Performance Degradation of LSCF Cathodes

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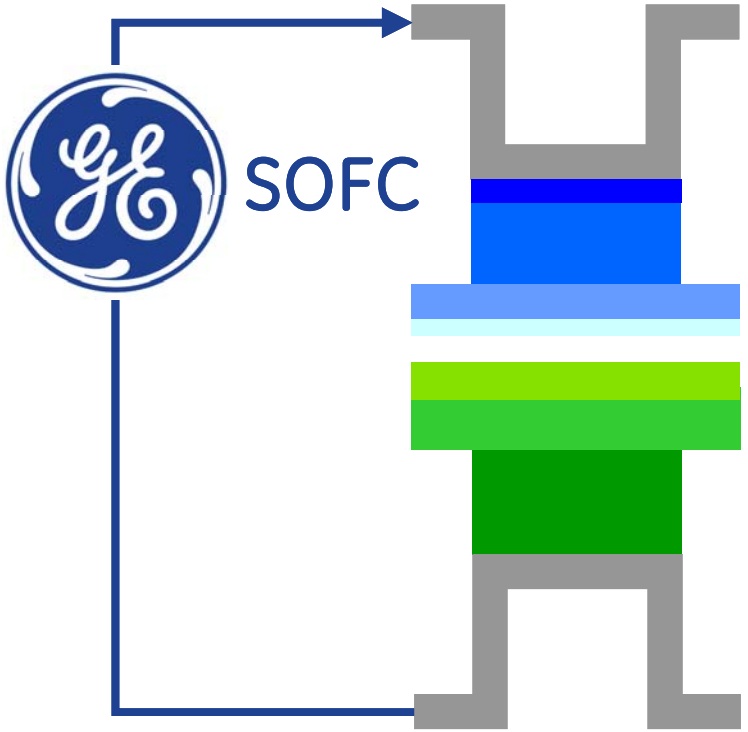

11th Annual SECA Workshop
Pittsburgh, PA
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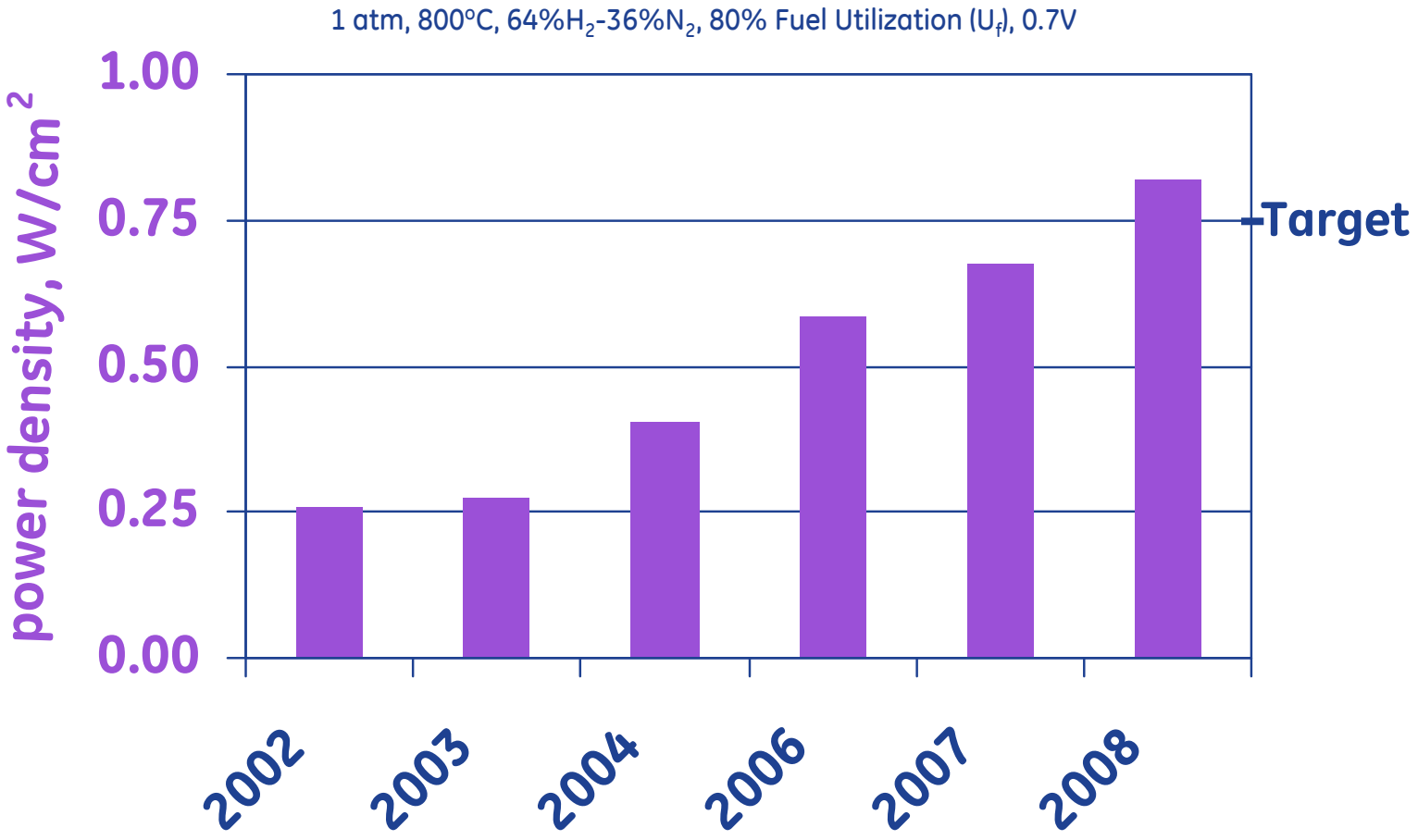
Project goals and objectives

