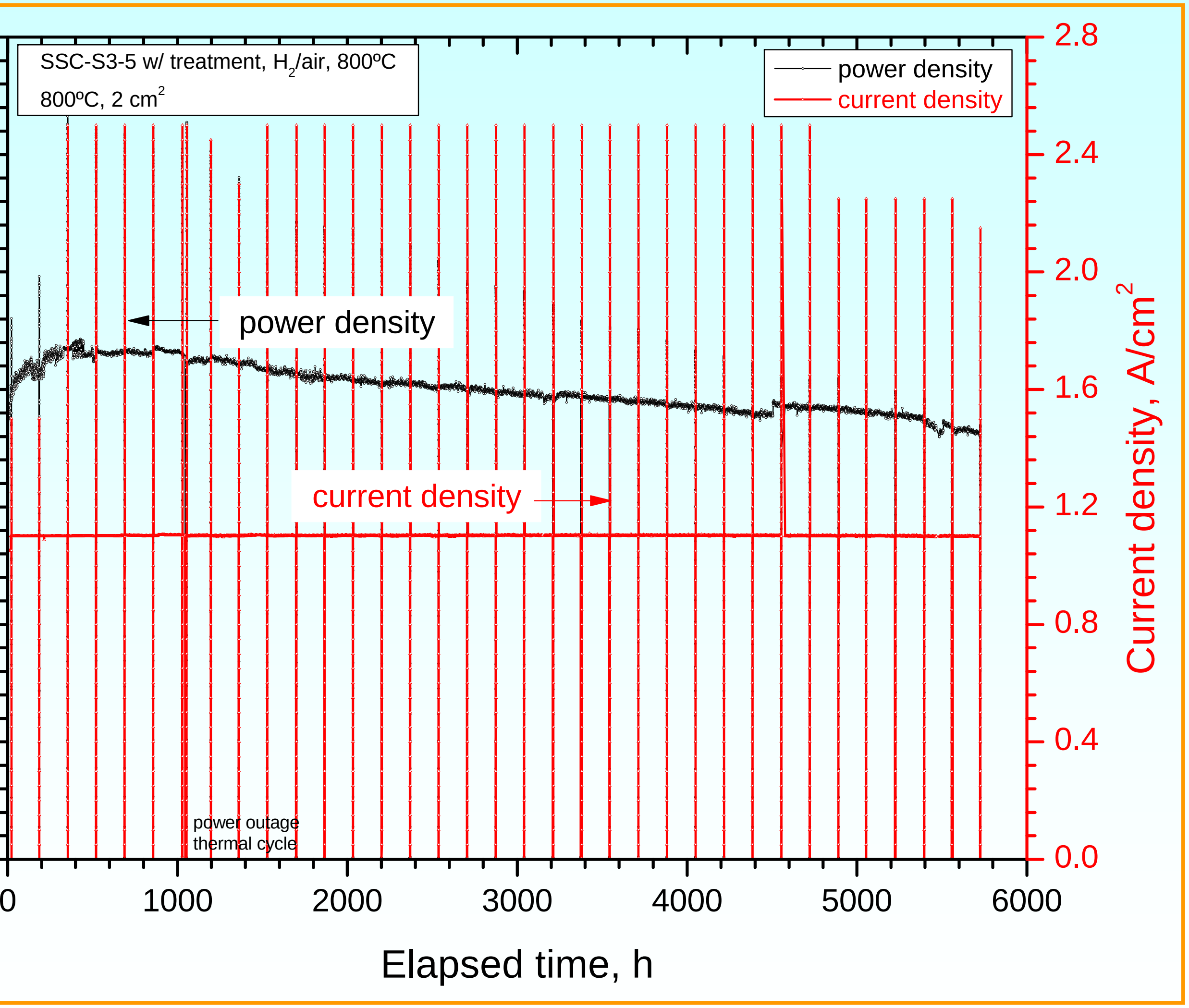
/SEM of the electrolyte/CIL interface

onstruct CIL and CTL to ensure an ient infiltration of a catalyst kly into the ERSs (TPB & 2PB)

- Engineer the catalyst precursor solution, upon infiltration, to avoid excessive agglomerates and to ensure a good coverage of a catalyst along the cathode grains

