NEXTECH MATERIALS

Commercial Services
Invent, Develop, Deliver

Manufacturing Analysis of SOFC Interconnect Coating Processes

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11th Annual SECA Workshop, Pittsburgh, PA
July 28, 2010

Cost-Effective IC Coating Process Development

- Objectives: To Determine--
  - Manufacturing cost for 400MW/year interconnect coatings. ($5-7 each at 400 MW)
  - What manufacturing route(s) present the most cost-effective and technically feasible IC coating.
  - Whether MCO, MCO-REE or other coatings present the best opportunities for commercialization.

Conclusions

- **Aerosol is cost effective versus other approaches.**
  - At High Production Volume, $1.65 per 625 cm^2 plate
  - Low Capital Investment Compared to Competing Methods
- **Opportunities for cost reduction with lower cost materials and simplified processes.**
  - Coating Thickness Can Be Further Reduced
  - Alternative Materials Can Cut High Volume Costs
- **MCO and Perovskite aerosol coatings stable and high performance**
  - Lifetimes >1500 hours demonstrated in Phase I
  - ASR values < 0.05 ohm-cm^2 for coated IC Components after 1000 hour tests w/ thermal cycing

Commercialization

- **Coating processes are scaled to large component sizes**
  - Up to 1200 cm^2 Area Components
  - Masking, Dual Coatings, High Relief Surfaces Demonstrated
- **Aerosol production capacity (# of parts) easily scaled**
  - Spray Coating Times are Short
  - Furnace Requirements Easily Met by Conventional Equipment
- **Immediate and Future Products**
  - Value-added paints, inks and spray suspensions
  - Interconnect coating services
  - Interconnect manufacturing services
- **Intellectual Property Protection and Access**
  - Filed Provisional Patents on Perovskite Coatings
  - Licensing Strategy in Place to Provide Clients Freedom to Operate

NEXTECH MATERIALS

NexTech Materials, Ltd.

- Founded in 1994
- Currently 35 full-time employees
- **Technology Developer – advanced ceramics, electrochemical devices**
- Product Developer – fuel cells, catalysts and sensors
- Manufacturer/Distributor – fuel cells and related products
- **Service Provider—Materials and Processes Tailored for Client**

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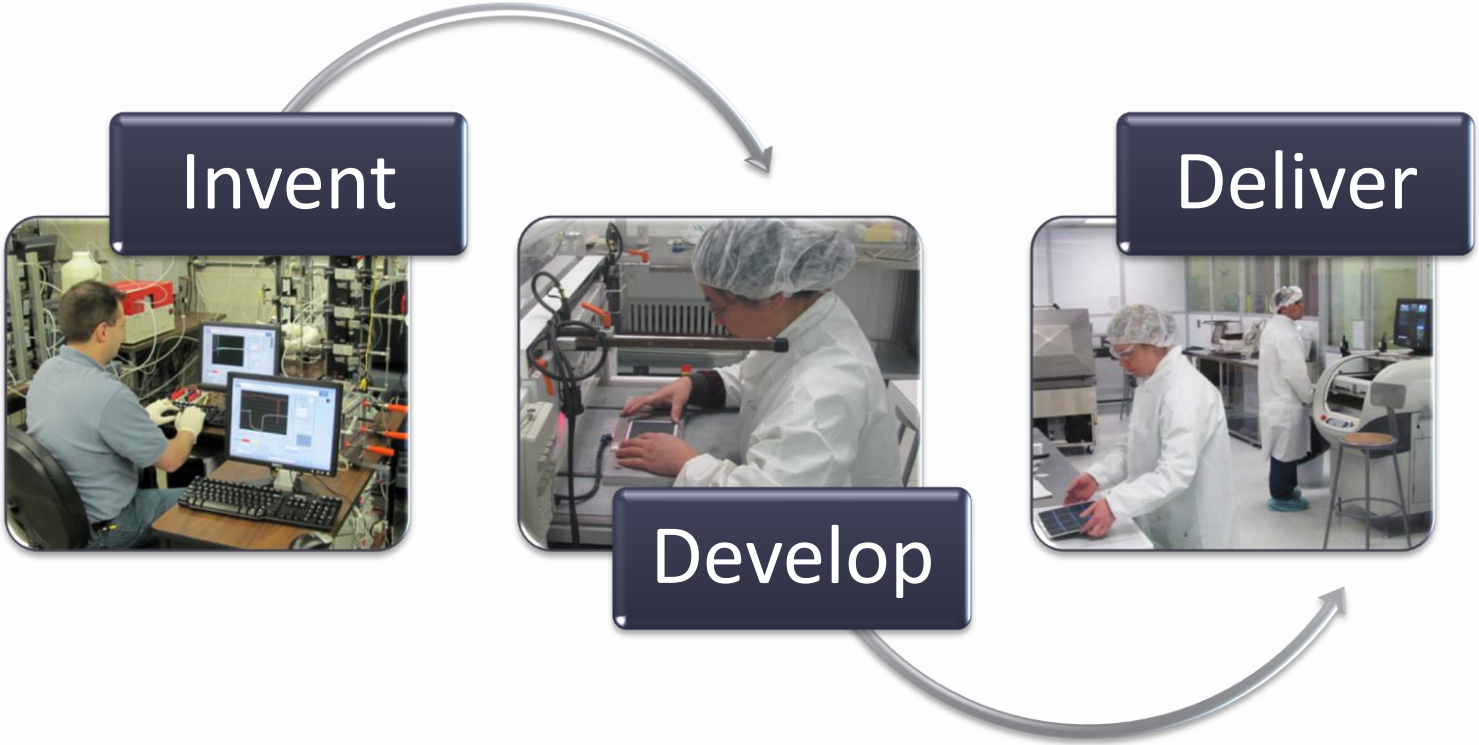
Commercial Services accelerates client success by direct collaboration in materials, process and component development.



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Commercial Service Examples

Electrolyte Powders → Tailored Properties → Tape Casting

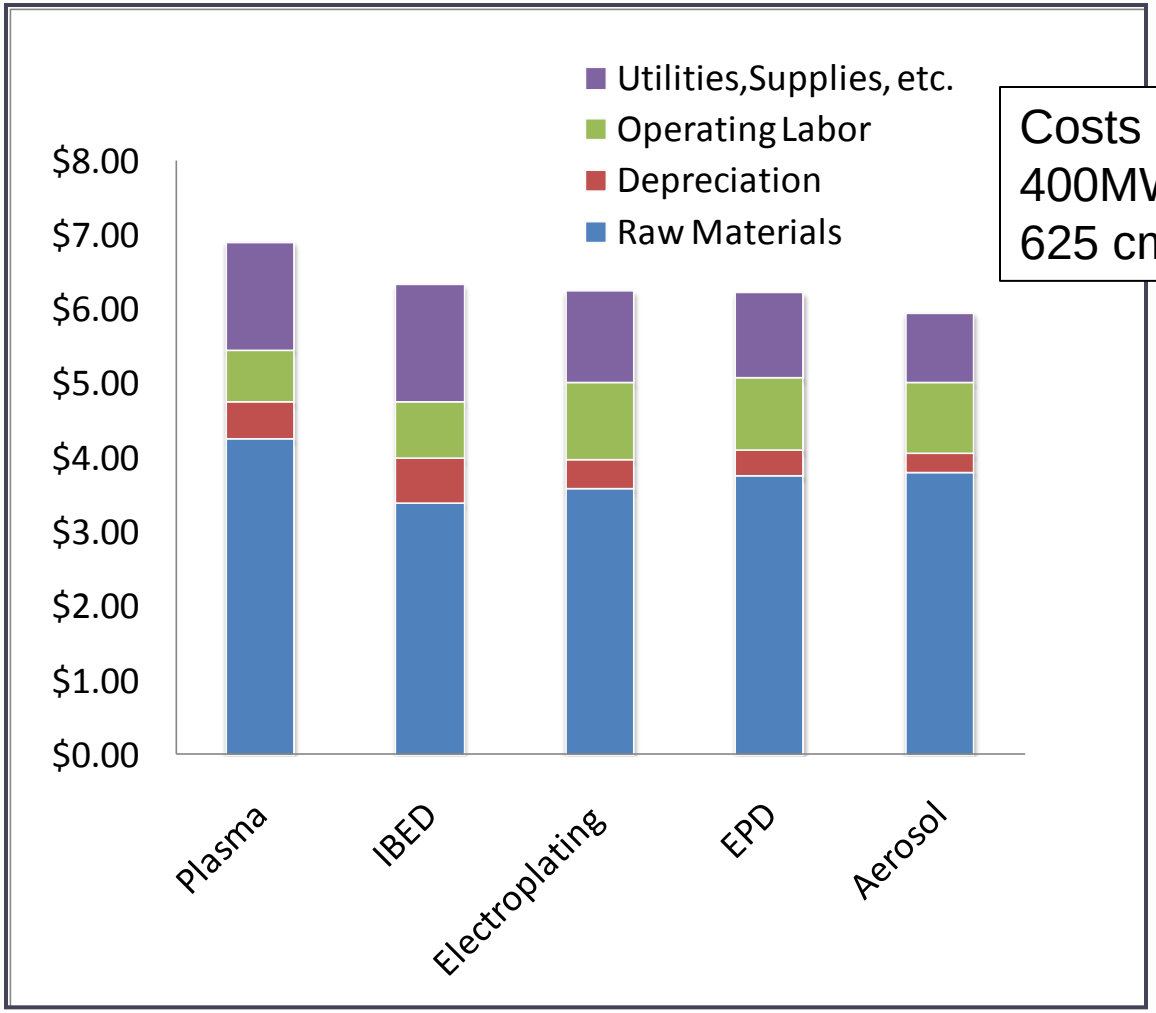
Electrode Powders → Tailored Current Collect → Custom Cell Solution

