SOFC Degradation Program at GE Global Research

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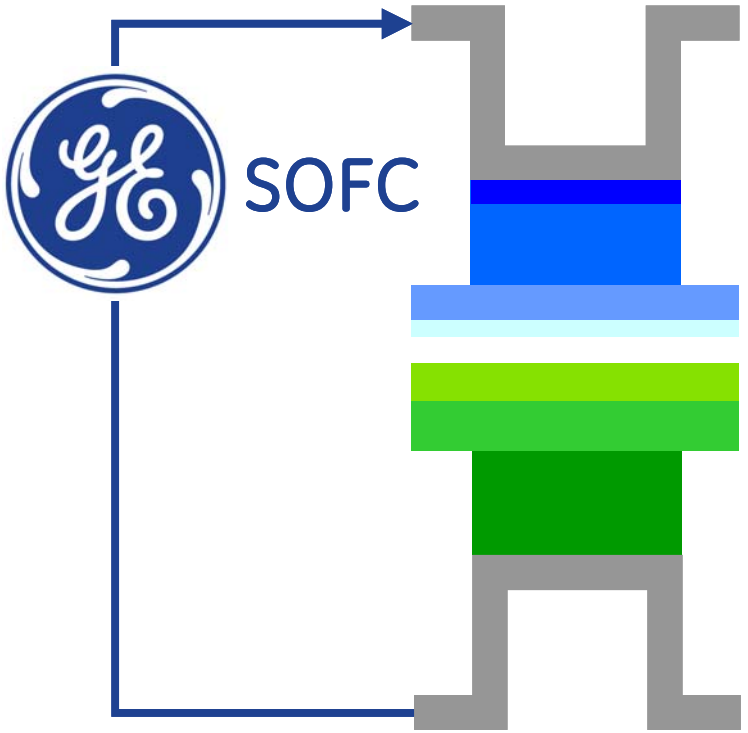

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Project Goals and Objectives

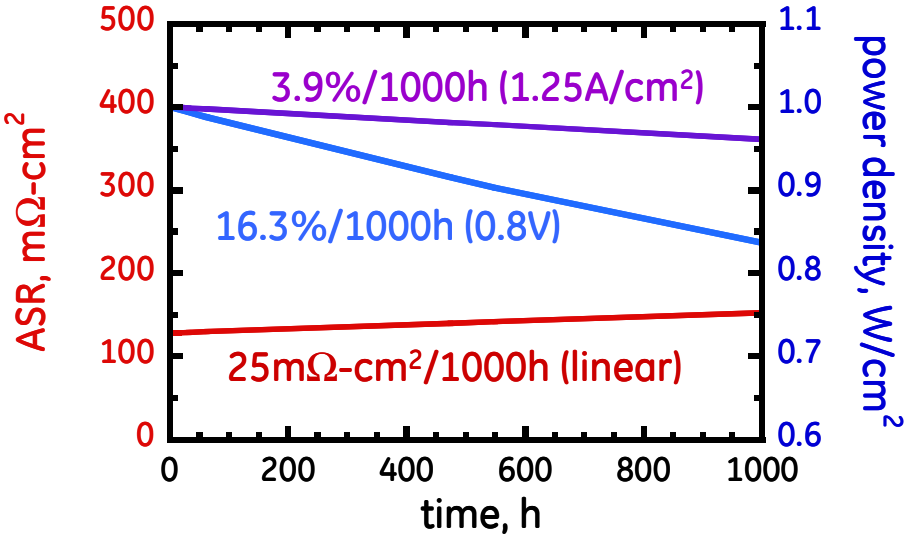
- Develop high performance (>0.75 W/cm^2), low degradation (<1%/1000h power density) SOFCs operating at 800°C
  - Identify dominant degradation mechanisms
  - Develop and implement cost effective degradation mitigation strategies

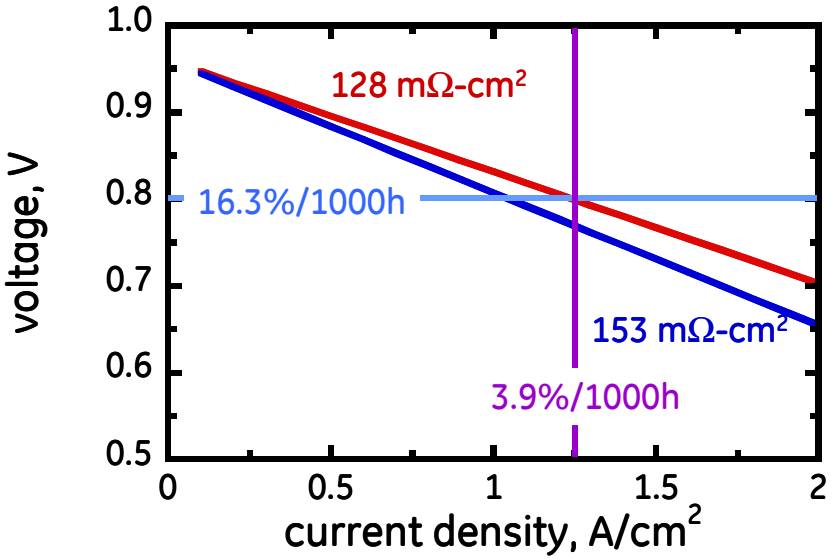
Program Status and Highlights

- Developed suite of testing and characterization for degradation mechanism identification, enabling paths to mitigation
- Determined LSCF cathode stability critical to degradation and demonstrated modified architecture capable of significant improvement.
- Demonstrated inherent electrical and electrochemical stability of LSCF-based SOFCs.

Degradation Rate Reporting

Constant Voltage Vs Constant Current





$$\mathrm{PD}_{\mathrm{V=const}} = \frac{V_{op}\left(OCV - V_{op}\right)}{ASR}$$

$$\mathrm{PD}_{\mathrm{J=const}} = \left(OCV - ASR * j\right) j$$

$$DegradationRate_{V=const} = \left(1 - \frac{ASR_0}{ASR_1}\right)$$

$$DegradationRate_{J=const} = \left(\frac{J\left(ASR_1 - ASR_0\right)}{OCV - J \times ASR_0}\right)$$

Power density degradation rate 'appears' greater for potentiostatic.
ASR preferred metric to study degradation.

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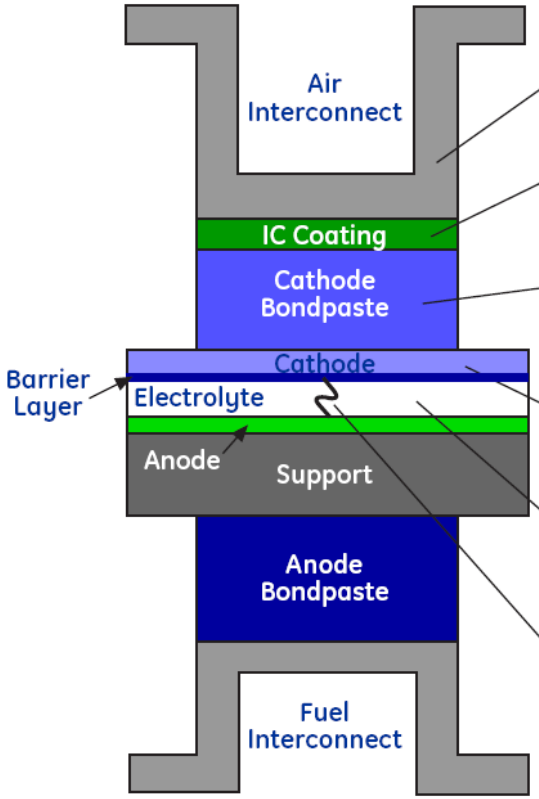
Experimental Approach

