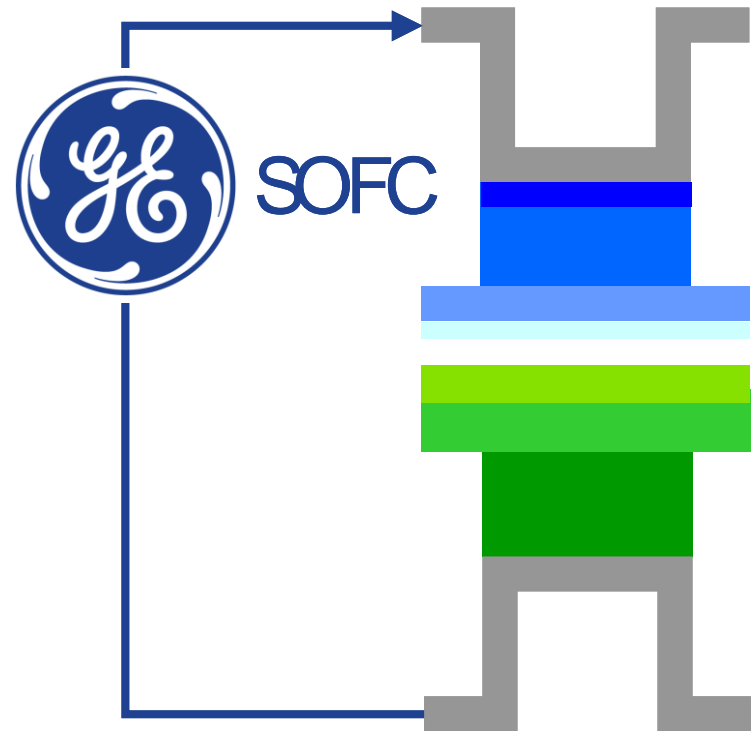


# SOFC Manufacturing Development at GE Global Research

Matt Alinger  
GE Global Research  
Niskayuna, NY

13<sup>th</sup> Annual SECA Workshop  
Pittsburgh, PA  
July 24-25, 2012



imagination at work

# GE Unveils Advanced-Manufacturing Battery Facility with Grand Opening

July 10, 2012

Disruptive technology for  
Transportation ... rail, marine,  
road, mining

Growth opportunity for  
telecommunications,  
uninterruptible power supplies,  
smart grid

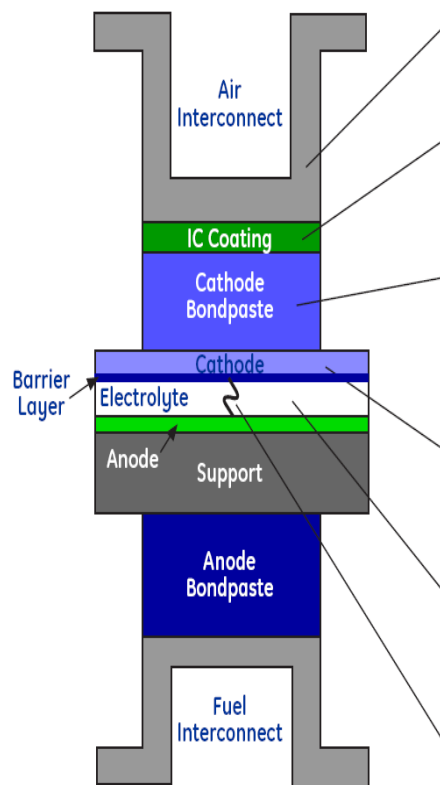
Novel chemistry and materials  
creating a \$1B business



220,000 ft facility  
\$150M+ factory investment

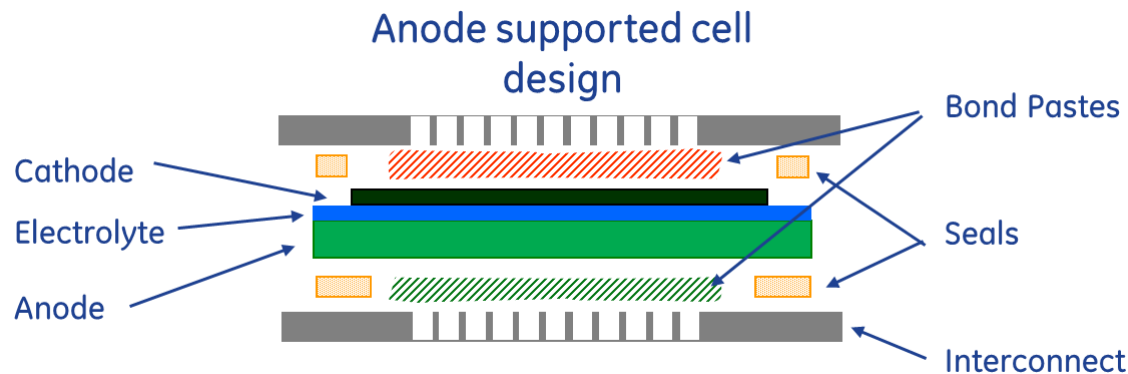
## Sodium Metal Halide Battery

# Anode Supported Solid Oxide Fuel Cell



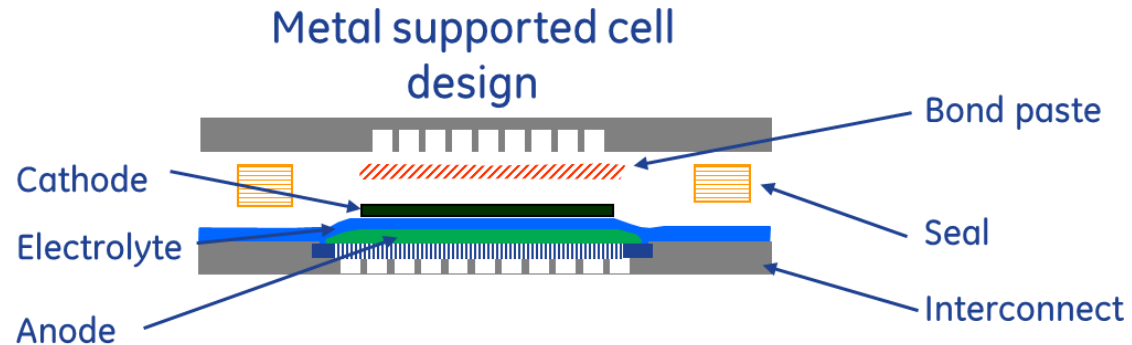
	Layer	Function	Material	Thickness
Air Side	Interconnect	Gas & Electron Transport	Ferritic Stainless Steel	500 $\mu\text{m}$
	Protective Coating	Prevent interconnect Cr from poisoning cathode	$(\text{Mn,Co})_3\text{O}_4$	10 $\mu\text{m}$
	Cathode Contact Paste	Electrically connect cell with air interconnect	$(\text{La,Sr})\text{CoO}_3$	100 $\mu\text{m}$
	Cathode	Air electrode	$(\text{La,Sr})(\text{Co,Fe})\text{O}_3$	40 $\mu\text{m}$
	Barrier Layer	Prevent cathode Sr from reacting with electrolyte Zr	GDC $(\text{Ce}_{0.8}\text{Gd}_{0.2})\text{O}_2$	10 $\mu\text{m}$
Fuel Side	Electrolyte	Permit $\text{O}^{2-}$ transport, prevent air/fuel mixing	YSZ $(\text{ZrO}_2 + 8 \text{ mol } \text{Y}_2\text{O}_3)$	10 $\mu\text{m}$
	Functional Anode	Fuel electrode	NiO/YSZ	20 $\mu\text{m}$
	Porous Support	Mechanically supports Anode & Electrolyte	Ferritic Stainless Steel	500 $\mu\text{m}$
	Interconnect	Gas & Electron Transport	Ferritic Stainless Steel	

