NEXTECH MATERIALS

Invent, Develop, Deliver

Oxide Coatings for Metallic SOFC Interconnects

N. Kidner, M. Seabaugh, K. Chenault, S. Ibanez, L. Thrun, M. Day

NexTech Materials, Ltd.
Lewis Center, OH 43035 USA
www.nextechmaterials.com

12th Annual SECA Workshop
Pittsburgh, PA
July 27th 2011

NEXTECH MATERIALS

Invent, Develop, Deliver

Outline

Cost Effective Interconnect Coating (IC) Process Development

- Phase I: Aerosol spray deposition (ASD) demonstrated as a commercially-viable process
- Phase II: Process Refinement and Validation

1. **Project Objectives and Conclusions**
2. **Summary of cost modeling**
3. **Overview of coating evaluation methodology**
4. **Performance evaluation results**
    - Oxidation kinetics
    - Long-term ASR results
    - Preliminary mechanical testing (collaboration with OSU)
    - Cr vaporization testing (collaboration with UConn)
    - Continuous process improvements
5. **Extension of coating process to adjacent markets**

Project Objectives

Track I (Cost Modeling): Develop and production-validate cost models for ASD coating at various production volumes.

- ❖ Develop customer-specific cost curves.
- ❖ Develop Customer-preferred paths to market
- ❖ Identify and address customer specific technical hurdles.
- ❖ Identify manufacturing strategies to reduce volume manufacturing costs.

Track II (Performance Validation): Demonstrate ASD-coated ICs performance to reinforce value proposition.

- ❖ Identify test methods to simulate 40,000 hours service.
- ❖ Develop model for IC degradation.
- ❖ Based on models, identify cost and performance optimized coatings.
- ❖ Evaluate performance of ASD coated components.

Conclusions

❖ **Refined cost and manufacturing models to encompass volumes from prototyping through full volume production.**
- Market forecast and demand curves defined for three OEM profiles at various stages of commercialization.
- Three-stage technology roadmap developed.

❖ **Identified manufacturing strategies to reduce volume manufacturing costs.**
- Materials processing scale-up to 25 kg batch sizes and beyond

❖ **Defined key process limits for ASD coated ICs.**
- Lifetime stability tests in progress (> 1800 hrs operation at 800 °C in both single and dual atmosphere configurations).

❖ **Identified key failure mechanisms and acceleration factors.**
- Predictive lifetime models successfully applied to long-term stability tests.

NEXTECH
MATERIALS

Invent, Develop, Deliver

Integrated Spray/Dry System

Cleaning System (incoming substrates)

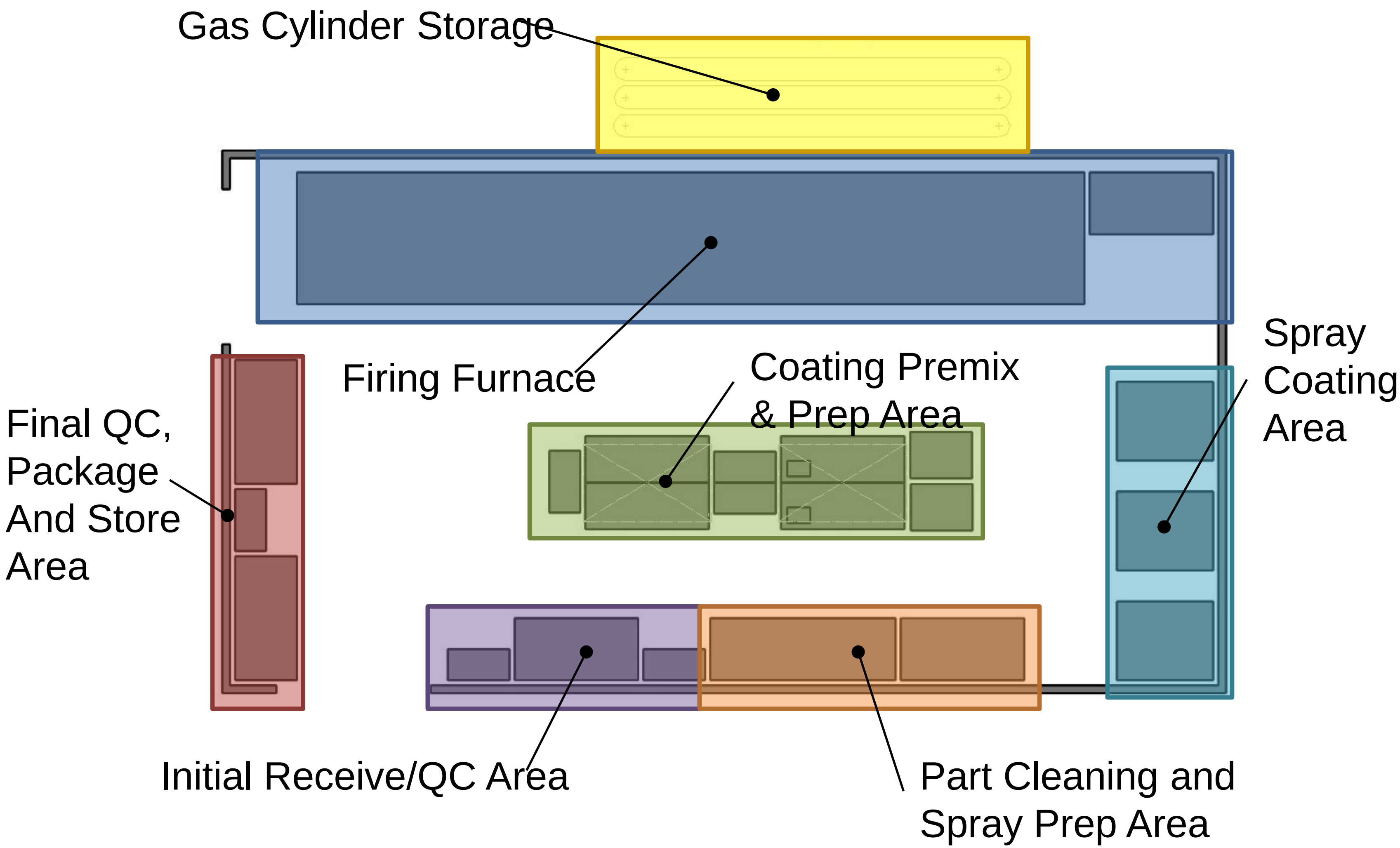
Controlled Atmosphere Electric Pusher Kiln