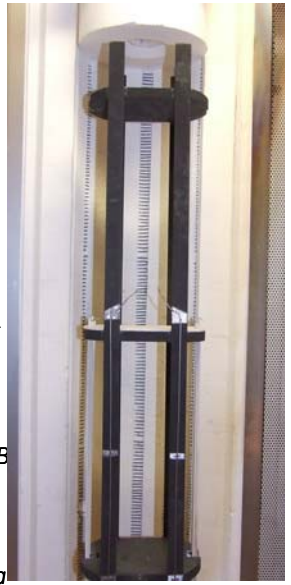
SOFC degradation - materials focused approach



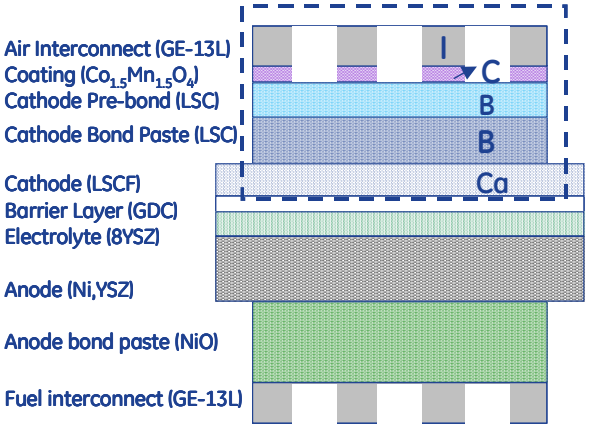
Mechanism	Type
Air Interconnect	
• Chromia scale resistance (Cr_2O_3)	Chemical
• Insulating scale growth (SiO_2)	Chemical
Protective Coating	
• Coating resistance (MnCo spinel)	Chemical
Cathode Bondpaste/Coating Interface	
• $SrCrO_4$ layer resistance	Chemical
• $SrMnO_3$ layer resistance	Chemical
• 'Other' reaction phase formation	Chemical/Structural
• Mechanical delamination	Structural
Cathode	
• Chromia poisoning	Chemical
• Coarsening	Structural
Cathode/Electrolyte/ Barrier Layer Interface	
• Zirconate resistive layer	Chemical
• Cathode poisoning	Chemical
• Delamination	Structural
Leakage-Driven Degradation	
• Cathode reduction	Chemical/Structural
• Anode oxidation	Chemical/Structural
• Combustion thermal	Chemical/Structural

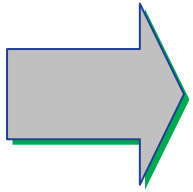
With a 'fixed' materials set: Focus on cathode side, high-impact degradation mechanisms

Ohmic and polarization losses

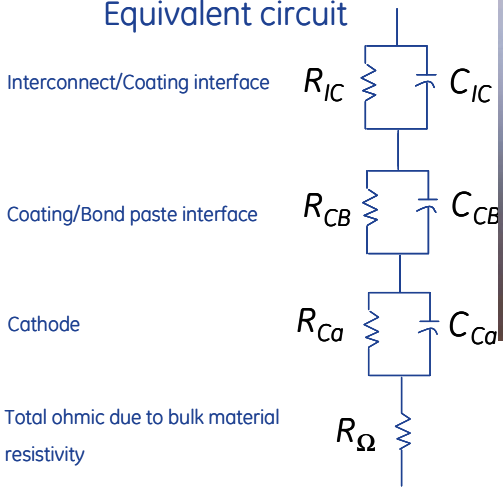


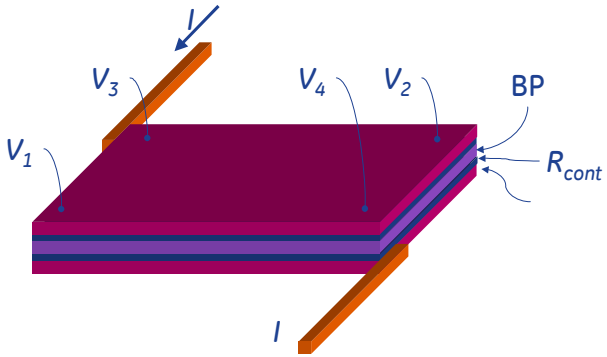
Electrochemical cell configuration

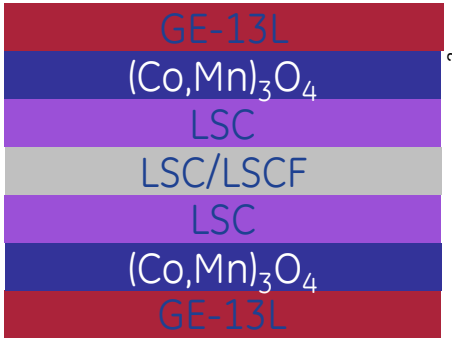


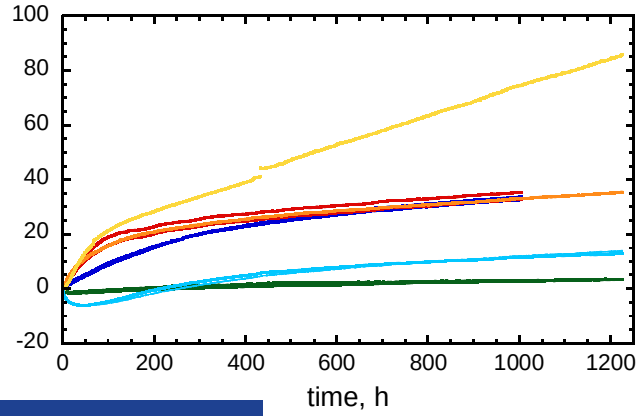


Equivalent circuit









Direct measurement of interface contribution for ASR breakdown and mechanism isolation

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Button Cell testing for high-throughput screening

Baseline test conditions:
800°C
Galvanostatic, 1.25 A/cm^2
LSCF Cathode
LSC Bond paste
Interconnects – Ferritic SS

'6-gun'

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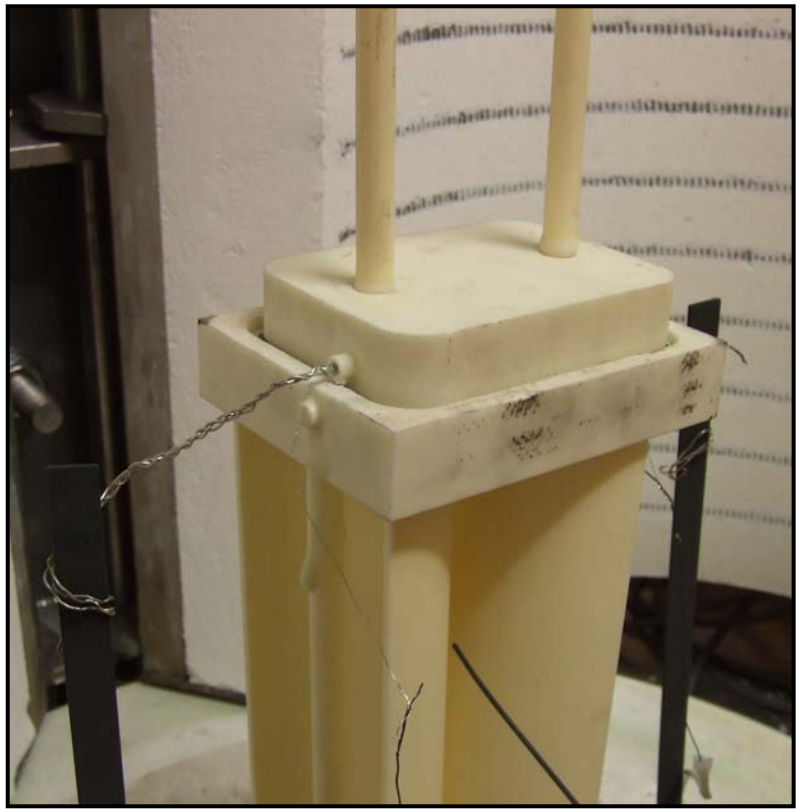
Ceramic Test Vehicle – The Browaller*