# Metal supported cell



## Advantages:

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

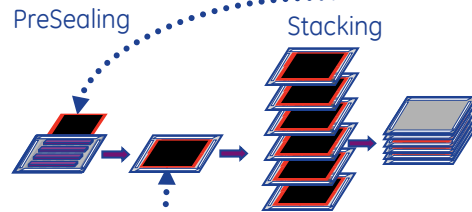
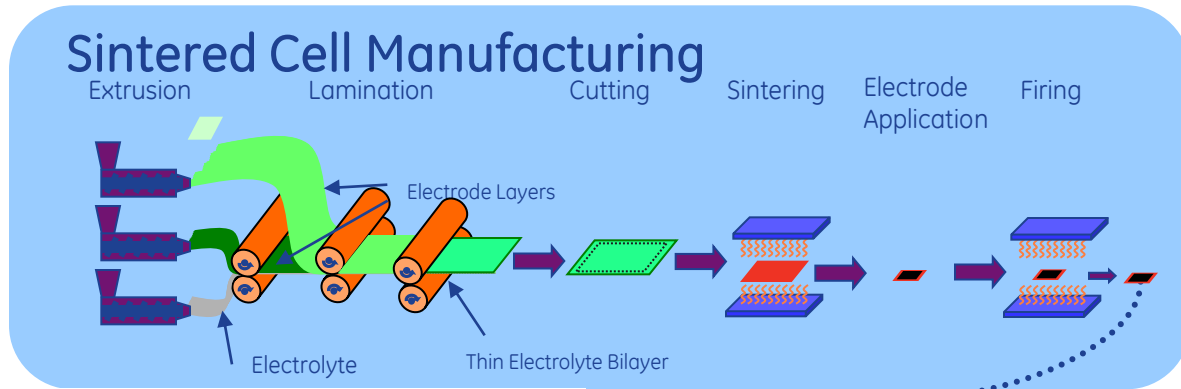


## Challenges:

- Dense / hermetic electrolyte
- Porous metal substrate degradation

# Low-cost manufacturing

## Sintered Cell Manufacturing



## Advantages

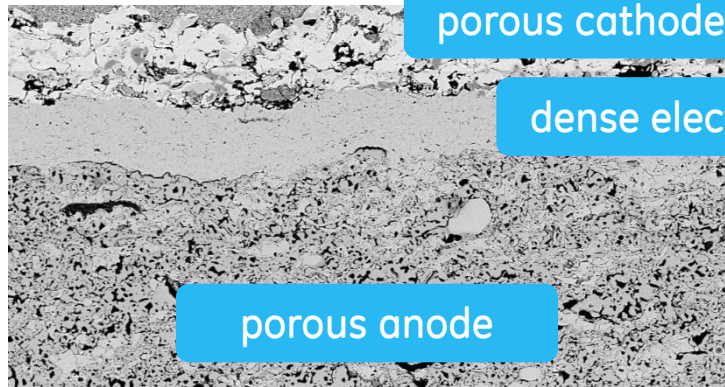
- Larger area / Scalable
- Simplified sealing
- Low Capex / Modular
- Lean Manufacturing

## Thermal Spray



Leverage GE thermal spray expertise

# Thermal spray manufacturing challenges

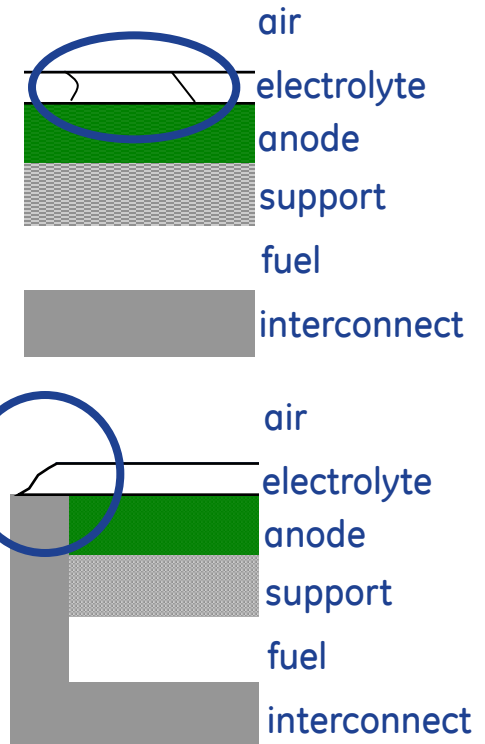


Electrolyte functions:  
1) Transport  $O^{2-}$  ions  
2) Separate air/fuel

Thin & dense (on porous substrate) ✓

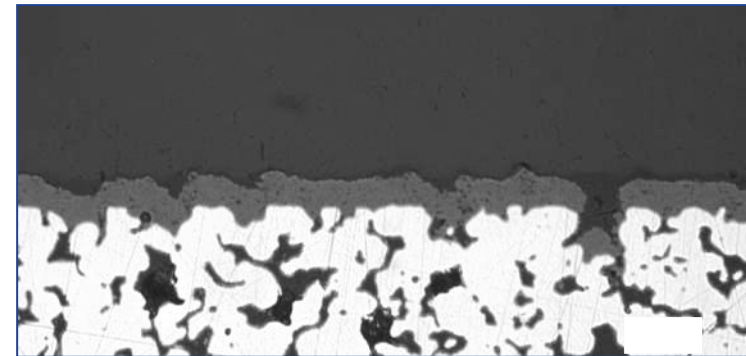
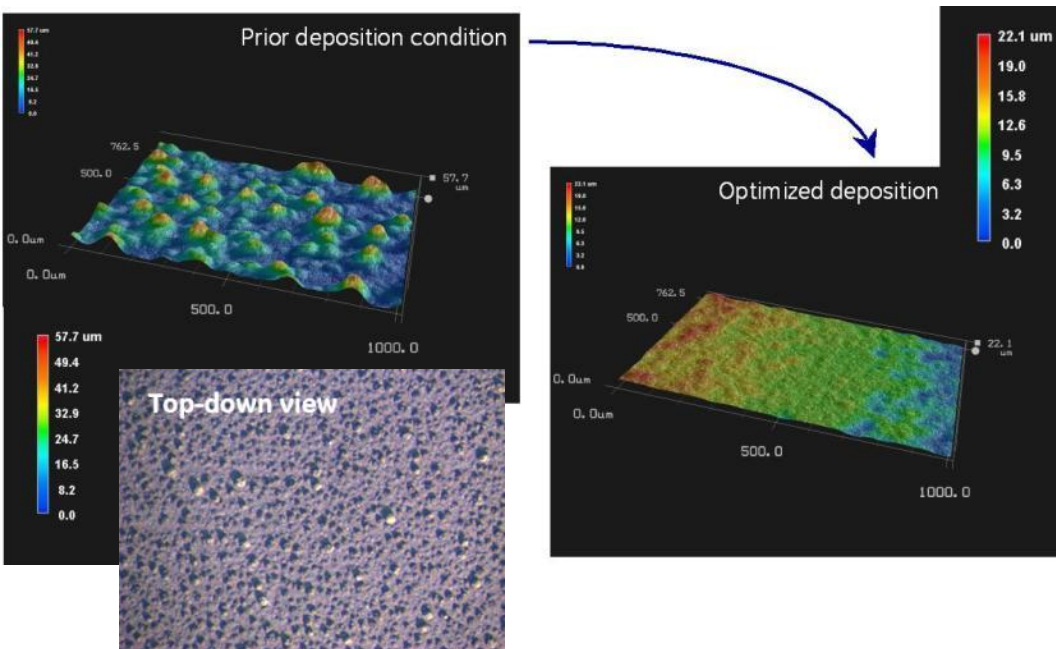
Crack-free / hermetic strength, residual stress ✓