Automated QA/QC Inspection Equipment

NEXTECH MATERIALS

Invent, Develop, Deliver

Production Plant Layout (35 x 65' facility)



NEXTECH MATERIALS

Invent, Develop, Deliver

Outline

Cost Effective Interconnect Coating (IC) Process Development

- Phase I: Aerosol spray deposition (ASD) demonstrated as a commercially-viable process
- Phase II: Process Refinement and Validation

1. **Project Objectives and Conclusions**
2. **Summary of cost modeling**
3. **Overview of coating evaluation methodology**
4. **Performance evaluation results**
   - Oxidation kinetics
   - Long-term ASR results
   - Preliminary mechanical testing (collaboration with OSU)
   - Cr vaporization testing (collaboration with UConn)
   - Continuous process improvements
5. **Extension of coating process to adjacent markets**

NEXTECH MATERIALS

Invent, Develop, Deliver

Validation testing methodology

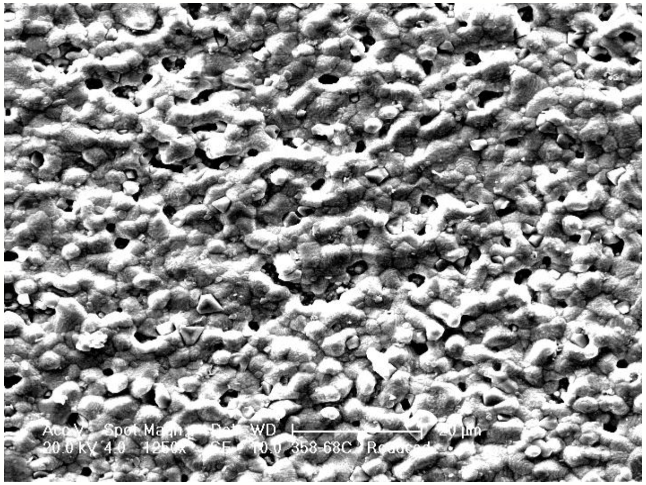
Initial testing

Preliminary coating quality assessment

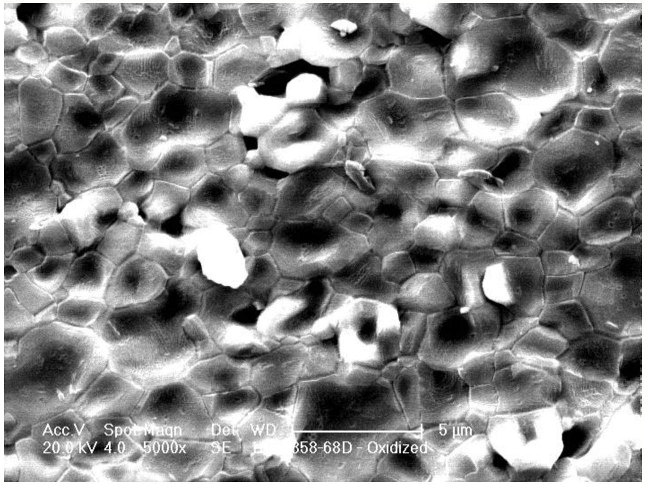
Integrated Interconnect coating lifetime model

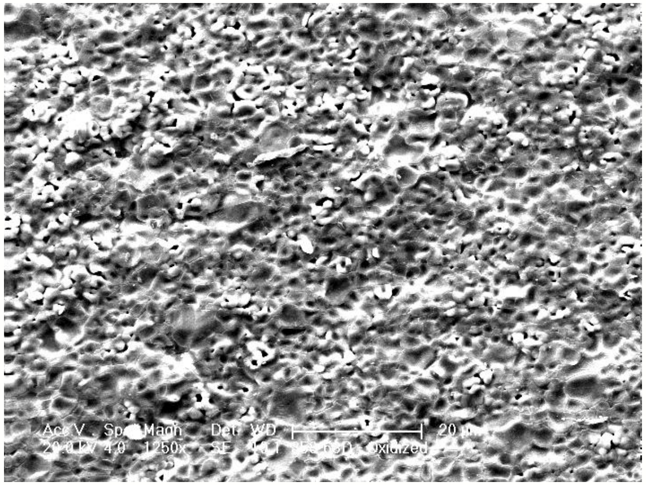
MCO Coating Morphology

Reduced



Oxidized





NEXTECH MATERIALS

Invent, Develop, Deliver

Validation testing methodology

Initial testing

Preliminary coating quality assessment

Oxidation Kinetics

Coated Interconnect Failure Analysis

Integrated Interconnect coating lifetime model

NEXTECH MATERIALS

Invent, Develop, Deliver

Oxidation testing

- ❖ Initial coating performance influenced by a range of factors (substrate, coating)
- ❖ Oxidation driven failure mechanisms identified as most likely limiter of component life
- ❖ Oxidation-based model for long-term coating behavior.

