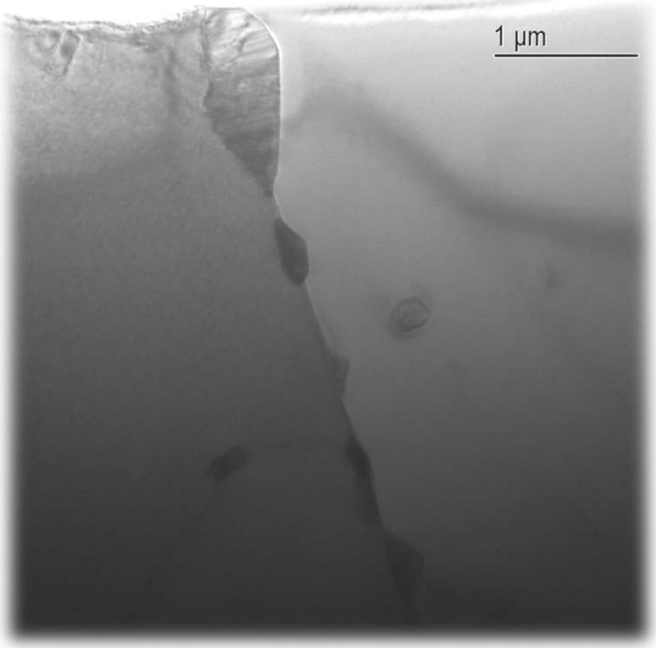


# SOFC Metallic Interconnect Retrospective

## *A Collaborative Success*

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U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

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# Metallic Interconnect Development

## *Drivers and Challenges*

### Drivers

1. **Low cost**
2. **Commercial alloys available in large volumes**
3. **No densification required**

   *vs. Lanthanum Chromite
4. **Easier to post-process**

   *e.g. stamp

**Enabled by anode-support (thin electrolyte & lower temp)**

### Challenges

1. **Low-cost material**
2. **Identify commercial alloy**
3. **Dual atmospheres (C, S, $H_2$, $H_2O$)**
4. **High temperatures**
5. **Electrically conductive**

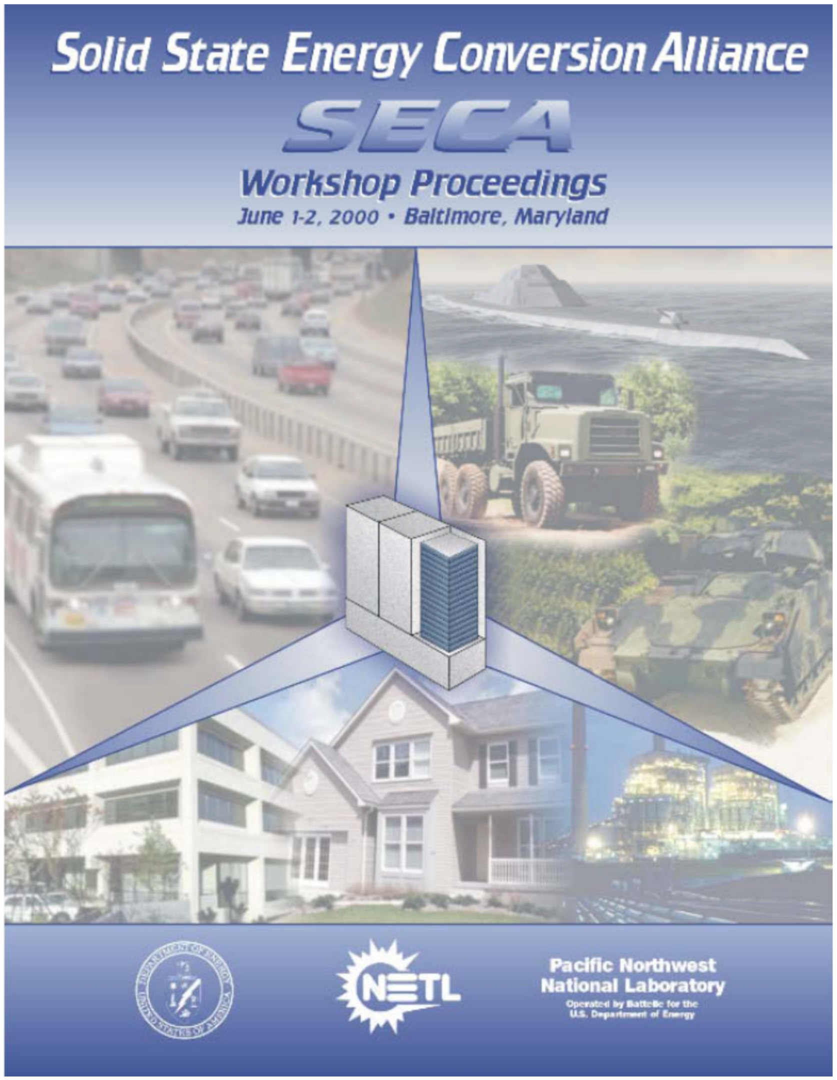
   Scale & coating
6. **Low-volatility (chrome)**
7. **Adherent scale**