Edge sealing  
Mechanical design  
Thermal management ✓



# Smooth Anode Summary

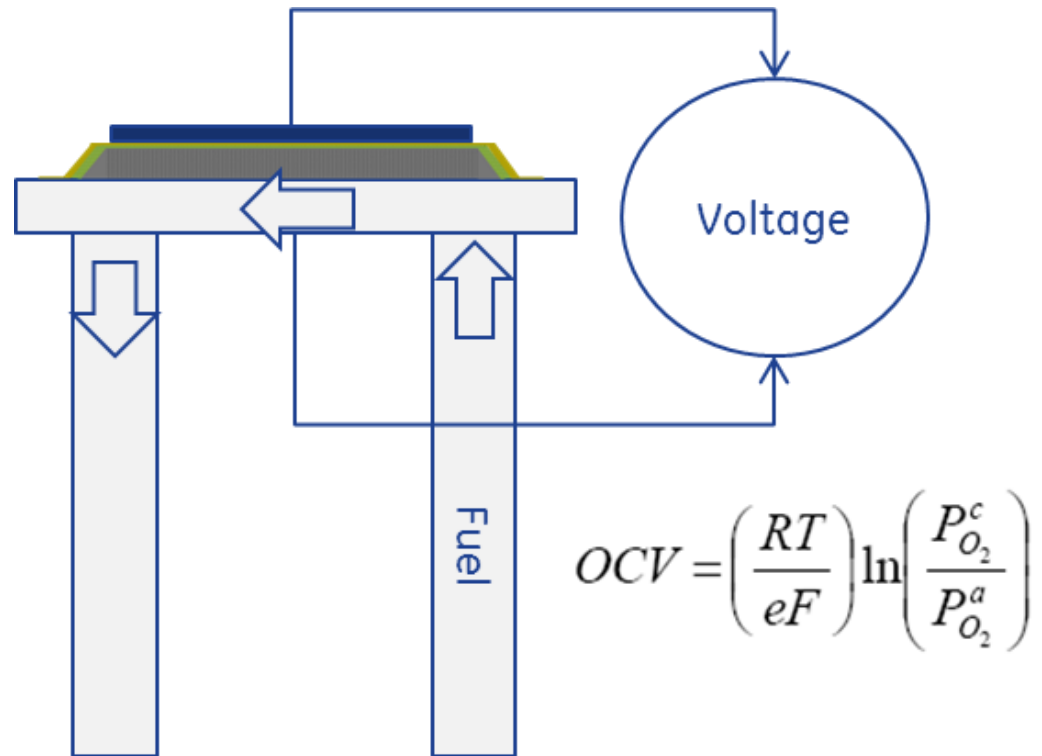
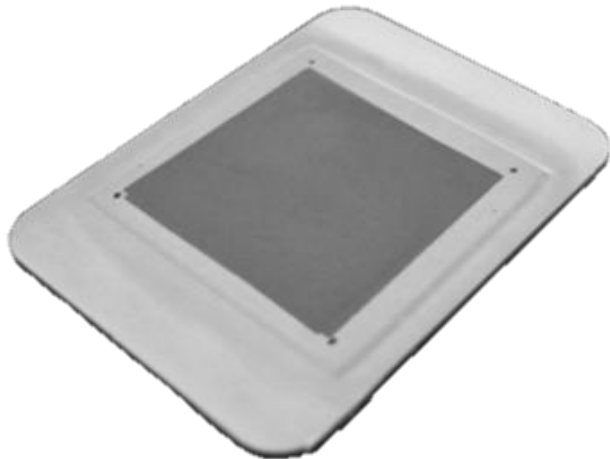
## Full coating coverage