Oxidation kinetics

- Understand oxidation resistance of coated and uncoated components
- Leverage accelerated testing conditions

Coating performance

- Relate electrical and mechanical properties of the coated component to underlying oxidation-driven mechanisms

Coating lifetime model

- Predictive model for coating lifetime based on anticipated failure mechanisms

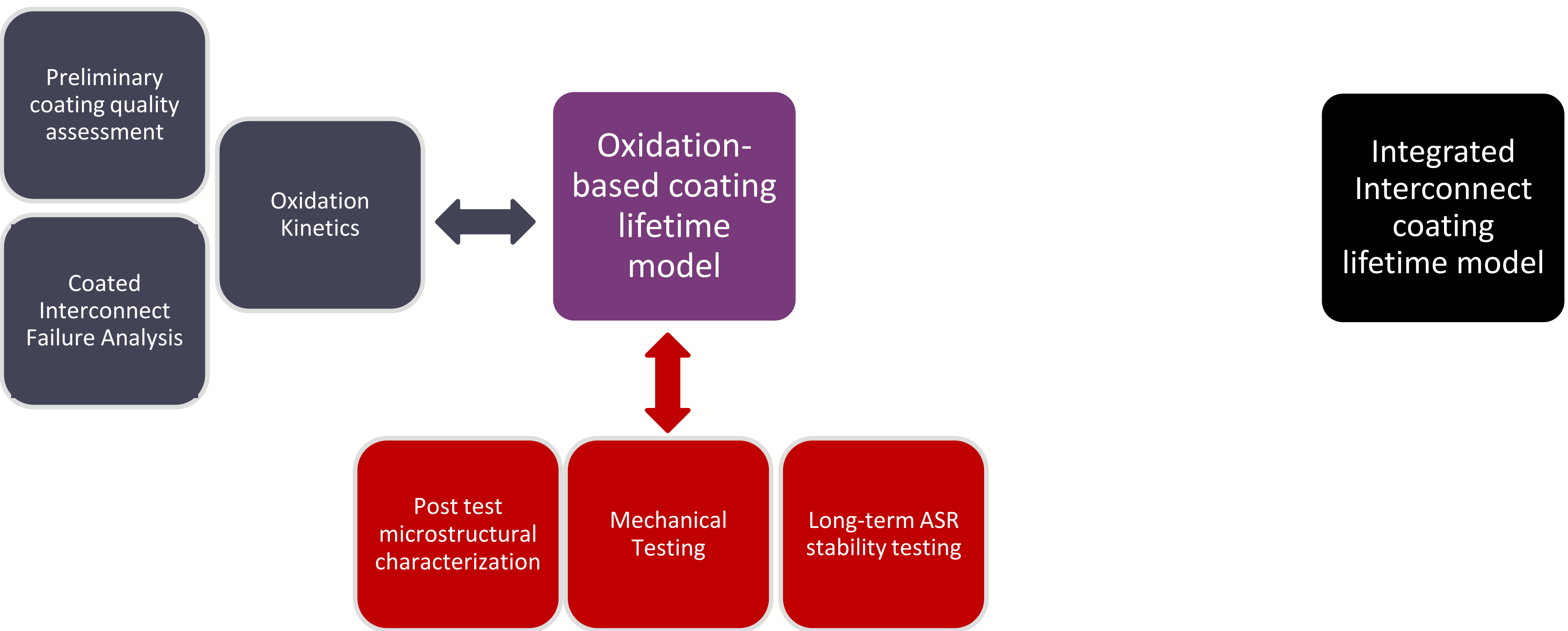
10 μm MCO coating on SS441 substrate
900 °C, 200 hours, Air