IC Protective Powder → Custom Spray Process → Tailored Interconnects

Summary of Coating Cost Analyses

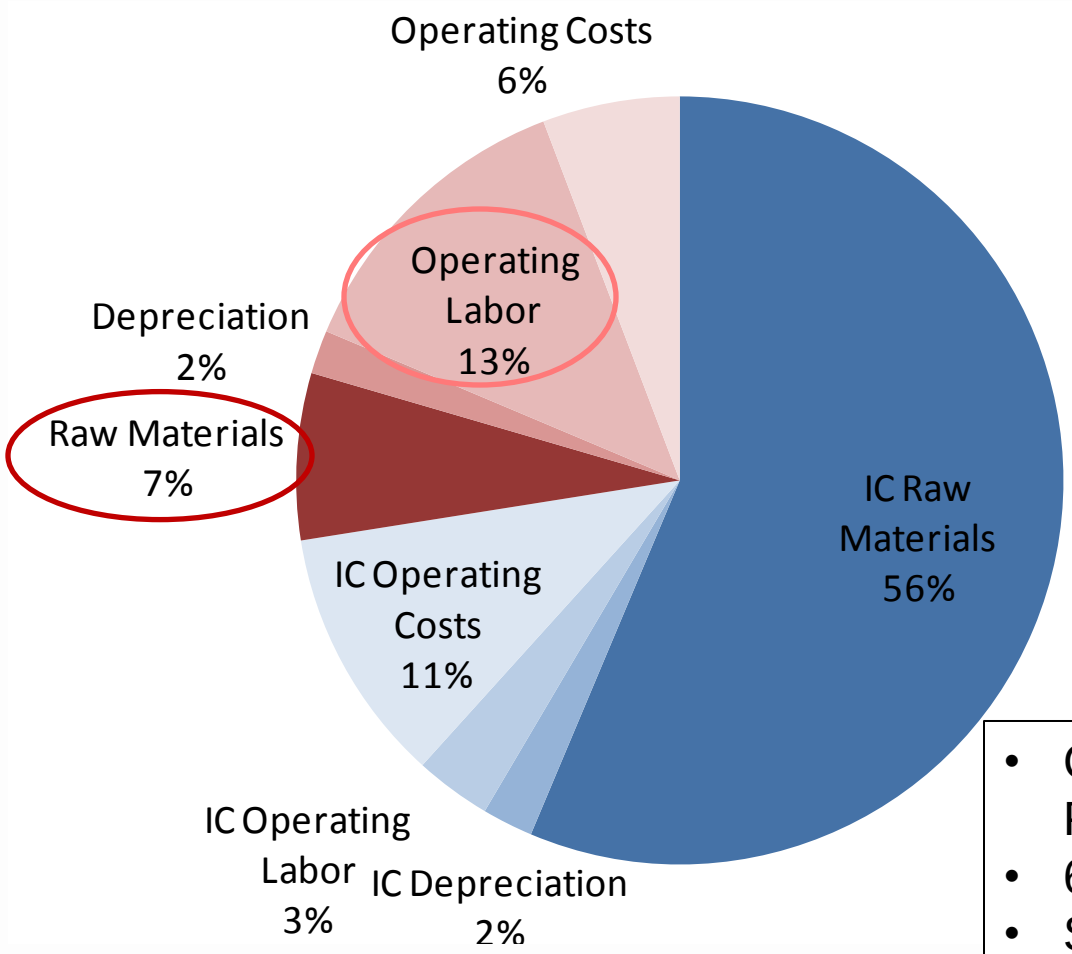
Comparison of Prevalent IC Coating Technologies *(Estimated at 400 MW/year production)*					
Metric/Technique	**Plasma**	**IBED**	**Electroplating**	**EPD**	***ASD***
Coating Density	Intermed.	Excel.	High	Intermed.	*Intermed.*
Coating Thickness (µm)	> 20	< 5	1-10	5-20	*5-20*
Composition Flexibility	Good	Low	Limited	Excellent	*Excellent*
Capital Cost ($)	3.1M	3.7M	2.5M	2.2M	*1.5M*
Operating Cost ($)	1.1M	1.2M	1.6M	1.5M	*1.5M*
Coating Cost per interconnect ($/part)	$2.61	$2.03	$1.95	$1.93	$1.65
Coating Cost per Kilowatt ($/kW)	$10.44	$8.12	$7.80	$7.72	$6.60

Breakdown of Coated IC Costs



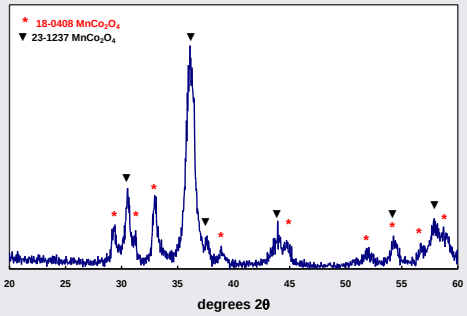
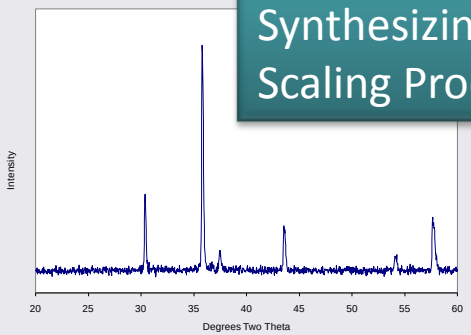
Costs Modeled for
400MW Production
625 cm^2 Interconnect Area

Breakdown of Coated IC Cost: Aerosol Deposition



- Costs Modeled for 400MW Production
- 625 cm^2 IC Area
- Stamped 0.5 mm thick IC
- $8.80/kg Steel Cost

