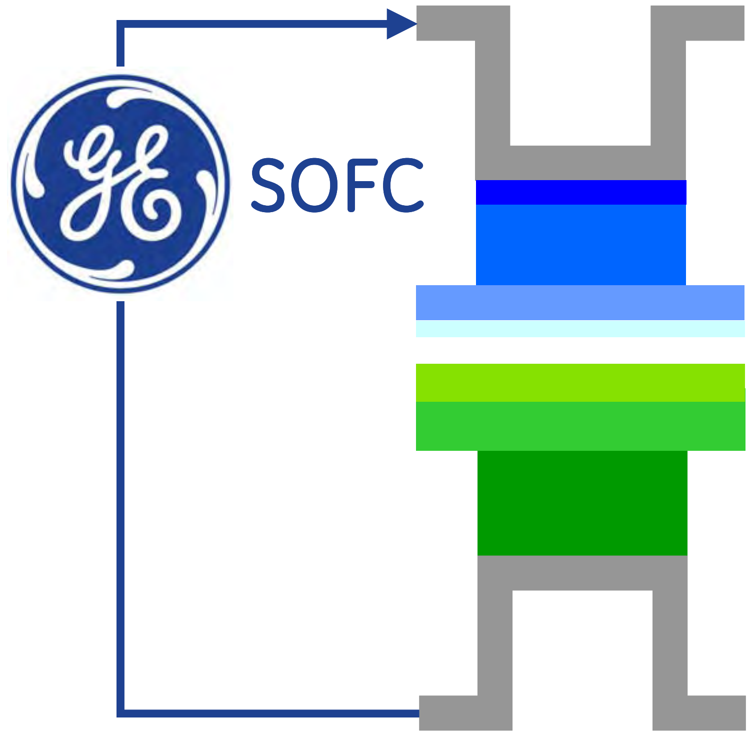
SOFC Development at GE Global Research

Matt Alinger
GE Global Research
Niskayuna, NY

12th Annual SECA Workshop
Pittsburgh, PA
July 26-28, 2011



imagination at work

GE today

Aligned for growth

imagination at work

Global reach and connectivity

Appliances | Aviation | Energy | Healthcare | Transportation | Lighting | O&G | Water

Business Program Offices

Global Technology Domains

- Aero-Thermal & Mechanical Systems
- Chemistry & Chemical Engineering
- Diagnostics & Biomedical Technologies
- Electrical Technologies & Systems
- Manufacturing & Materials Technologies
- Software Sciences & Analytics

Technology Center Leaders

- China
- India
- Germany
- Brazil

40,000 technologists across GE

Global Research annual funding

GE business programs

- Next generation product technology
- Short-term technical challenges

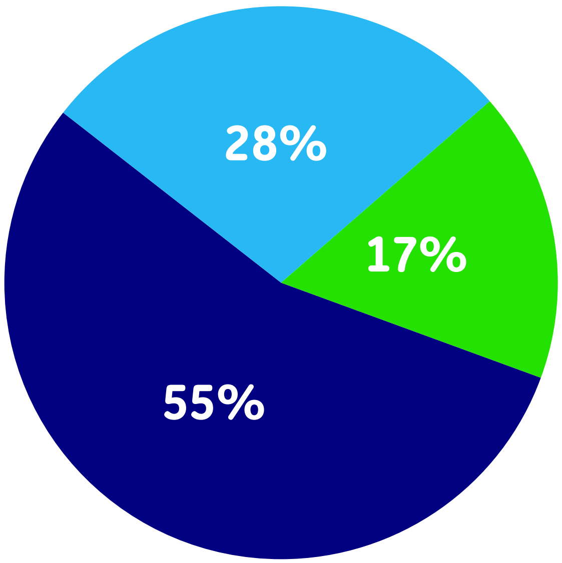
GE corporate programs

- Advanced Technology programs
- New ideas
- High-risk/high reward

External partnerships and gov't. funded

- Joint technology
- Specific customer focus

~$600 M



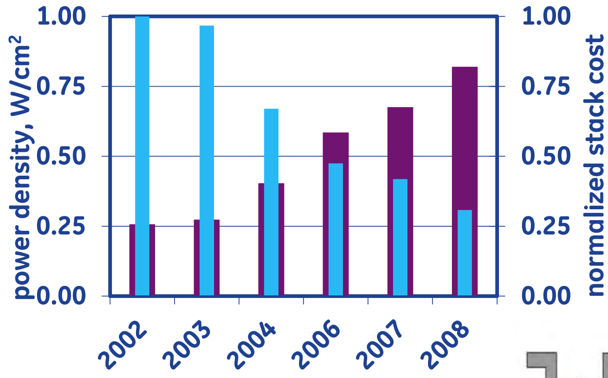
imagination at work

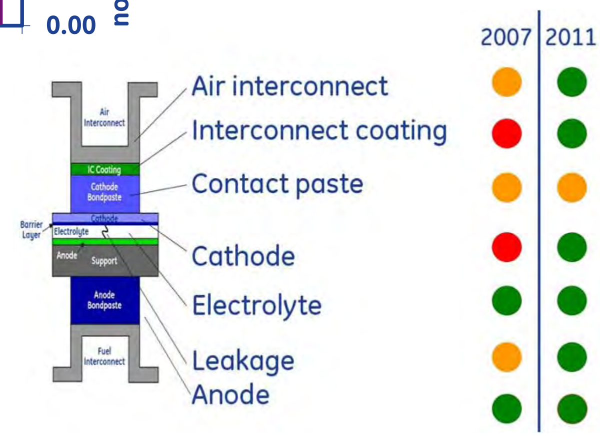
Technology Challenges for SOFCs

- Materials set
  - High power density
  - Low degradation / stable
- Scale-up
  - Larger cells
  - Bigger stacks
- System design & integration
  - Improved design for reliability
  - Operability (start-up, shut down, transients, …)