NEXTECH MATERIALS

Invent, Develop, Deliver

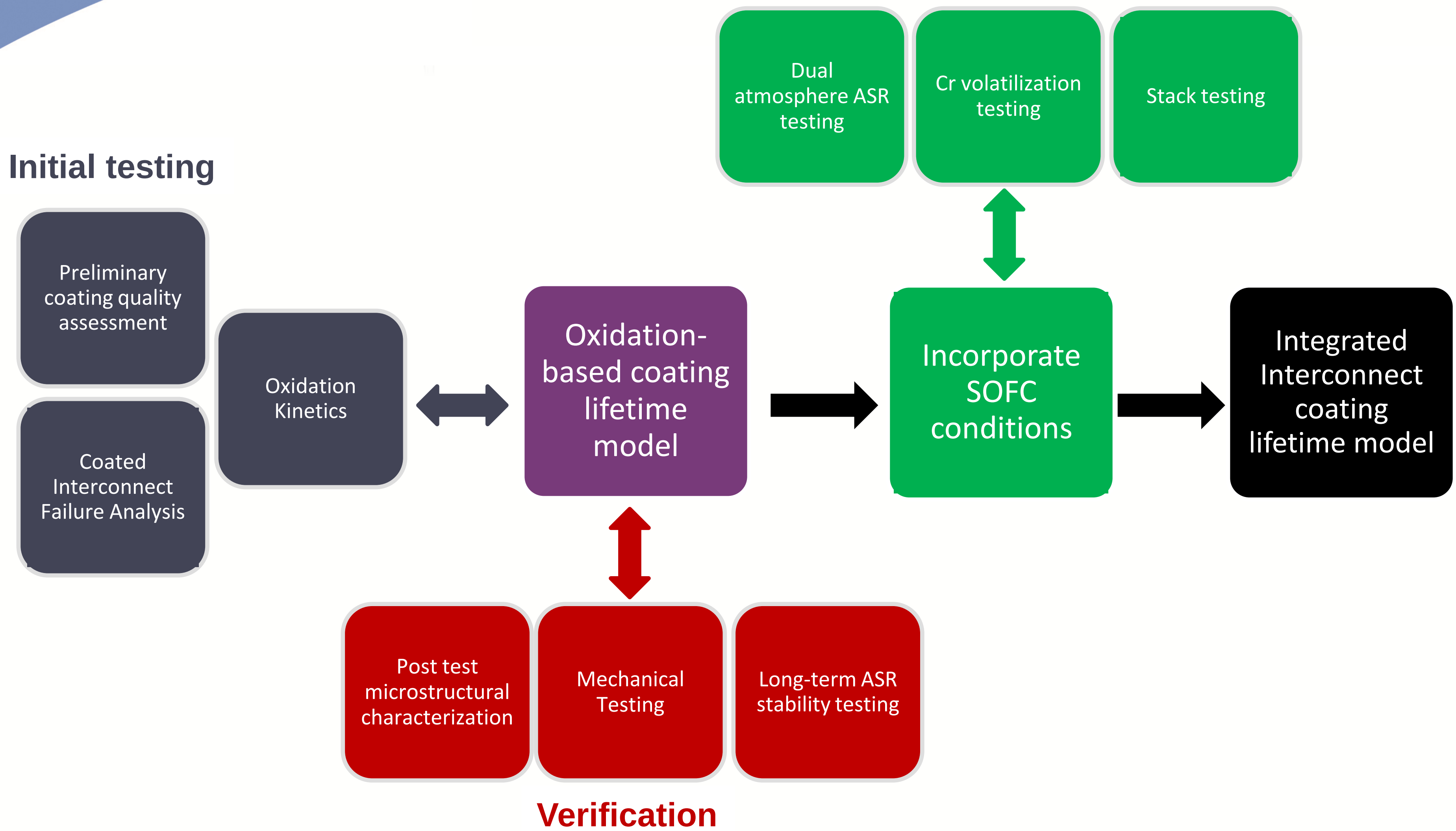
Validation testing methodology

Initial testing



Verification

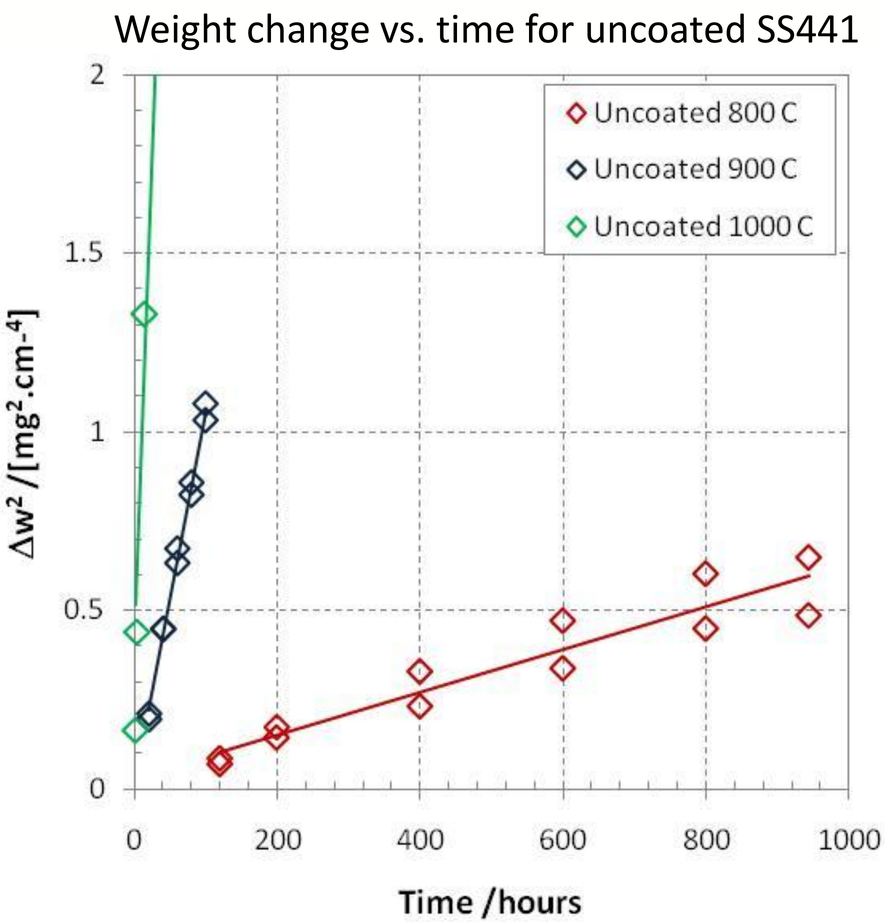
Validation testing methodology



NEXTECH MATERIALS
Invent, Develop, Deliver

Oxidation experiments

- Investigate oxidation kinetics for uncoated and MCO coated SS441 (800 -1000 °C).
- Uncoated samples show accelerated oxidation kinetics with increasing temperature