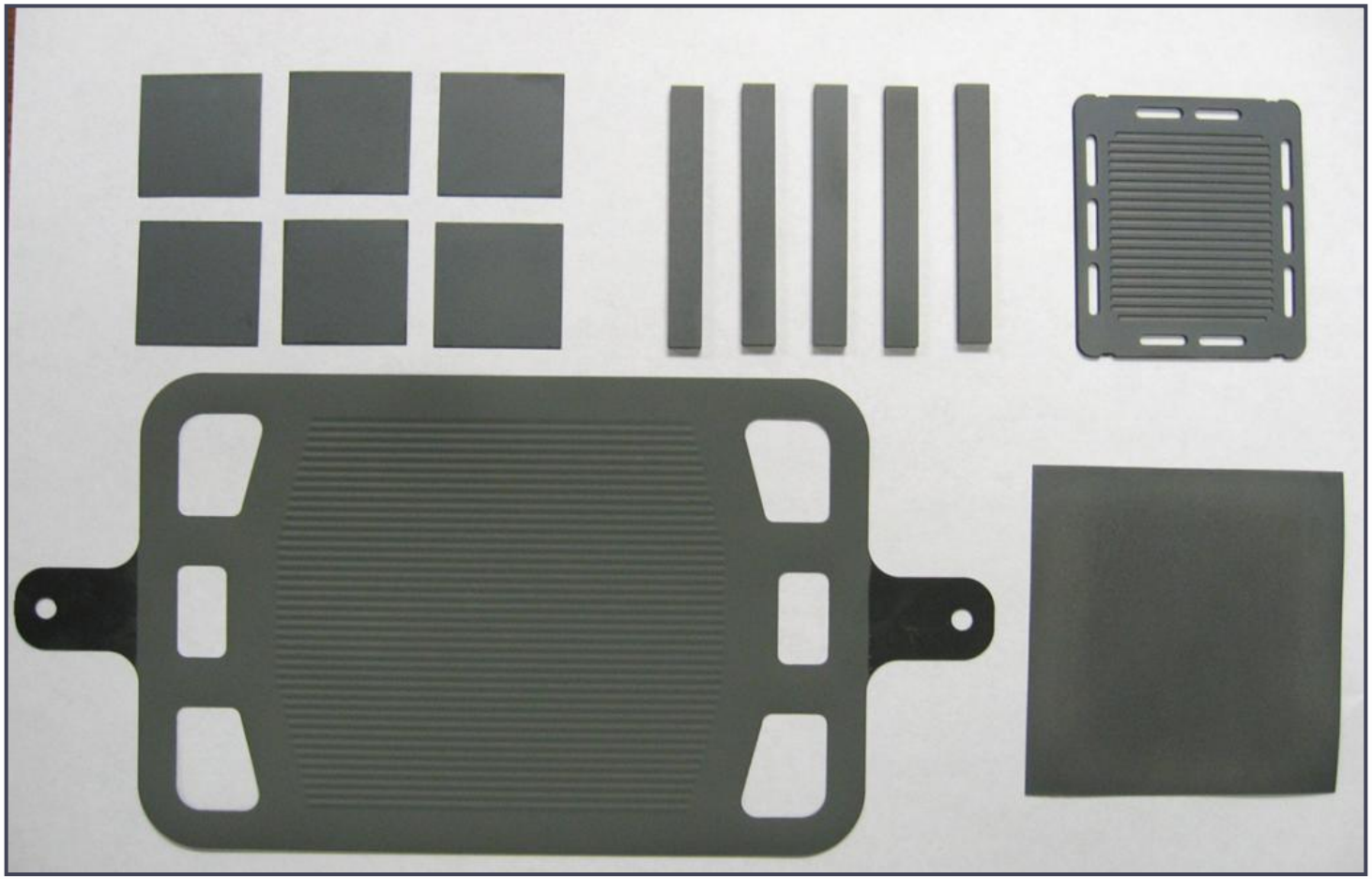
MCO Materials Synthesis

Material	$Mn_{1.5}Co_{1.5}O_{4-\delta}$	$MnCo_2O_{4-\delta}$
CTE (RT-1000°C)	11.4 ppm/°C*	13.5 ppm/°C**
Bulk Conductivity	~60 S/cm, 800°C†	36 S/cm, 800°C††
Surface Area	8-14 m^2/g	8-14 m^2/g
XRD	Mixed (Cub +Tet) Spinel 	Cubic Spinel 

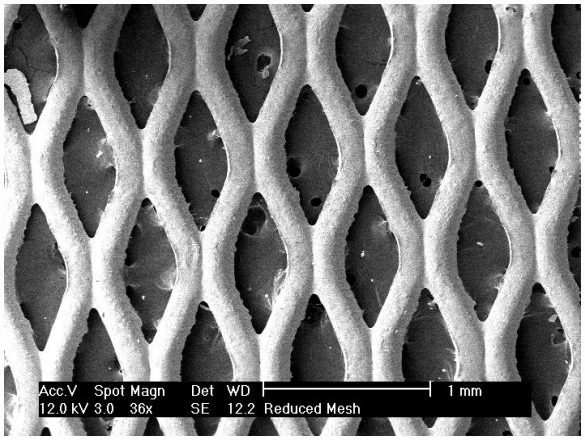
Synthesizing 25-100 kg lots
Scaling Production to 500kg

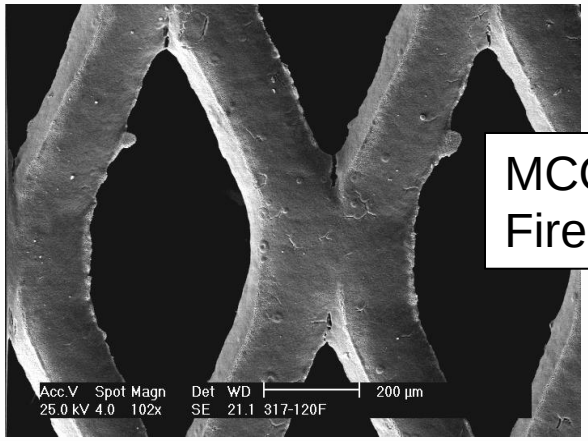
* Yang et al, Electrochem. and Sol. State Lett. 8 A168-A170 (2005)
** Kiefer et al, 26th Riso Int. Symposium on Mat. Sci., Solid State Electrochemistry p 261-266
†Chen et al, Solid State Ionics, 176 (5-6) 425-33 (2005)
††Yang et al, Int. J. of Hydrogen Energy, 32 (2007), 3648-3654