plement & Evaluate Mitigation Strategies

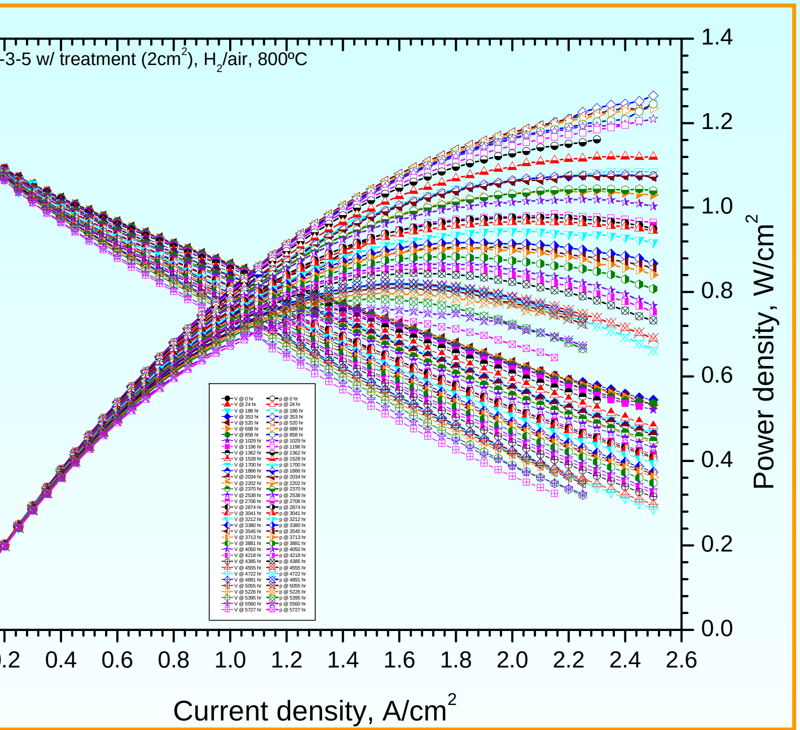
Long-term test results of a button cell

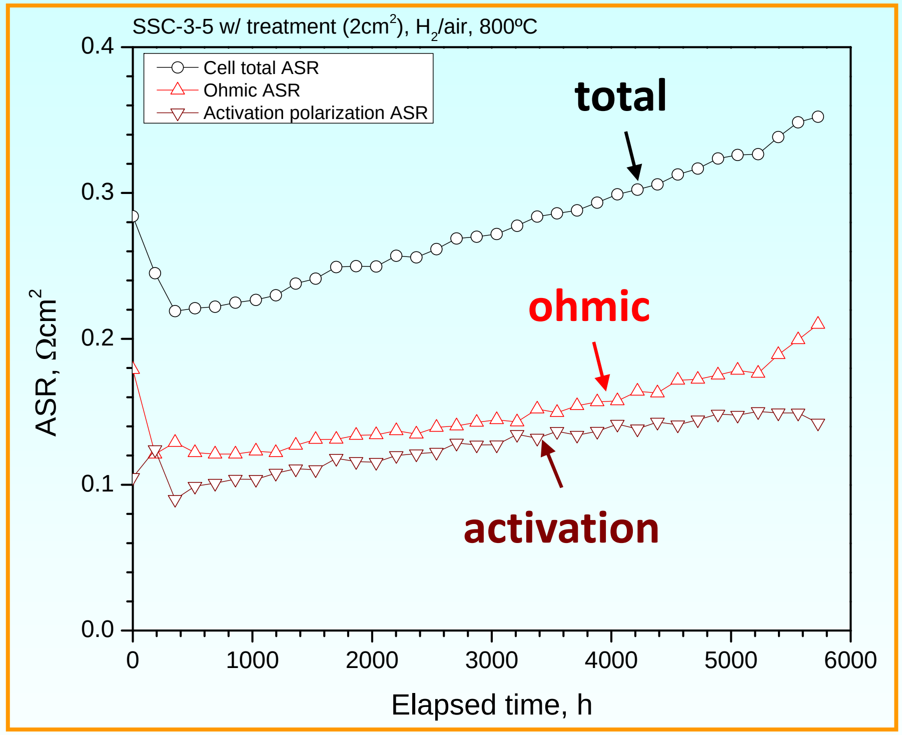


- upon infiltration, cell power density at 0.7V increased from 0.55 W/cm^2 to 0.86 W/cm^2 (> **60% improvement**)
- performance improved over **+4.5%/1khrs** during the initial 1000 hrs test until a power outage,
- cell was still under full load (2.2A, 0.27V) at 690ºC during a power outage over a weekend
- cell overall degradation rate @ **-2.56%/1khrs** over **57,00 hrs (over 8 months**)
- the mitigation strategies showed great promises to improve performance and stability

Significance of Catalyst Infiltration

VI tests & EIS measurement at scheduled time (weekly)