## Low-roughness coating

# Key to thin, dense, crack-free electrolyte is high-quality anode

# 2" cell (25 cm<sup>2</sup>) test Set-Up

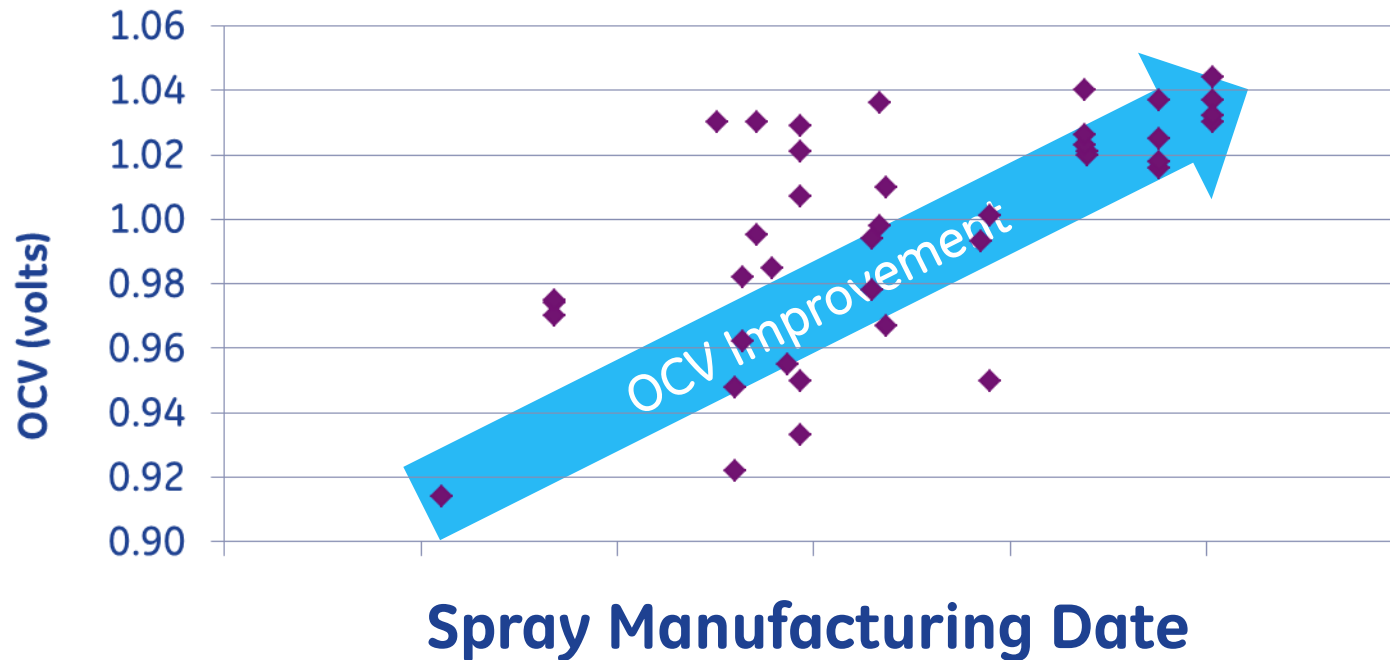


2" vehicle representative of stackable architecture



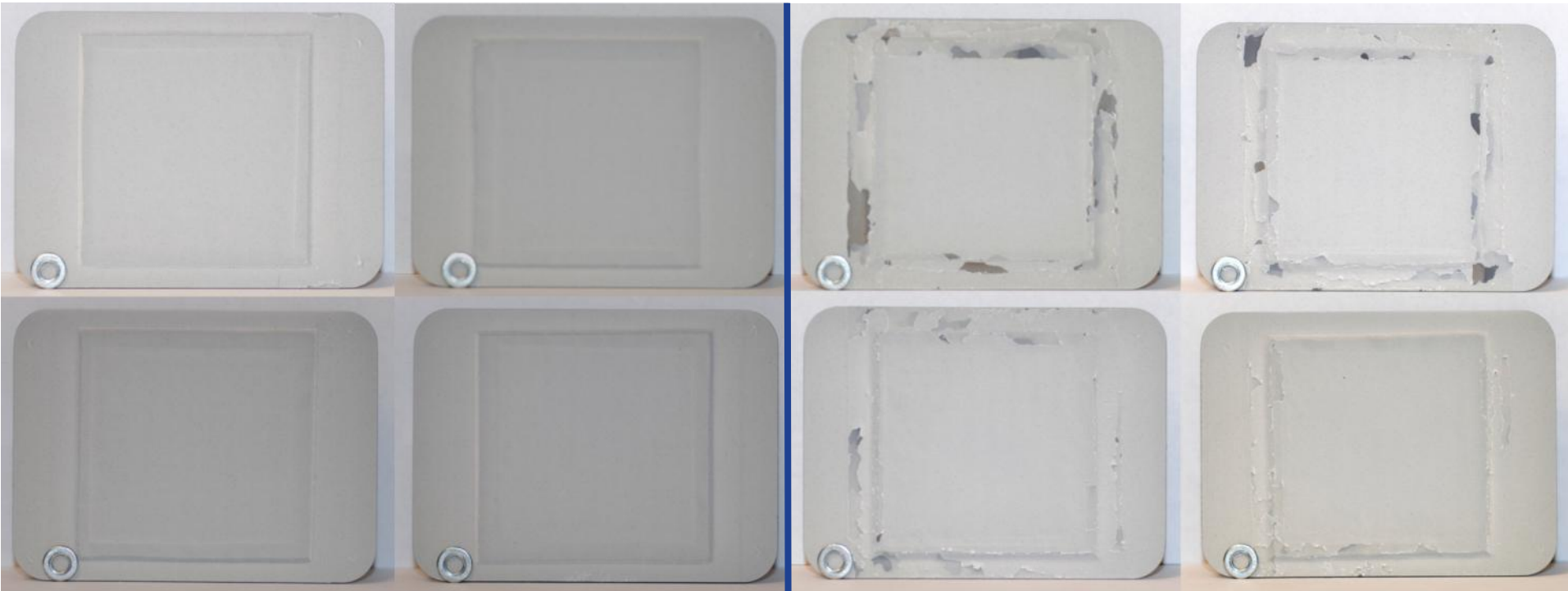
# OCV Testing

High OCV indicative of dense, crack-free coating



2" cell demonstrated with good OCV

# Influence of Thermal Spray Conditions on Coating Quality

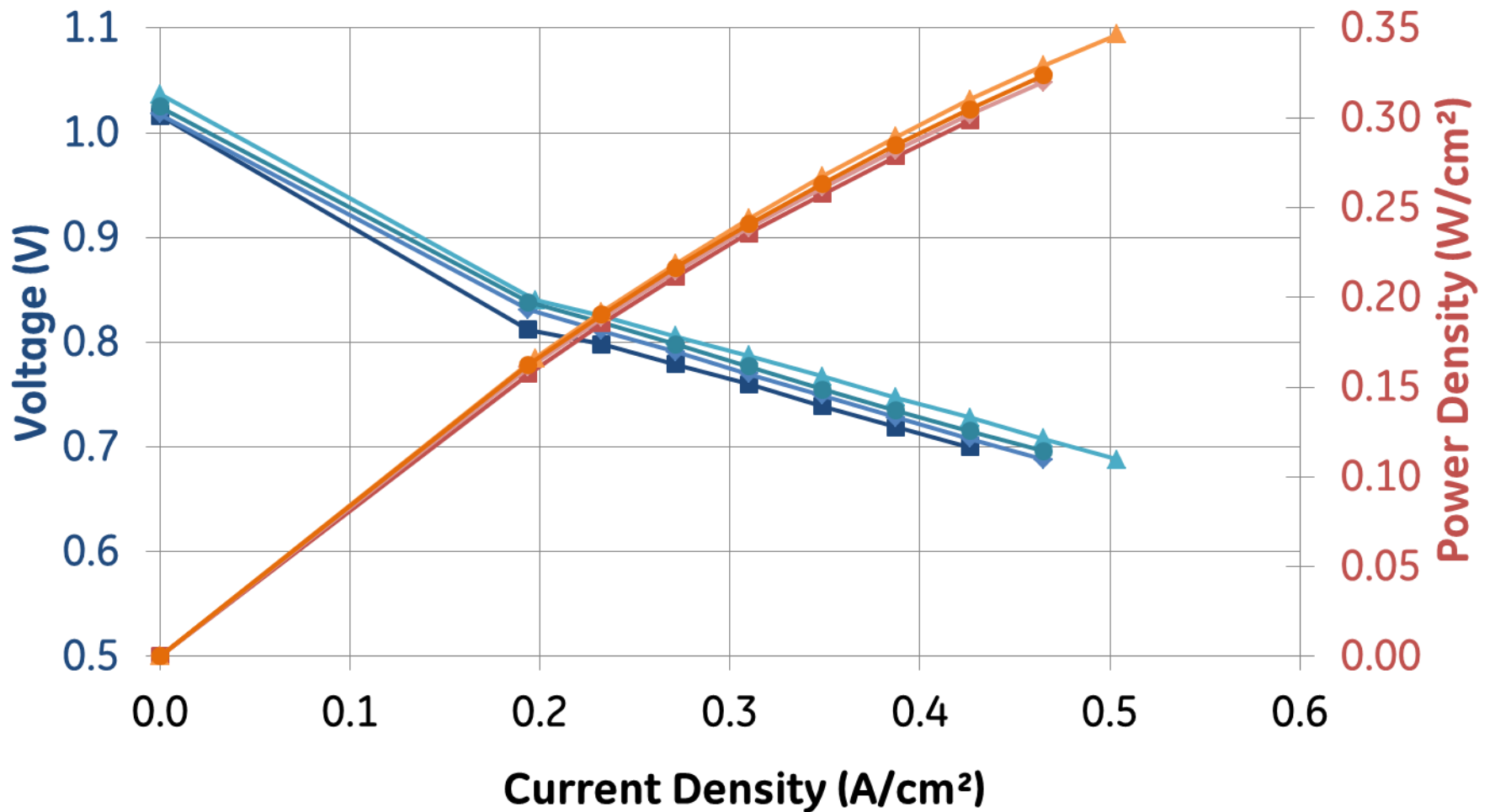


Good quality

Poor quality

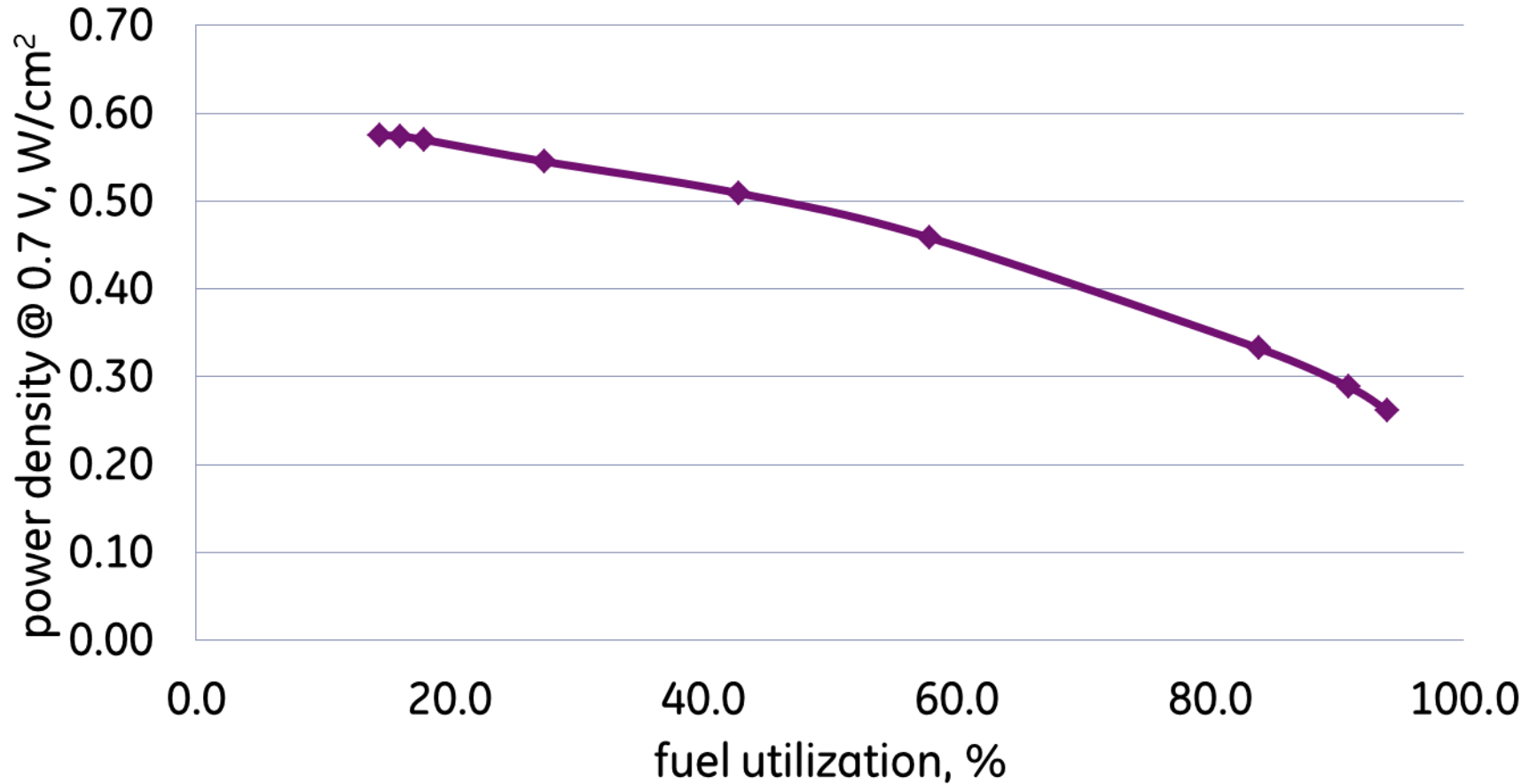
Thermal spray conditions significantly  
impact coating quality