- 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

SOFC performance evolution



Assumption:
No performance degradation

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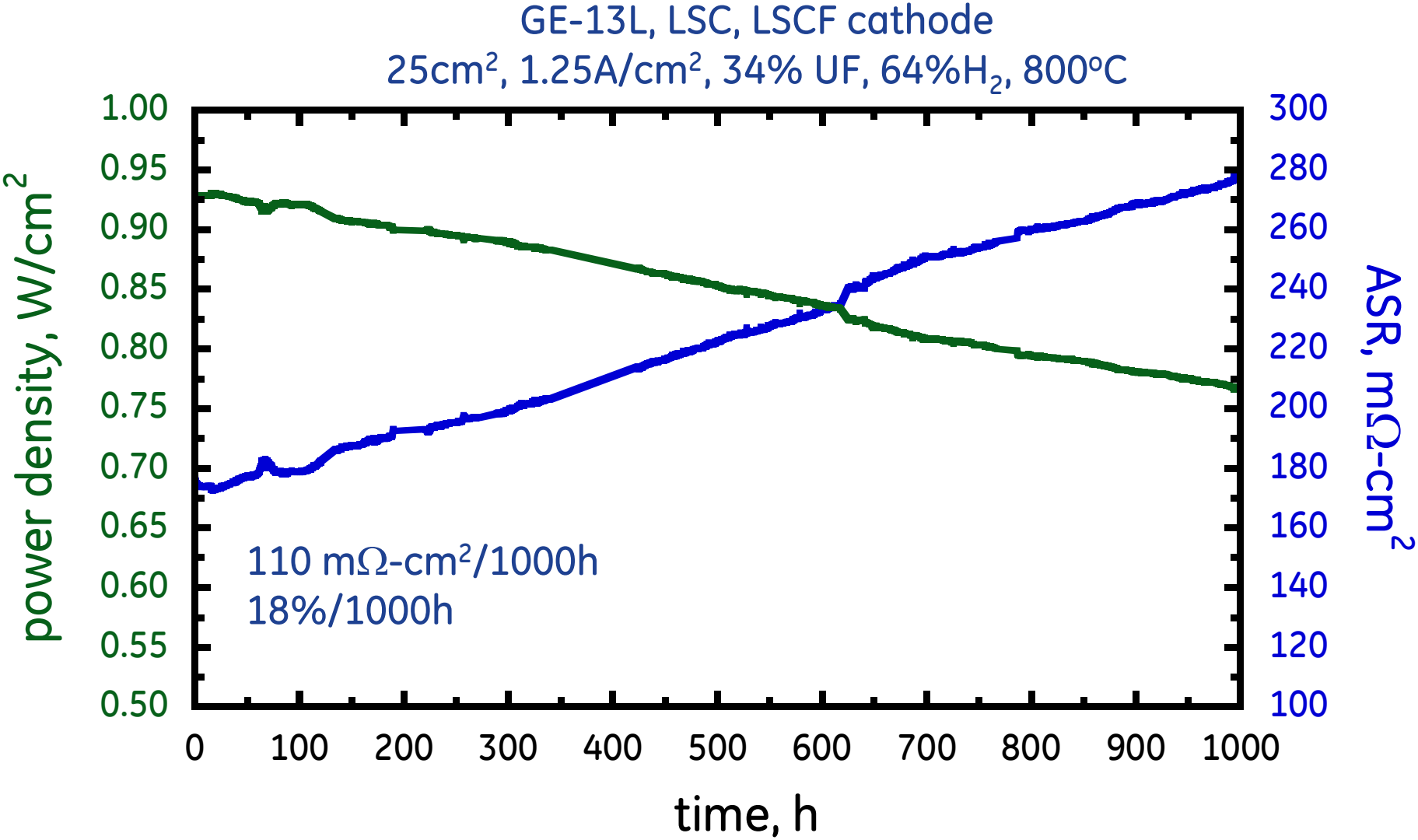
25cm² cell degradation (2008)



High power density and high degradation rate

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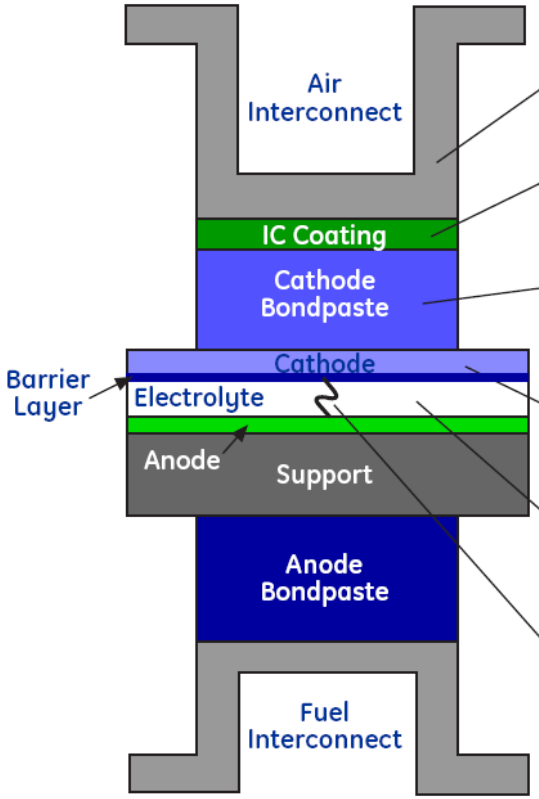
SOFC degradation - materials focused approach



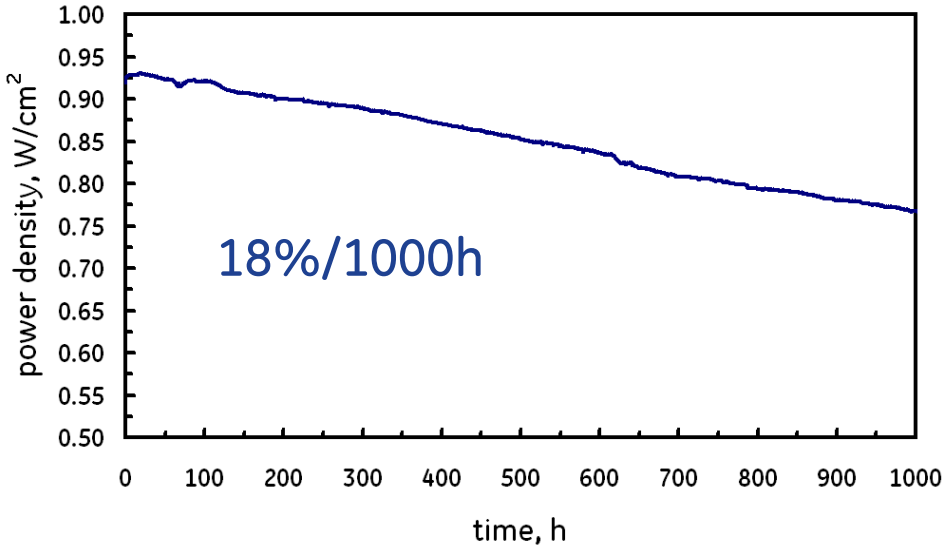
Mechanism	Type
Air Interconnect	
• Chromia scale resistance (Cr_2O_3)	Chemical
• Insulating scale growth (SiO_2)	Chemical
Protective Coating	
• Coating resistance (MnCo spinel)	Chemical
Cathode Bondpaste/Coating Interface	
• $SrCrO_4$ layer resistance	Chemical
• $SrMnO_3$ layer resistance	Chemical
• '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