   Thermal cycles

   Several year service life

# State Of The Art at SECA Start

## *Approaches Identified*




**Materials Breakout Notes – Session A**

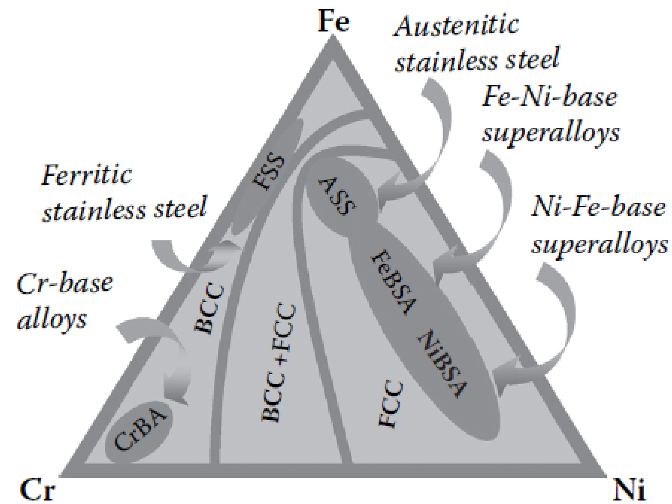
1. Investigation of commercially available alloys
2. Cathode side surface treatments on commercially available metallic interconnect
3. Investigation of developmental alloys
4. Interconnect designs that minimize material use
5. Investigation o f the interconnect and electrode interface

**Materials Breakout Notes – Session B**

1. Examine interface and coatings inter-relations and stability
2. Examine stability and electric transport at interface
3. Conduct surface modification studies

# Commercial Alloy Selection

## *Key Elements*




**Initial Approaches:**

- **Ni-based superalloys (Haynes)**
- **Hi-chrome alloys (E-Brite)**
- **400-series steels**

| Alloys | Cr | Mn | Fe | C | Al | Si | P | S | Ti | Misc |
|---|---|---|---|---|---|---|---|---|---|---|
| Haynes 230 | 22-26 | 0.5-0.7 | 3 | | 0.3 | | | | | 5 Co **Bal Ni** |
| E-Brite | 26-27 | <0.1 | Bal | | <0.05 | 0.03-0.2 | | | <0.05 | 1 Mo |
| Crofer 22 APU | 23 | 0.4-0.8 | Bal | 0.030 | <0.02 | <0.02 | 0.02 | 0.05 | 0.02 | **0.20 La** |
| 430 | **16-18** | **<1.0** | Bal | <0.12 | | **<1.0** | <0.04 | <0.03 | | |
| 441 | **18** | **0.35** | Bal | 0.01 | 0.05 | **0.34** | 0.023 | 0.002 | **0.22** | **0.5 Nb** 0.3 Ni |