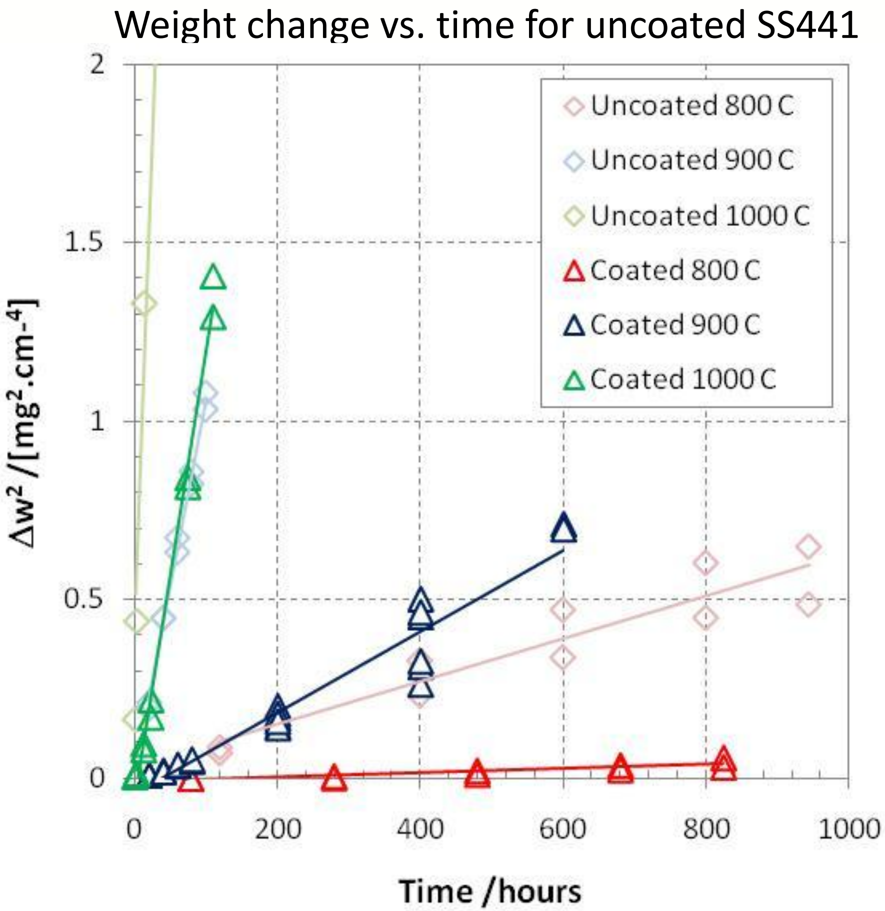


NEXTECH MATERIALS

Invent, Develop, Deliver

Oxidation experiments

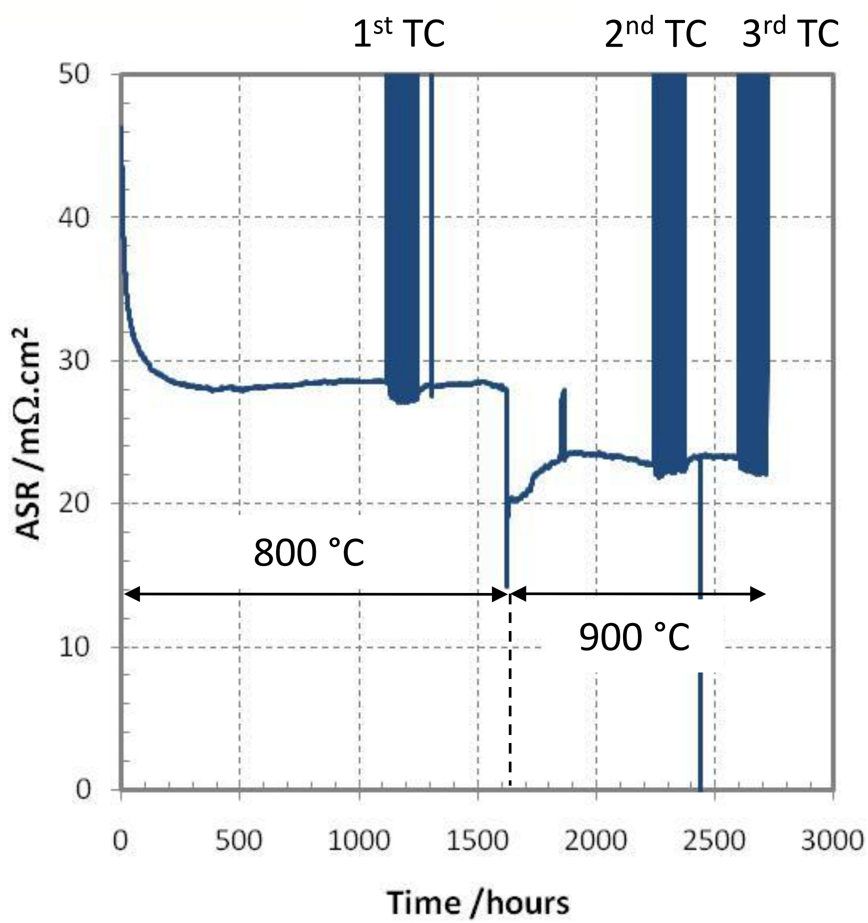
- ❖ MCO coating significantly improves oxidation resistance at all temperatures (~ 10 X reduction vs. uncoated samples).
- ❖ Similar T dependence for coated samples: oxidation kinetics increases ~ 20X [800 → 900 °C]



NEXTECH MATERIALS

Invent, Develop, Deliver

Symmetric ASR behavior



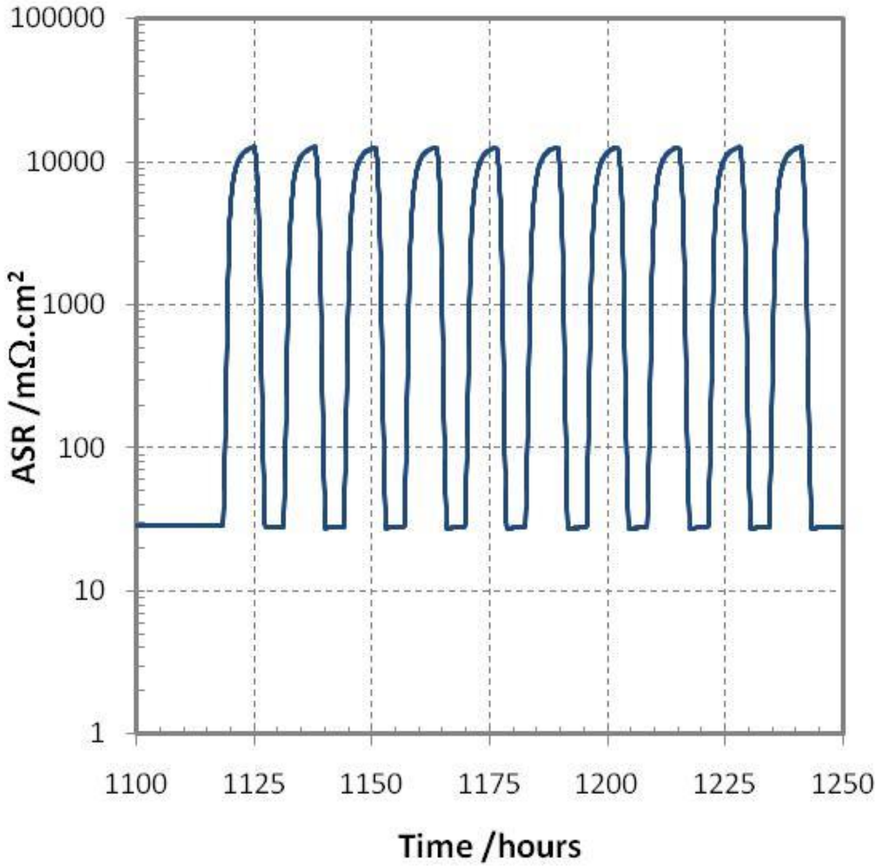
Symmetrically MCO coated SS441
Humidified air, 800 °C / 900 °C
Current Density 0.5 A.cm^{-2}