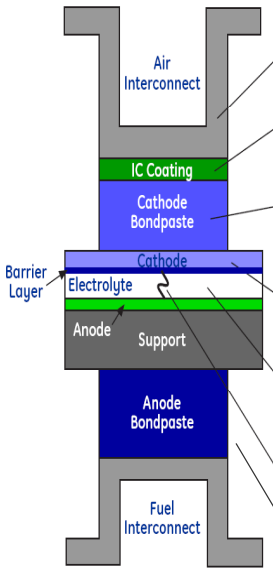
With a 'fixed' materials set: Focus on cathode side, high-impact degradation mechanisms

2008 25cm^2 cell degradation

Requirements	
Degradation (%/kh)	< 1
Stack Life (hours)	>40,000

25cm^2, 1.25A/cm^2, 34% UF, 64%H_2, 800°C





2007

- Air interconnect
- Interconnect coating
- Contact paste
- Cathode
- Electrolyte
- Leakage
- Anode

High power density and high degradation rate
Degradation mechanisms identified

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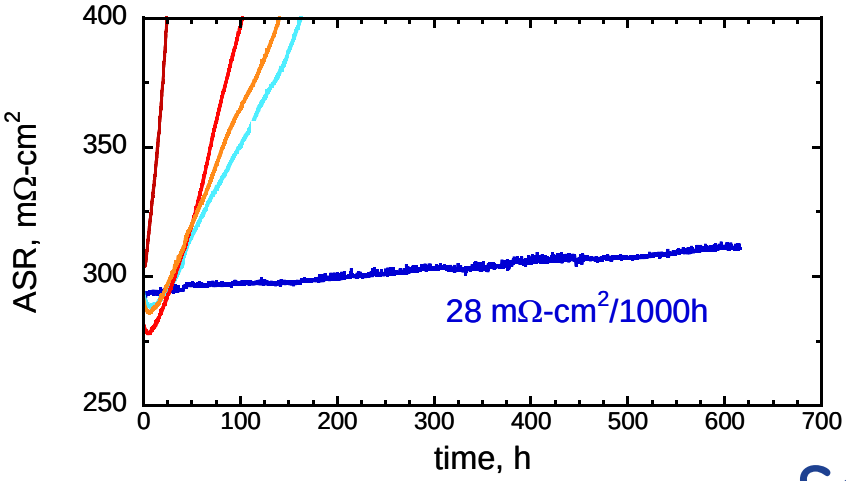
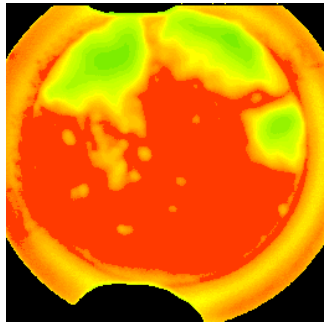
Barrier layer delamination

Delamination dominating



Evidence

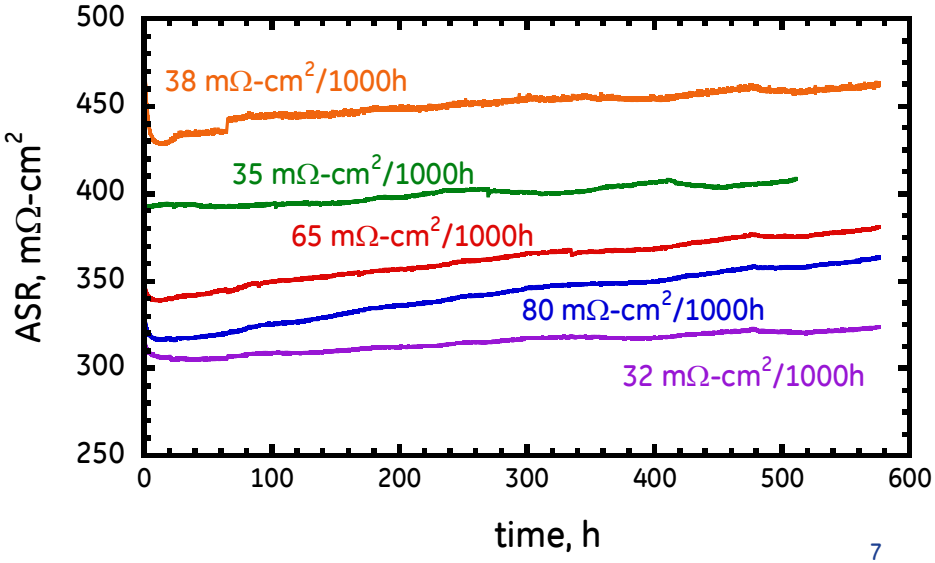
Ohmic and polarization resistance rate increase equal



Flash IR

Solution

Improved barrier layer adhesion
Reduced interfacial stress



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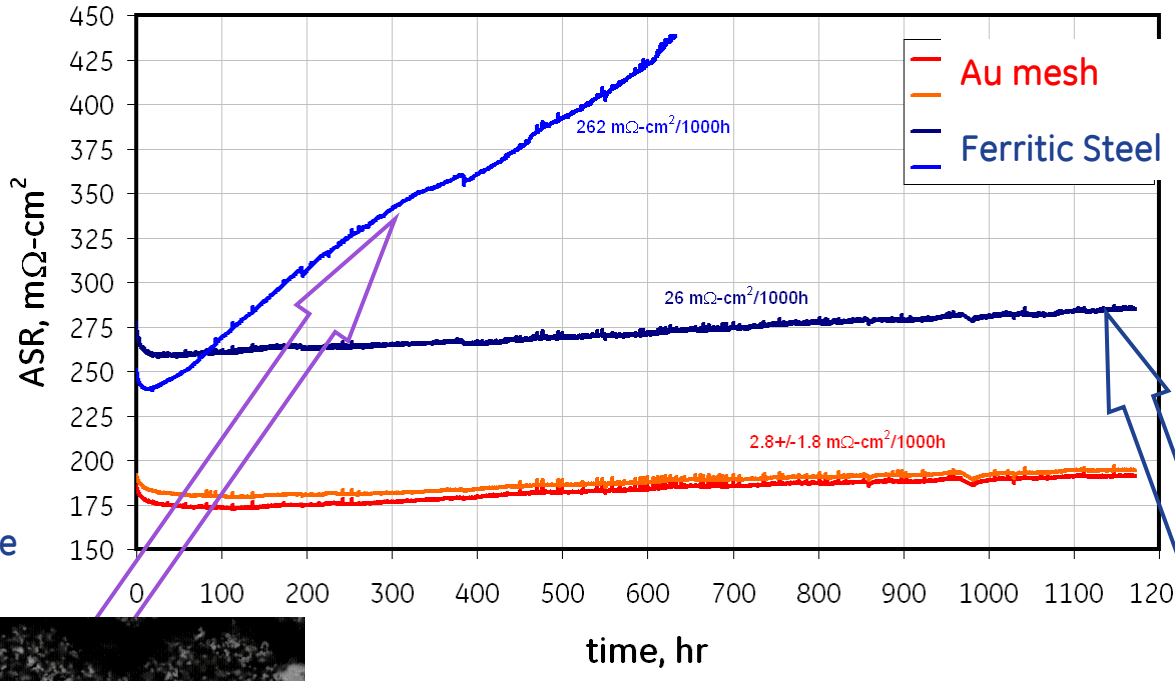
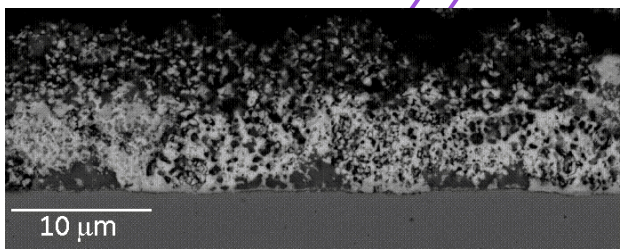
Chromium poisoning