Examples of Coated Components



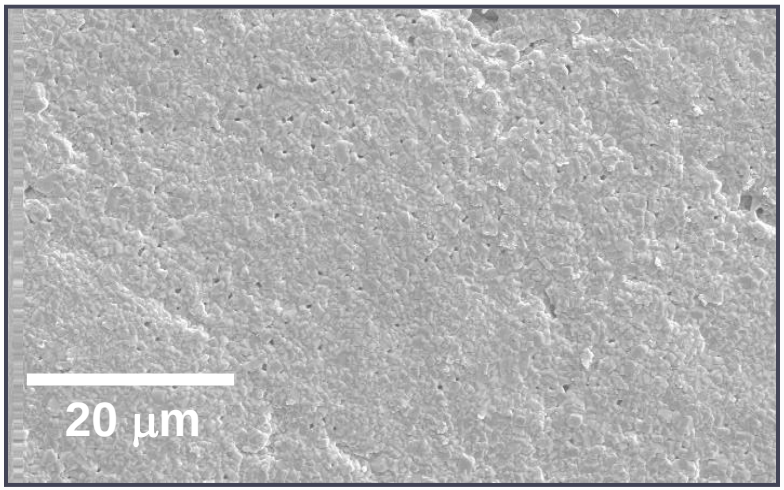
Extension to Cathode Current Collection

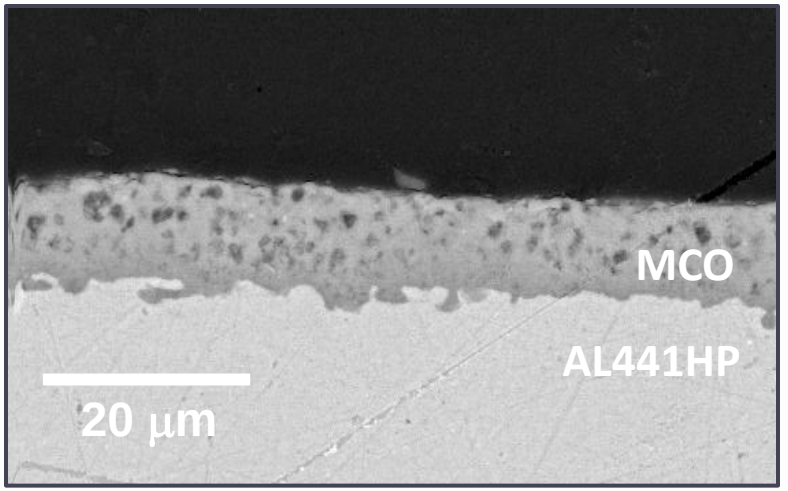




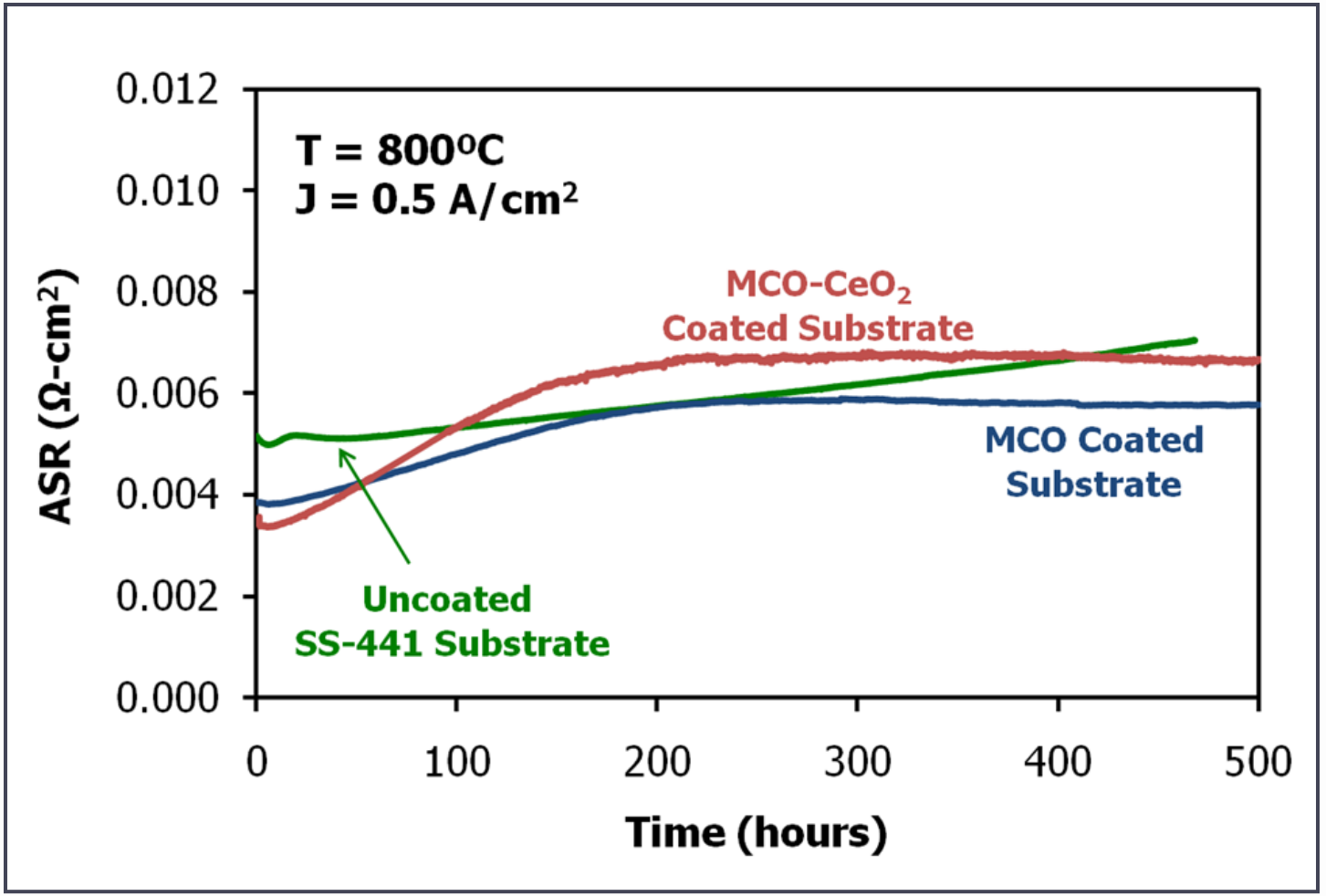
MCO Coating
Fired, 10 microns thick

Microstructure of $Mn_{1.5}Co_{1.5}O_{4-\delta}$ Coatings