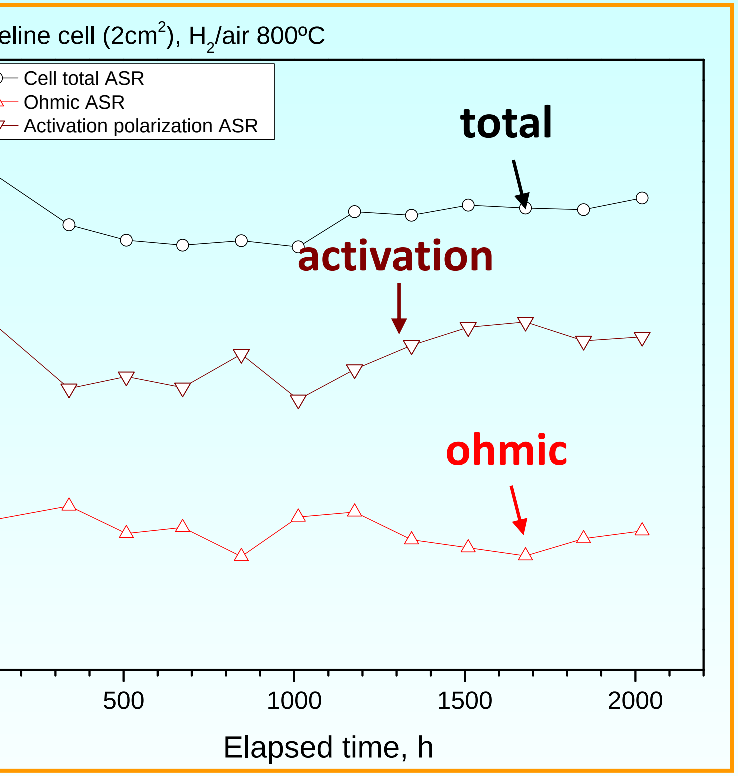


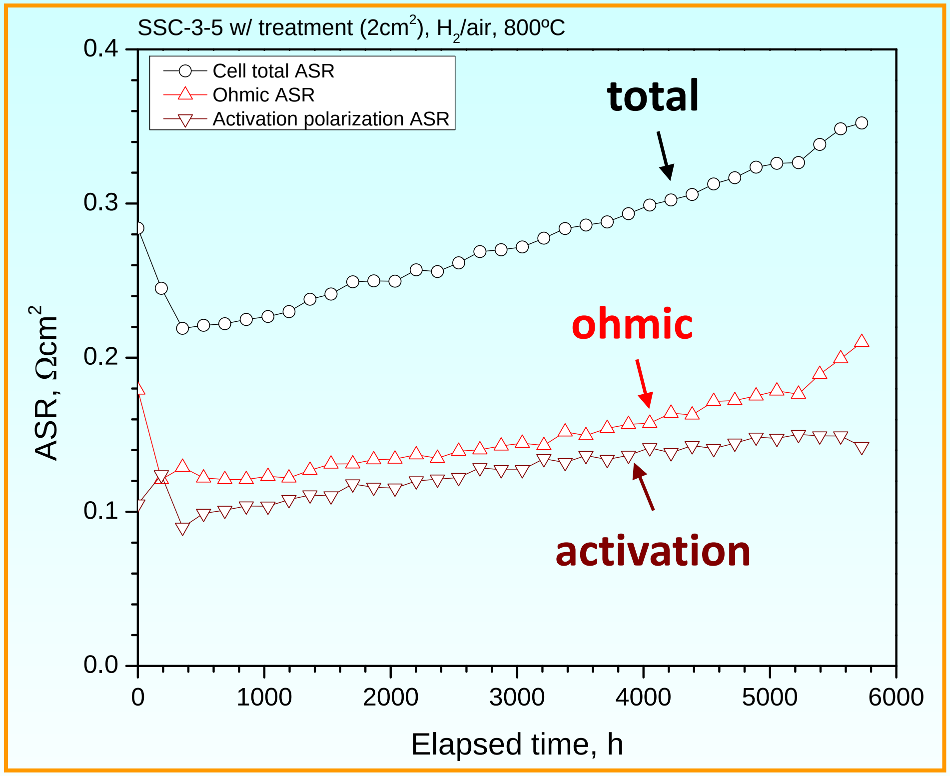
Activation polarization losses were less than Ohmic losses

nefits from Catalyst Infiltration – ASR standpoint

Baseline cell (w/o infiltration)

Cell (infiltrated w/ SSC)