# Power Curve Repeatability



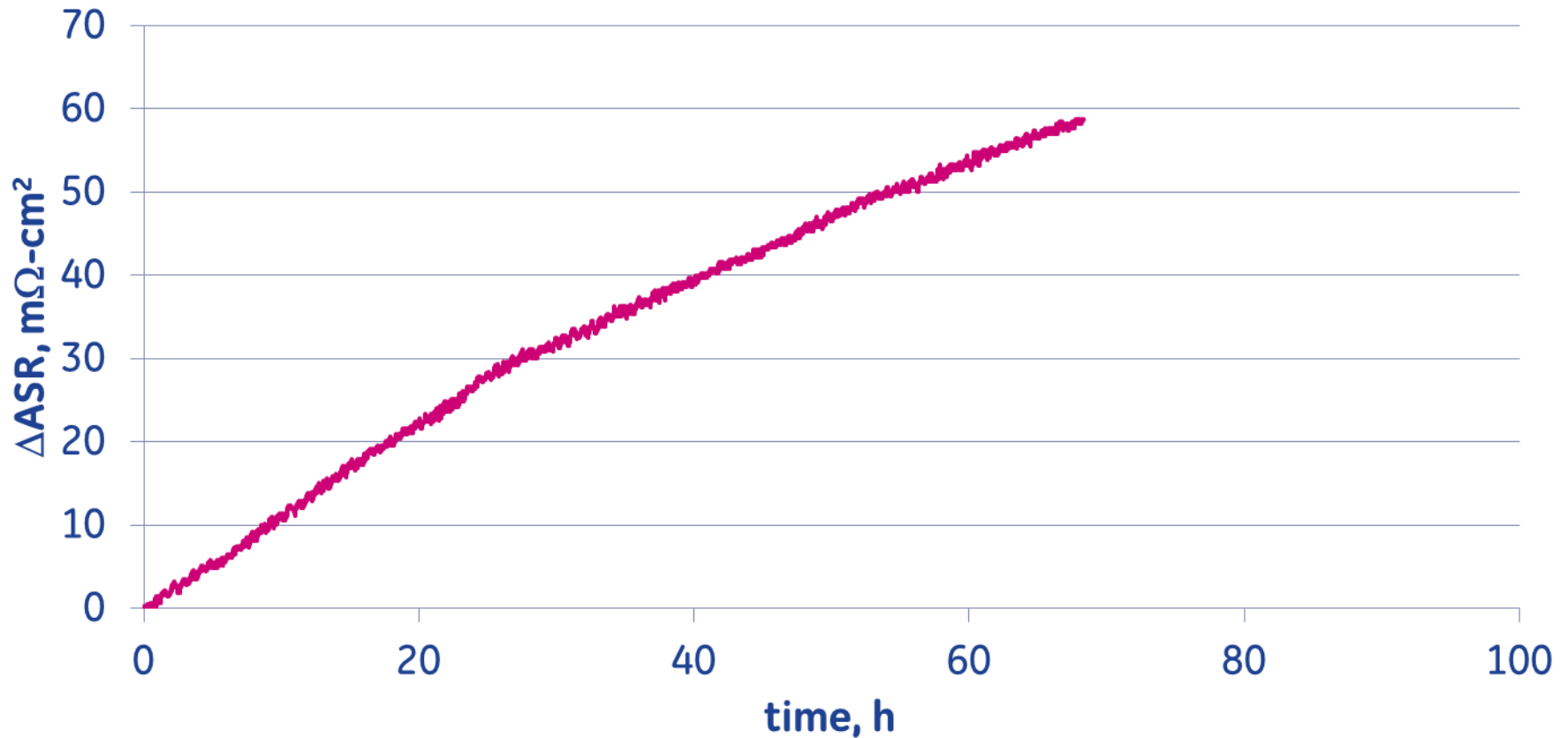
Repeatable cell performance  
from run to run

# Fuel Utilization Curve



Flow-field optimization will lead to improved fuel utilization

# Thermal Sprayed Barrier Layer Need

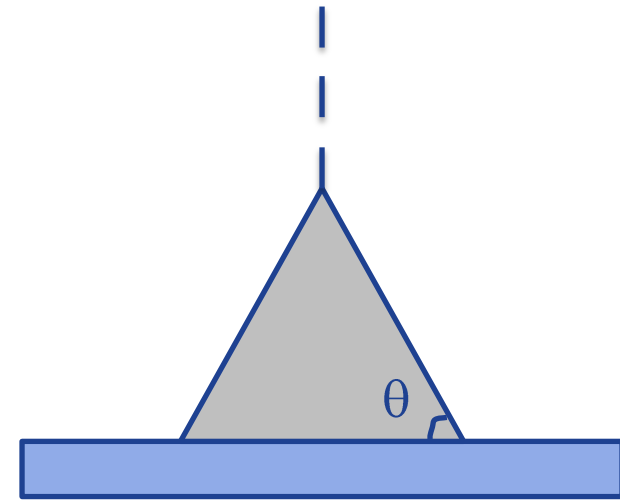


Process in place for anode, electrolyte and cathode  
-Need to develop ceria barrier layer process

# Flowability Measurements

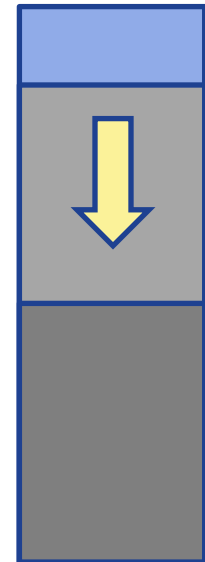
## Angle of Repose

- Measure steepest angle of poured pile
- Carr Index from ASTM D6393-08



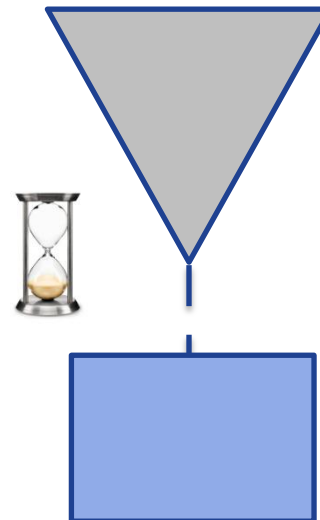
## Compressibility Index

- Ratio of poured density to packed density (Hausner Ratio)