Idealized test fixture (2”x2” active area)

- Simulate real SOFC operating conditions
  - Known ‘boundary conditions’
- High performance (<200 mΩ-cm^2)
- High utilization (80% UF)
  - Monitor fuel and air gases
- Interchangeable interconnect
  - Gold
  - Ferritic stainless steel



Provide confidence and accuracy in degradation measurement

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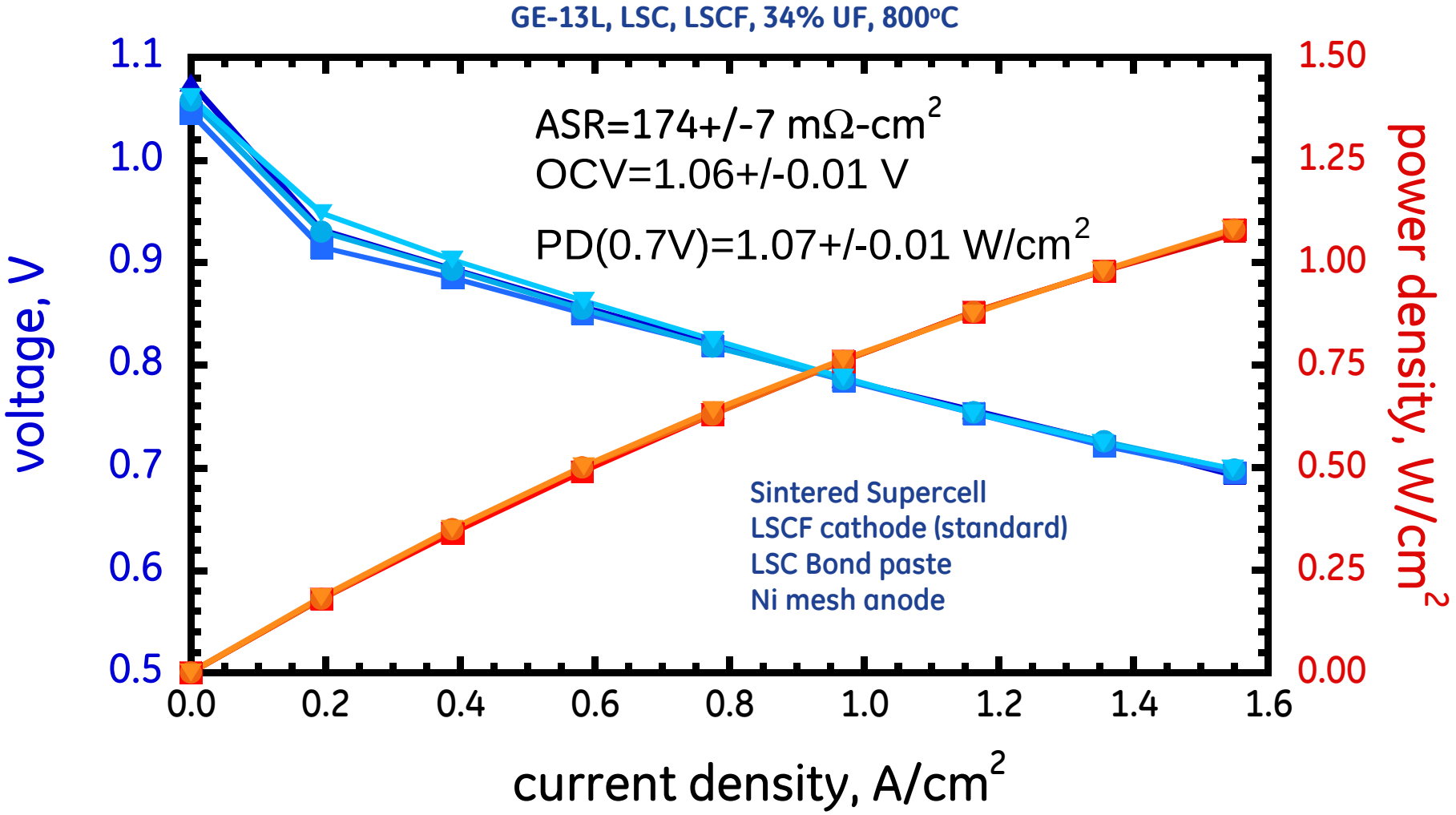
*after Ken Browall, ret 6/1/07

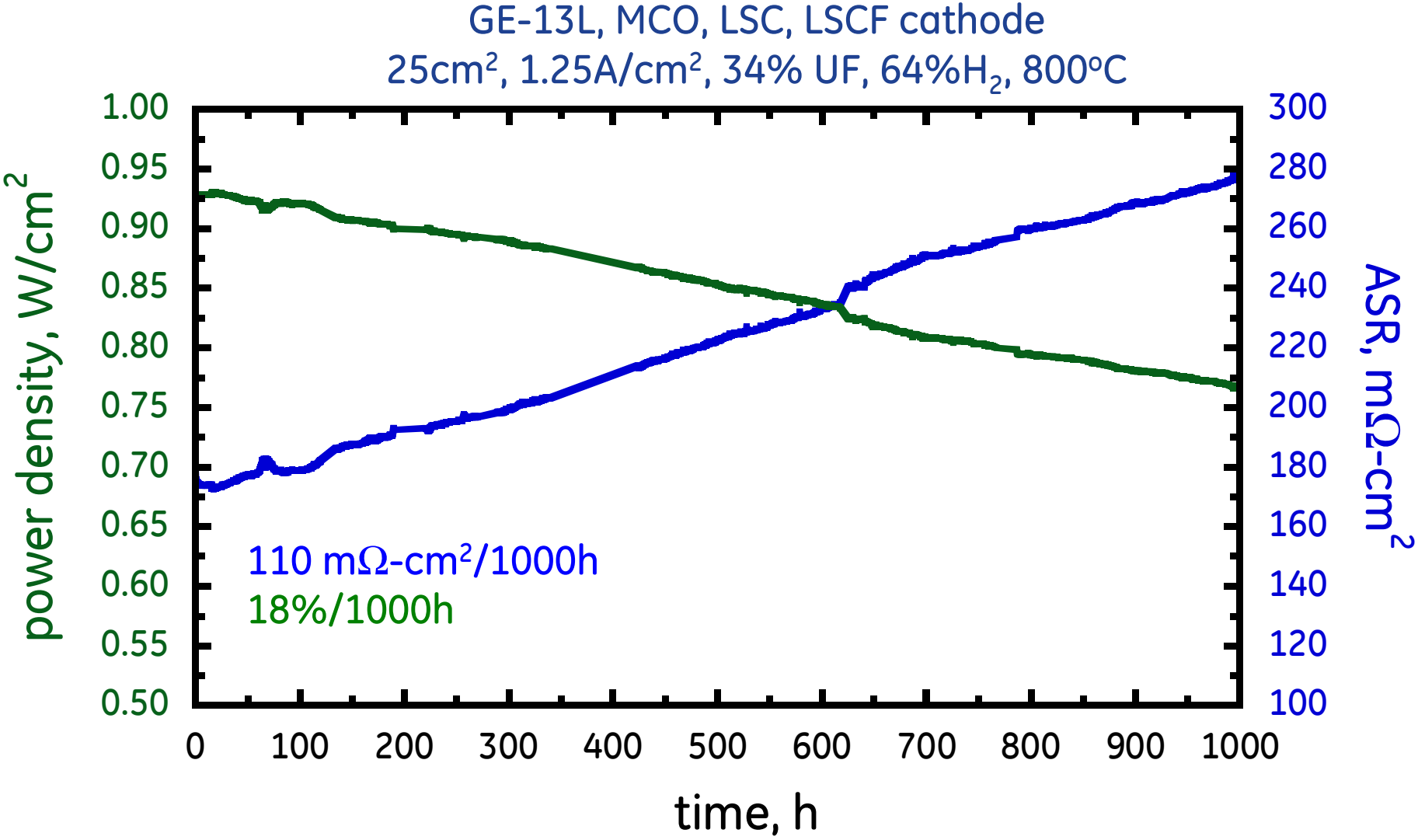
Results

25cm² cell performance



- Excellent cell performance – equal to buttons
- Repeatable test results
- Fully sealed – no leakage, cracking