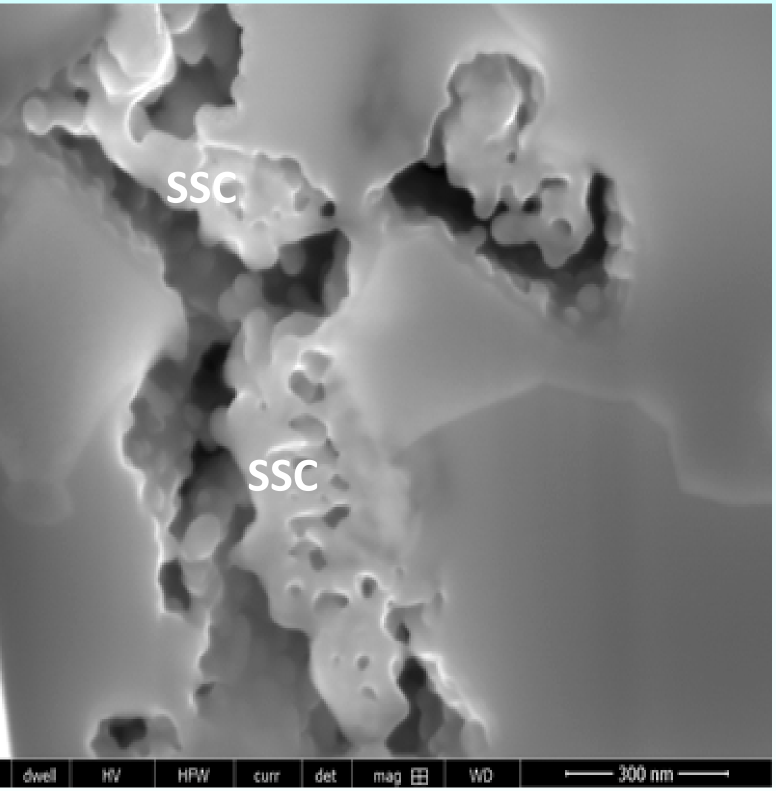




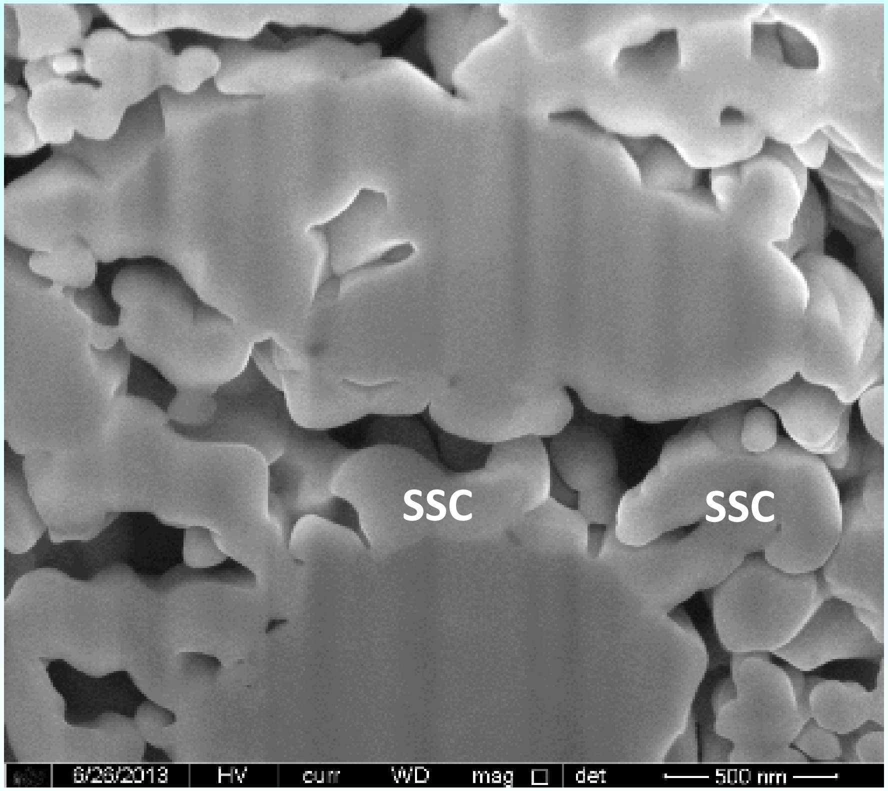
Cell ASR ~ 0.44 Ωcm² consisting of
Ohmic ASR ~ 0.13 Ωcm²
Activation ASR ~ 0.31 Ωcm²

Cell ASR ~ 0.22 →0.34 Ωcm² consisting of
Ohmic ASR ~ 0.12 → 0.22 Ωcm²
Activation ASR ~ 0.1 → 0.12 Ωcm²

crostructure Changes after Long-term Tests

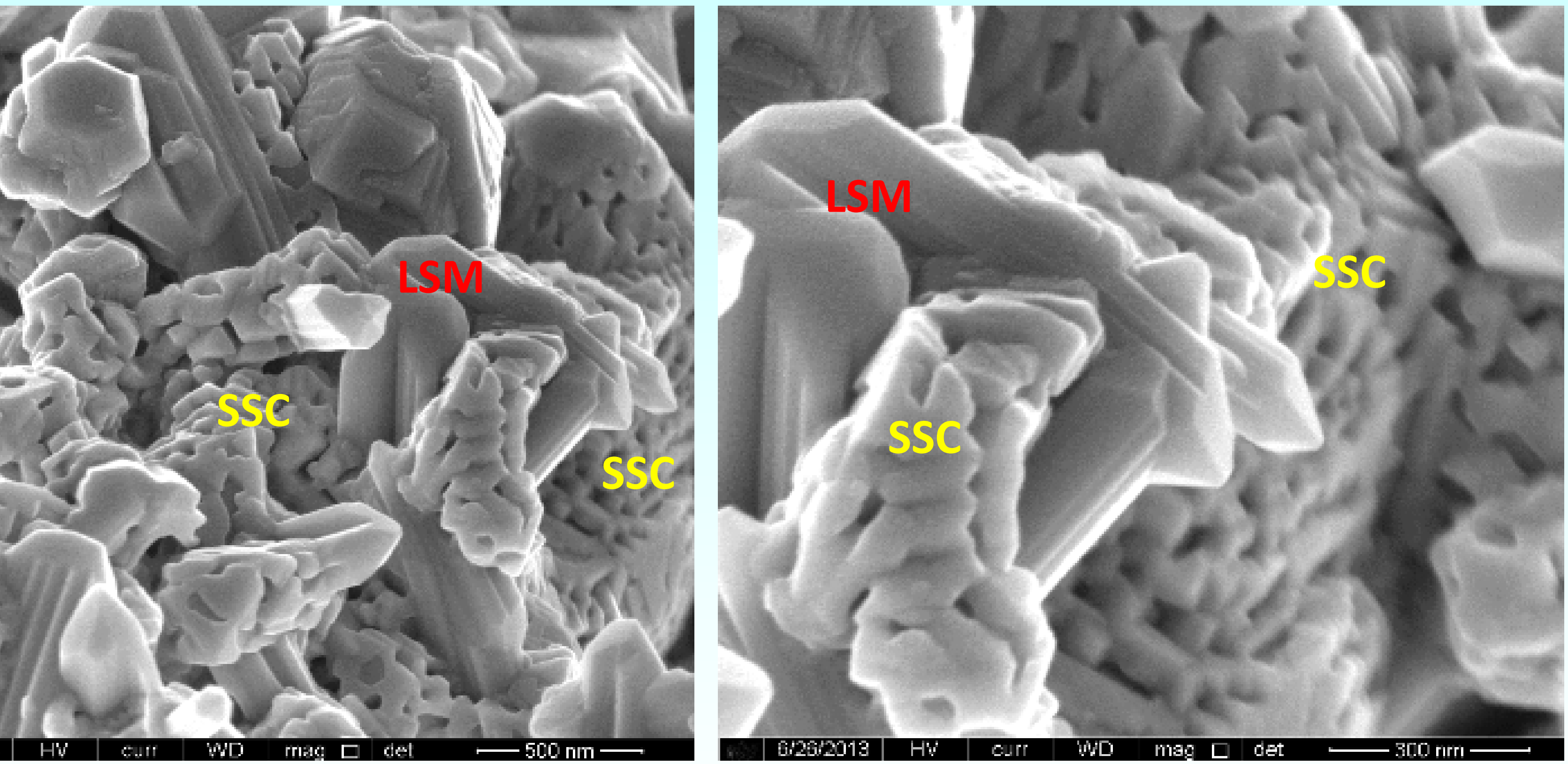


e cell w/ SSC infiltration, sample was
ed by FIB cut near electrolyte (CIL)