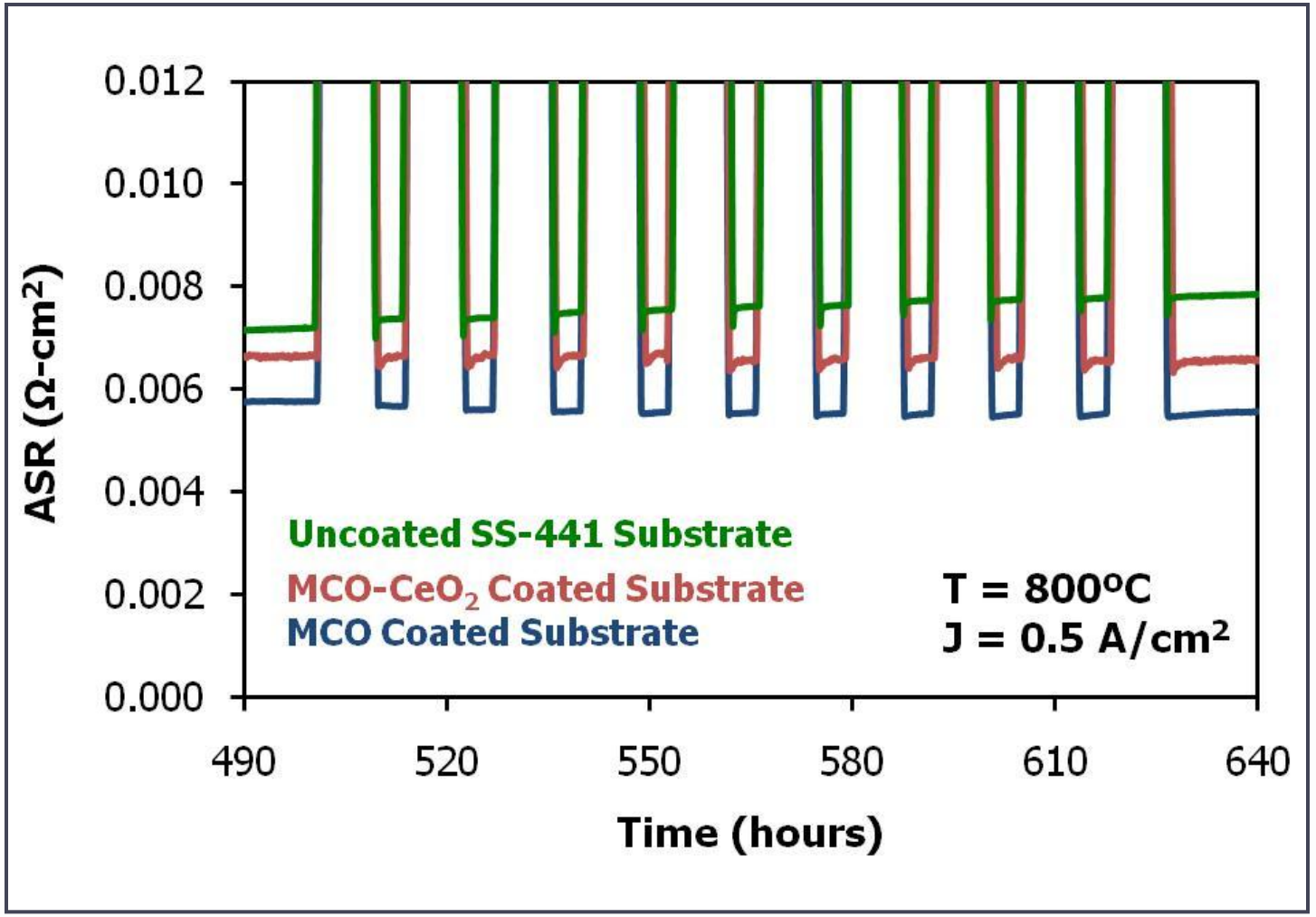




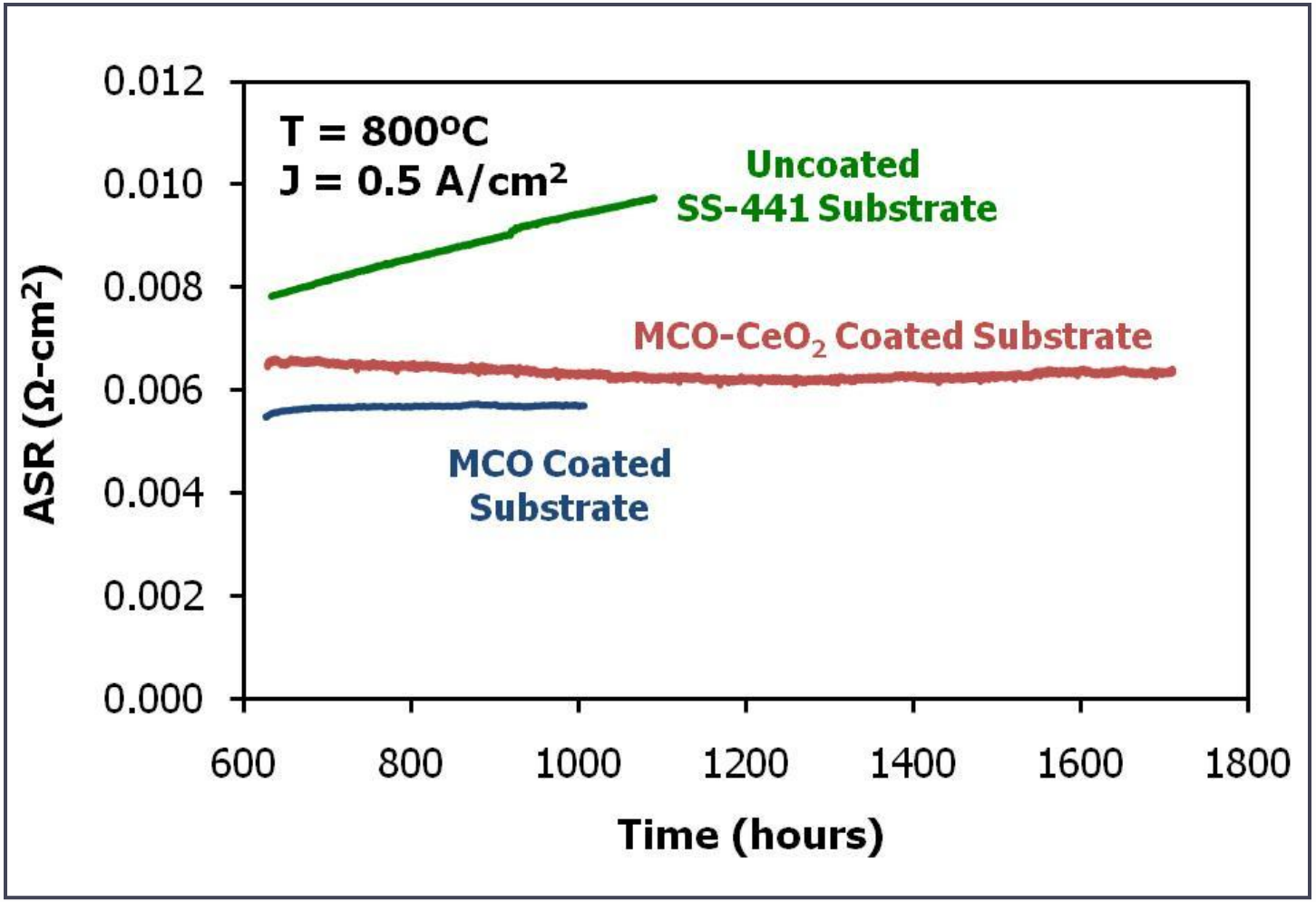
Initial Performance MCO v. Uncoated



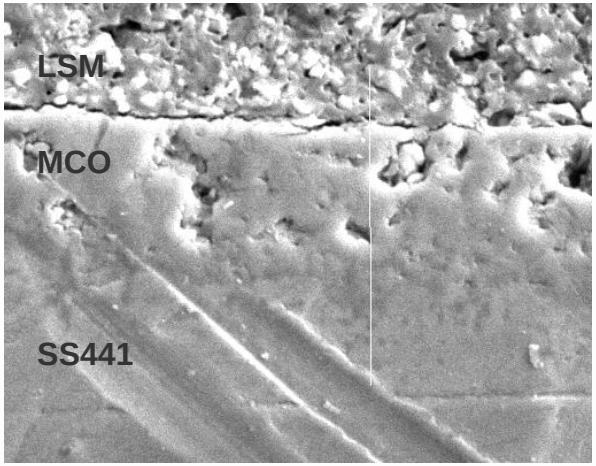
Thermal Cycling MCO v. Uncoated



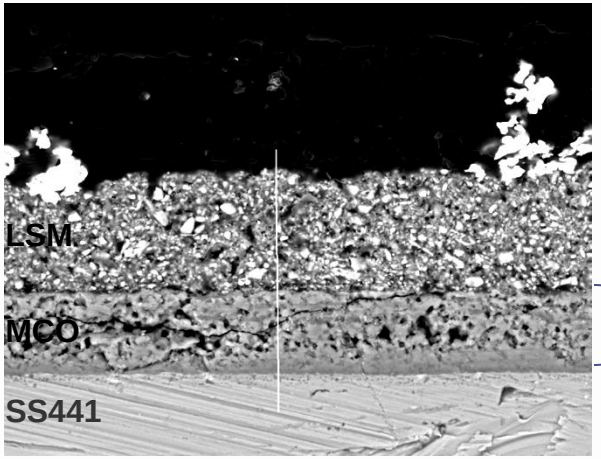
Lifetime Stability MCO v. Uncoated