❖ Multiple samples running long-term stability tests

NEXTECH MATERIALS
Invent, Develop, Deliver

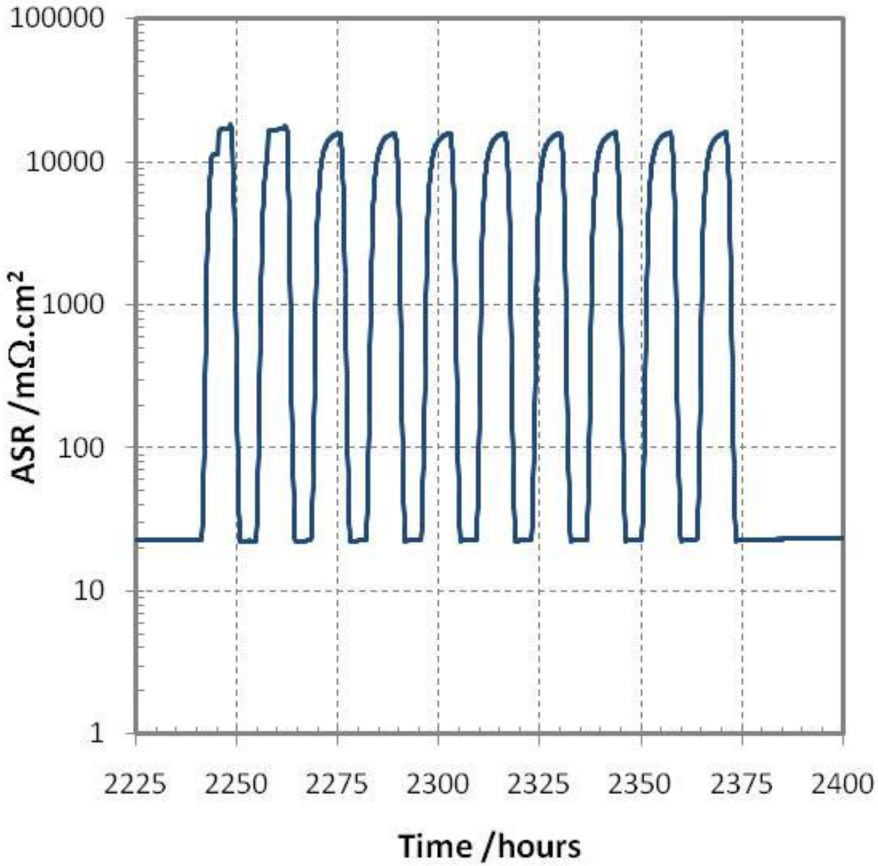
Thermal Cycling

10X thermal cycling 800 °C



Symmetrically MCO coated SS441
Humidified air, 800 °C to 50 °C, 0.5 A.cm^{-2}

3rd 10X thermal cycling 900 °C

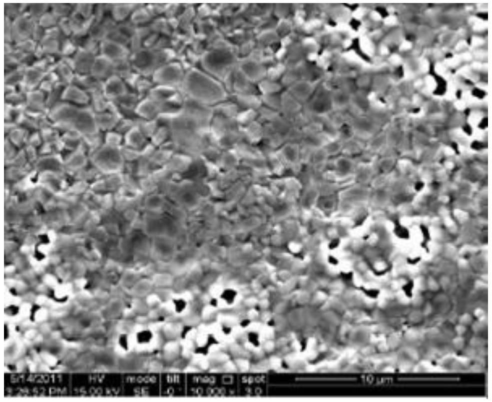


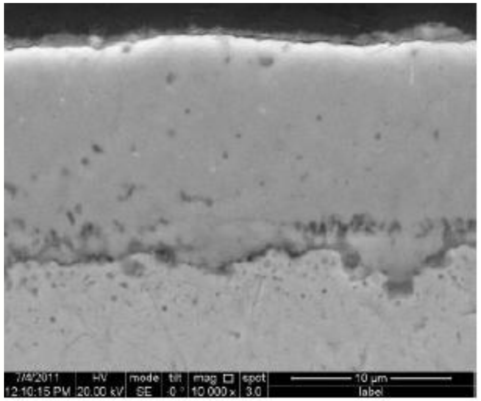
Symmetrically MCO coated SS441
Humidified air, 900 °C to 50 °C, 0.5 A.cm^{-2}

Cr vaporization characterization

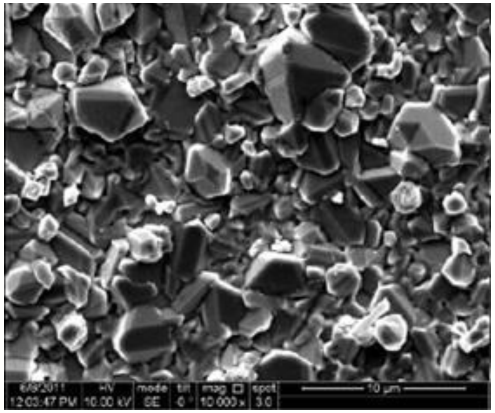
- Collaborating with Dr. Singh at the University of Connecticut to evaluate the effectiveness of the MCO coating at preventing Cr vaporization.