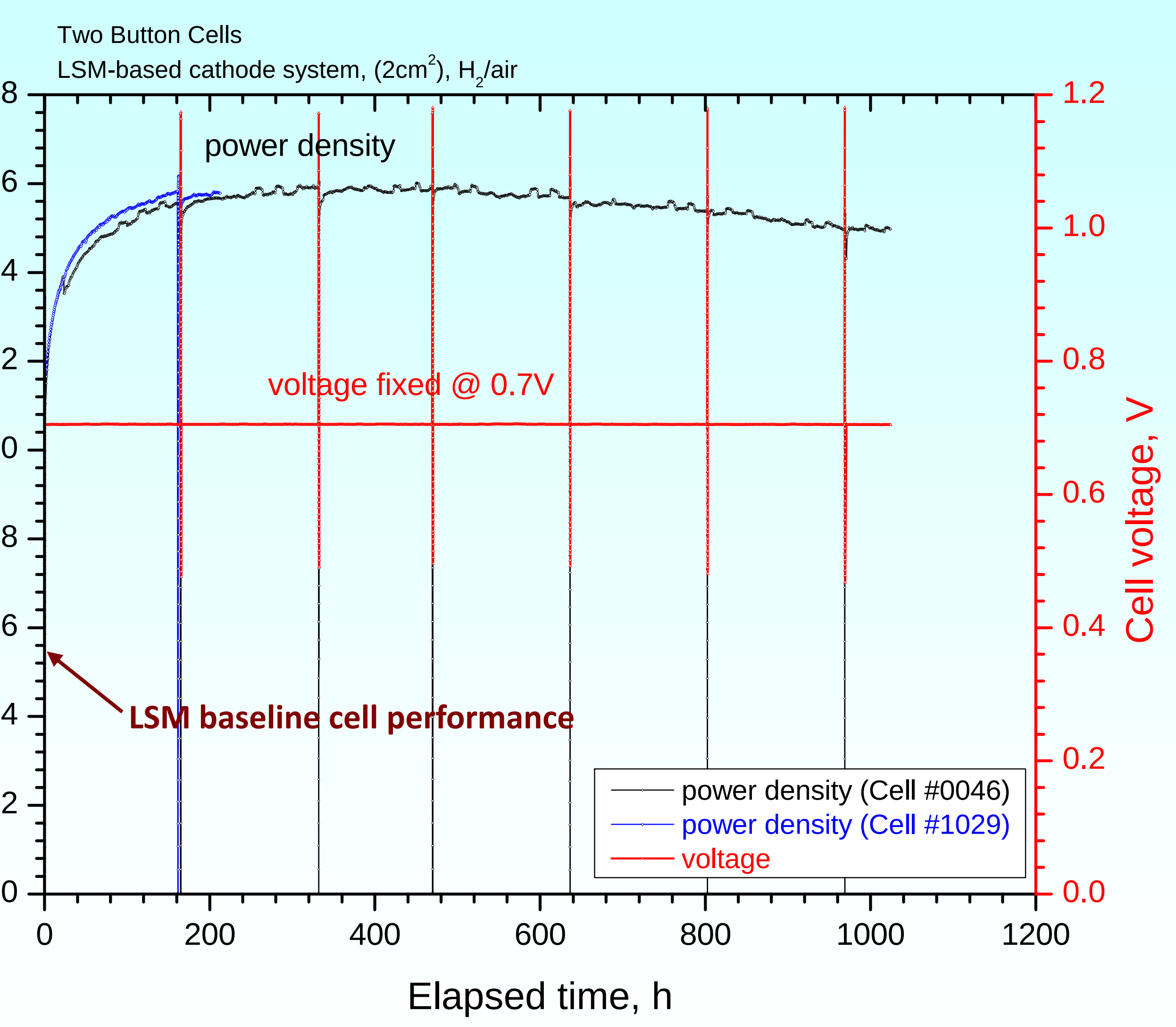
Cell after thousands of hours test.
Sample was prepared by FIB cut near electrolyte (CIL)

crostructure Changes after Long-term Tests



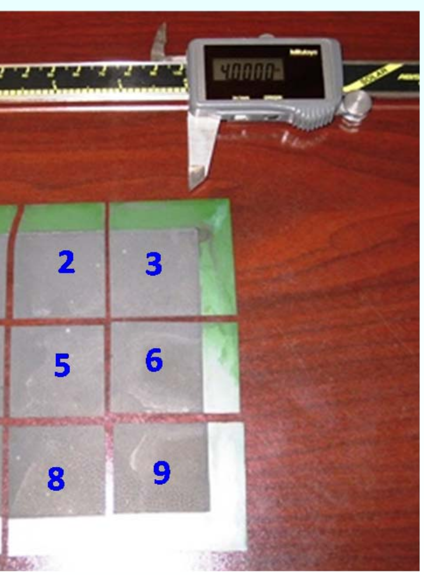
a cell after ~ 53,00 hours test (1.5A/cm^2 @ 0.7V)