Presentation Outline

- Materials Set
  - Cost
  - Performance
  - Degradation



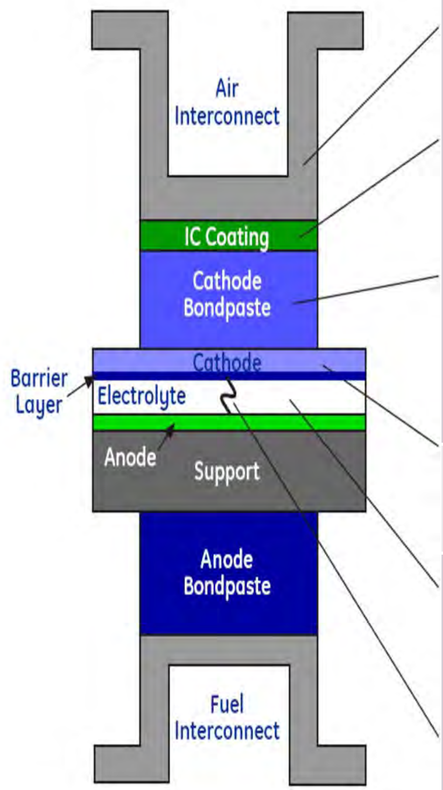


- Scale-up
  - Manufacturing

imagination at work

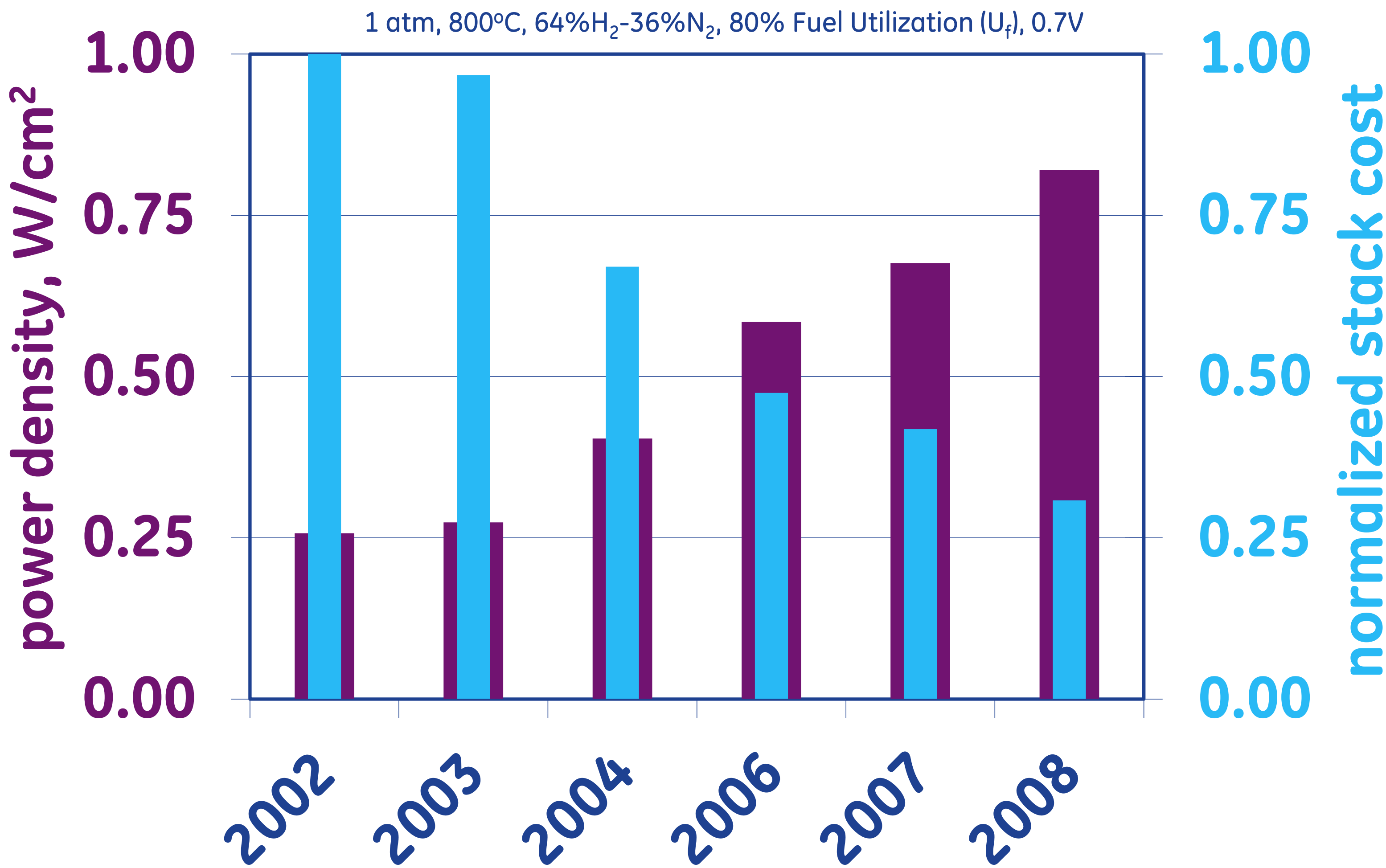
Materials Set

Anode Supported Solid Oxide Fuel Cell



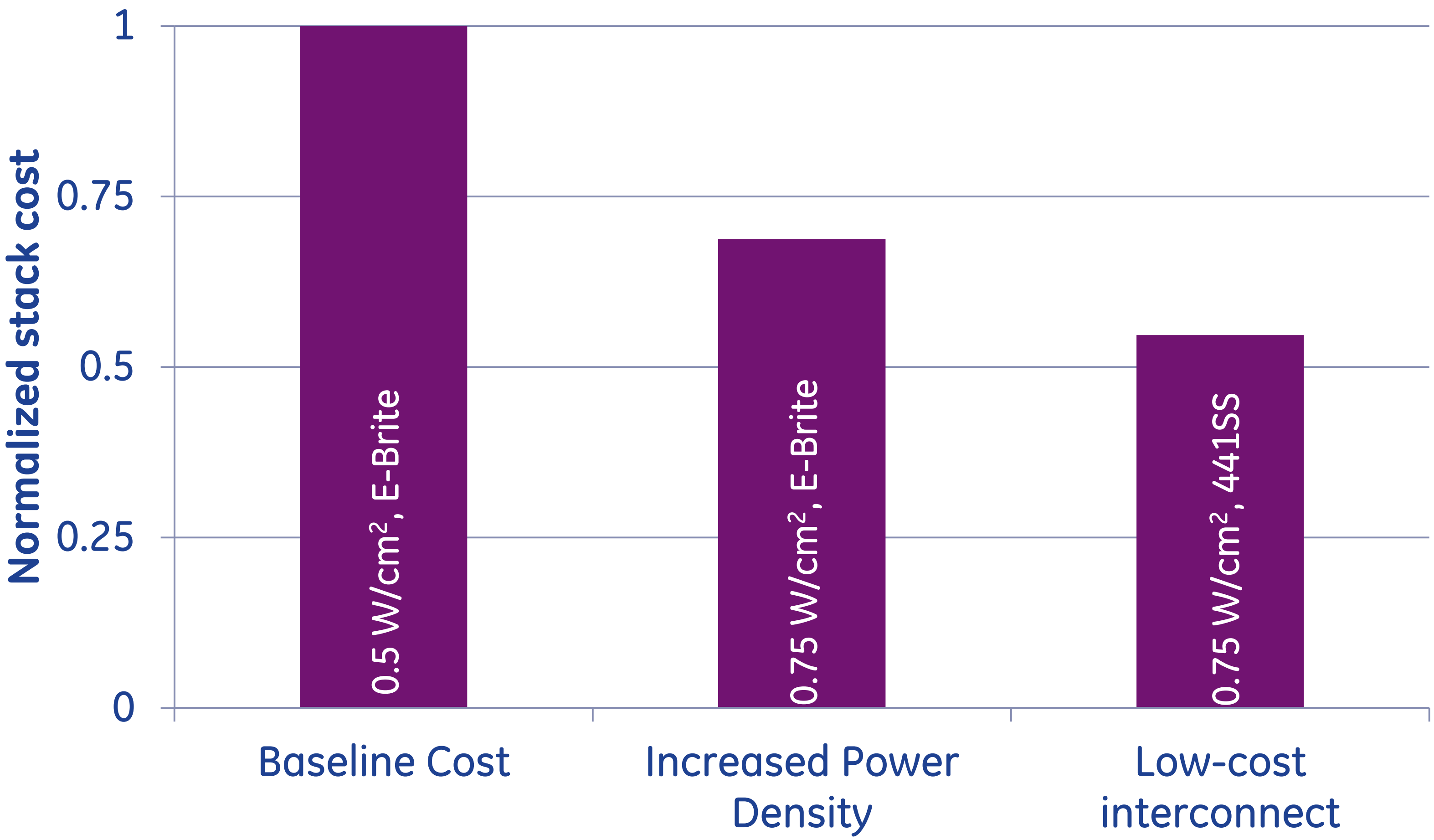
	Layer	Function	Material	Thickness
Air Side	Interconnect	Gas & Electron Transport	Ferritic Stainless Steel	500 µm
Air Side	Protective Coating	Prevent interconnect Cr from poisoning cathode	$(Mn,Co)_3O_4$	10 µm
Air Side	Cathode Contact Paste	Electrically connect cell with air interconnect	$(La,Sr)CoO_3$	100 µm
Air Side	Cathode	Air electrode	$(La,Sr)(Co,Fe)O_3$	40 µm
Air Side	Barrier Layer	Prevent cathode Sr from reacting with electrolyte Zr	GDC $(Ce_{0.8}Gd_{0.2})O_2$	10 µm
	Electrolyte	Permit O^{2-} transport, prevent air/fuel mixing	YSZ $(ZrO_2 + 8\ mol\ Y_2O_3)$	10 µm
Fuel Side	Functional Anode	Fuel electrode	NiO/YSZ	20 µm
Fuel Side	Anode Support	Mechanically supports Anode & Electrolyte	NiO/YSZ	200 µm
Fuel Side	Anode Contact Paste	Electrically connect cell with fuel interconnect	NiO	100 µm
Fuel Side	Interconnect	Gas & Electron Transport	Ferritic Stainless Steel	500 µm

Performance status



Significant performance improvement
Sufficient to meet cost targets, though higher performance directly impacts stack cost

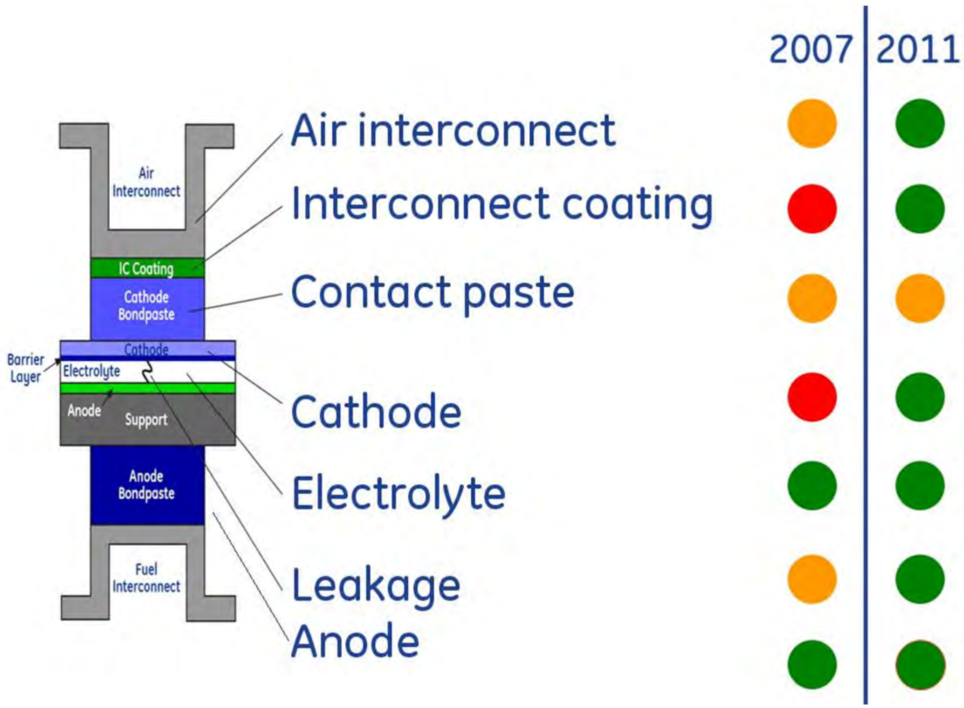
Stack cost status



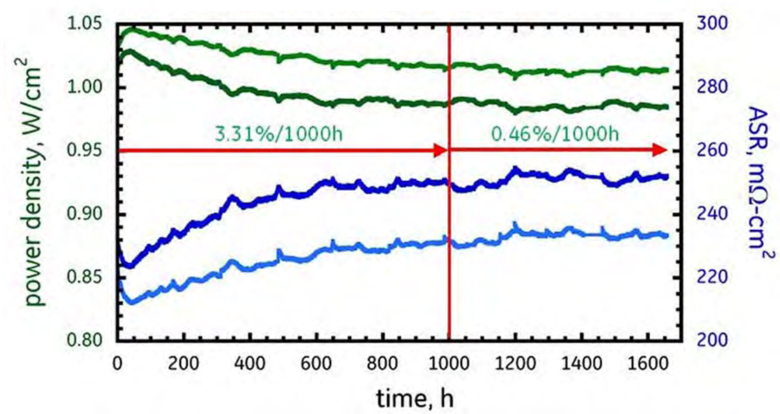
Cost reduction through performance improvement and interconnect alloy

imagination at work

Degradation reduction



800°C, 1.25A/cm², 441SS



Degradation mechanisms identified and mitigation strategies validated

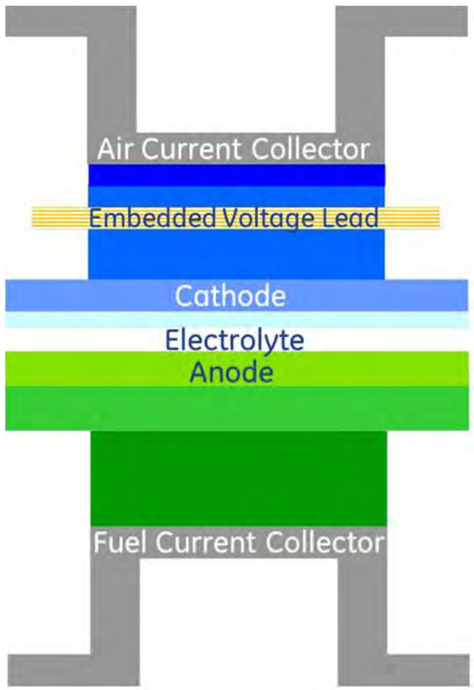
-Developed interconnect coating
-Stabilized cathode
-Validated low-cost interconnect alloy

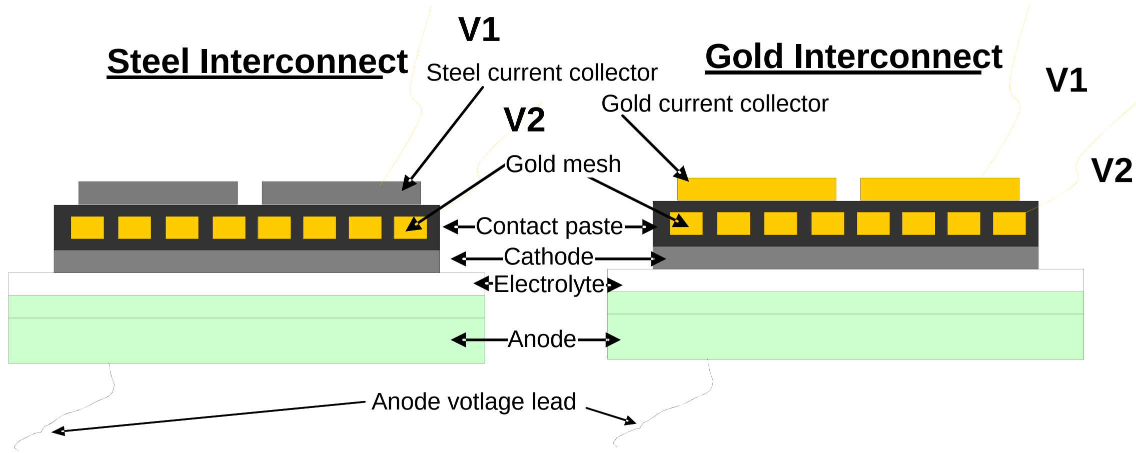
Cost and degradation risk significantly reduced

Engineering solutions exist, however, significant work remains to understand degradation fundamentals.