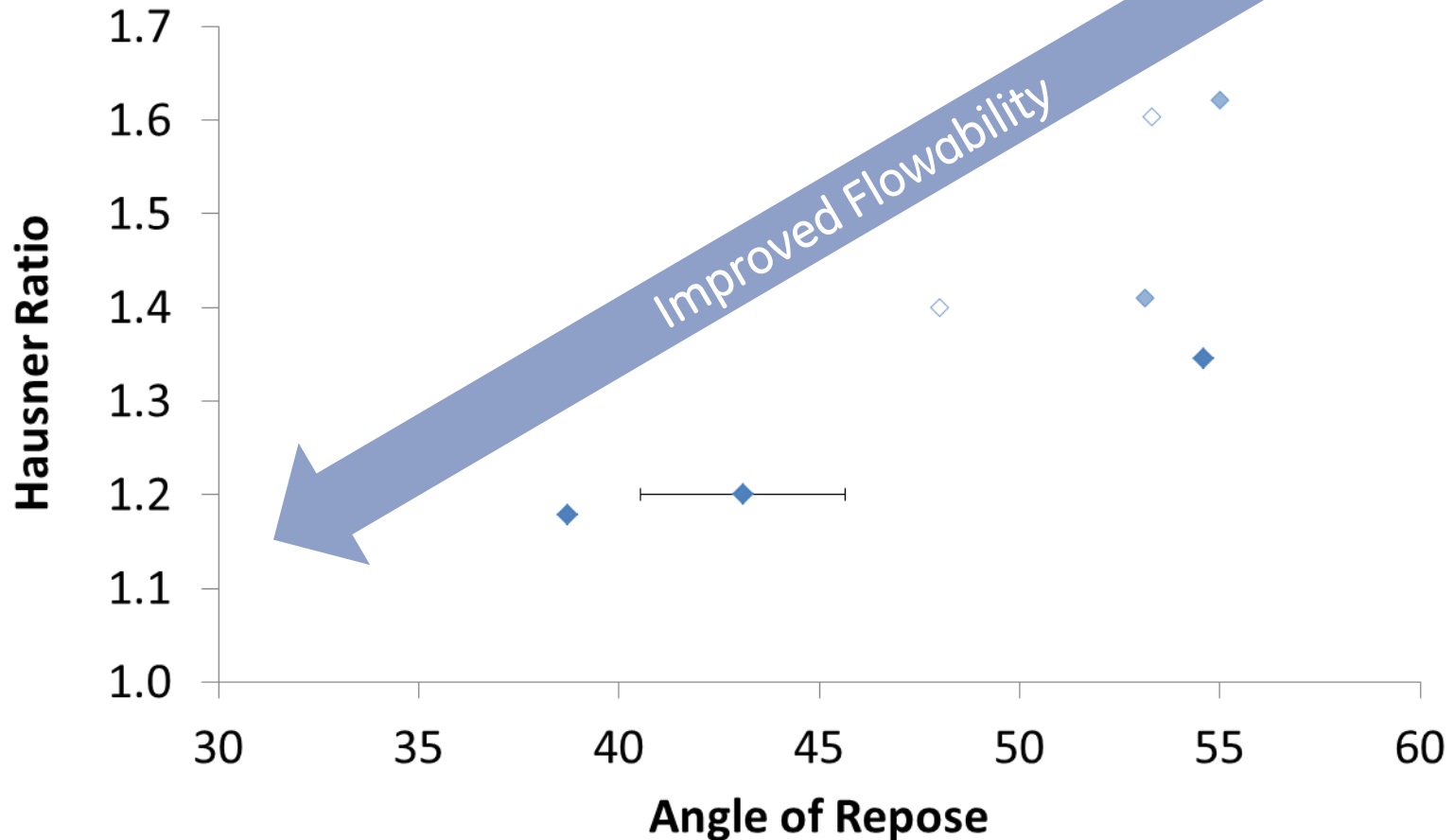


## Hall Flow

- Time to flow through orifice
- Use Carney funnel (0.20")
- ASTM standard B213-03

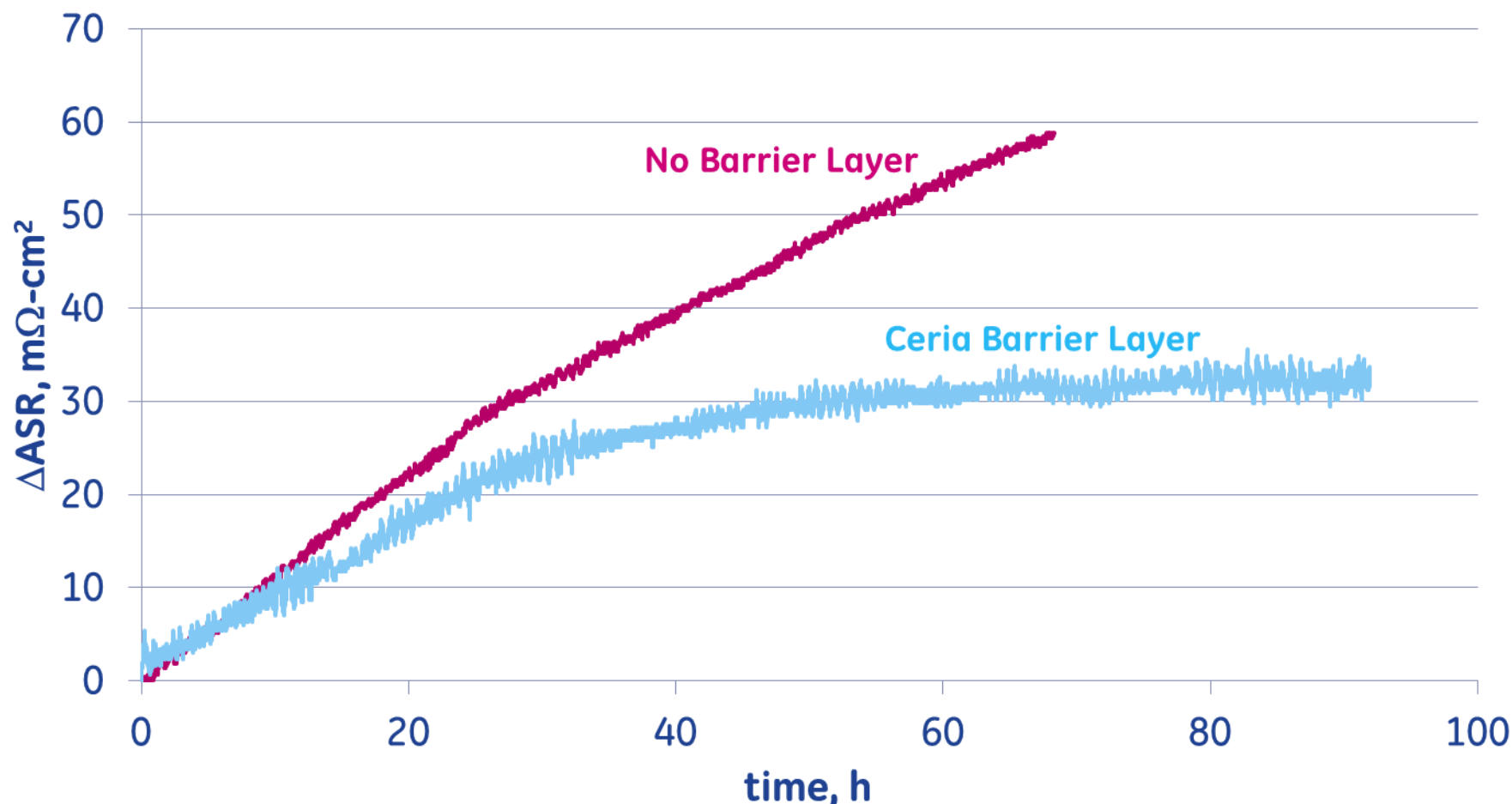


# Flowability Data



Particle sizes, size distributions, morphology, ...  
influence flowability

# Ceria Barrier Layer

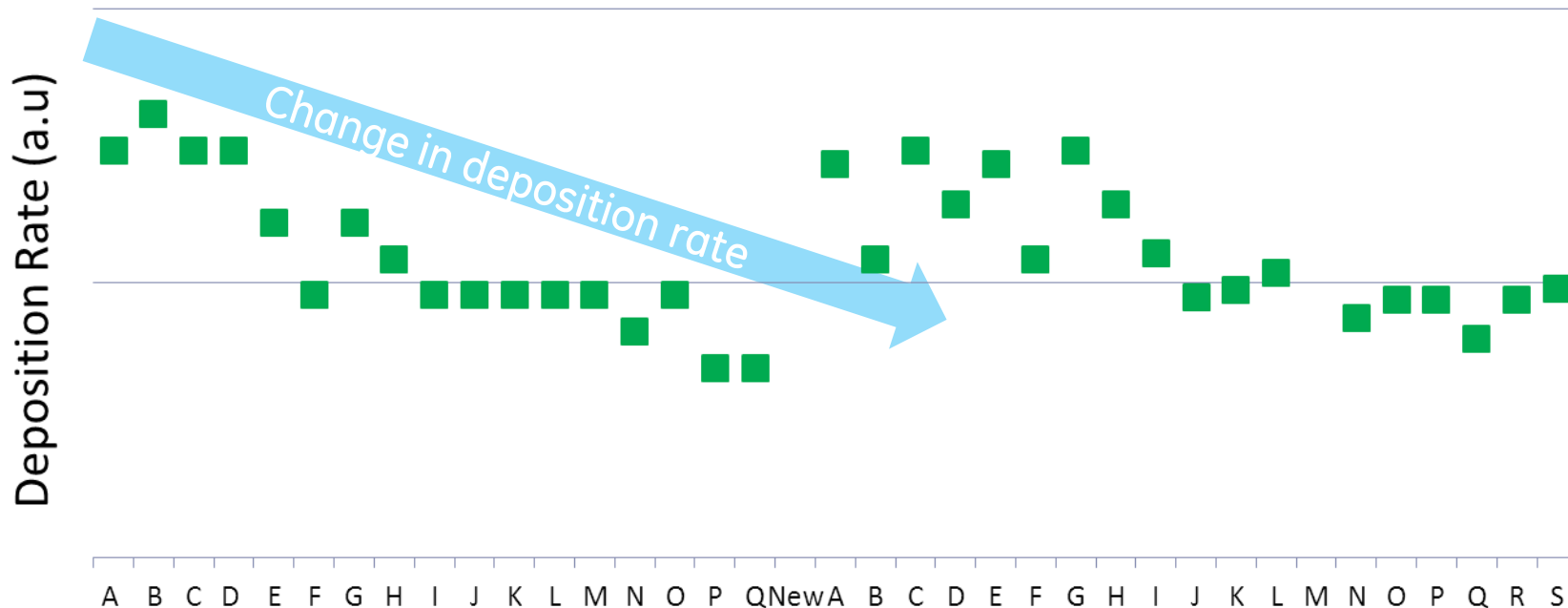


Addition of barrier layer significantly reduces degradation rate  
Longer duration testing required to validate degradation