25cm² Browaller cell degradation



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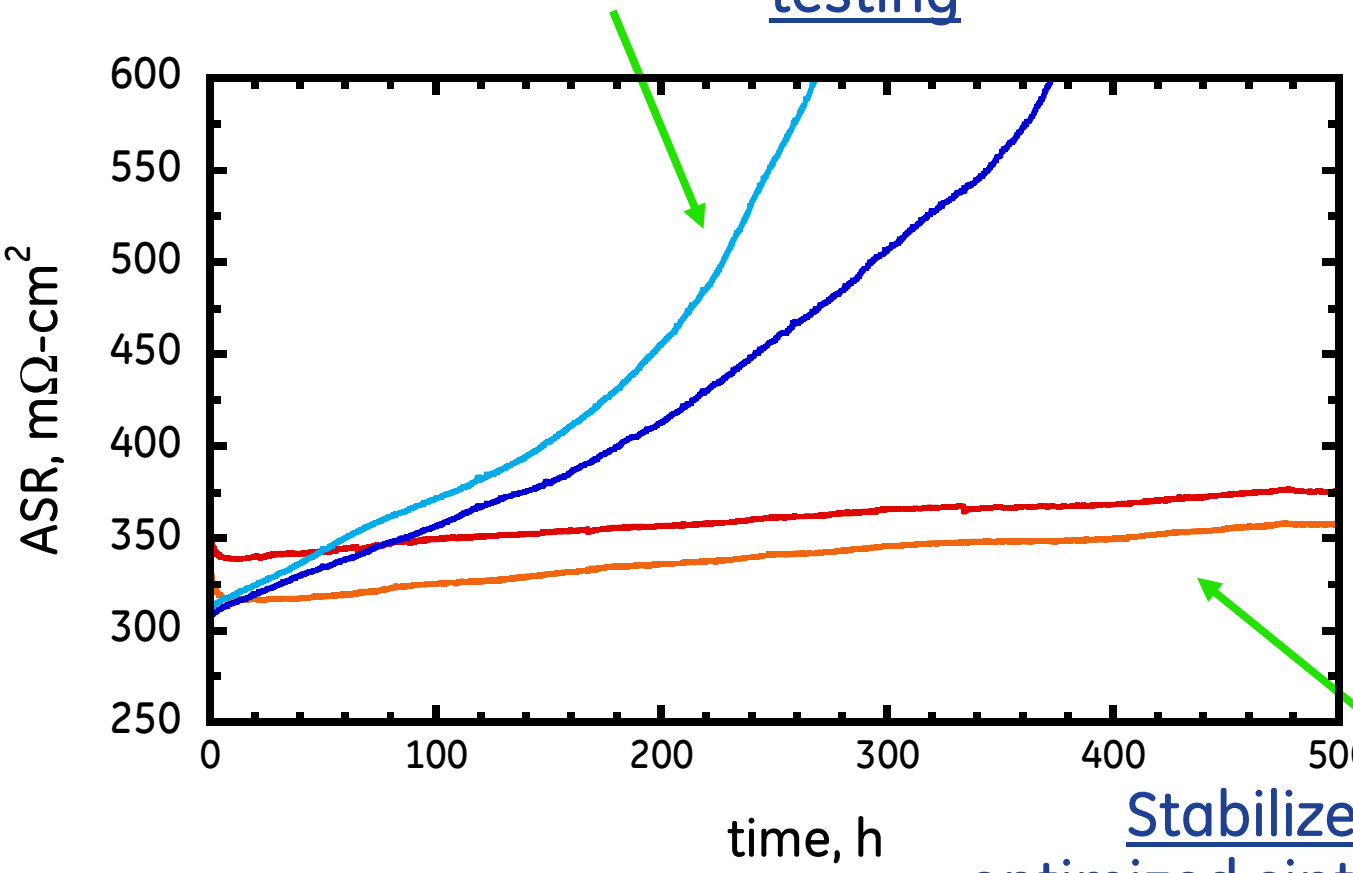
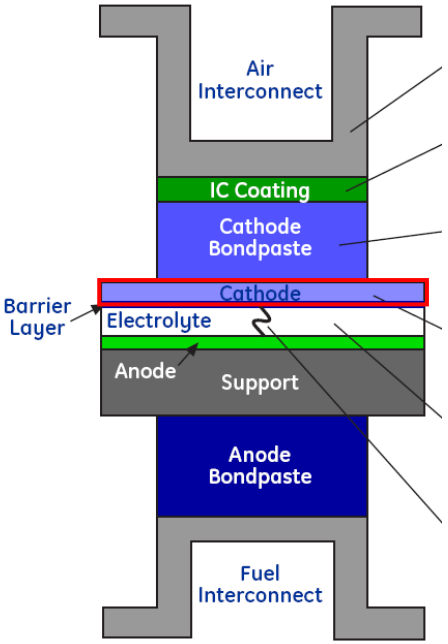
Relatively high power density and high degradation rate

Cathode Stability

LSCF Cathode stability

Rapid degradation during testing





Stabilized Cathode optimized sintering conditions

Significant improvement in button cell repeatability with stabilized LSCF cathode.