Measurement of location-specific degradation

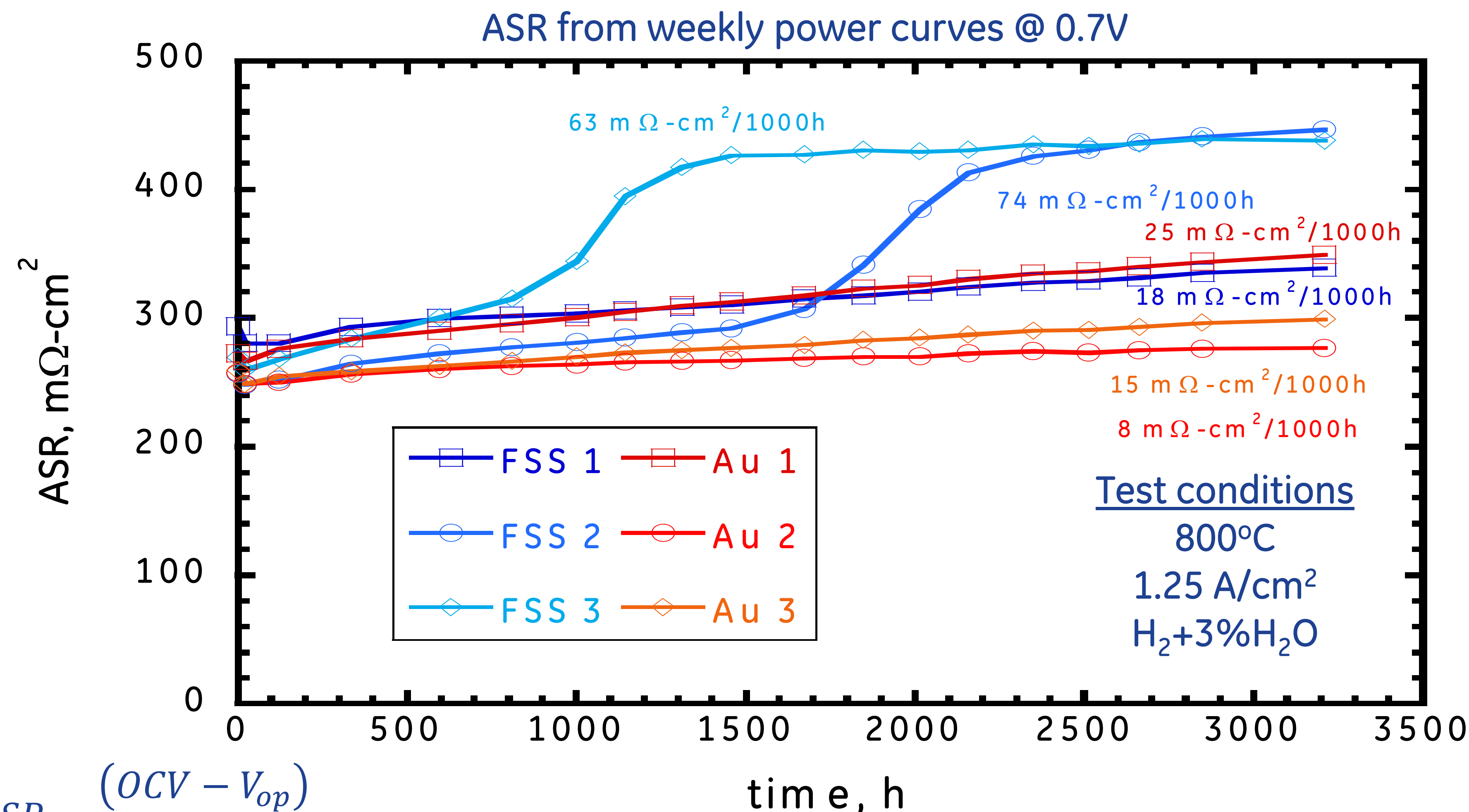
Test Conditions: 800°C
1.25 A/cm²
H_2+3%H_2O





Location-specific degradation can be measured from embedded gold mesh (voltage point)