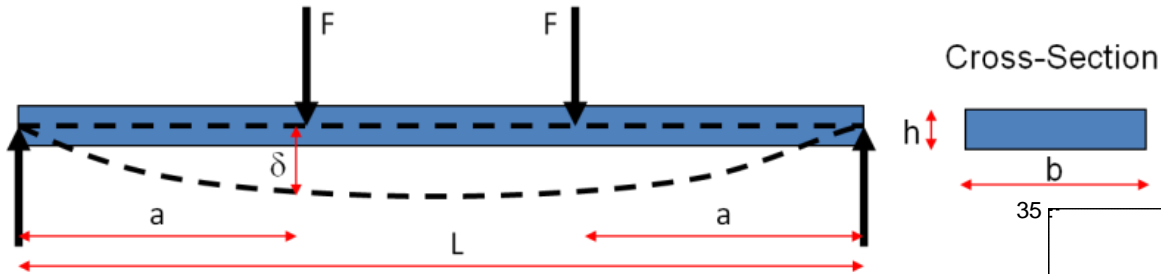
# Process Control

Deposition efficiency used to establish process specifications & control

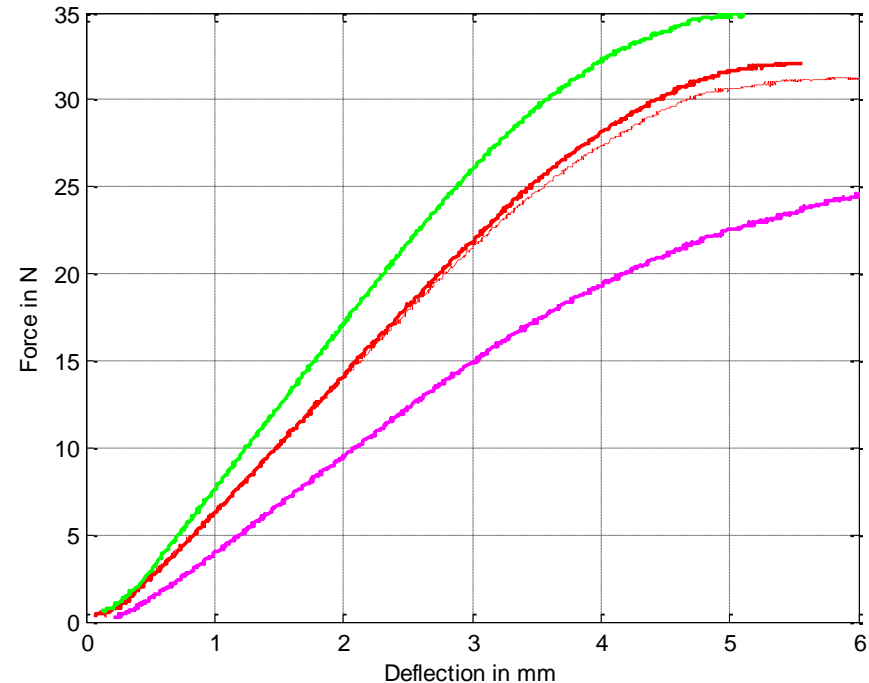


Transfer function developed to indicate hardware end-of-life

# Mechanical Characterization of SOFC materials

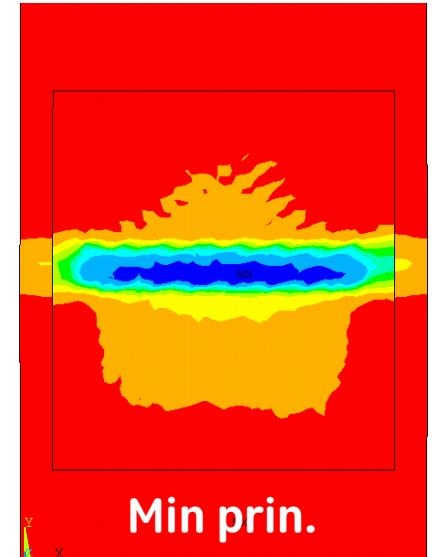
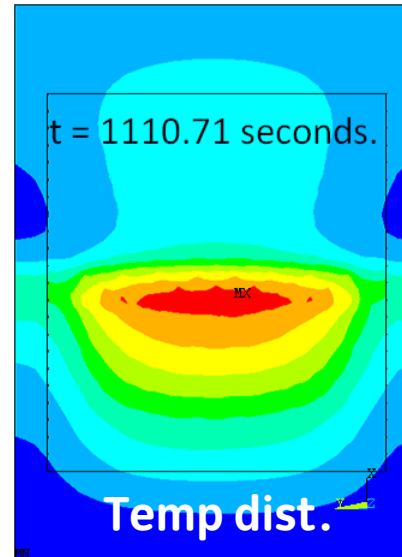
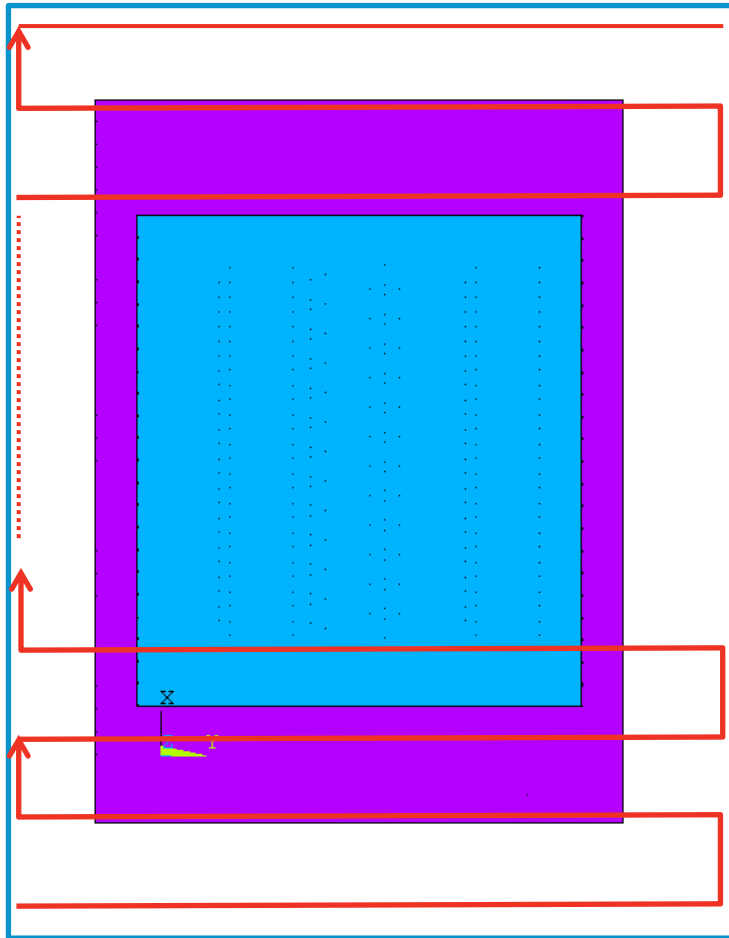


4 pt bend test of thermal sprayed coatings to determine modulus, failure criteria