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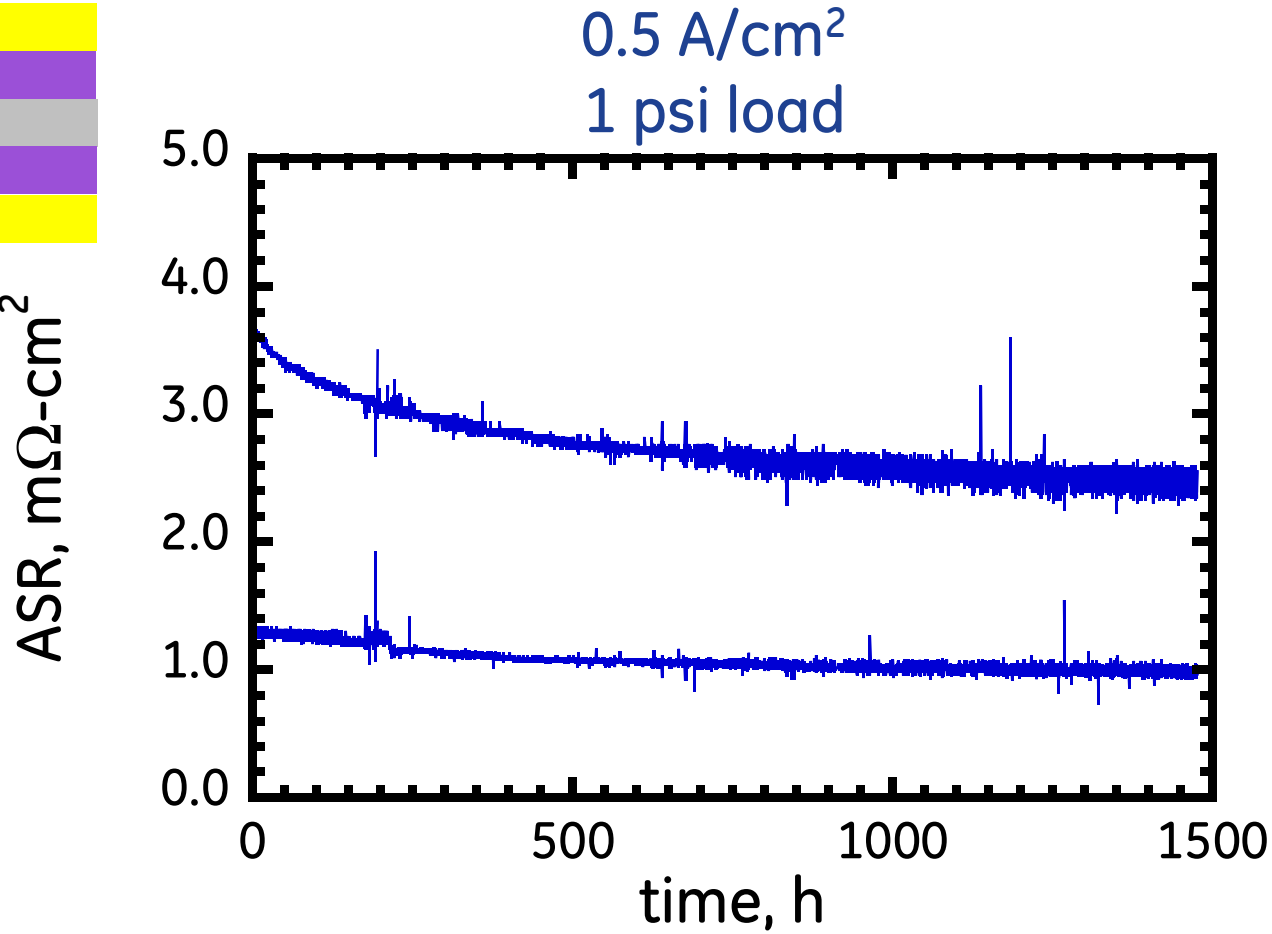
Stability of Materials Set

Bond Paste & Cathode Contact Resistance



- Cathode (LSCF) high conductivity - stable
- Bond paste (LSC) high conductivity – stable
- No ohmic degradation with gold interconnect

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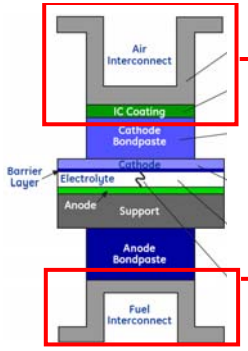
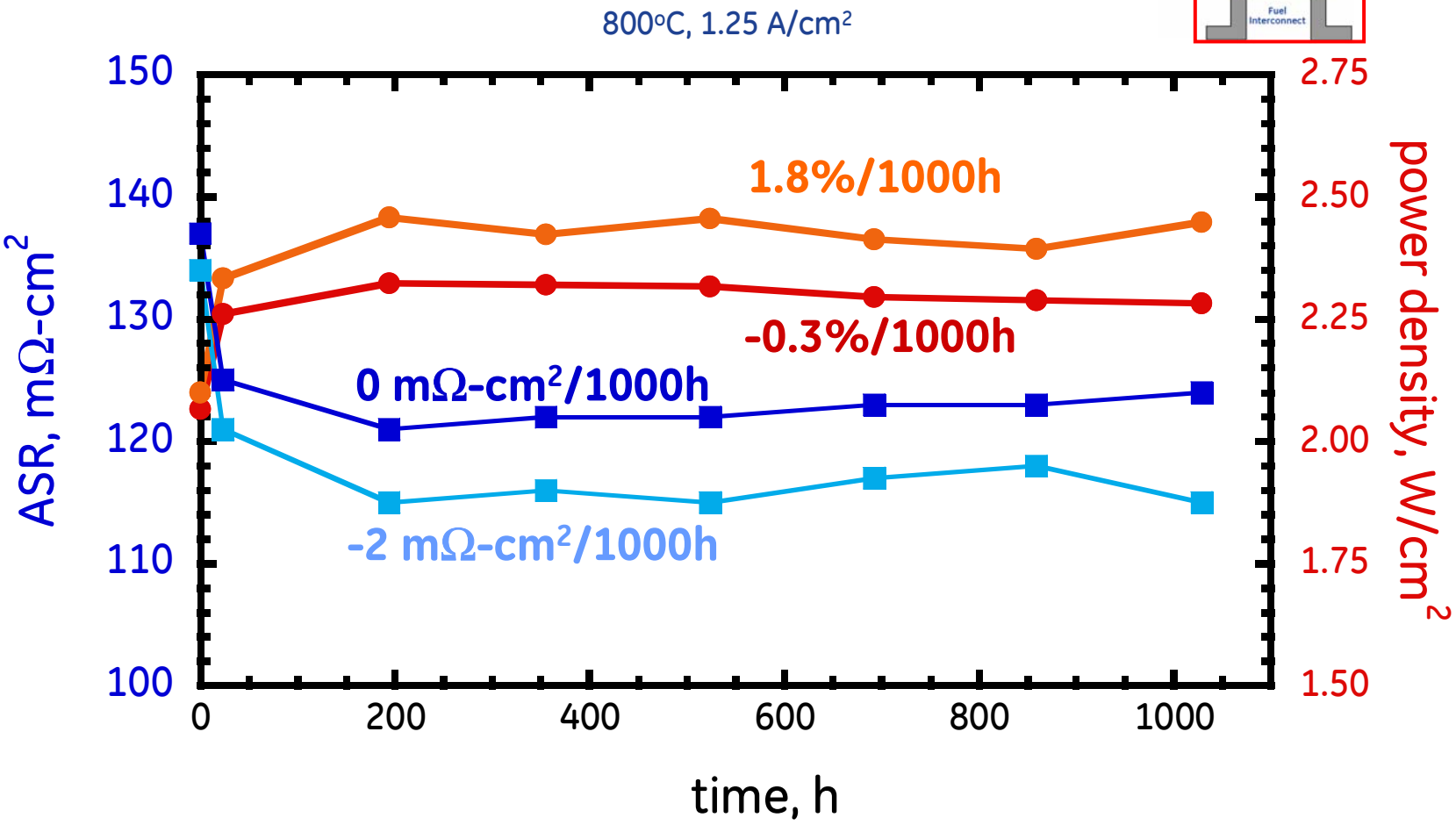
Ni paste anode current collector



Au mesh

Ni / NiO



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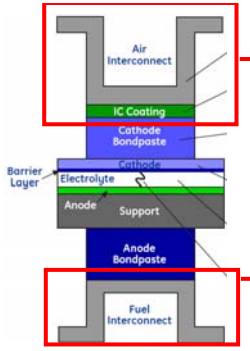
>2W/cm²
Entitlement for performance and degradation