Other Nano-sized Electrocatalysts

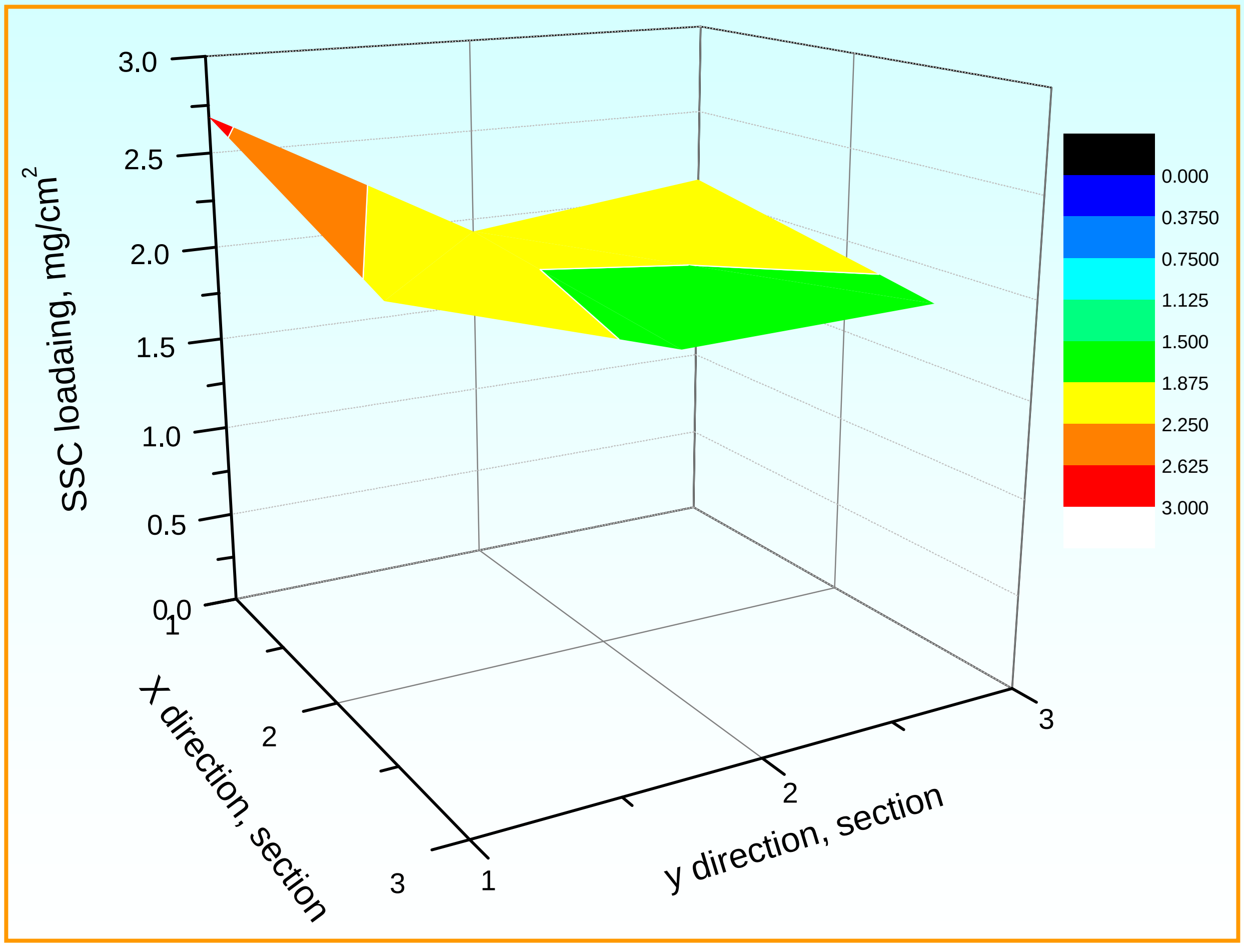


- Non-precious metal catalyst
- upon infiltration, cell power density at 0.7V increased from 0.55 W/cm^2 to **1.5 W/cm^2** (> **170% improvement**)
- 1.5%/1khr improvement over 1khr test
- Tests are still on-going