Chromium in cathode and barrier layer



No microstructural evidence of degradation

Implication: Loss of Sr from cathode - strontium chromate

Solutions:Densification of cathode interconnect coating

Improved process control to ensure full coverage

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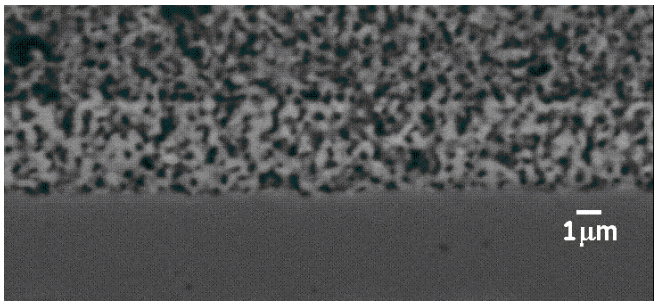
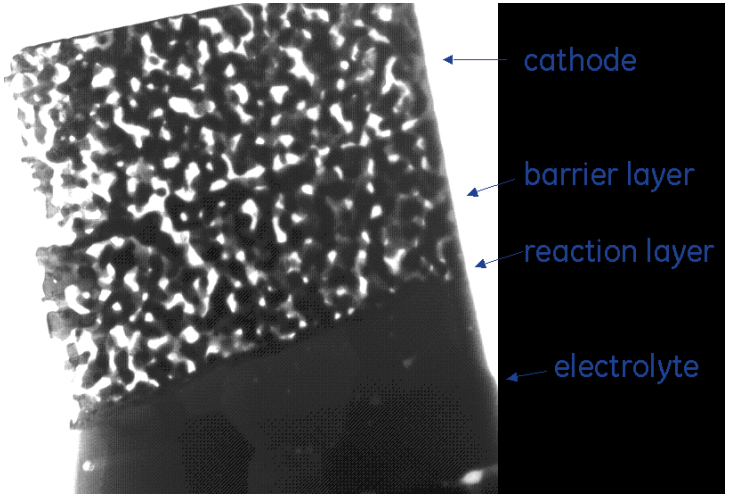
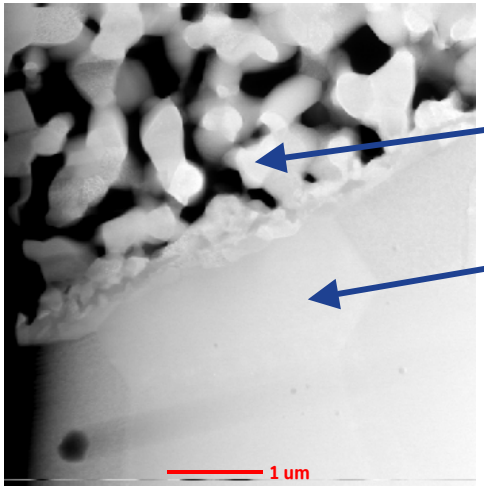
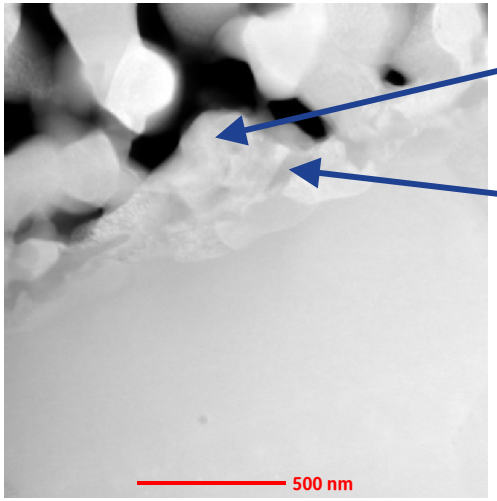
Zirconate phase formation

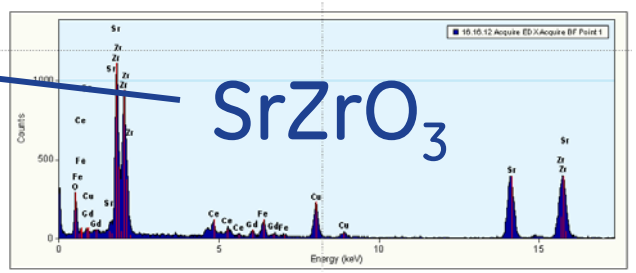
2876h @ 1.25 A/cm^2, 800^{o}C











Implication: $SrZrO_3$ phase formation - resistive

Solution: Densification of barrier layer possible

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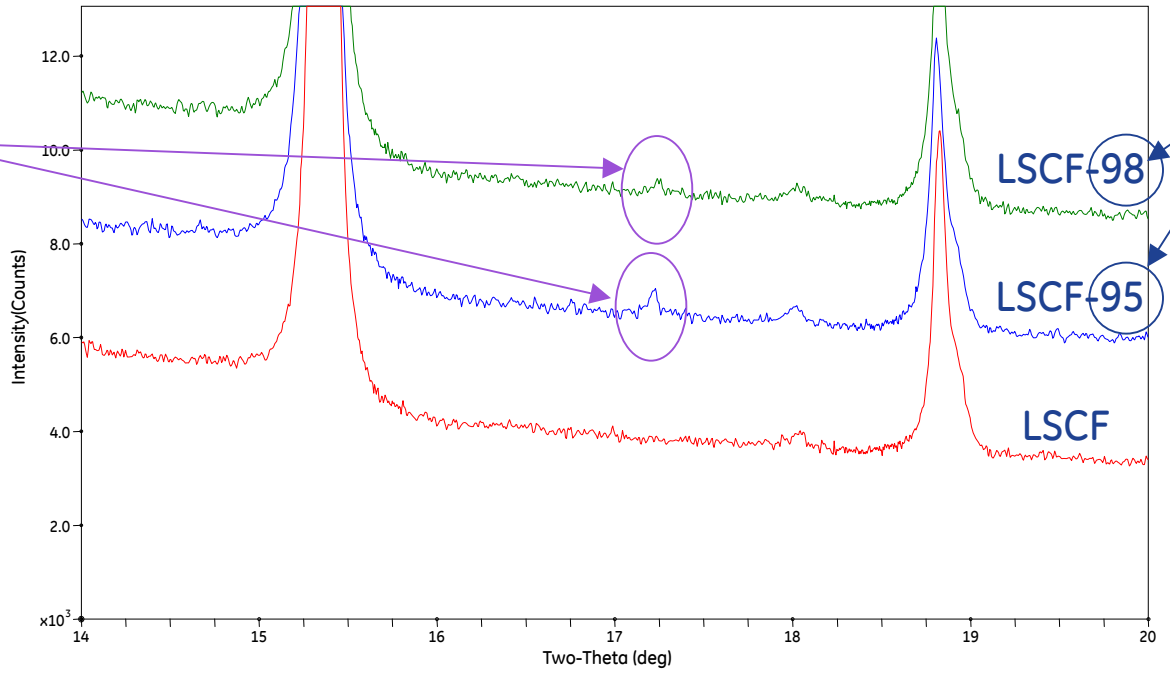
Implications of Sr loss (LSCF)