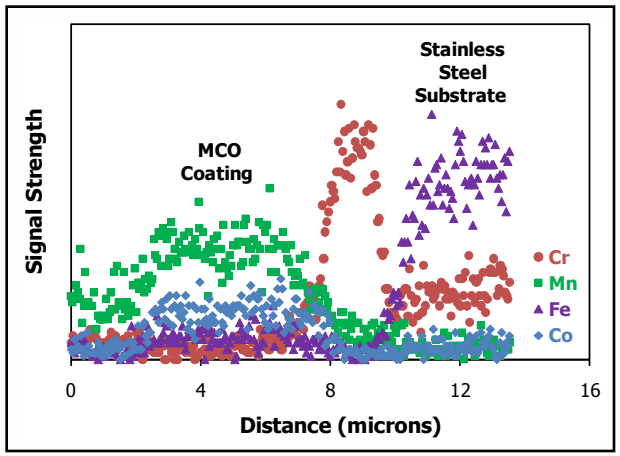
SEM Cross Sections

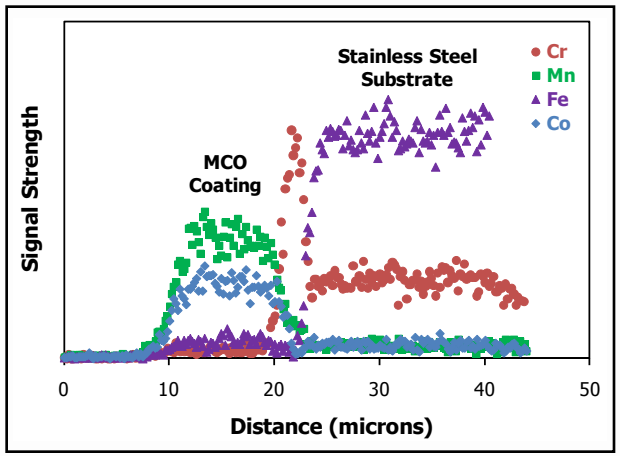


6 µm

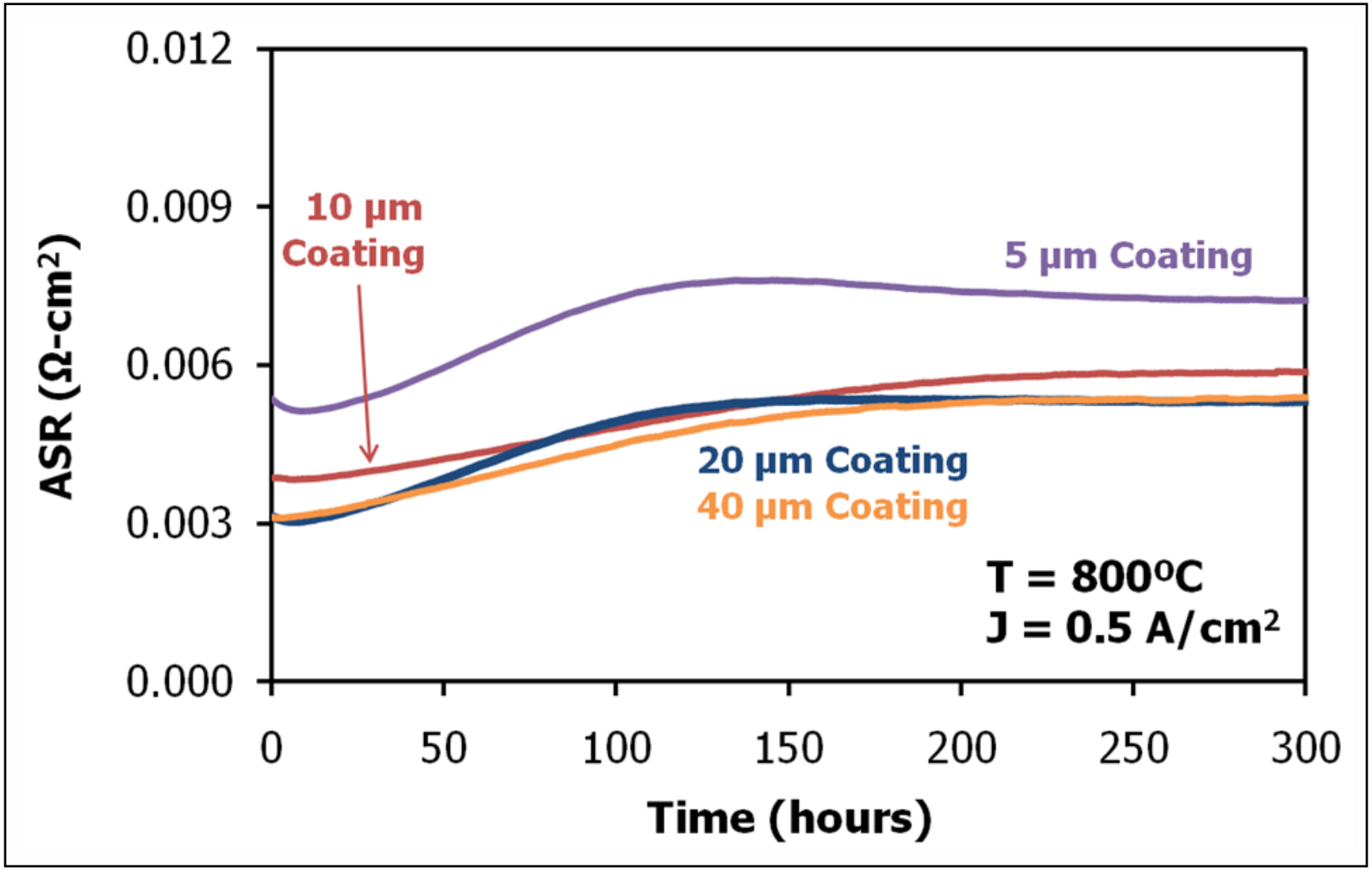


12 µm

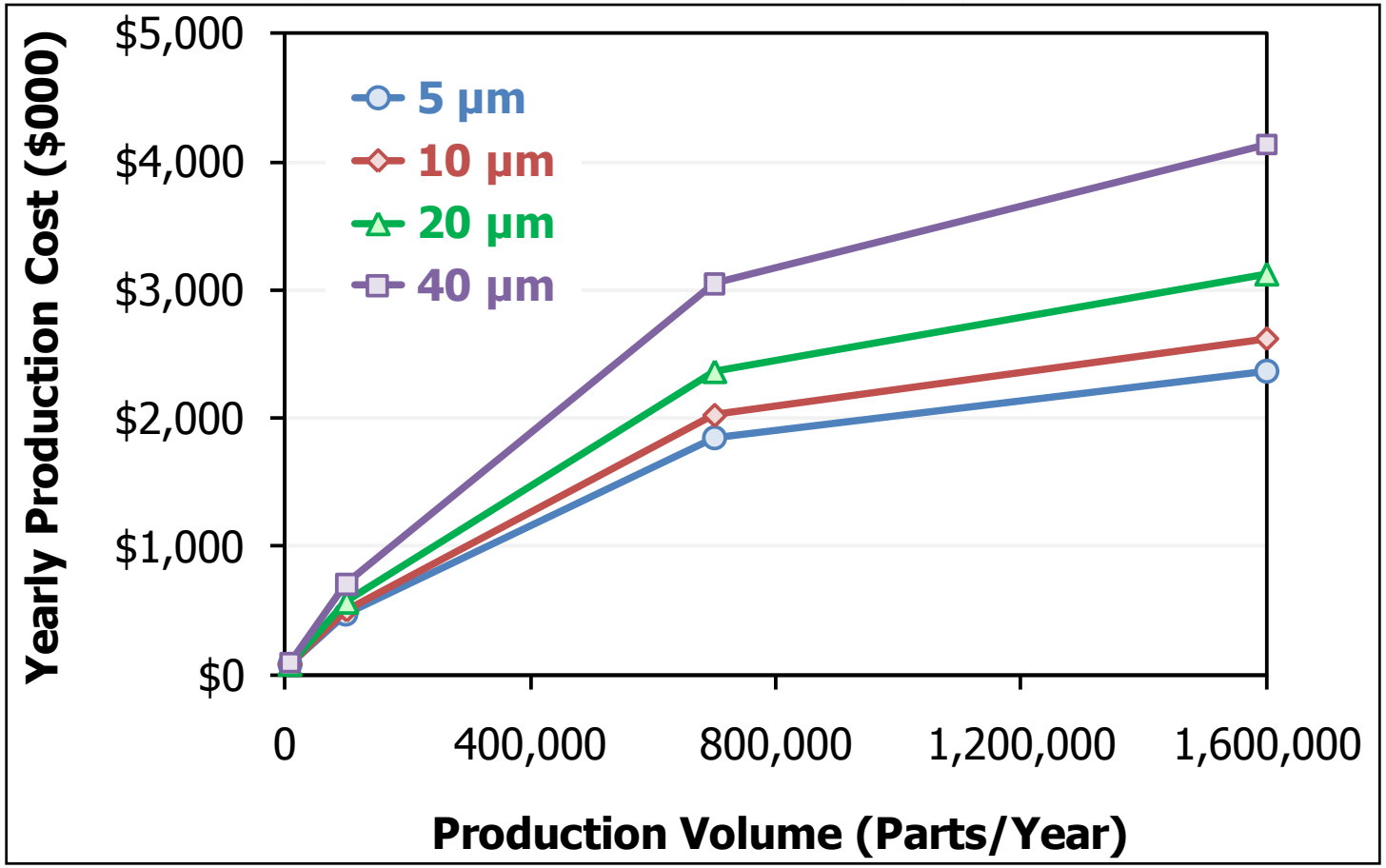




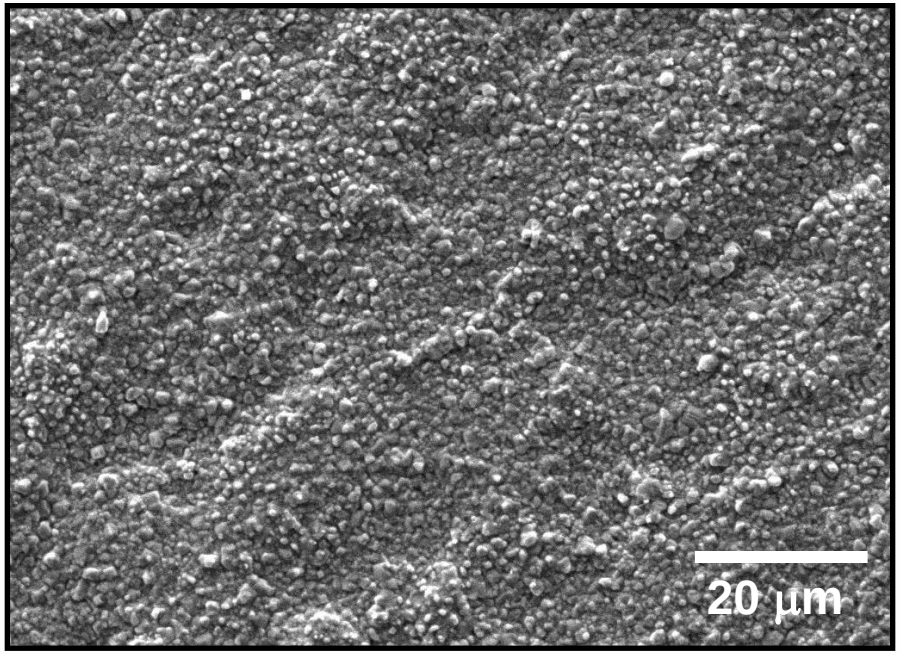
Impact of Coating Thickness Performance