aling-up from Button Cells to 100cm^2 Cells



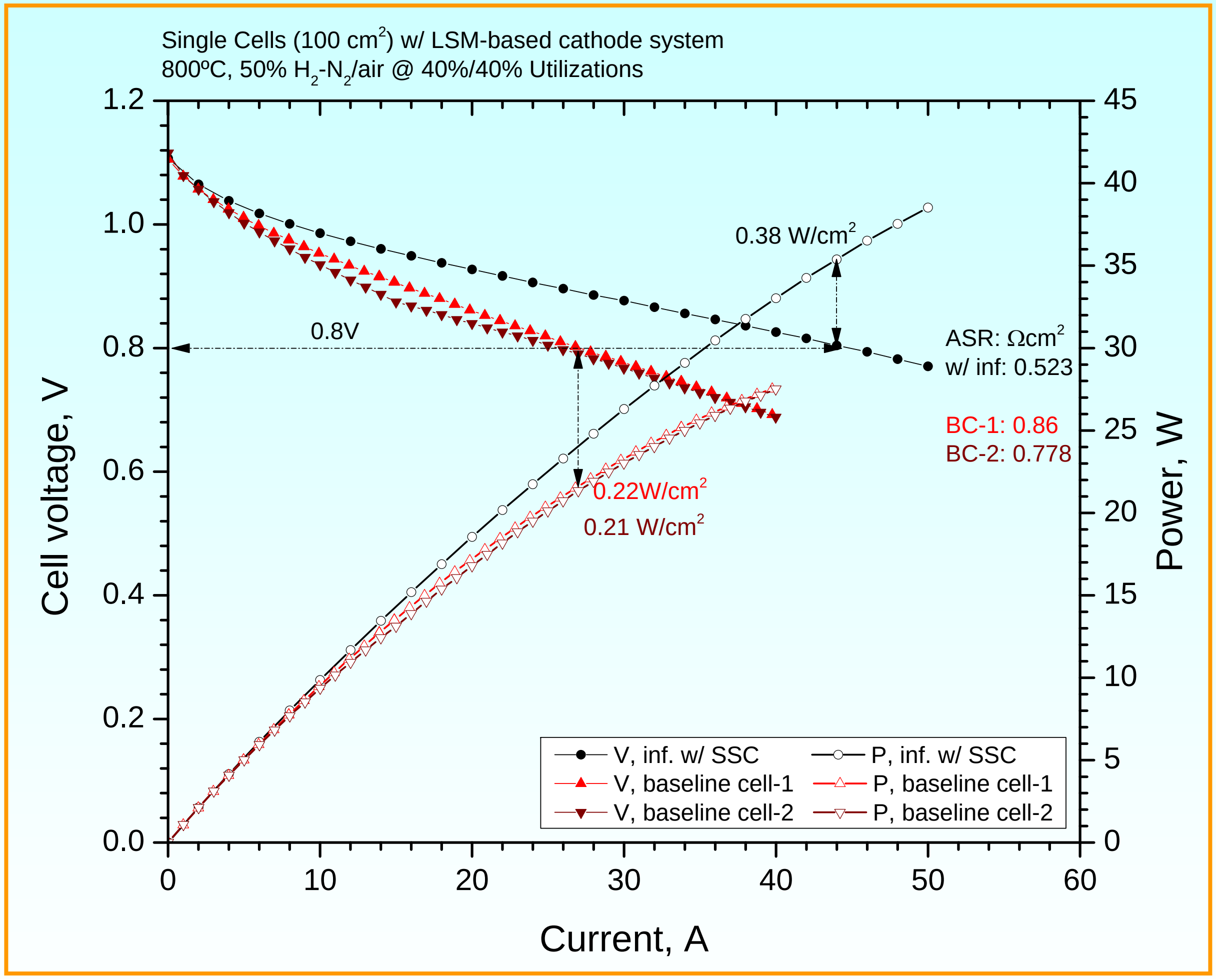
Study of SSC loading distribution along a 4”x4” single cell cathode surface (100 cm^2) – from corner to corner