After heat-treatment at 800°C for 500 hours

2nd phase formation

A-site deficiency



Diffraction measurements at the X14A beamline, the National Synchrotron Light Source, Brookhaven National Laboratory (λ= 0.73339 Å).

Loss of Sr (A-site deficiency) leads to formation of 2nd phase in LSCF cathodes.

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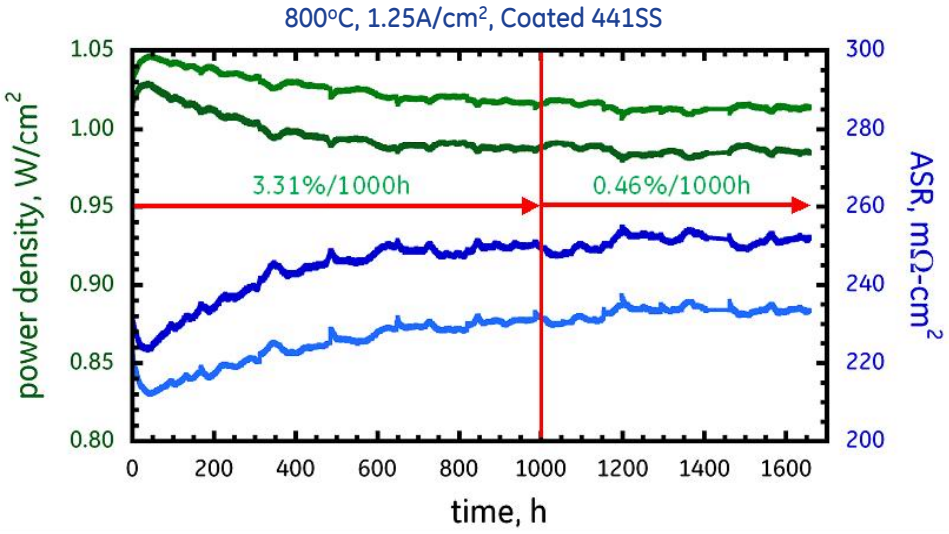
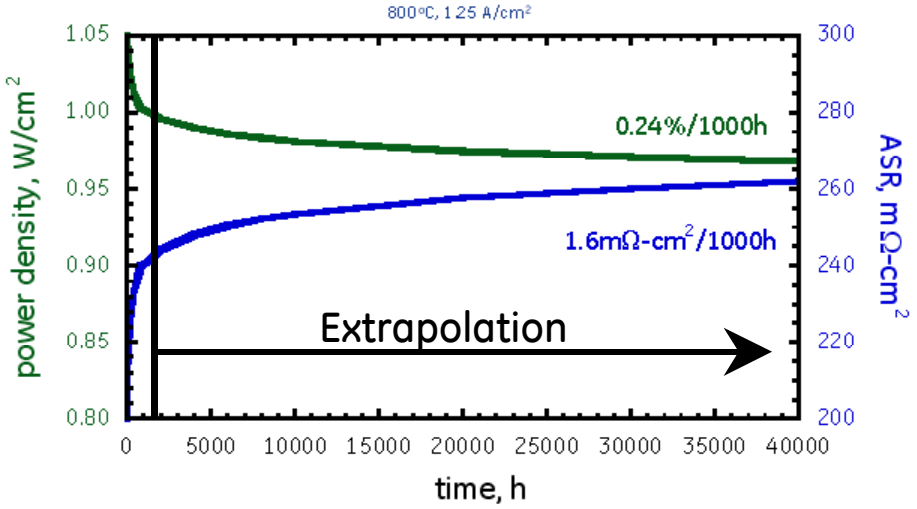
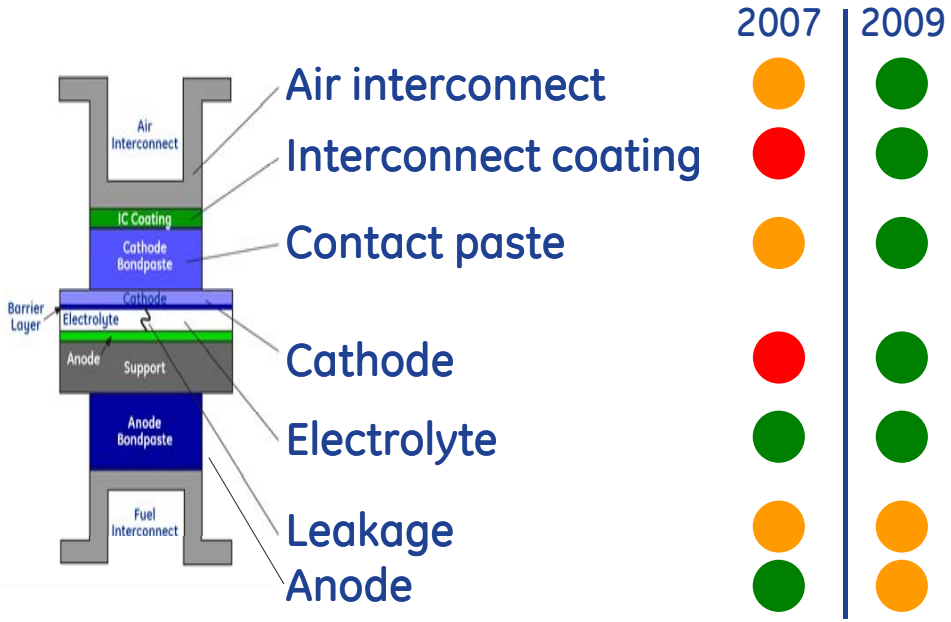
Current degradation status