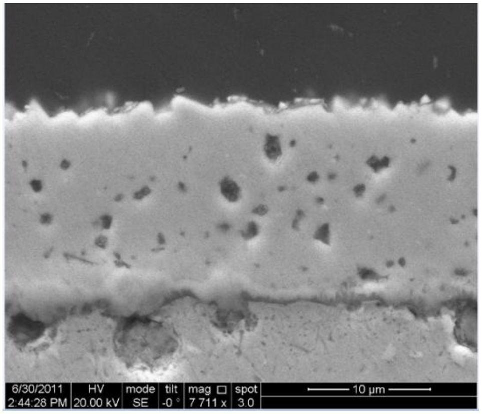
As received





After oxidation
850 °C, 500 hrs
90 % O_2–10 % N_2 3% H_2O)





NEXTECH MATERIALS

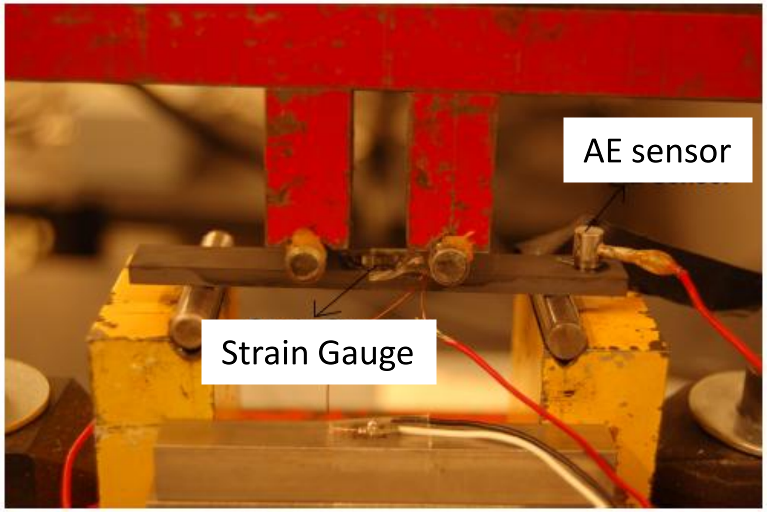
Invent, Develop, Deliver

THE OHIO STATE UNIVERSITY DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

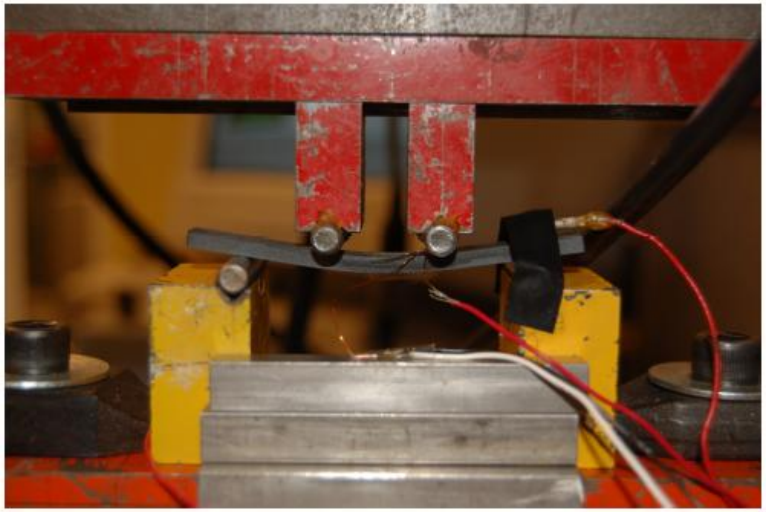
Mechanical Testing

- ❖ Collaborating with Dr. Mark Walter's group at OSU through NSF, GOALI program.
- ❖ Investigating interfacial strength of our coating on a range of substrates through synchronized four-point bend and acoustic emission testing

Four-point bend set-up



Coated IC bar undergoing test



- ❖ Investigating how interfacial strength changes with time to develop lifetime prediction for IC coating – enable design of optimized coating/substrate solutions.

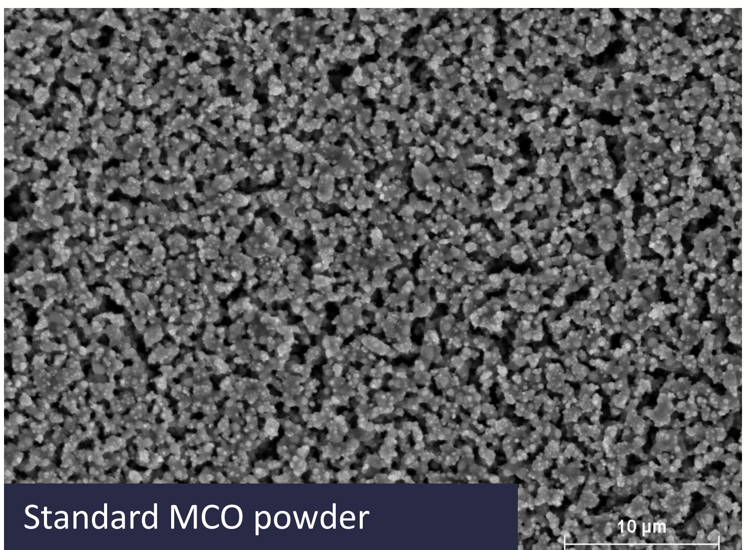
NEXTECH MATERIALS

Invent, Develop, Deliver

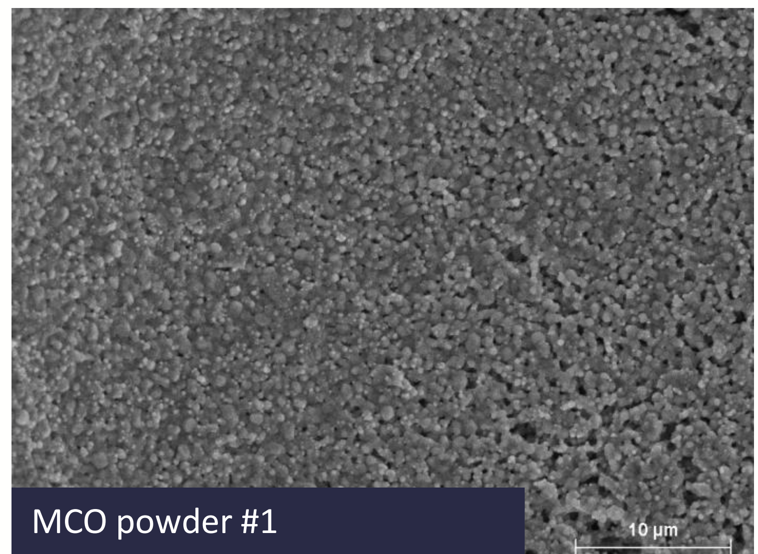
Continuous Coating Improvements

- Process improvements are focused on enhancing the performance of the coating and also improving the process capability.
- Example below is how modification of the source MCO powder is enabling improved coating quality