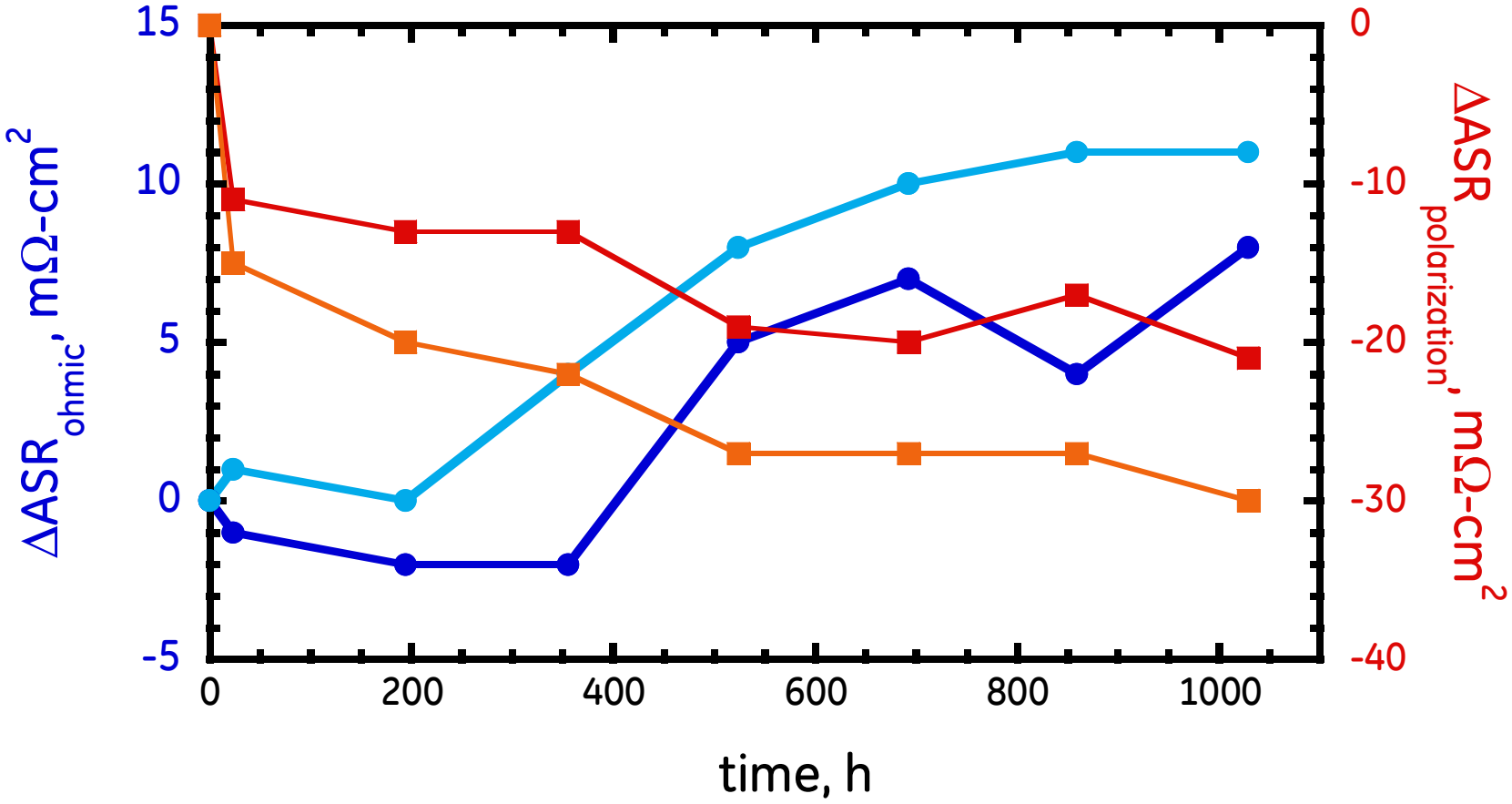
Ni paste anode current collector



Au mesh

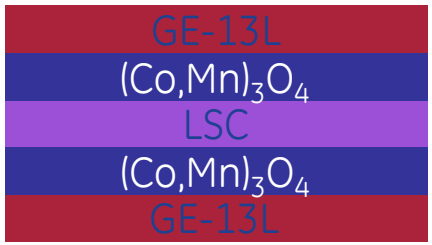
Ni / NiO

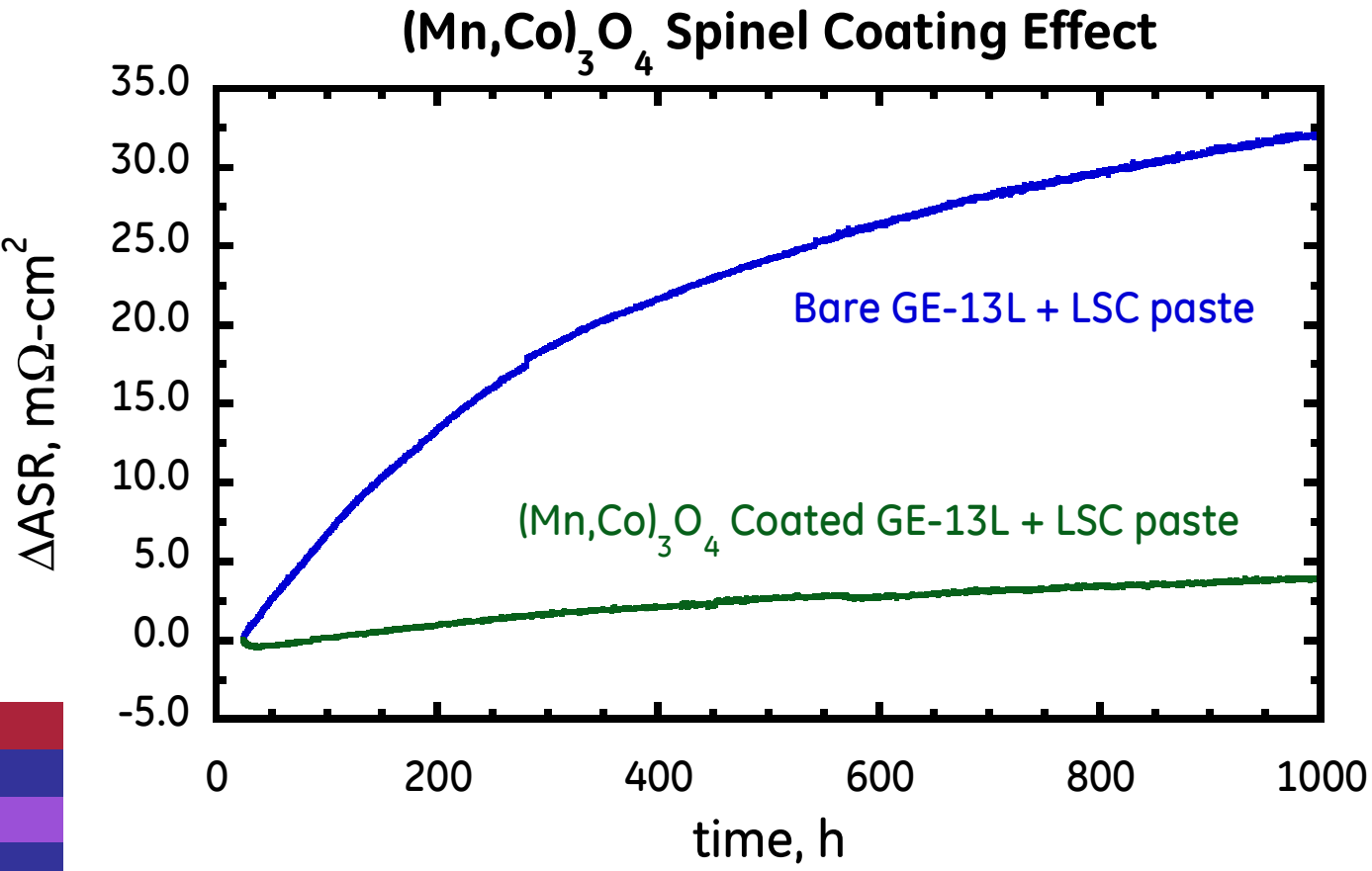
800°C, 1.25 A/cm²



Separate ohmic and polarization components of ASR to aid mechanism identification