Single Cell (100 cm²) Evaluation

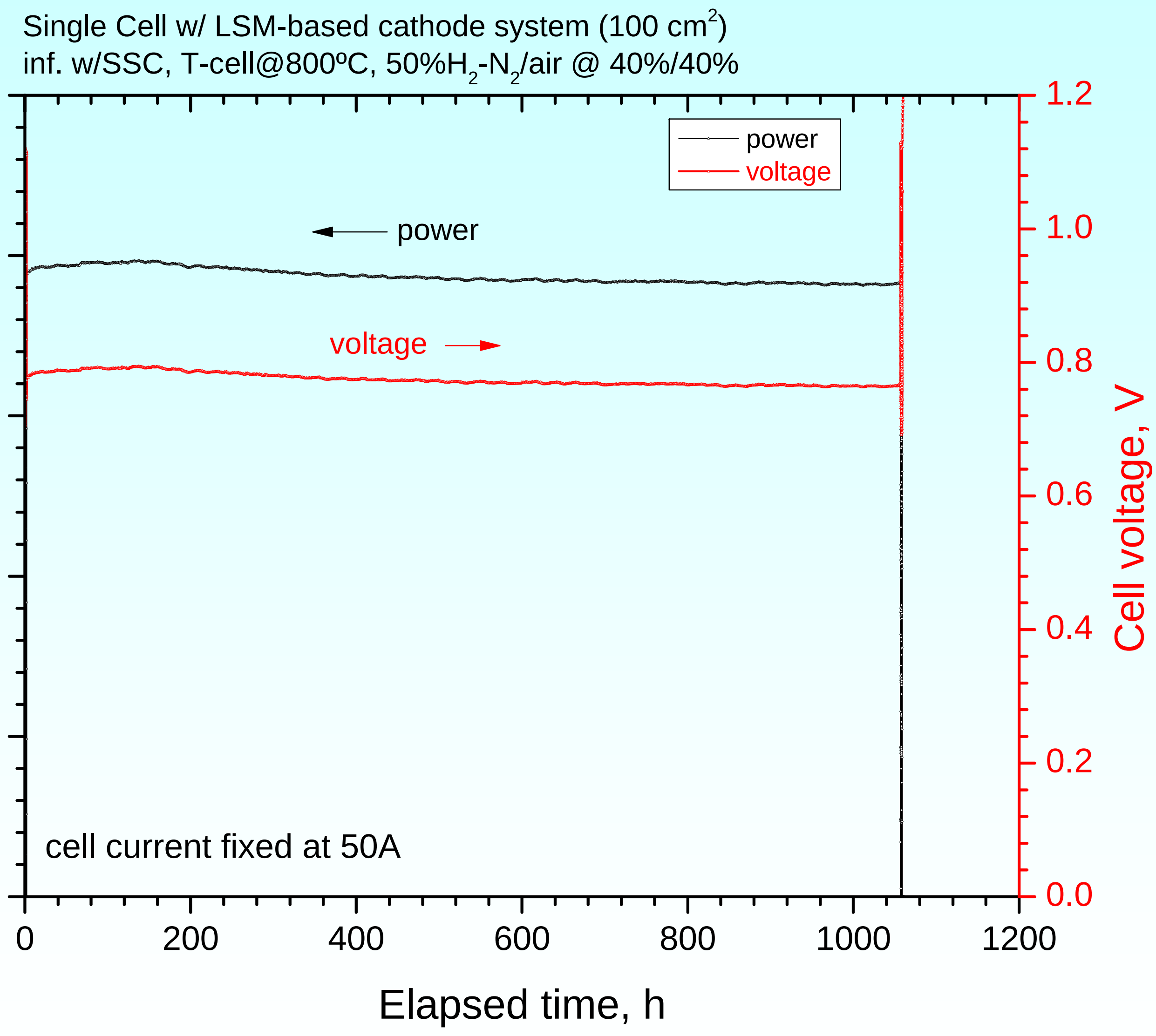
...mic test-rig for single
...ts

- ...-of Cr sources
- ...metallic IC
- ...ic stack compression &
- ... patterns



Single cell performance comparisons among two baseline cells and the one w/ SSC infiltration

ng-term Test of a Single Cell w/ SSC Infiltration

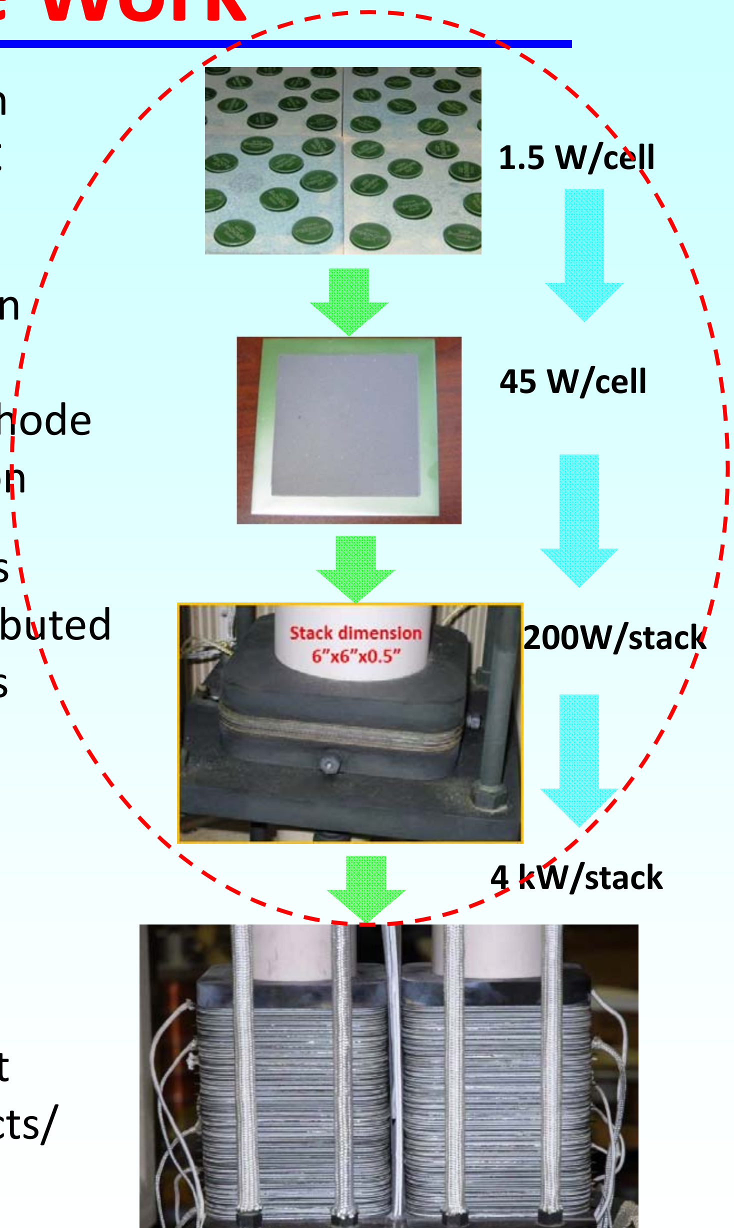


Long-term test result of a single cell w/ SSC infiltration

- Cell temperature adjusted to 800ºC
- Dilute fuel w/ fixed 40% utilizations
- Under a constant current of 50 A (0.5A/cm^2)
- Cell voltage ~ 0.8 V
- Power improved by ~ +2%/1khr during initial 200-hr test
- Over the 1khr test, power degradation rate: -3.5%/1khr, or -0.014 mW/cm^2-hr

Summary/Future Work

- ltration of an electrochemically active catalyst is an cient and cost-effective approach to improve SOFC hode performance
- parameters determining the single-step infiltration ciency are critical to the success of the SOFC formance improvement, while pre-established cathode kbones also needs modification for implementation
- ls with a catalyst infiltration outperformed the cells hout infiltration by over 60% (at 0.7V), mainly attributed he activation polarization reduction from cathodes
- ntinue to perfect the VPIT processes
  - Explore other catalyst effects
  - Optimize catalyst structure
  - Identify the anode degradation attribute
  - Perform techno-economic evaluation
- luate scale-up cells and stacks for proof-of-concept monstration (built-on MSRI's standard SOFC products/ tforms)



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Thank you!