Baseline coating



Coating with MCO powder improvement



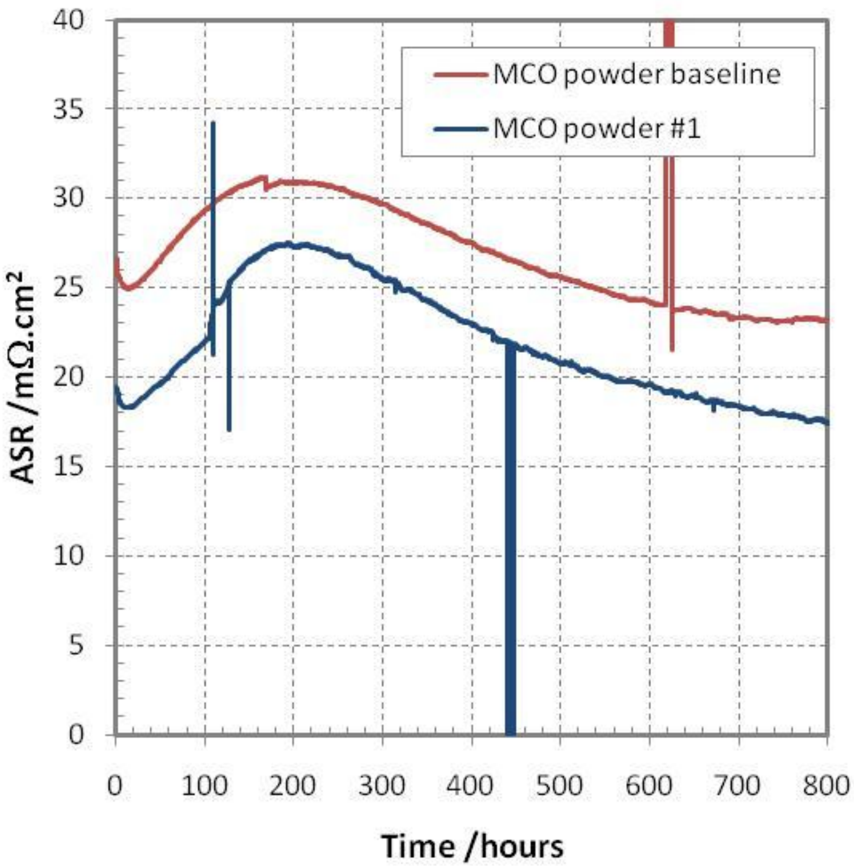
Top-down SEM of MCO coating in reduced state

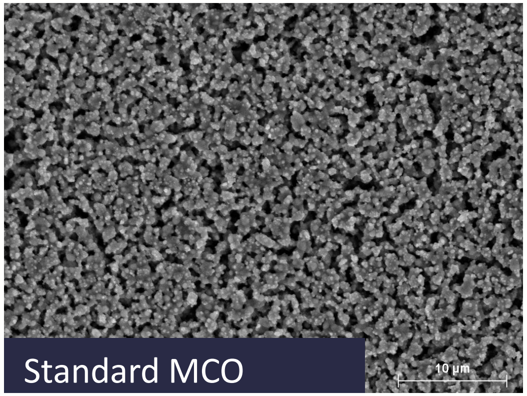
NEXTECH MATERIALS

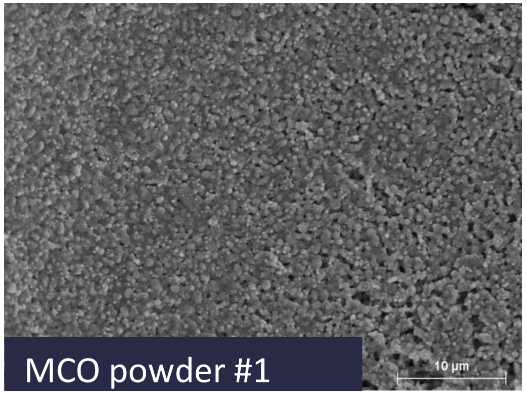
Invent, Develop, Deliver

Continuous Coating Improvements

ASR vs. time for improved MCO powder coating







Process Compatibility

Chemical Corrosion Protection

"Anti-Seize Coatings"

Air Side Current Collector

Balance of Plant Protection

Alternative Coating Compositions

Air Side Corrosion Protection

Anode Contacting Layers

Catalyst Layer Deposition

SMR Catalysts
Oxidation Catalysts

Range of Alloys

SOFC and Common Grades

Ferritic/Superalloys

Acknowledgements

- Clients, Colleagues and Collaborators
- U.S. Department of Energy
  - DE-PS02-08ER08-34,
    - Briggs White, Project Manager
- State of Ohio Third Frontier Program

CENTER FOR Clean Energy ENGINEERING UNIVERSITY OF CONNECTICUT

Dr. Prabhakar Singh
Le Ge

THE OHIO STATE UNIVERSITY DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

Dr. Mark Walter
Sajeder Akanda

For More Information:
Matthew Seabaugh
(614) 842-6606 extension 107
m.seabaugh@nextechmaterials.com
www.nextechmaterials.com