Risk:
Missing late-blooming mechanism
Stack level mechanisms

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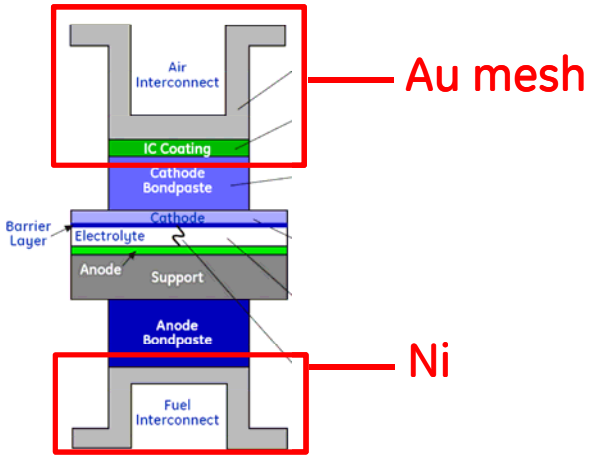
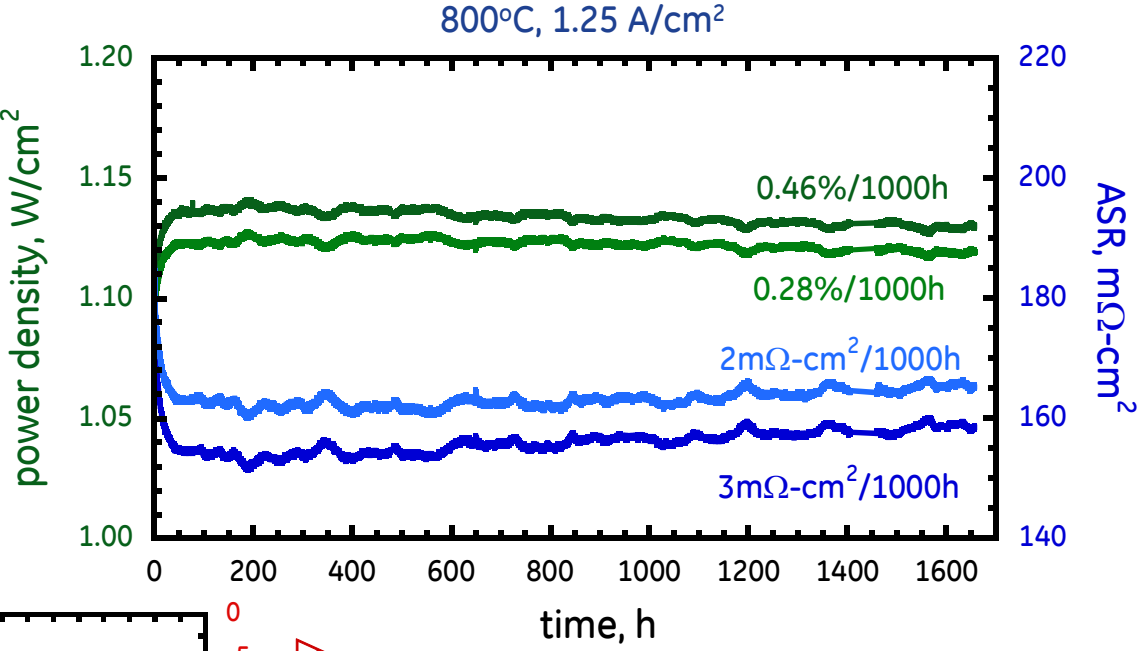
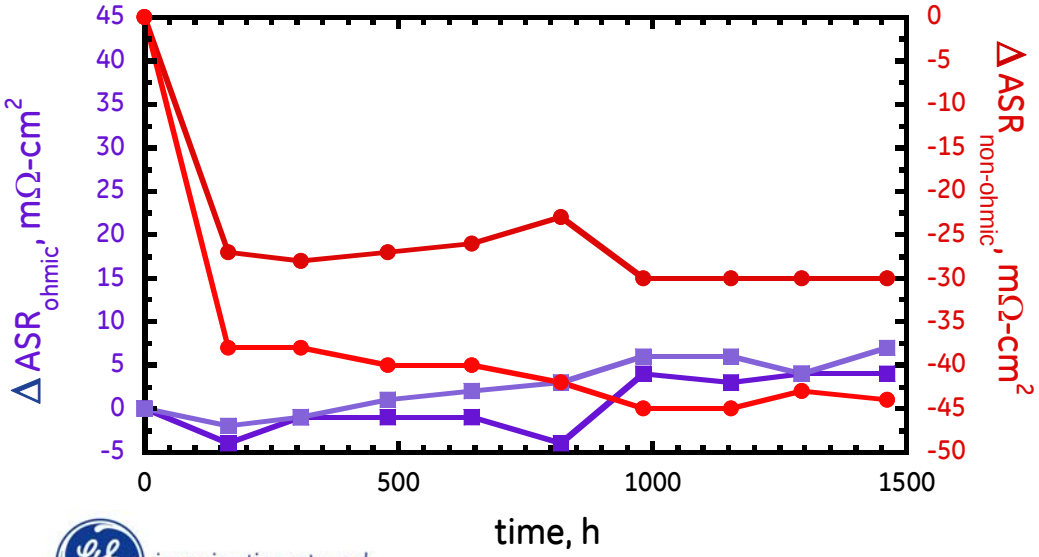
Entitlement (no steel interconnect)