ASR degradation from power curves

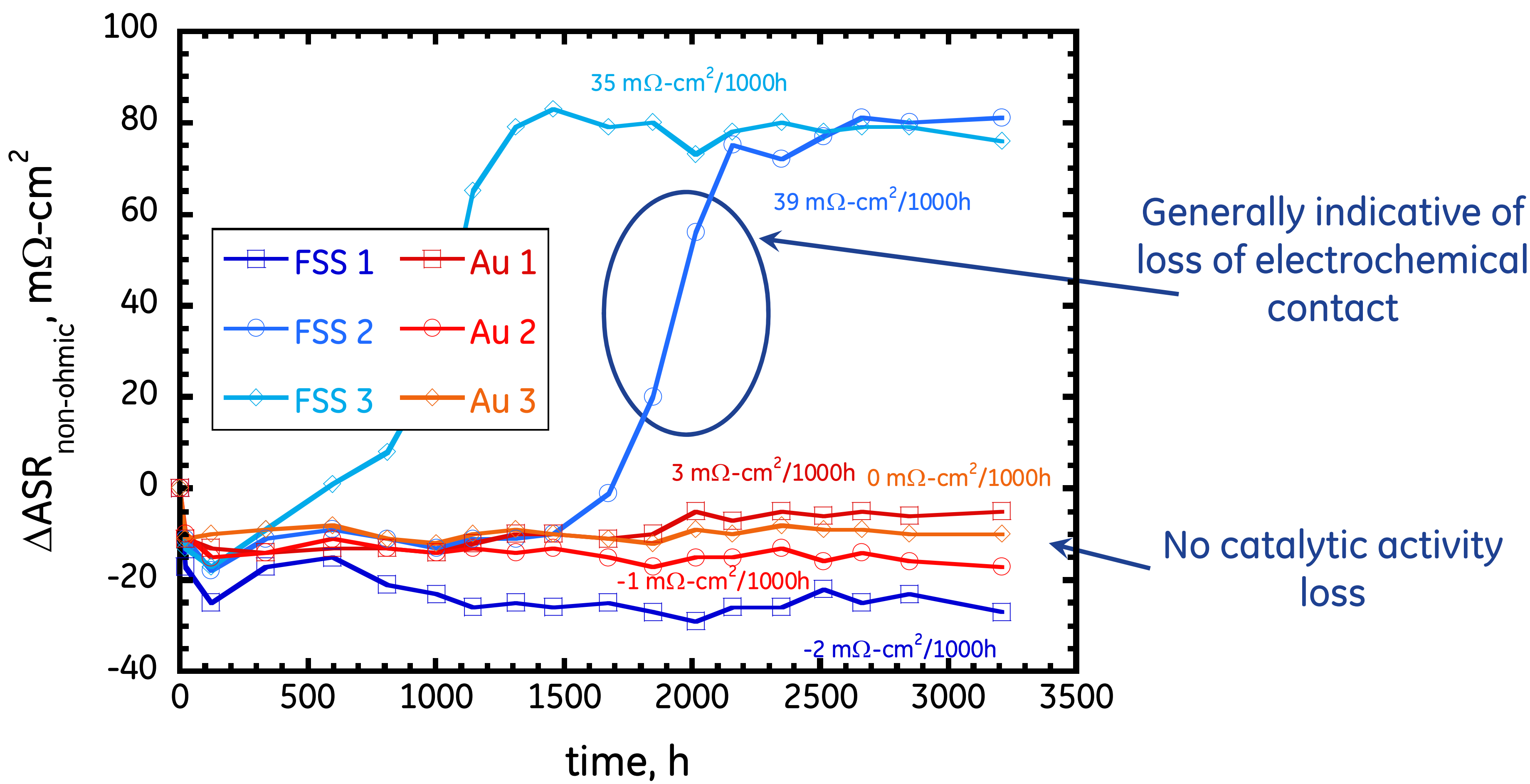


$$ASR = \frac{(OCV - V_{op})}{J_{op}}$$

ASR degradation consistent with traditional cell construction

Non-ohmic degradation

$$ASR_{total} = ASR_{ohmic} + ASR_{non-ohmic}$$

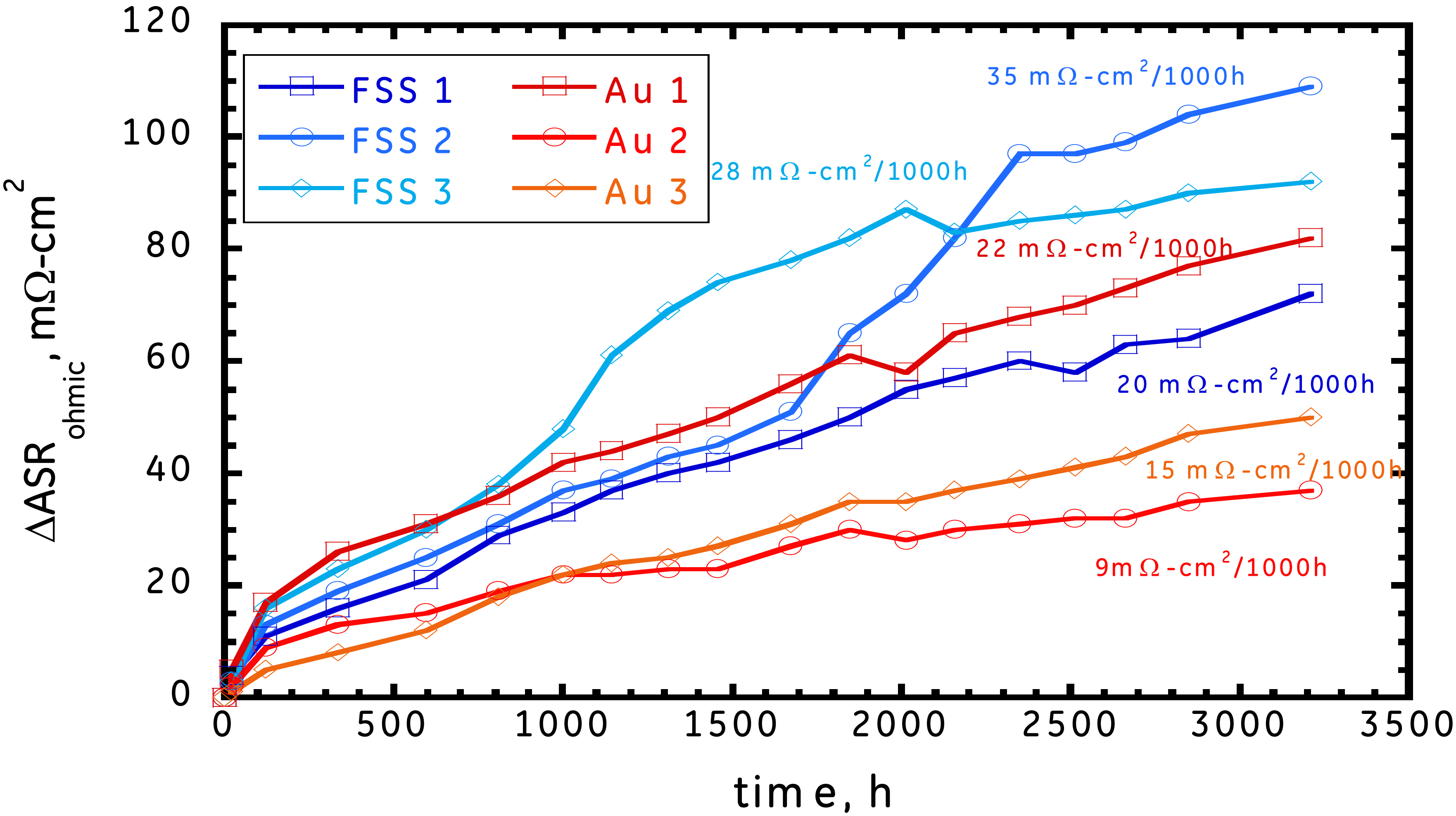


Non-ohmic degradation is nearly zero

imagination at work

Ohmic Degradation

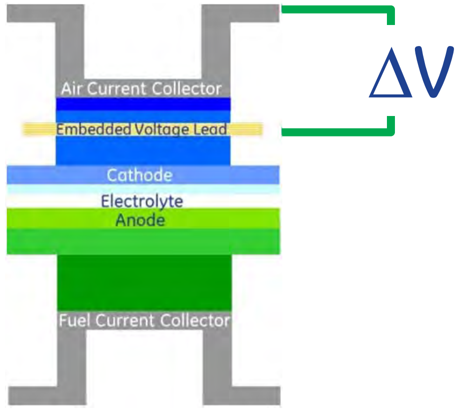
$$ASR_{total} = ASR_{ohmic} + ASR_{non-ohmic}$$

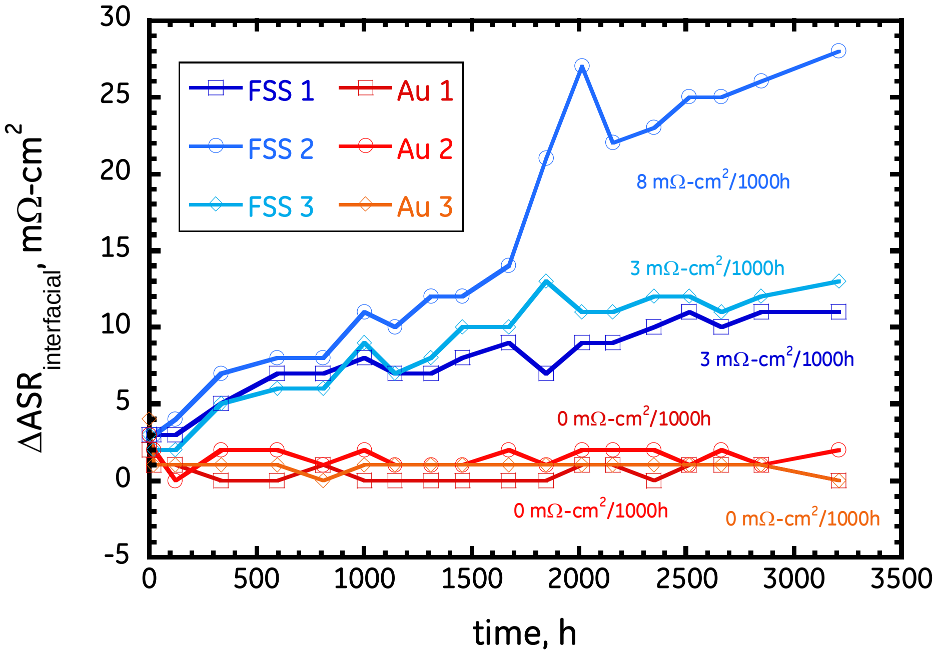


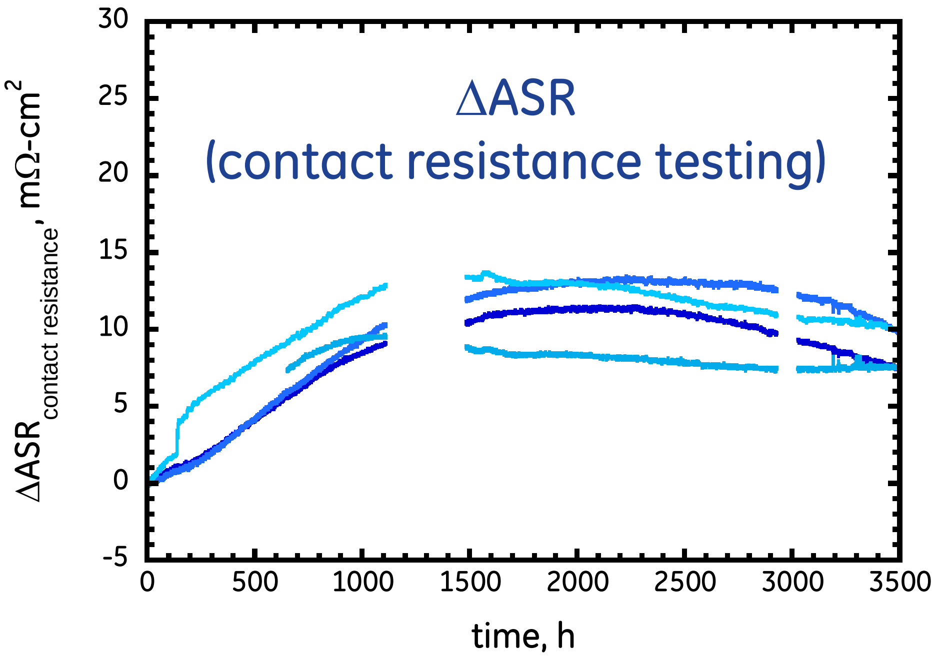
Measured degradation is nearly all ohmic in nature

imagination at work

Interfacial ASR



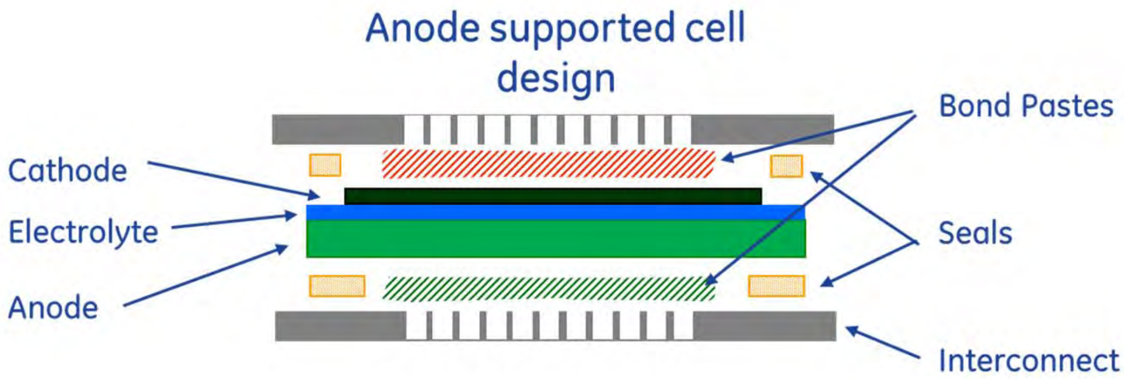




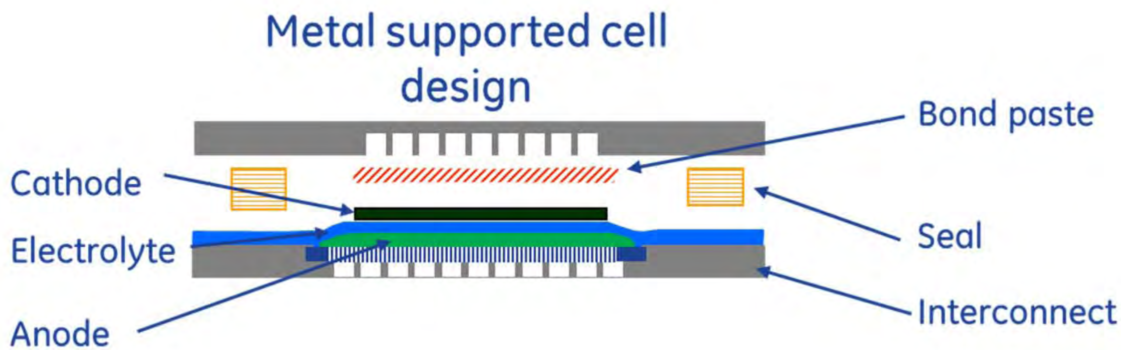
Confirms contact resistance data

Manufacturing

Metal supported cell



Advantages:
Integrated anode seal
Electrolyte in compression
Improved anode electrical contact
Increased active area
Lower anode polarization
Allows redesign of structures