Contact Resistance





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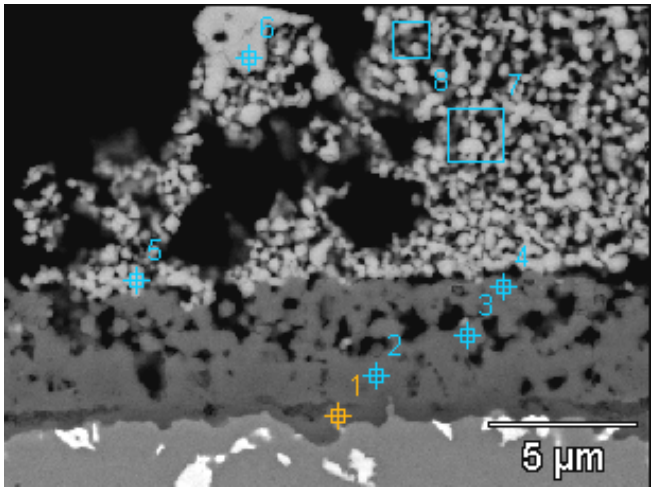
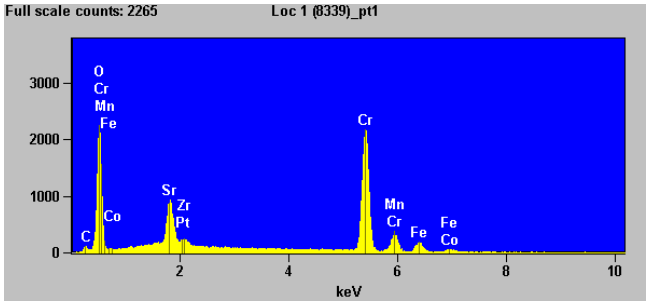
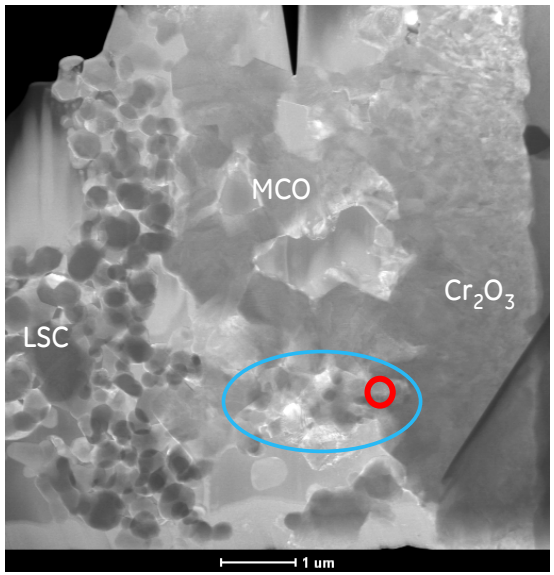
$(Mn,Co)_3O_4$ coating essential to prevent resistive layer formation

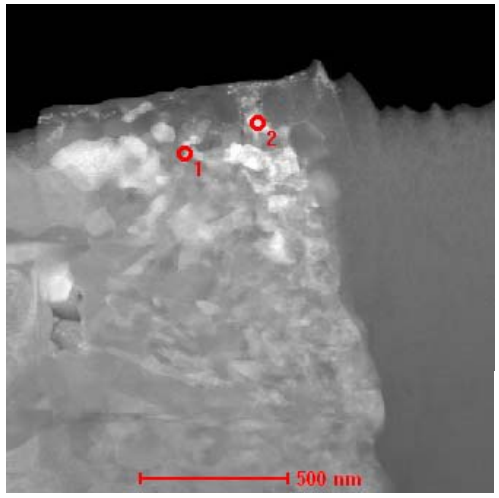
$(Mn,Co)_3O_4$ Coating Stability

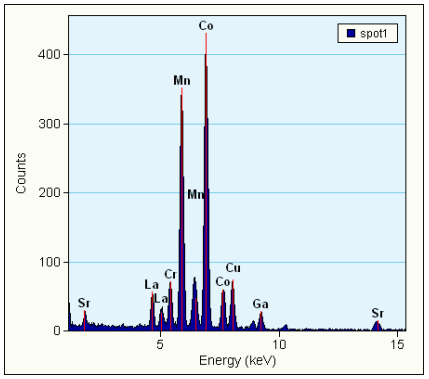




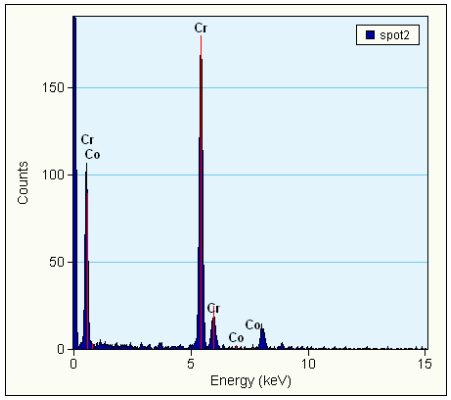
SEM-EDS shows presence of Sr in chromia scale







"Pocket" in MCO Layer contains La, Sr, perhaps indicating LSC particle.



Chromia scale shows Co incorporation, but no evidence of Sr.

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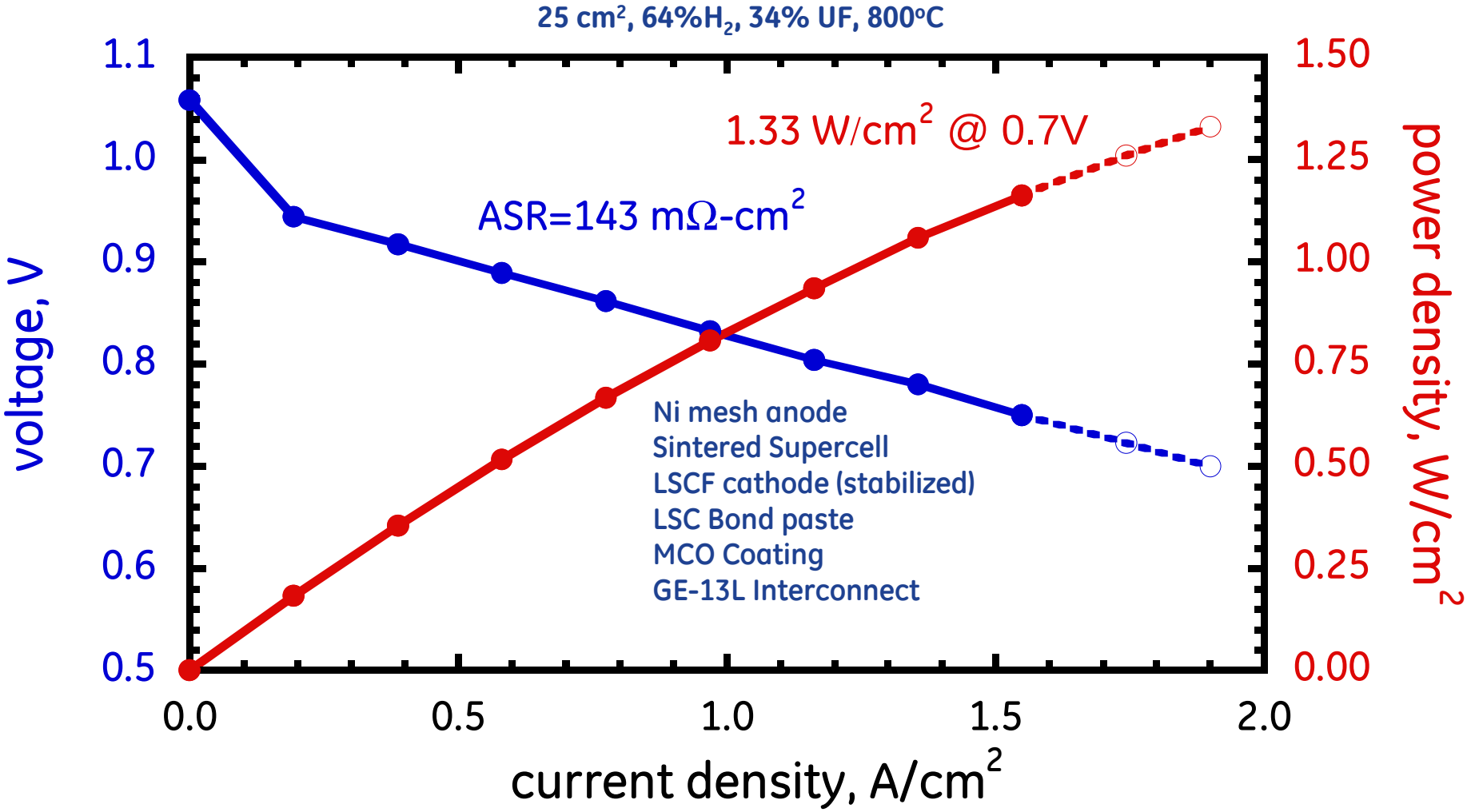
$(Mn,Co)_3O_4$ coating capable of suppressing Sr diffusion.