Very stable performance
No polarization degradation
Negligible ohmic degradation

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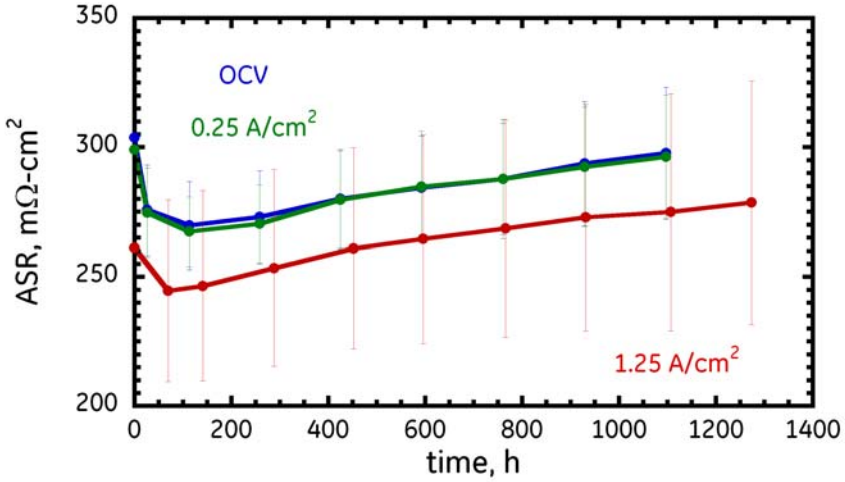
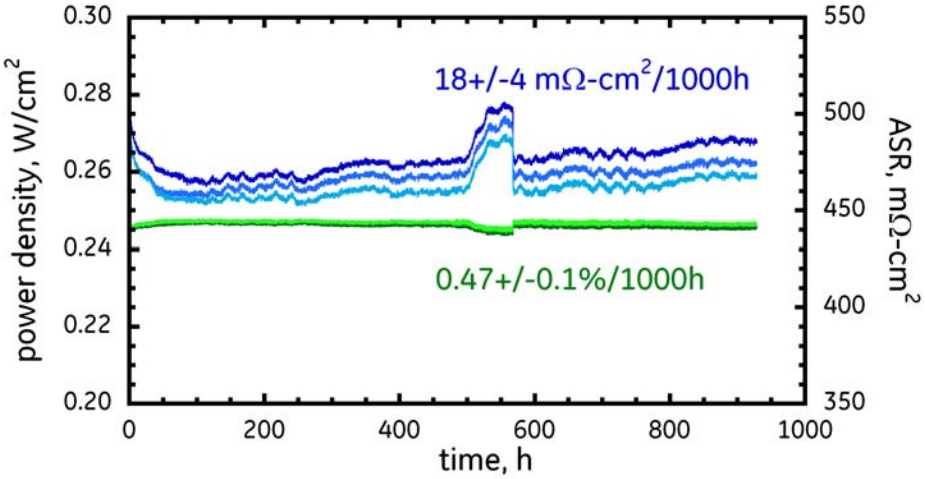
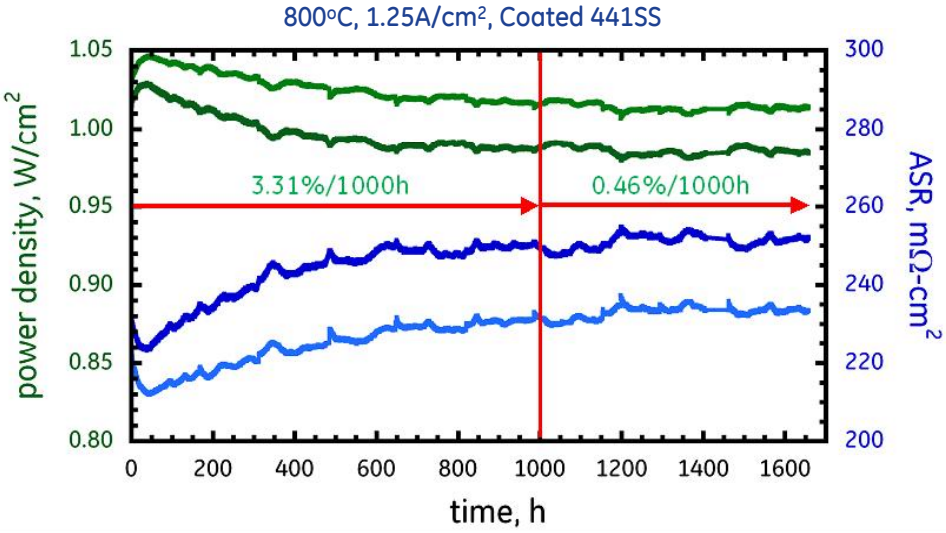
Effect of operating current (800°C)



Operating current not significant driver for degradation differentiation





Perceived degradation rate strong function of operating point

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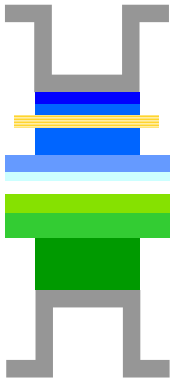
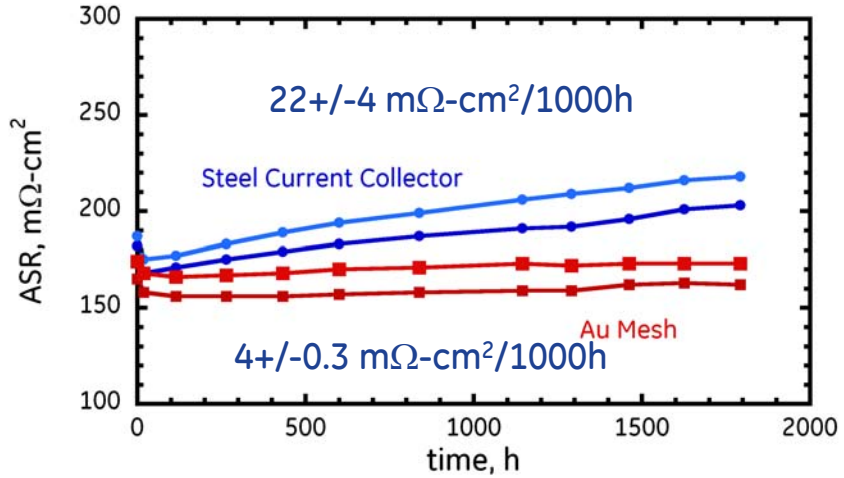
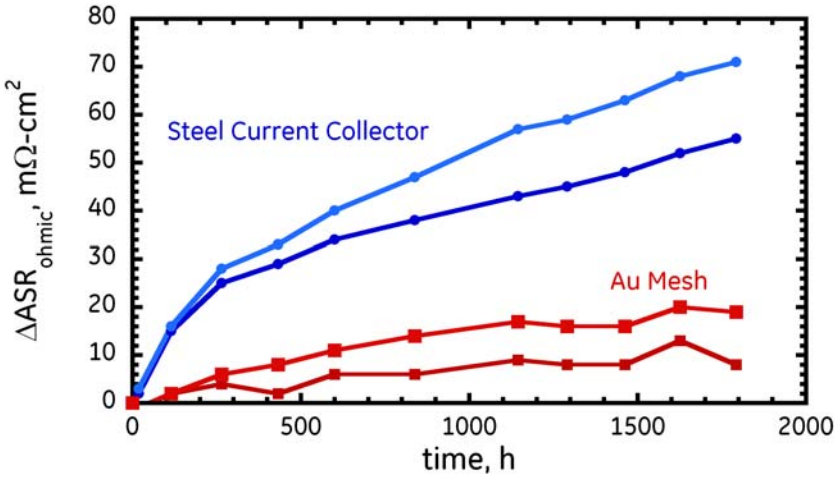
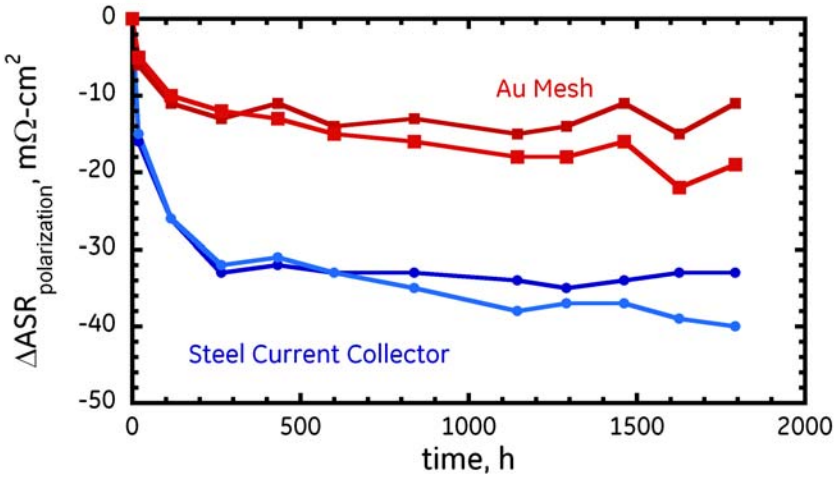
Direct measurement of current collector resistance during testing