# 441 Stainless Steel

## *Mufflers & Fuel Cells - An Amazing Coincidence*

### Key 441 Features

Economical, mass produced

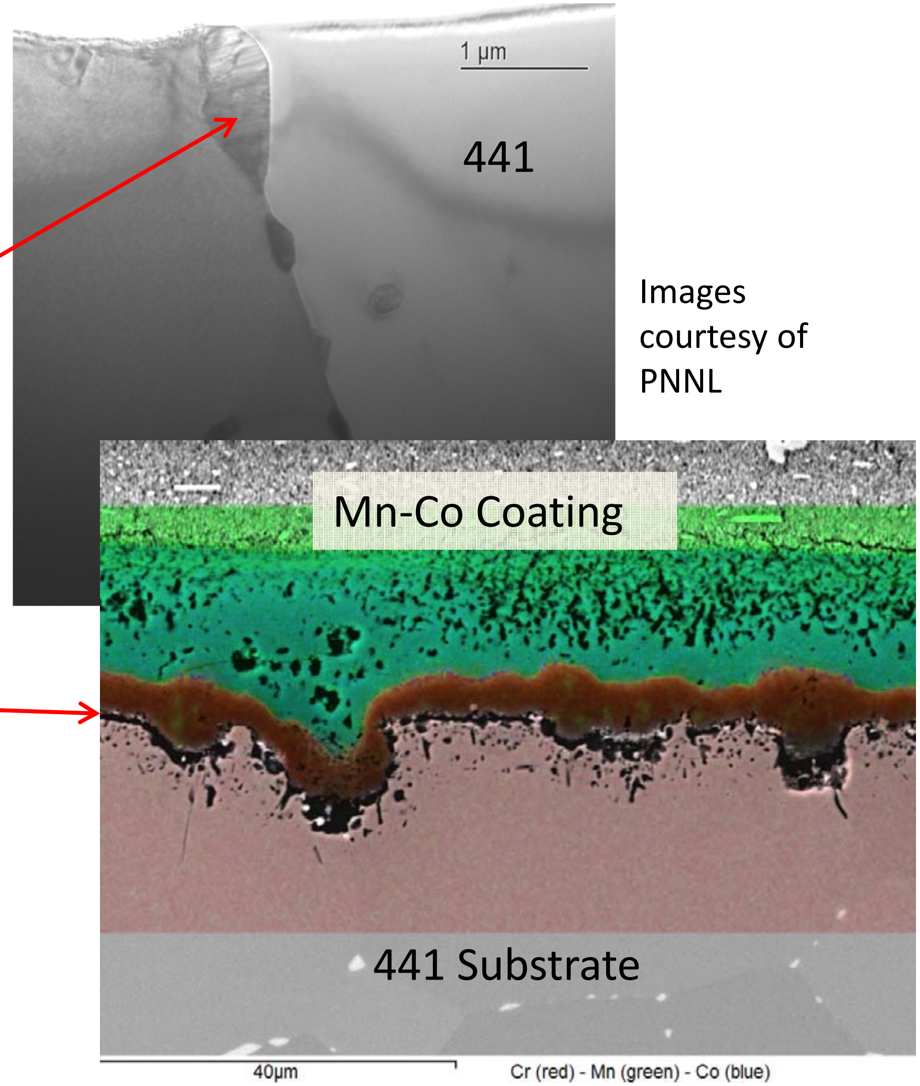
Expansion matched

Laves phases

Chromia former

Maintains conductive scale

Dual-atmosphere stability




Images courtesy of PNNL

# Timeline

## *Workshops, Development, Tech Transfer*

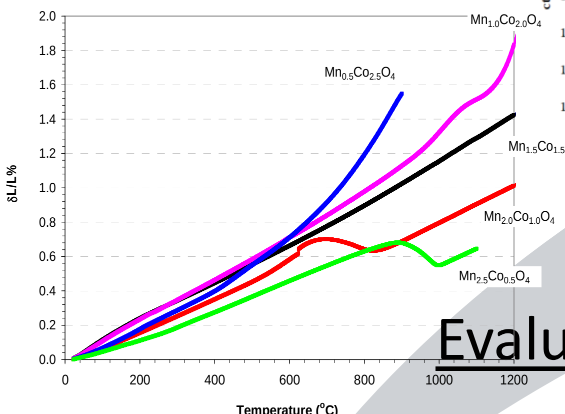
2000: SECA Workshop Breakout Sessions
2001: SECA Workshop Materials Roadmapping
2004: Interconnect Workshop at ANL
2006: Industry-National Lab Cr poisoning study

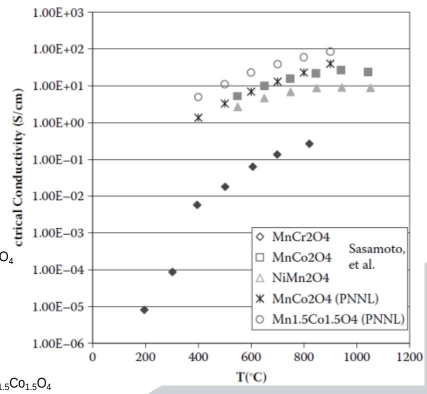
2000: Pre-screening of alloys
2001: Down-selection to ferritic stainless steels
2002: Screening of alloy properties
2003: Evaluation of protective coatings
2004: Identify spinel coatings
2007: Initial studies on 441
2008: Ce coatings and Ce-modified MnCo spinel coatings
2010: Physical modifications to steel surface
2013: 6,000h validation of surface-modifed, spinel-coated 441 in stack test fixture