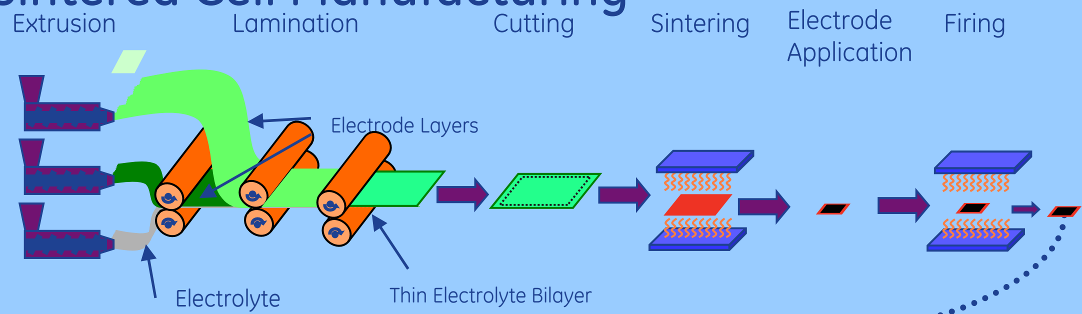


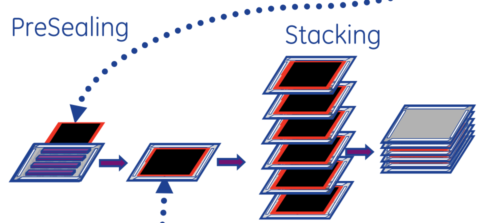
Challenges:
Dense / hermetic electrolyte
Porous metal substrate degradation

imagination at work

Low-cost manufacturing

Sintered Cell Manufacturing





Thermal Spray

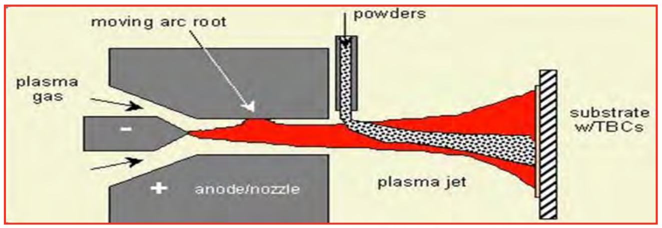
Leverage GE thermal spray expertise

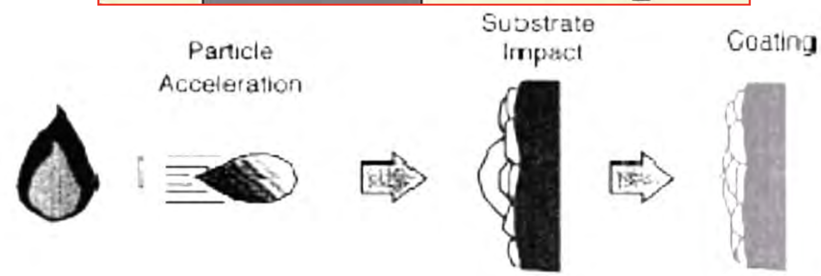
<u>Advantages</u>

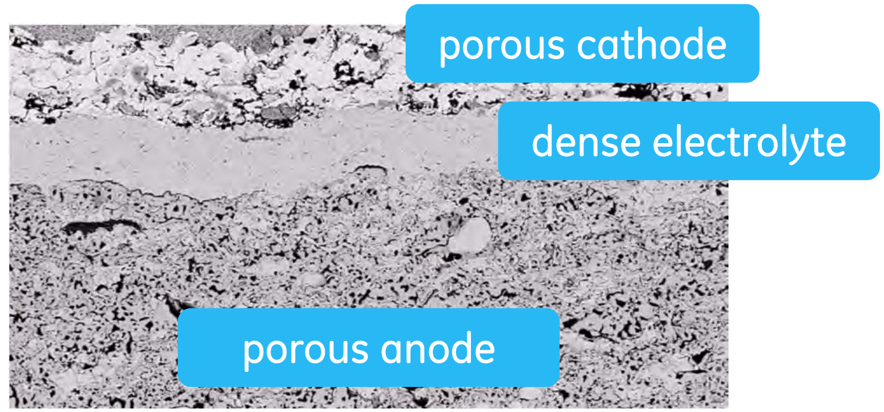
Larger area / Scalable
Simplified sealing
Low Capex / Modular
Lean Manufacturing

Cell Manufacturing Processes

Atmospheric Plasma Spray







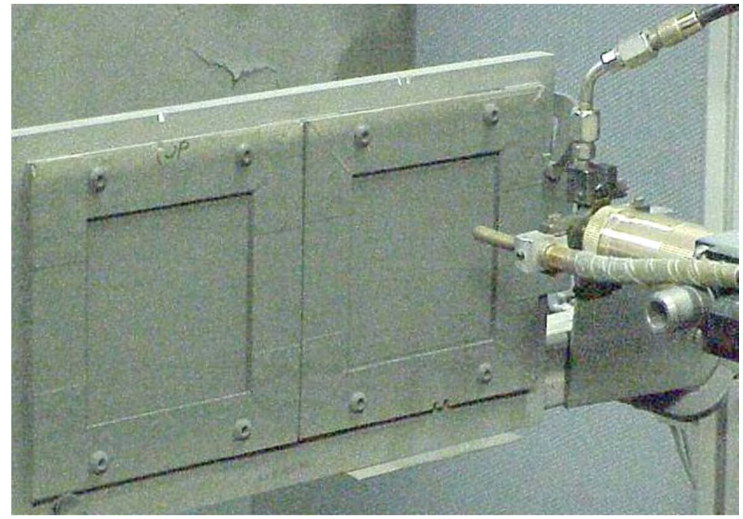
Enable larger, thinner cells
Exploration of different processes and cell structures
Goal is to demonstrate scalability

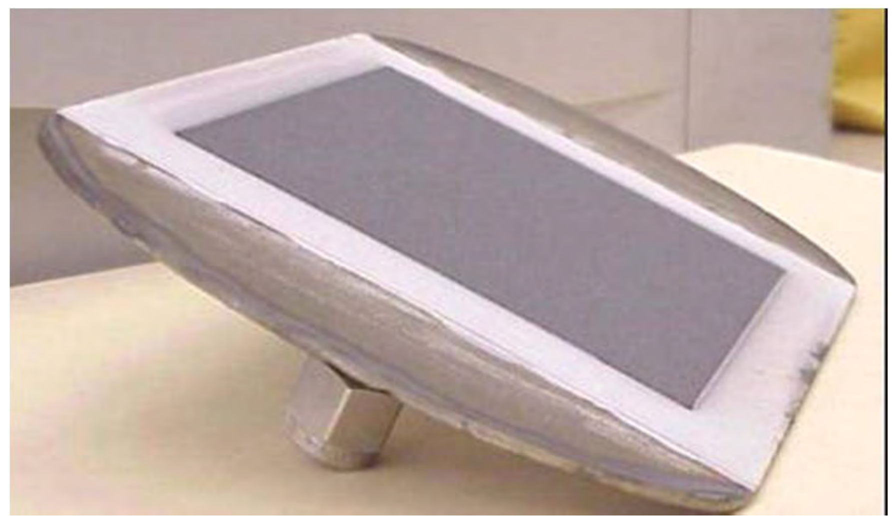
Disruptive to stack manufacturing cost structure

imagination at work

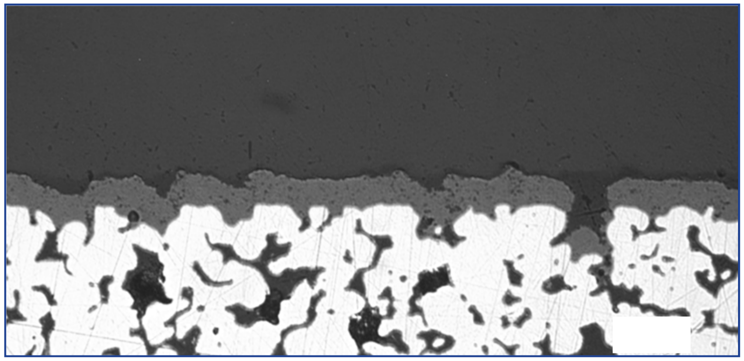
Deposition Technology Progress

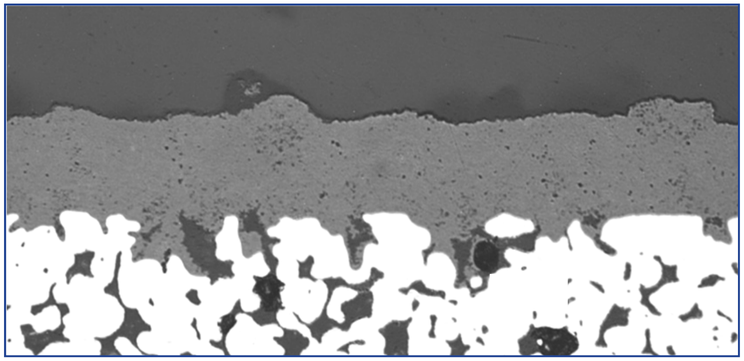
- High throughput, many different structures / compositions / formats can be tested
- Cell and stack design tailored to deposition processes
- Performance reaching sintered cell levels
- Scale-up to 4” and 12” cell on-going