Mechanical properties determined experimentally for modeling

# Thermo-mechanical Modeling of SOFC Components

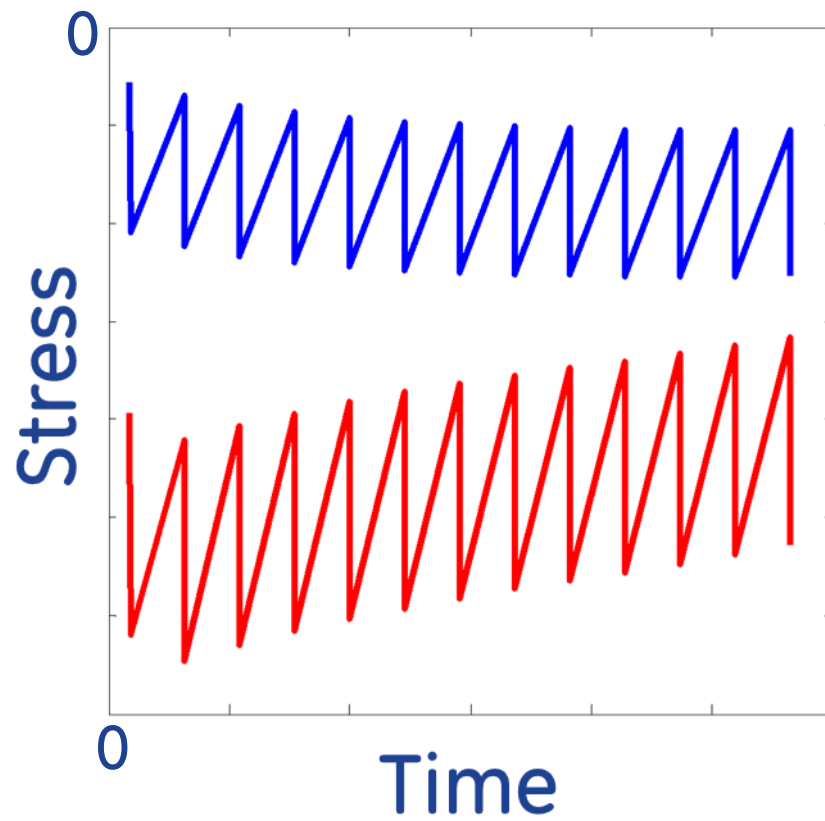
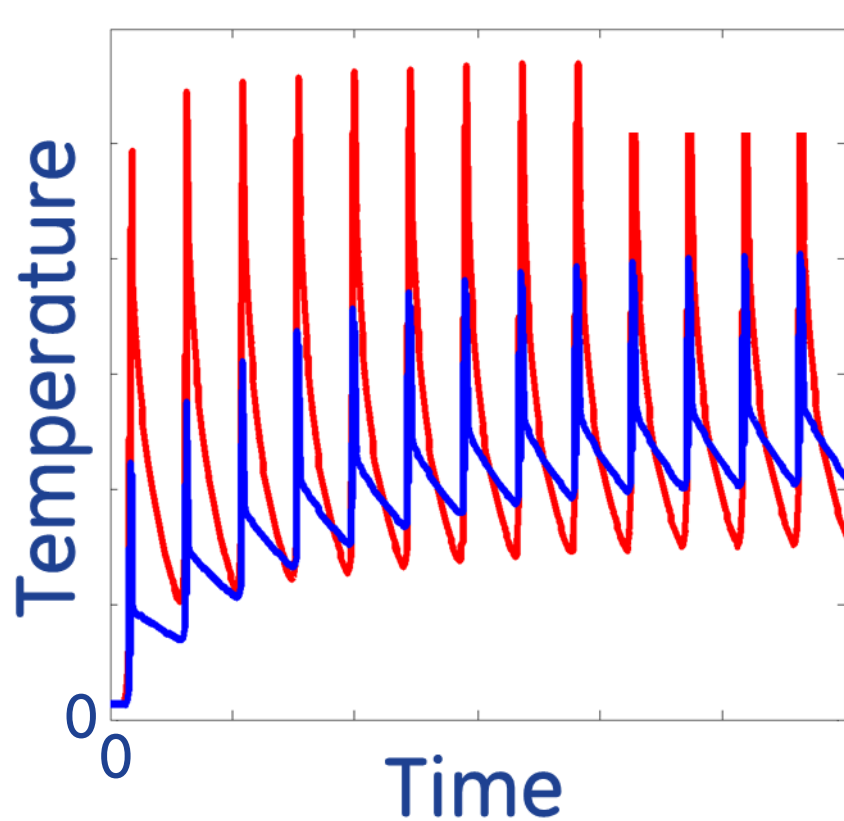


Heat transfer analysis of the thermal spray process for a 2" cell

# Comparison of thermal management stress state

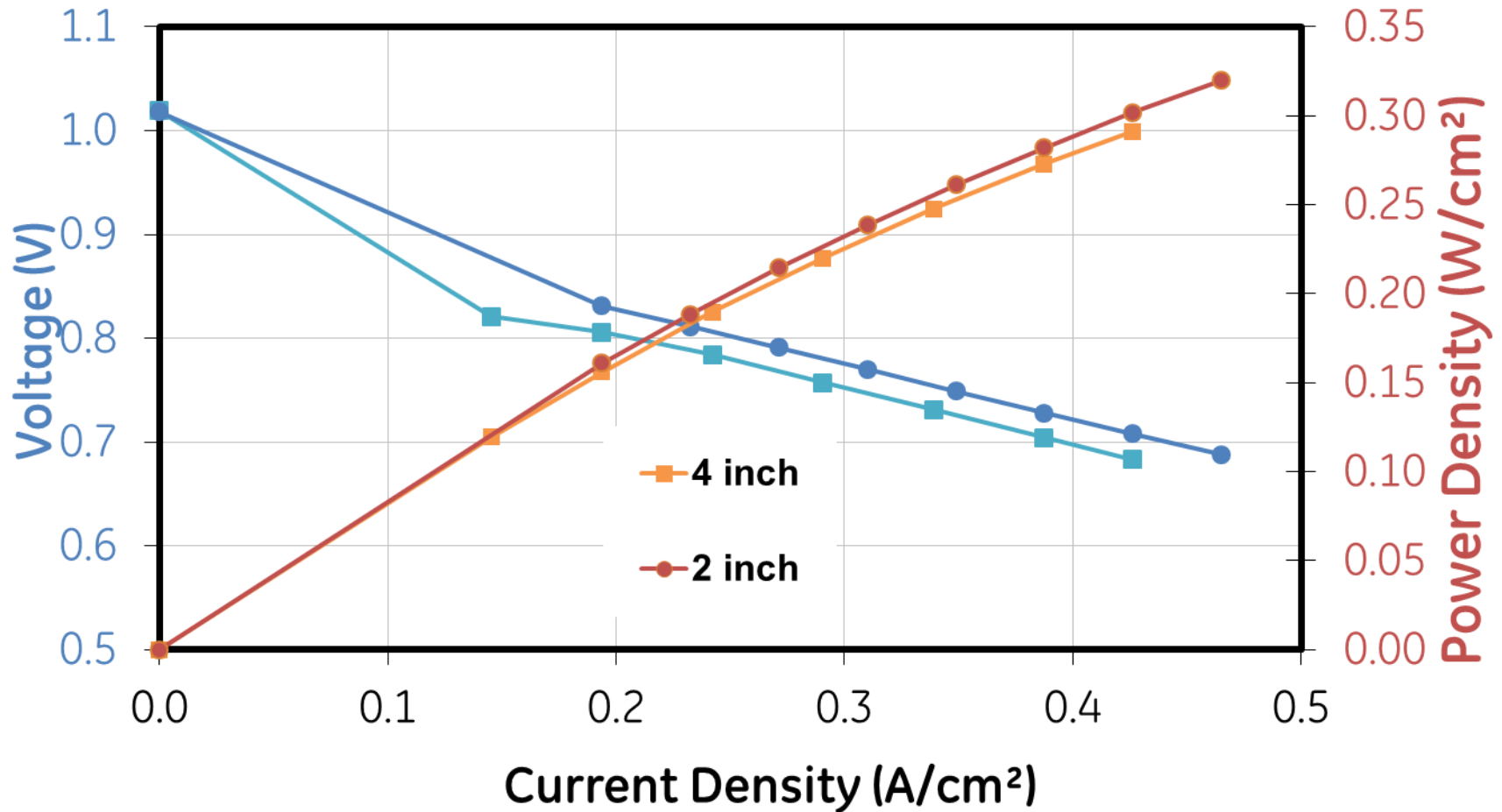
Good thermal management

Poor thermal management



Thermal management impacts coating stress state

# Scale-up (25 cm<sup>2</sup> to 100 cm<sup>2</sup>)



Thermal management important  
in scaling from 2" to 4"

# Summary

- Developed thermal spray conditions and suitable substrate to enable high OCV
- Scaled thermal spray manufacturing from 2.85 cm<sup>2</sup> to 25 cm<sup>2</sup> to 100 cm<sup>2</sup>
- Demonstrated thermal sprayed barrier layer
- Establishing thermal spray process control metrics
- Evolved thermo-mechanical FE models to support development and scale-up

# Acknowledgements

- Joe Stoffa, Heather Quedenfeld and Dan Driscoll of DOE/NETL
- SECA partners
- GE SOFC Team
  
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imagination at work