Majority of degradation from interconnect / bond paste region

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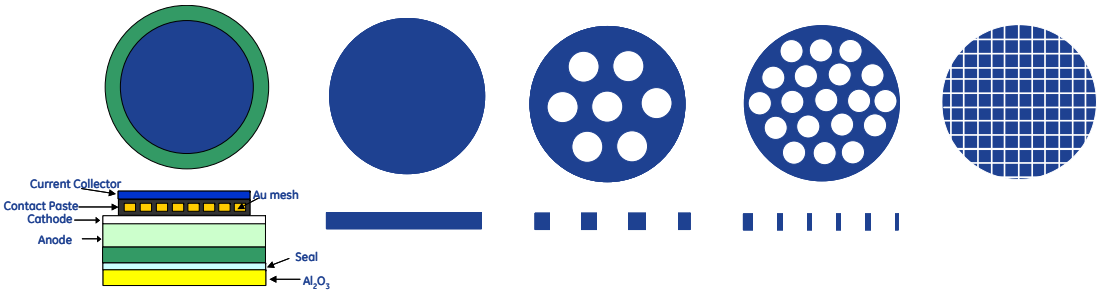
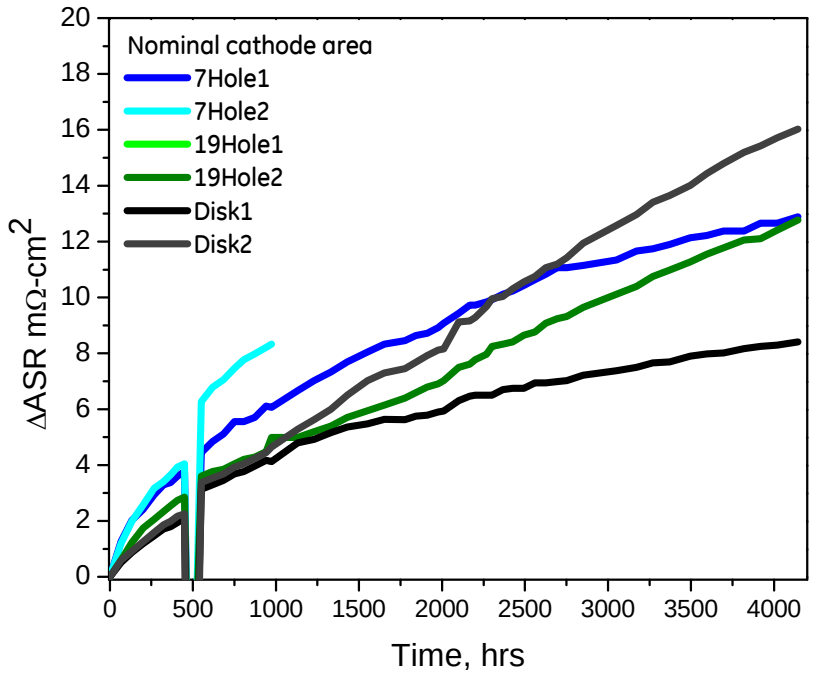
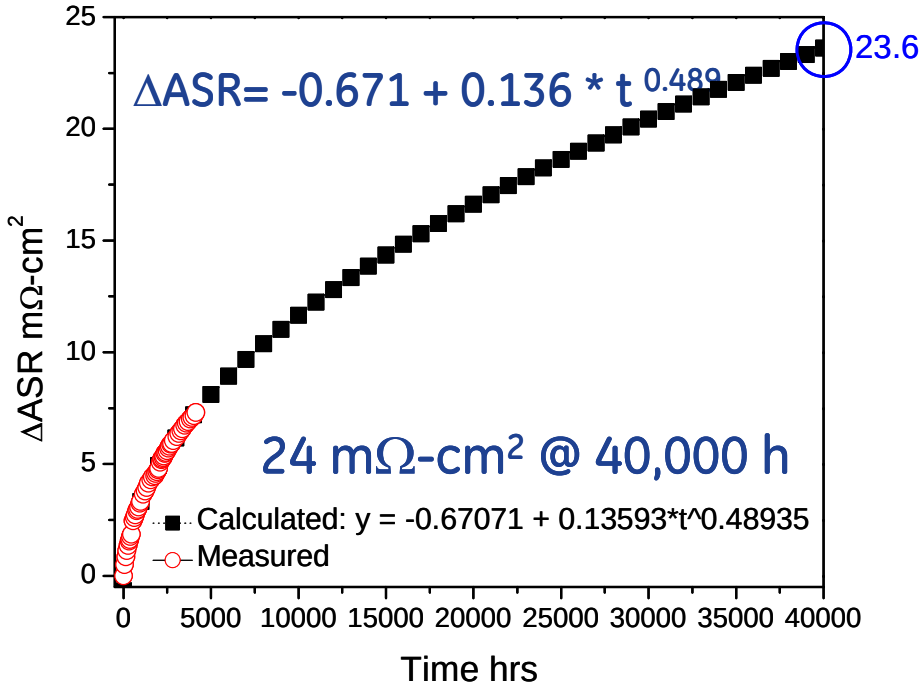
Contact resistance testing



Interconnect Geometry	Nominal Area (cm^2)	Real Area (cm^2)	Area Fraction	Current (A)
Disk	2.85	2.85	1	0.7
7-Hole	2.85	1.42	0.5	0.7
19-Hole	2.85	1.42	0.5	0.7
Mesh	2.85	1.42	0.5	0.7





Data indicates diffusion limited ($t^{1/2}$) kinetics governed by oxide growth

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Summary

- LSCF materials set capable of meeting performance goals (>0.75 W/cm^2 & <1%/1000h degradation)

- Degradation behavior significantly impacted by specific dominant mechanism
  - Many potential mechanisms
  - Rate dependent on mechanism

- >10,000 h testing required to fully validate LSCF materials set
  - Extrapolation of 1000-3000 hr data promising

Acknowledgements

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