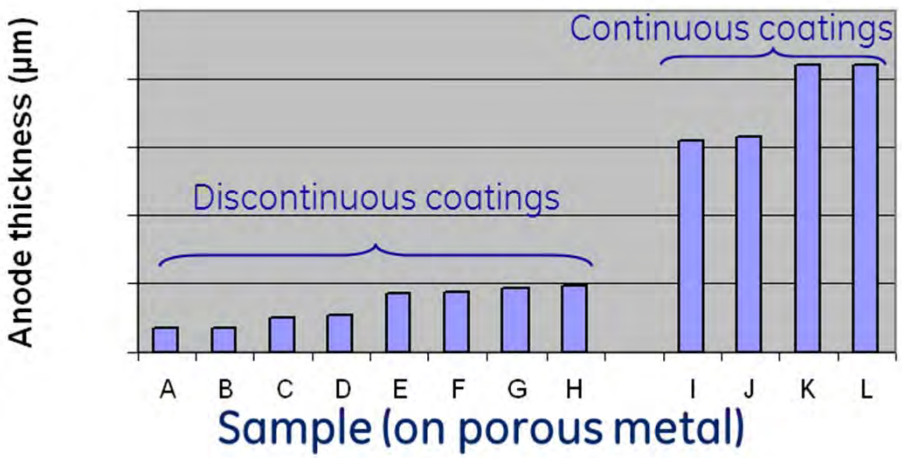




Smooth Anode Development

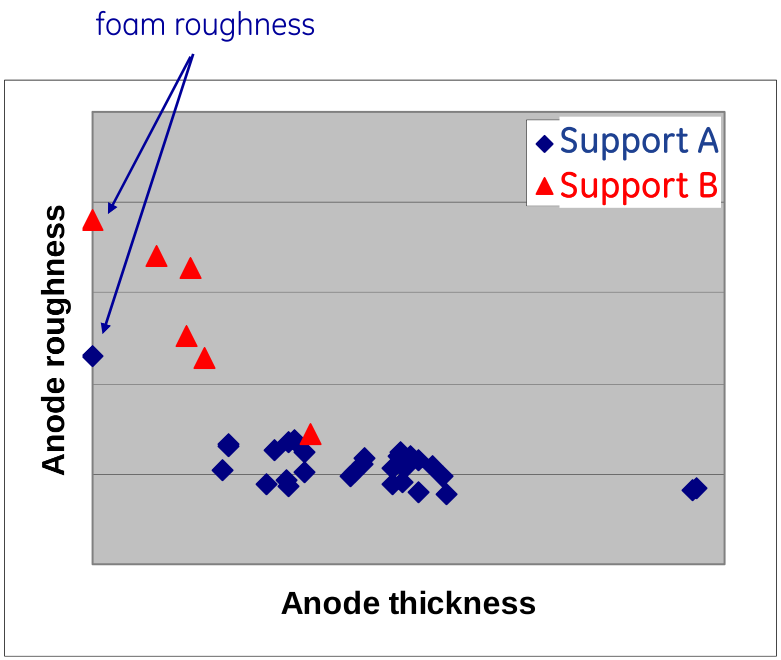




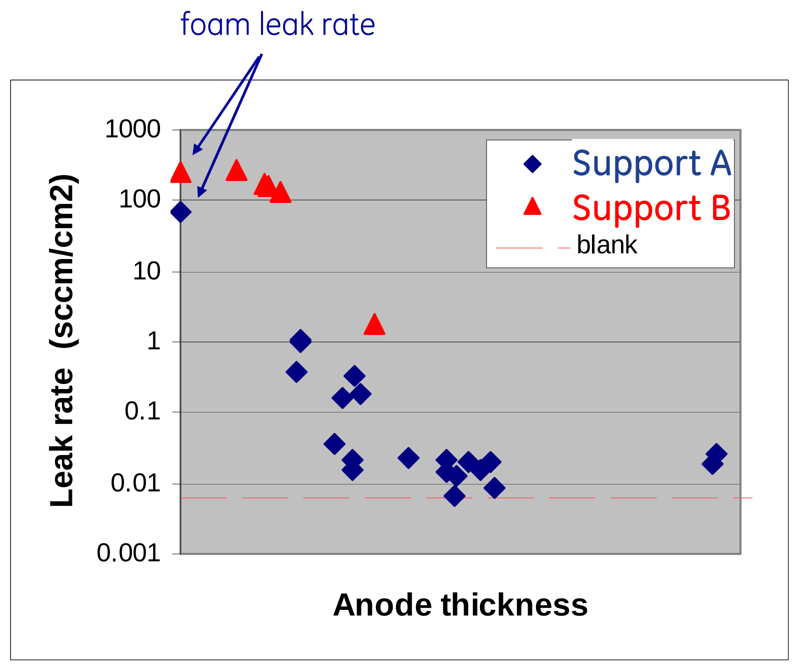


Minimum thickness required for deposition of a continuous anode on a porous substrate.

Smooth Anode Development



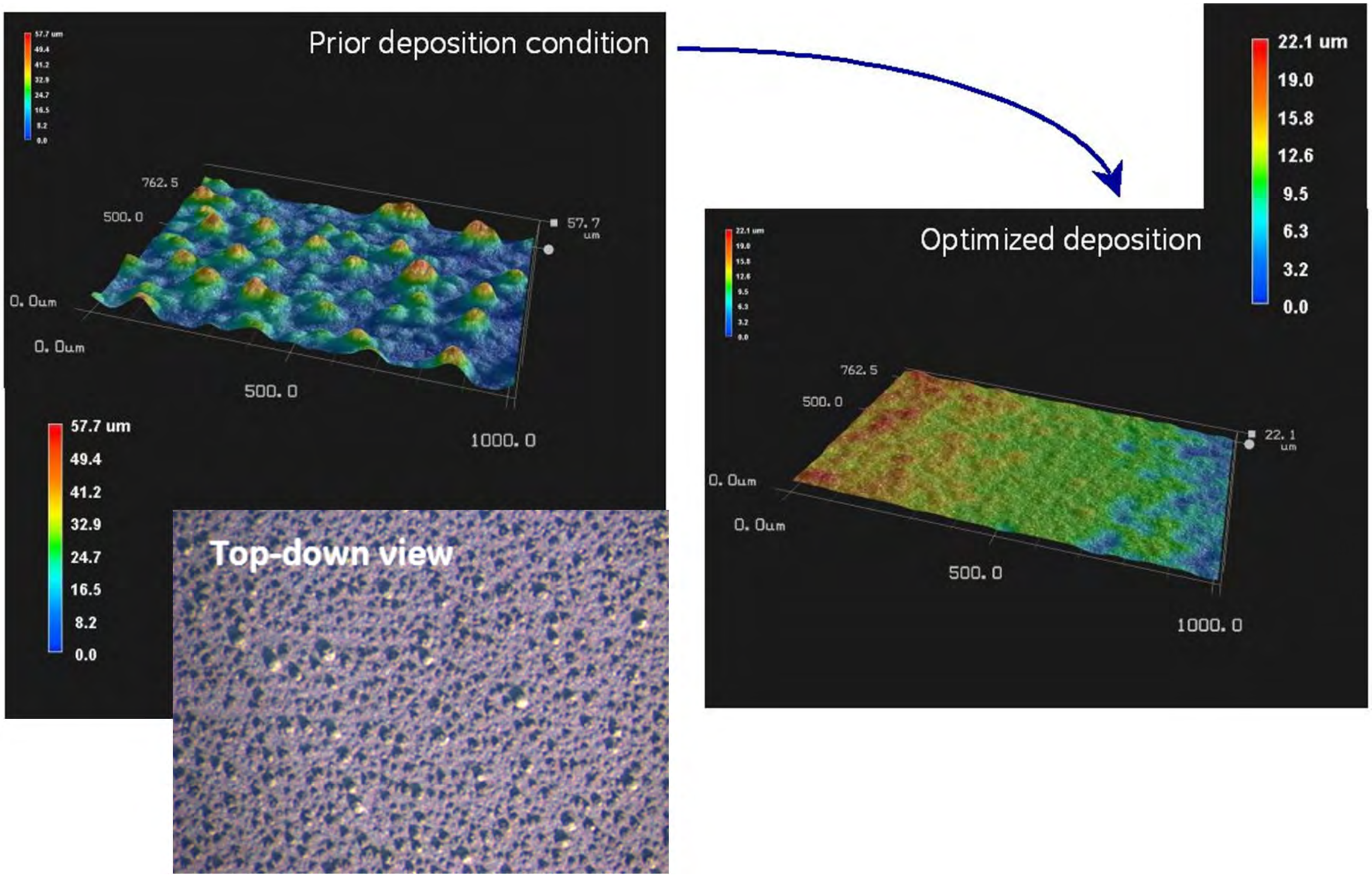
Anode roughness initially decreases with increasing thickness, then stabilizes to a fairly constant value. Transition is indicative of full foam coverage.



Leak rate decreases with increasing anode thickness until it stabilizes, which is indicative of full foam coverage.