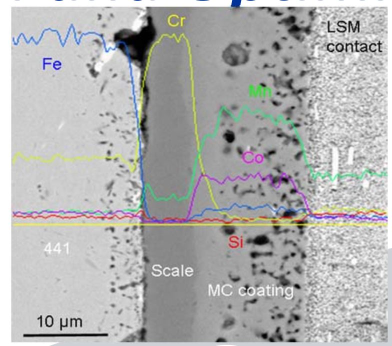
2008: ATI 441 order – National Labs & Industry Teams
2008: Topical Report on 441 & coatings transferred to Industry Teams
2010-2013: 2 patents, 2 R&D 100 awards

# Coating Development Progress

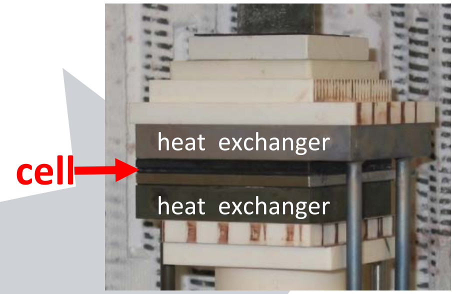
## *Rigorous Evaluation and Optimization*




SECA Stack Fixture




**Verification**

Long-term Testing

Stack Testing

**Optimization**

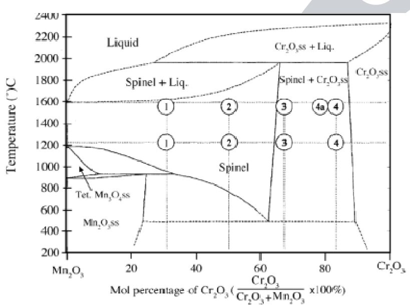
Composition

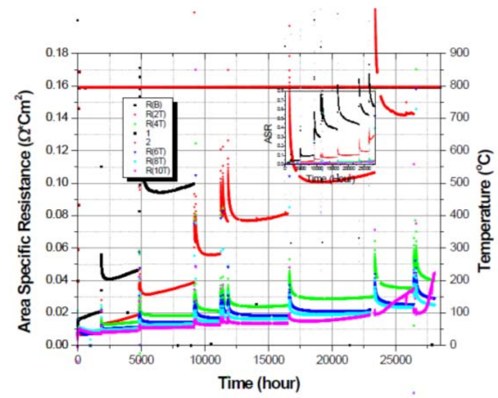
Processing

**Evaluation**

Materials

Characterization

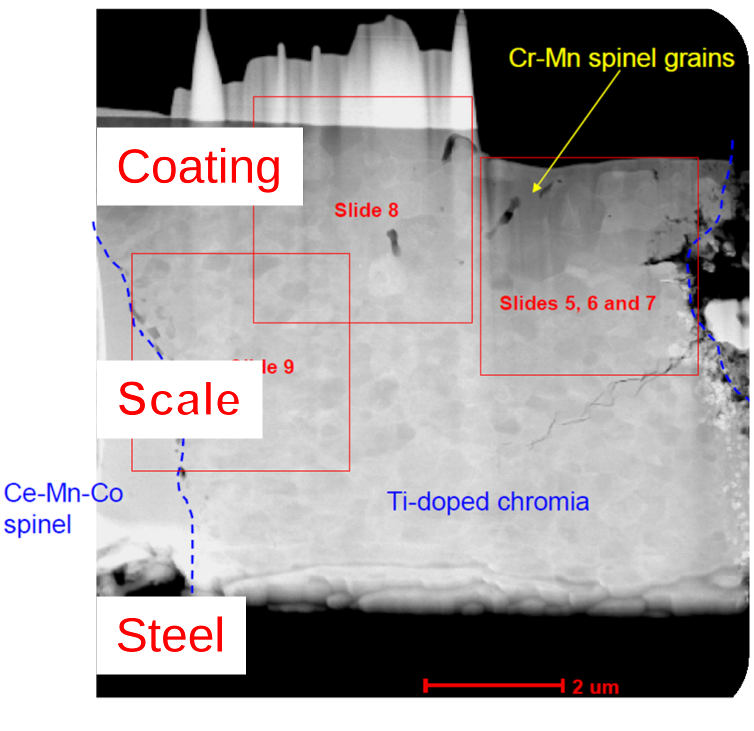


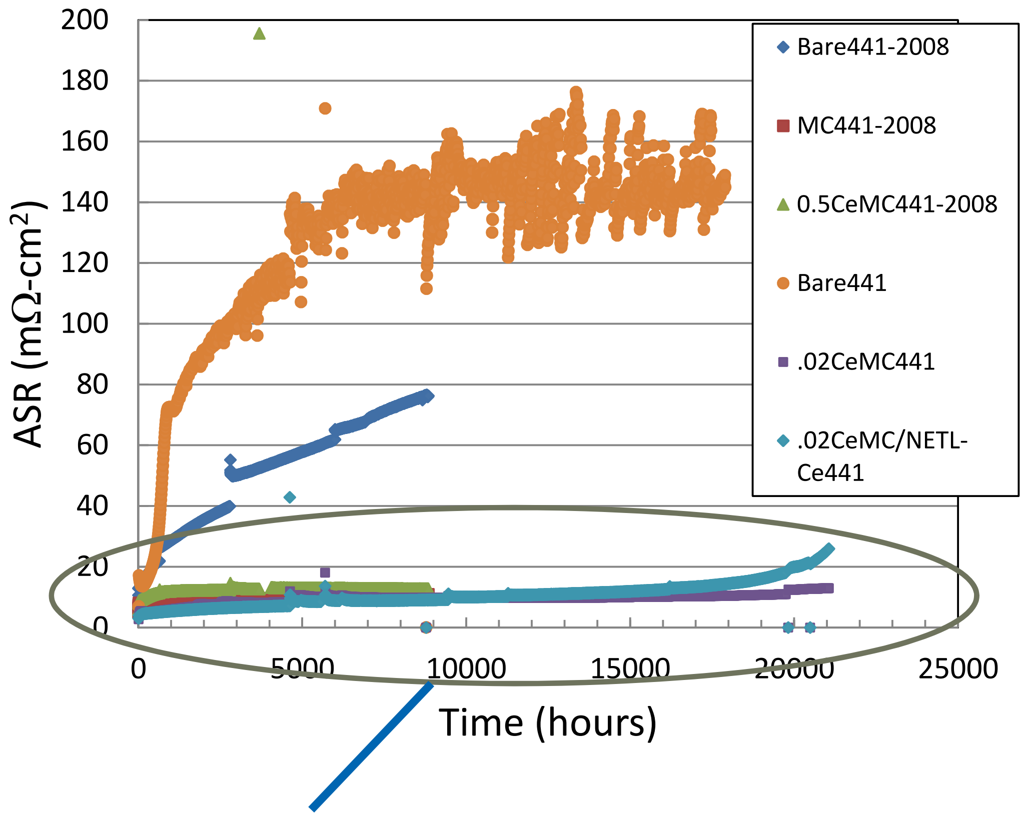



# Manganese-Cobalt Spinel Coating

## *Coating Performance Verified*

**Transmission Electron Microscopy (TEM) analysis shows unique steel-coating synergy**



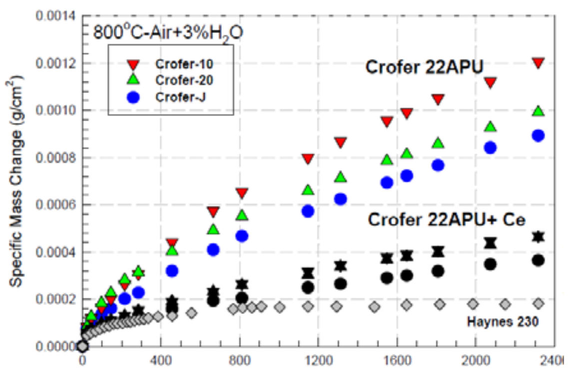




**Low stable Area-Specific Resistance (ASR) for >2 years at 800C**

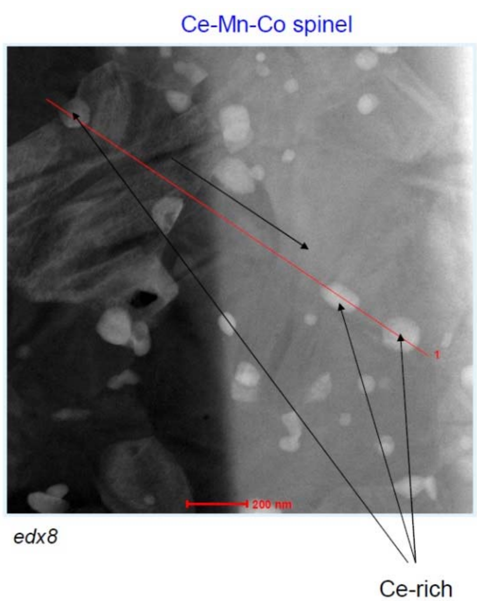