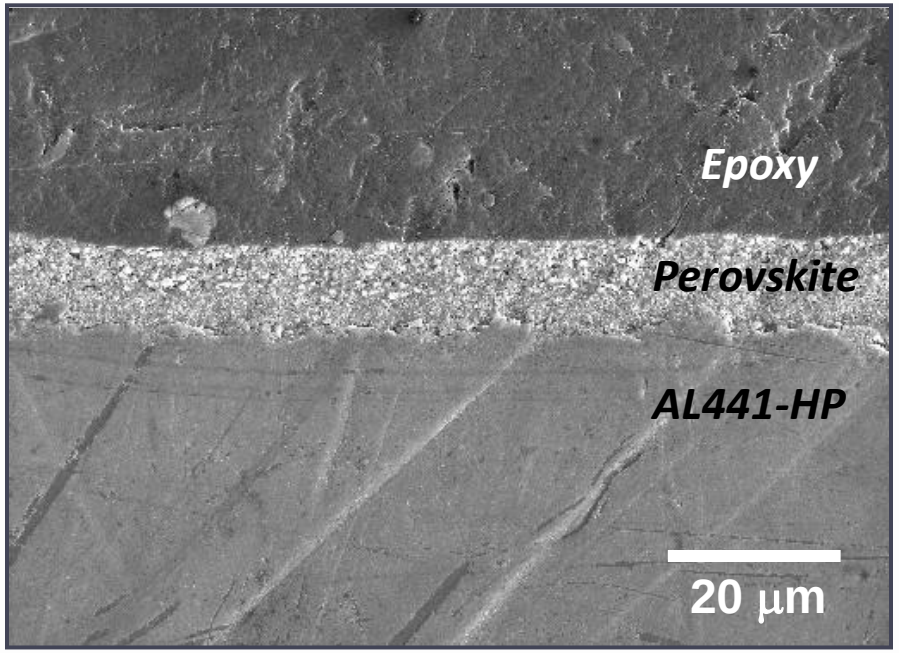


Impact of Coating Thickness Manufacturing Cost

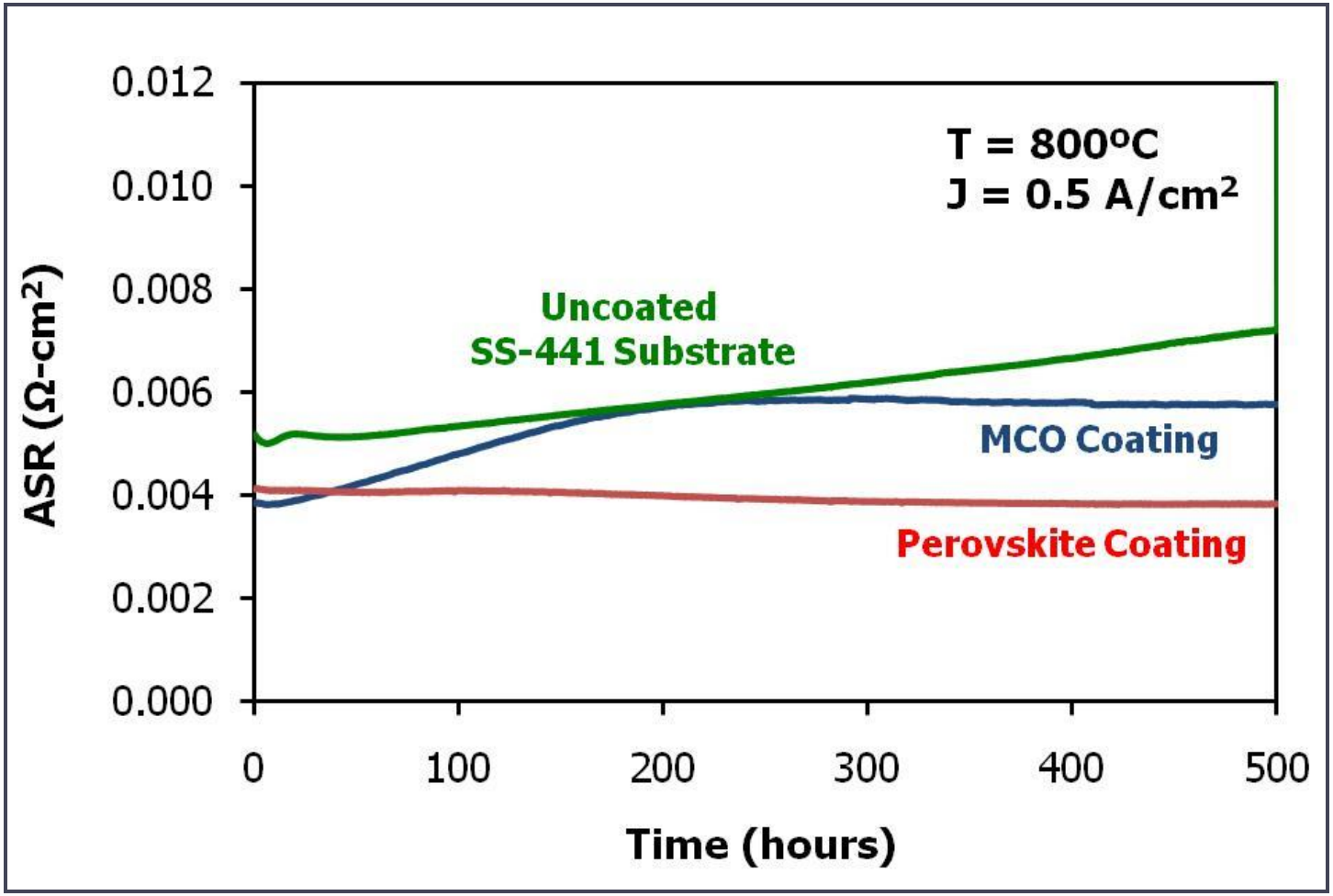


Perovskite Coating

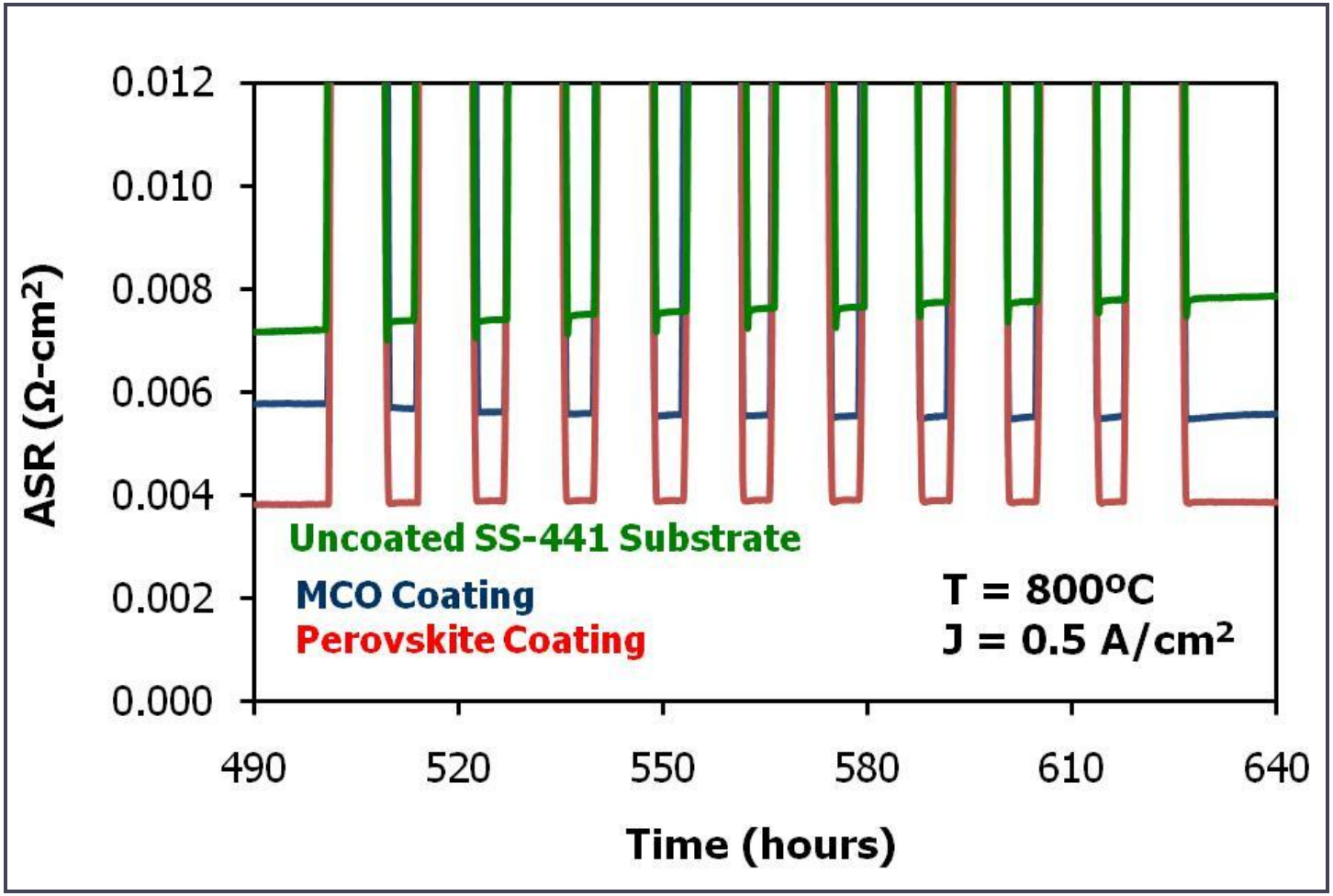




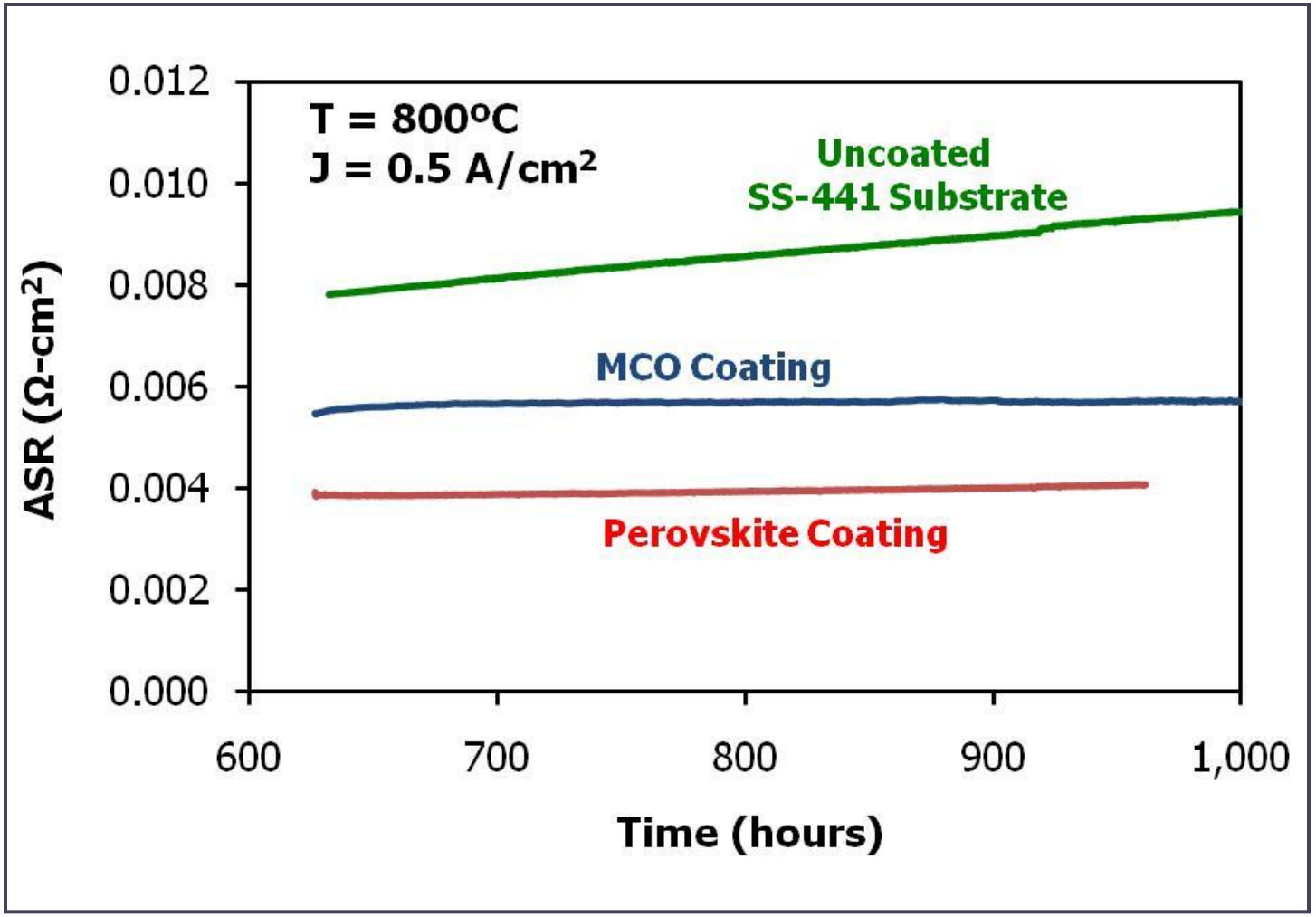
Initial Performance
Perovskite v. MCO & Uncoated