Minimum thickness established for full foam coverage with smooth anode

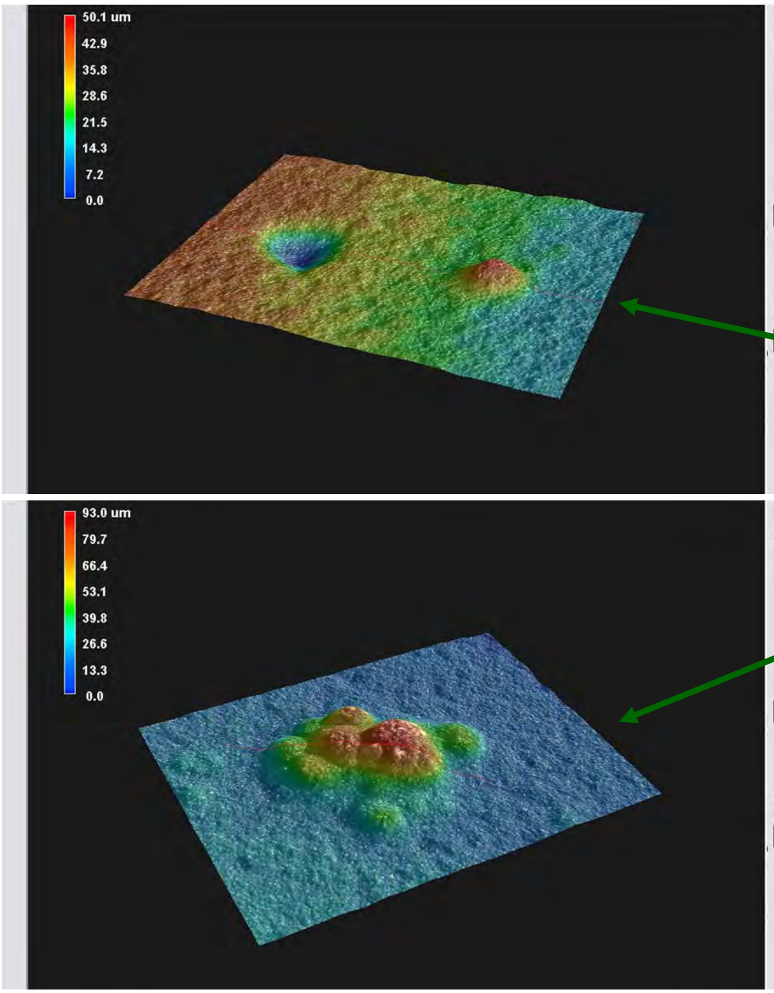
Smooth Anode Development

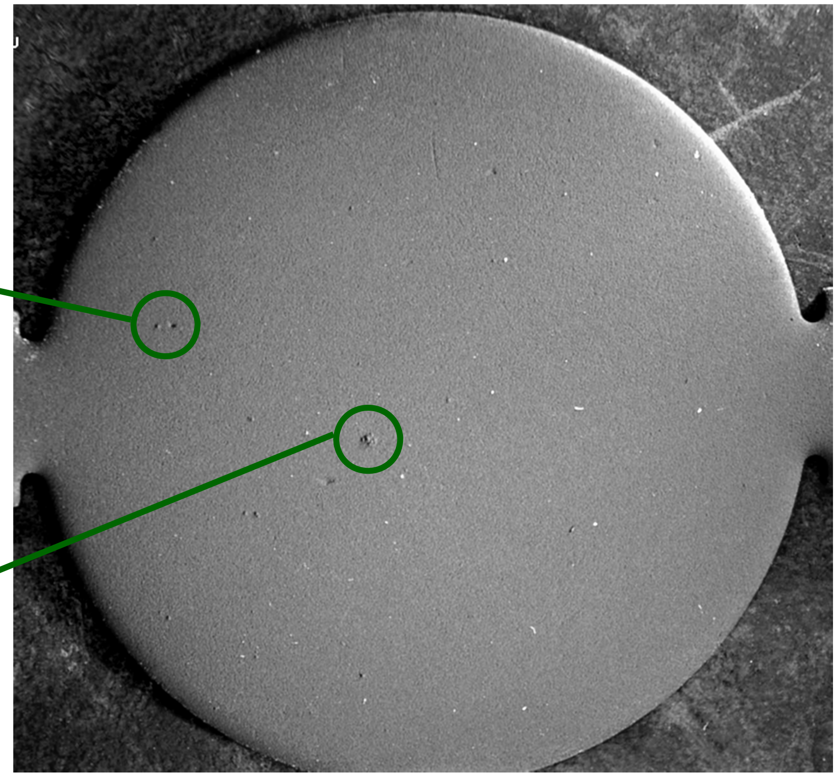


Deposition condition developed for smooth anode deposition onto foam support

imagination at work

Smooth Anode Development

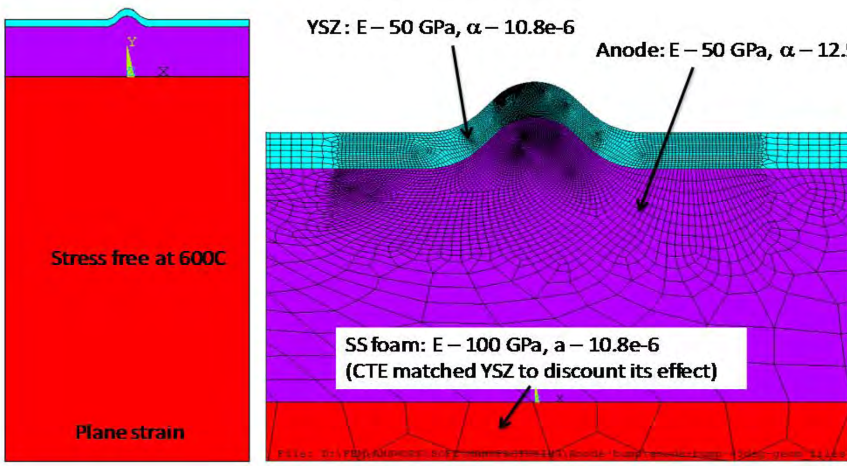


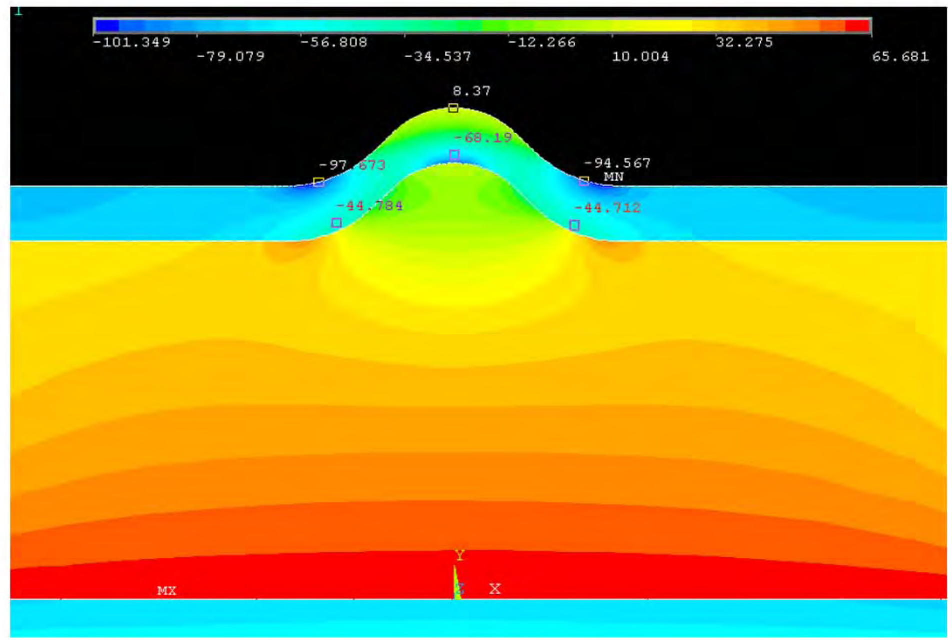


1" diameter foam coated with smooth anode. Surface is generally smooth, however a few localized defects can be identified.

Manufacturing defects may impact cell performance
Improved process control for removal

Effect of surface asperities on stress-state of thermal sprayed coating

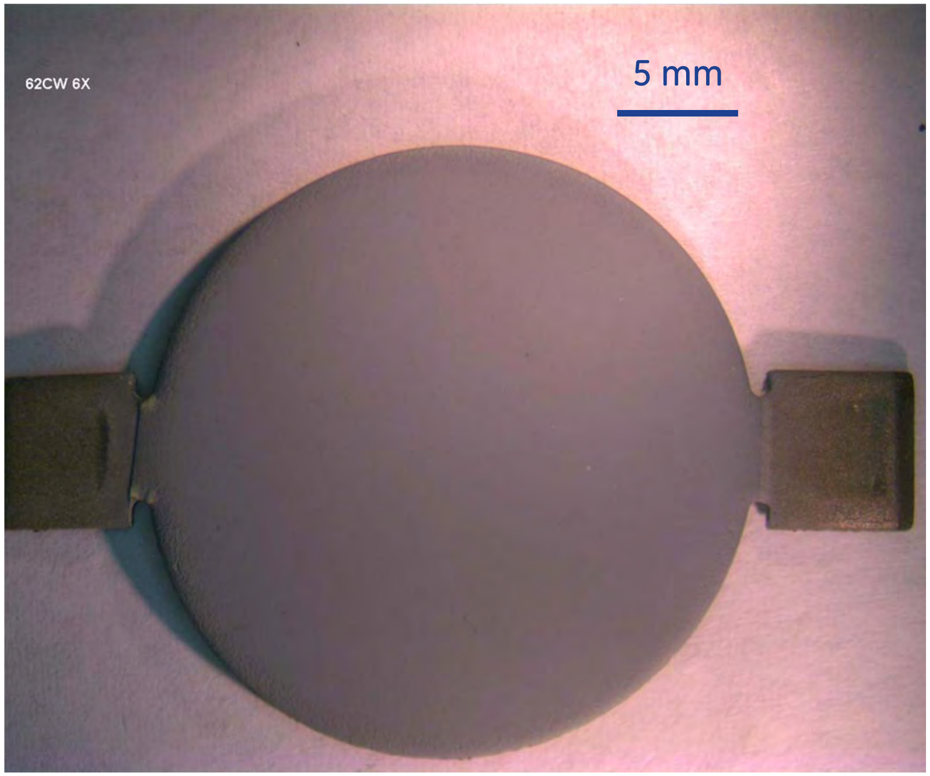




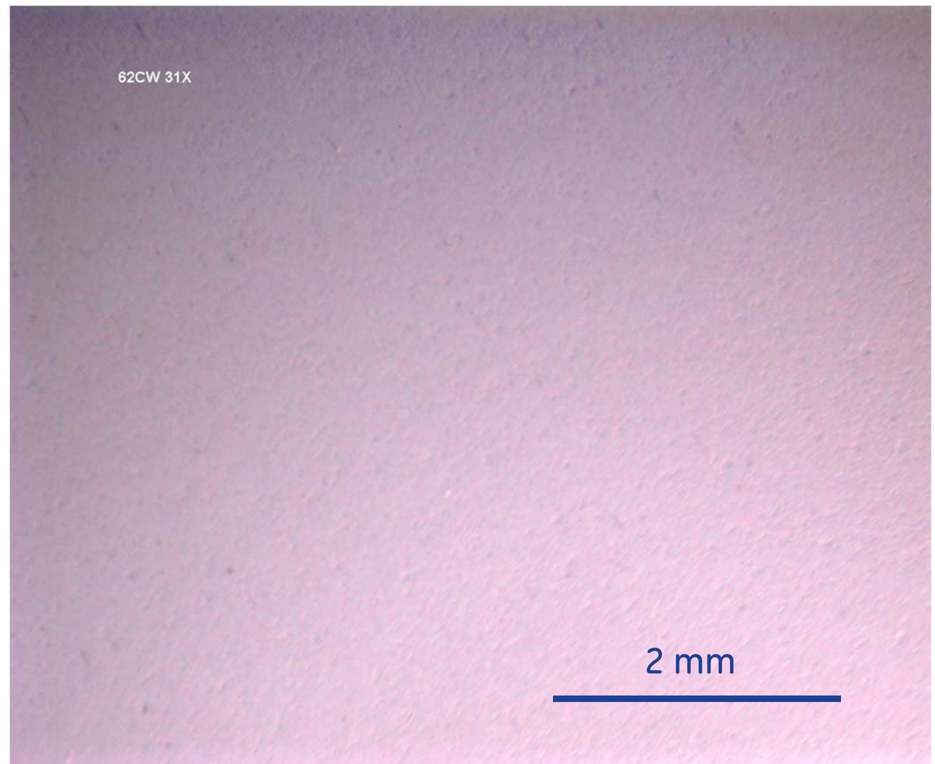
- Asperities cause local stress gradients in electrolyte
- Effect enhanced after anode reduction

imagination at work

Electrolyte optimization

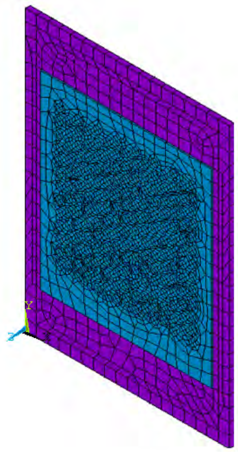


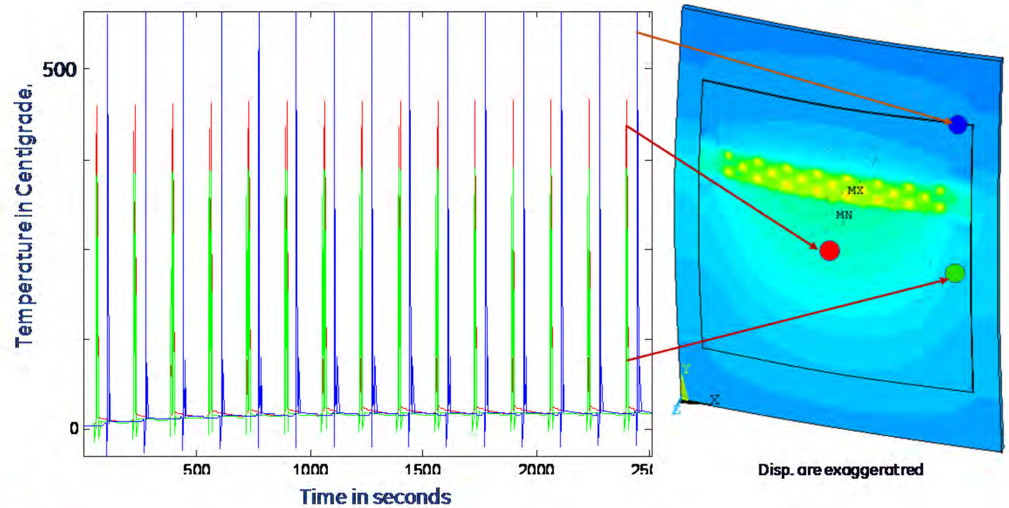
Top-down view of deposited coating on 1" diameter button cell