# Chemical & Physical Modifications

## *Options for enhanced reliability and lifetime*

### 2 Rare Earth Treatments




Ceria surface coating (alone or in combination with coating)




Integrate RE within coating

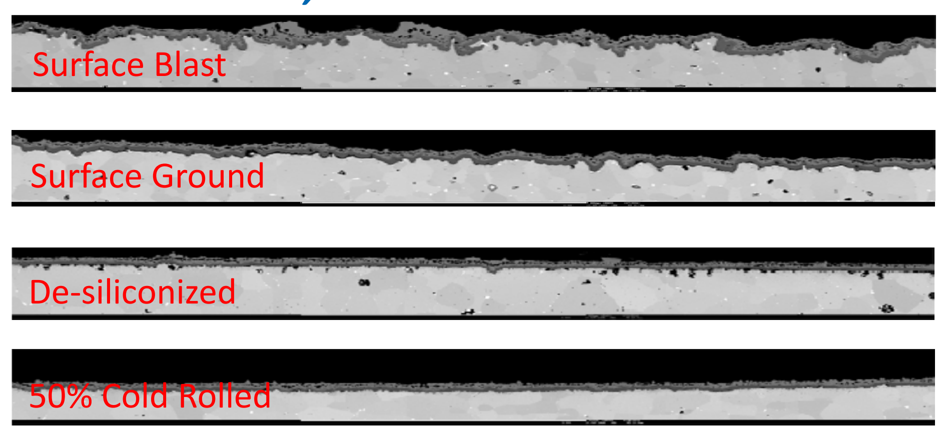
### Physical Surface Modifications

Multiple approaches improve upon as-received steel.

- Extends lifetime by delaying scale spallation
- Standard commercial processes

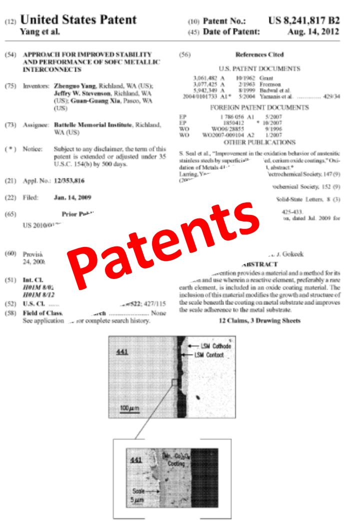
**More Adherent Scales**

***Tested 18,000 hours at 800 °C in air***



# R&D Over The Years
## *Numerous Successes*

1. 2011: Mn-Co Coating for Solid Oxide Fuel Cell Interconnects, Chris Johnson, Randy Gemmen, and Xingbo Liu (WVU)
2. 2010: Cerium Oxide Coating for Oxidation Rate Reduction in Stainless Steels and Nickel Superalloys, Paul Jablonski and Dave Alman




1. E.V. Stephens, X. Sun, W. Liu, J.W. Stevenson, W. Surdoval, and M.A. Khaleel, "Surface Modification to Prevent Oxide Scale Spallation," U.S. Patent 8,486,582 (2013).
2. Z.G. Yang, J.W. Stevenson, and G.G. Xia, "Approach for Improved Stability and Performance of SOFC Metallic Interconnects," U.S. Patent 8,241,817 (2012).

# State Of The Art

## *Final Thoughts*

**Low-cost stainless steel interconnects (and flow fields) are viable for anode-supported planar SOFCs**

- Substantial progress in alloy identification, coating development, processing development, and verification
- Commercial offerings now available:
  - Steel: 441, Crofer H, Sandvik
  - Coatings: MCO, Co, aerosol spray, electroplating, pre-coated
  - Surface treatments: shot-peening, rare-earths

**Strong collective effort within SECA (complemented world-wide)**

- Many groups involved
- Thank you for the hard work

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## *Thank You*

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