25 cm^2 cell test

25 cm² Browaller cell performance



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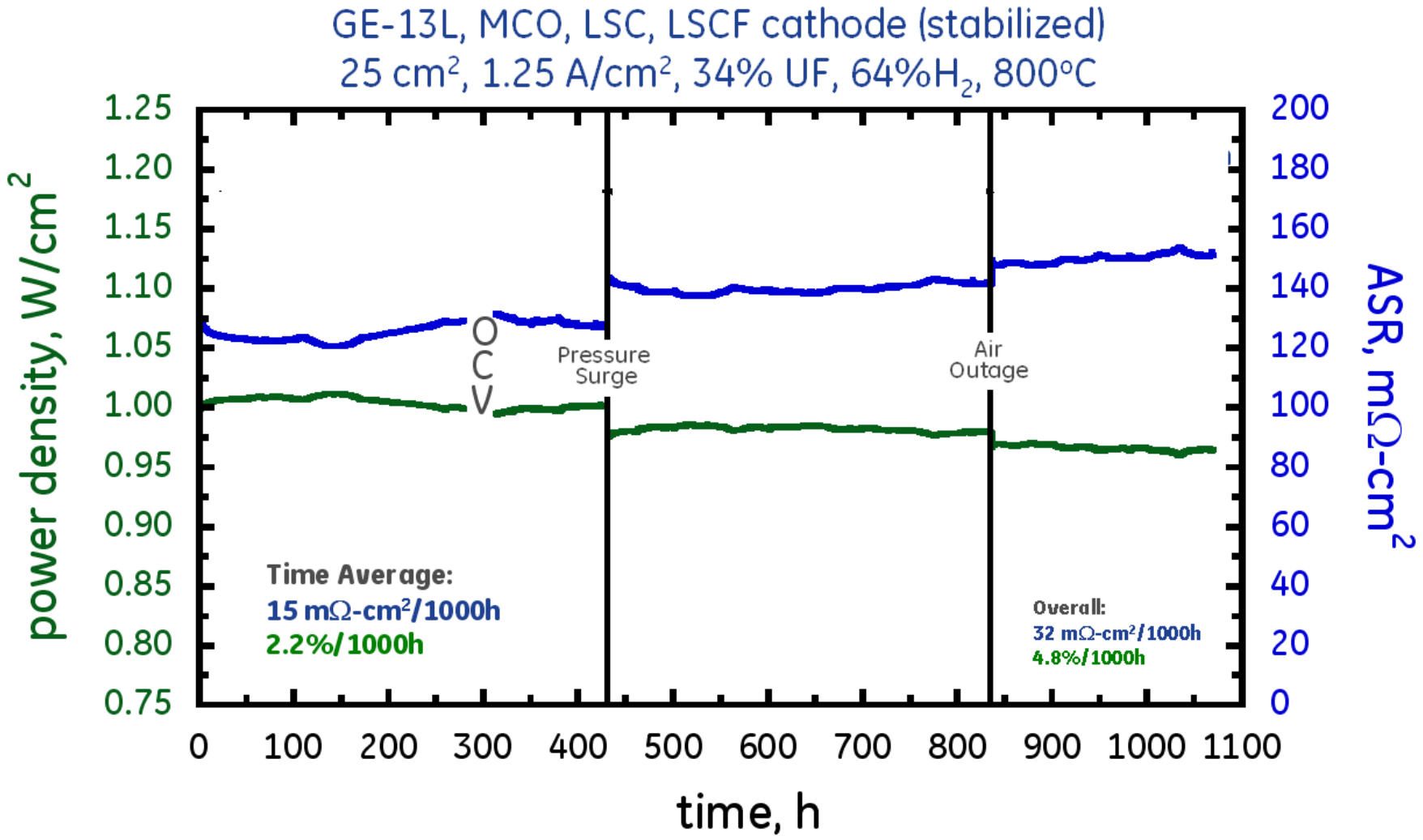
Stabilized cathode performance excellent
Note: Data extrapolated beyond 1.5A/cm²

25cm² Browaller cell degradation



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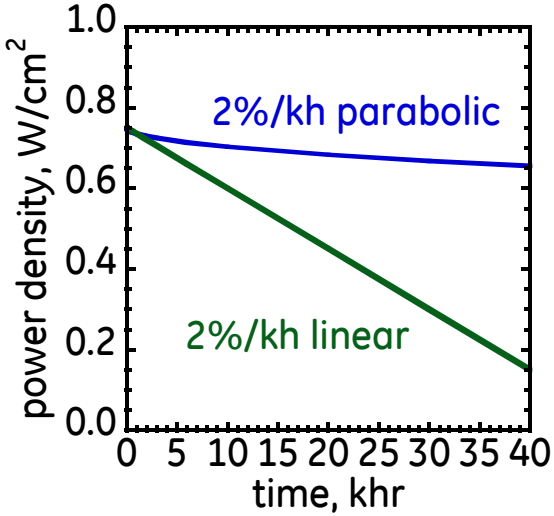
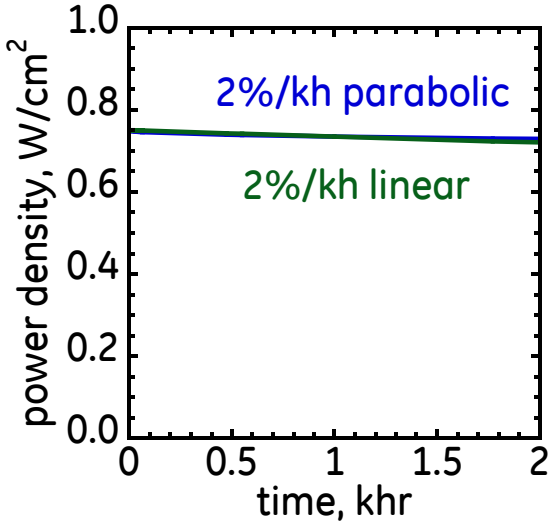
Low degradation and high power density

Primary Identified Risks

- Degradation is not parabolic
  - Dependent on mechanism

- 1000 hr testing not sufficient to understand longer-term degradation
  - Ability of interconnect coating to suppress Cr volatilization over life
  - Longer term testing needs to be performed
  - Fundamental diffusion kinetics experiments to support modeling effort





- Additional degradation mechanisms at stack level
  - Will be addressed subsequent to successful mitigation of degradation for materials set

Acknowledgements

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- GE SOFC Team
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