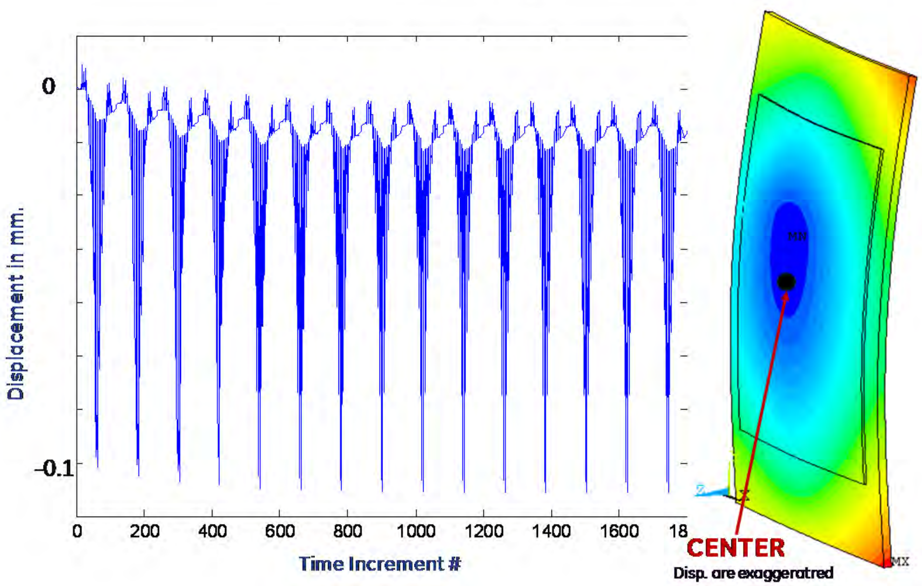


With a smooth anode & control of defects, high quality electrolytes can be deposited.

Thermal spray heat flux modeling



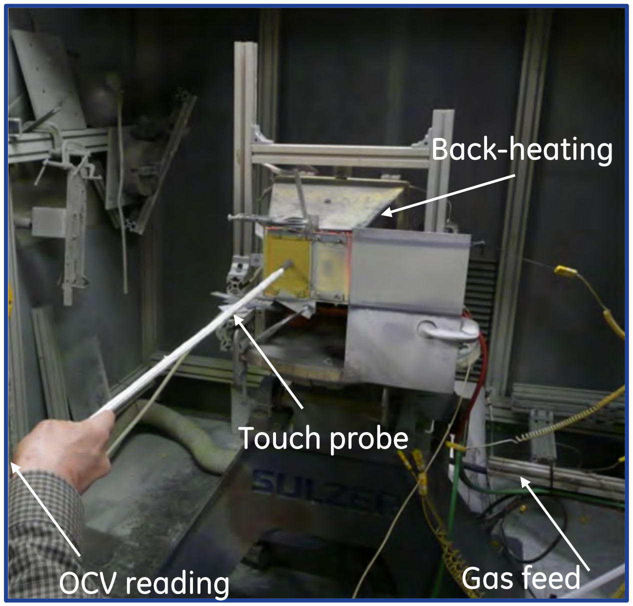




Thermal heat flux modeling to support large area cell thermal management

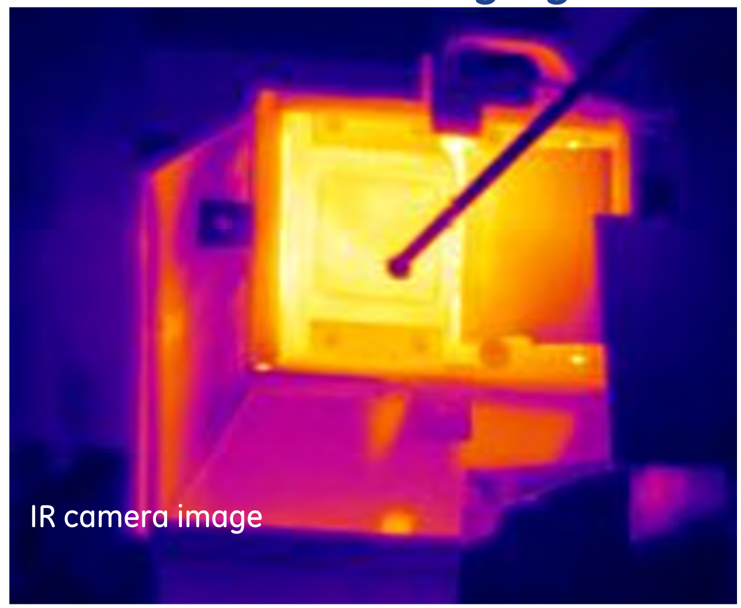
In-situ characterization for thermal sprayed cells

OCV measurement



OCV mapping can be performed across entire cell

Thermal Imaging

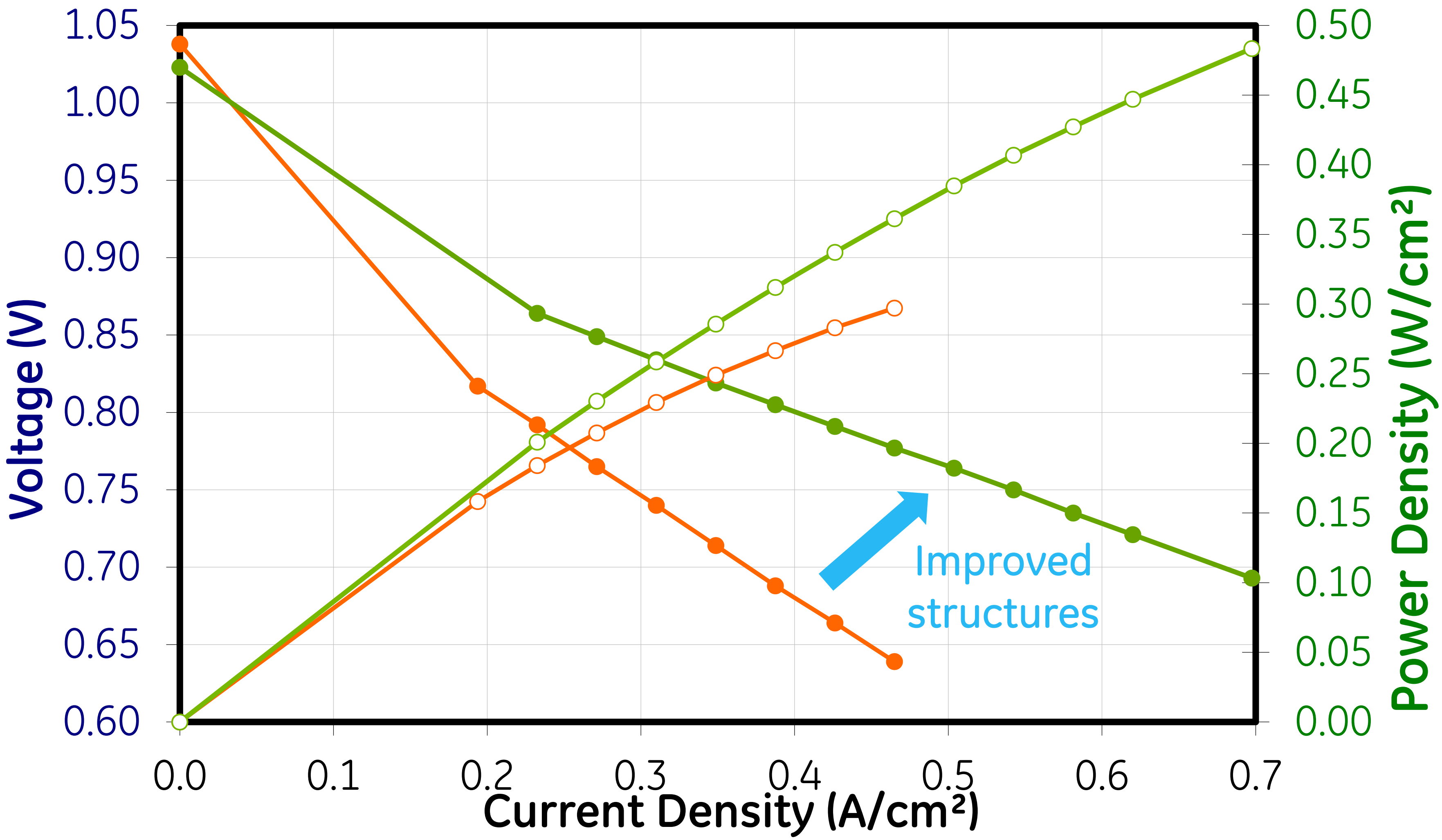


Imaging during OCV testing helps in further cell characterization

In-situ measurements in the spray cell permit rapid feedback for development

imagination at work

Thermal Sprayed Cells (25 cm²)



Optimizing electrodes and electrolyte for improved power density

Summary

- Identified high-impact fundamental degradation mechanisms and developed cost-effective mitigation solutions.
- Demonstrated high, stable performance of LSCF-based cathode SOFCs with gold current collectors.
- Demonstrated parabolic power density degradation behavior with ferritic stainless steel (AL441HP) current collectors that is indicative of chromia scale growth.
- Implemented and tested an integrated thermal spray manufacturing system for SOFCs.
- Identified anode roughness as a key criteria to enable hermetic electrolytes.
- Developed thermal spray conditions to produce a smooth fuel electrode (anode) on a porous metal support.
- Demonstrated operational performance on 25cm^2 thermal sprayed cells.

Acknowledgements

- Joe Stoffa, Briggs White, Travis Shultz, Heather Quedenfeld and Shailesh Vora of DOE/NETL
- Funding provided by the US Department of Energy through cooperative agreement DE-NT0004109.
- SECA partners
- GE SOFC Team

This material is based upon work supported by the Department of Energy under Award Number DE-NT0004109. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the DOE.

imagination at work