Thermal Cycling
Perovskite v. MCO & Uncoated

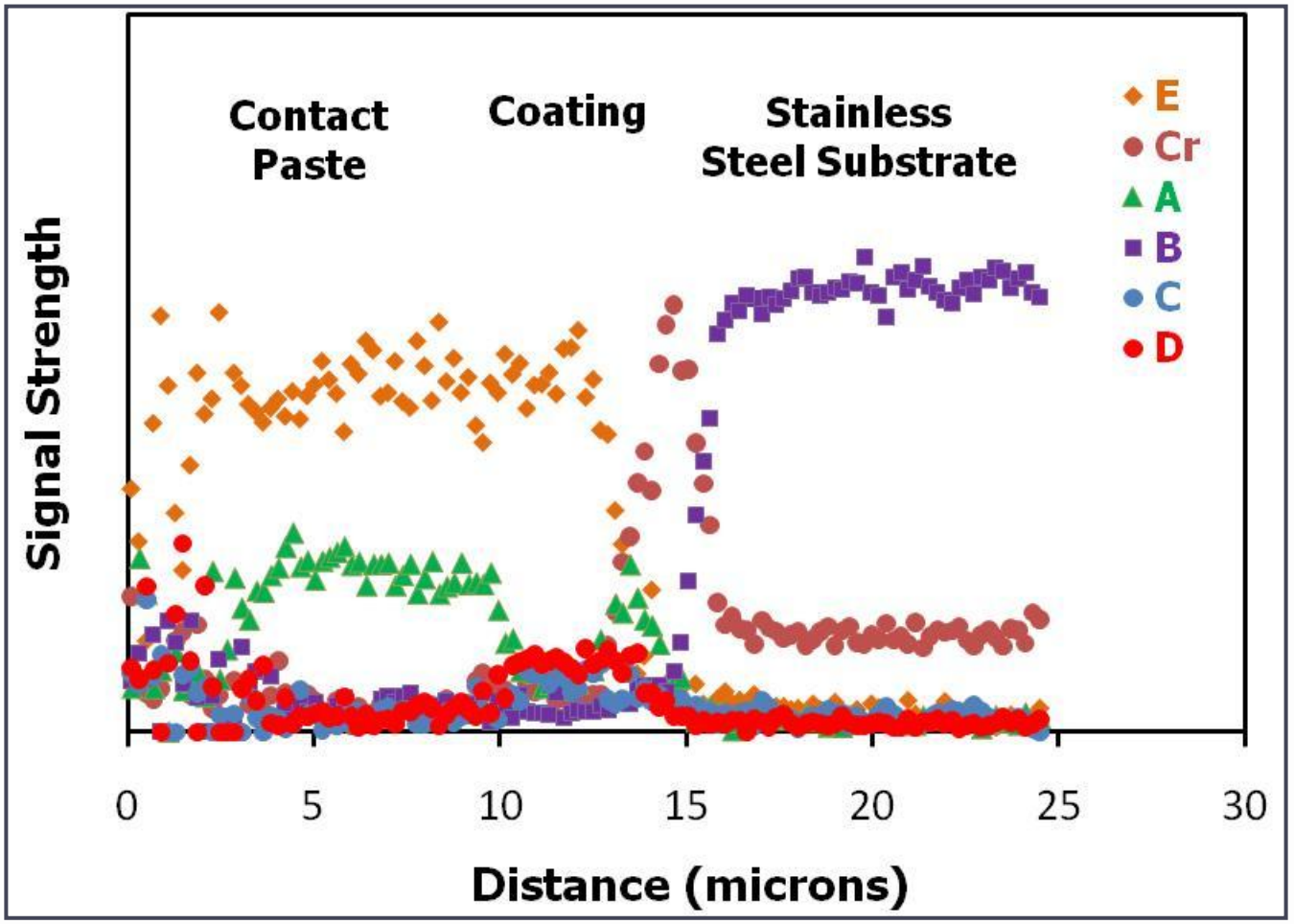


Lifetime Stability
Perovskite v. MCO & Uncoated

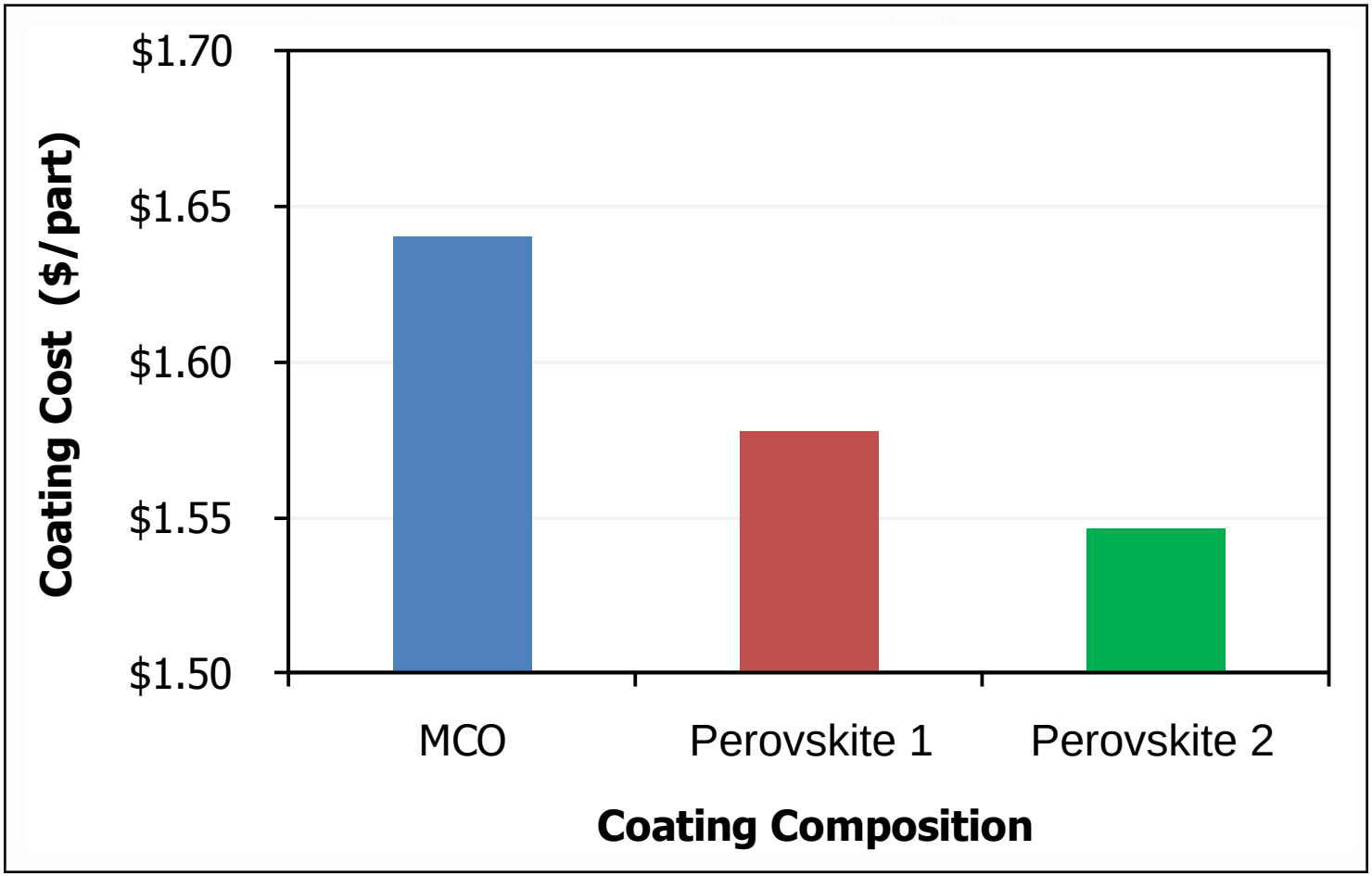


EDAX of Perovskite

Tested for 1000h, 800°C, 0.5A/cm²



Impact on Materials Selection Manufacturing Cost



Future Work

- Commercialization with Clients
  - Coating Services
  - Coating Value Added Materials
- Reducing Process Costs
  - Integration of Process into IC Manufacturing Cycles
  - Simplifying Process Cycles
  - Reducing Process Cycle Times
- Validating Materials Cost Reduction Strategies
  - Long Term Testing
  - Short Stack Validation

Acknowledgements

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

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