Electrodeposited Mn-Co Alloy Coating For SOFC Interconnects

H.A. McCrabb[1], Savidra Lucatero[1], T.D. Hall[1], H. Zhang[2], X. Liu[2], S. Snyder[1], and E.J. Taylor[1]

[1]Faraday Technology Inc., 315 Huls Dr., Clayton, OH 45315, USA

[2]West Virginia University, Dept. of Mechanical and Aerospace Eng. ESB, Morgantown, WV, 26506, USA

Overall Objective

Develop, optimize & validate an inexpensive manufacturing process for coating metallic SOFC interconnects with Co and Mn.

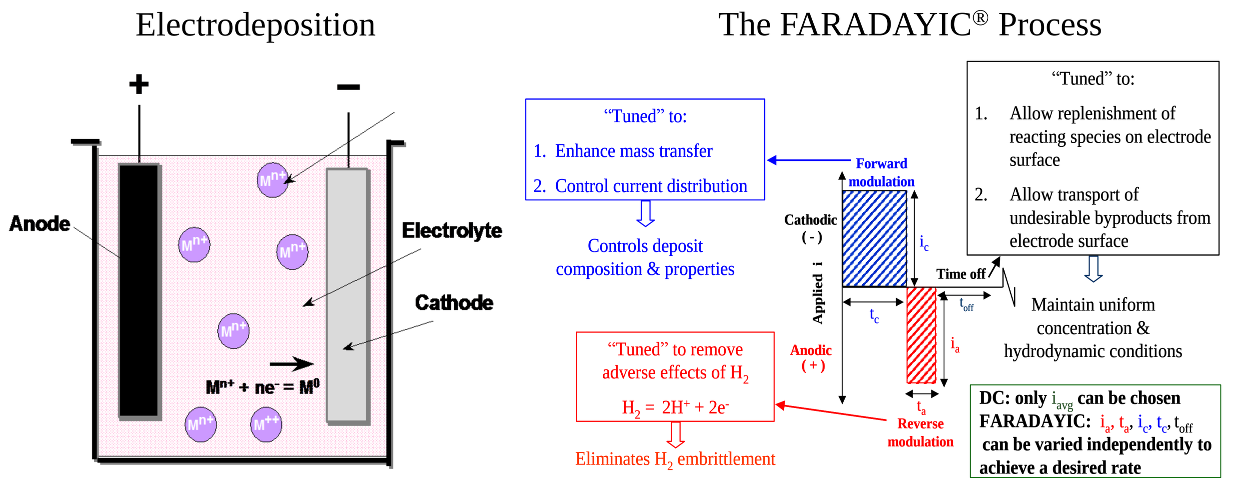
Introduction

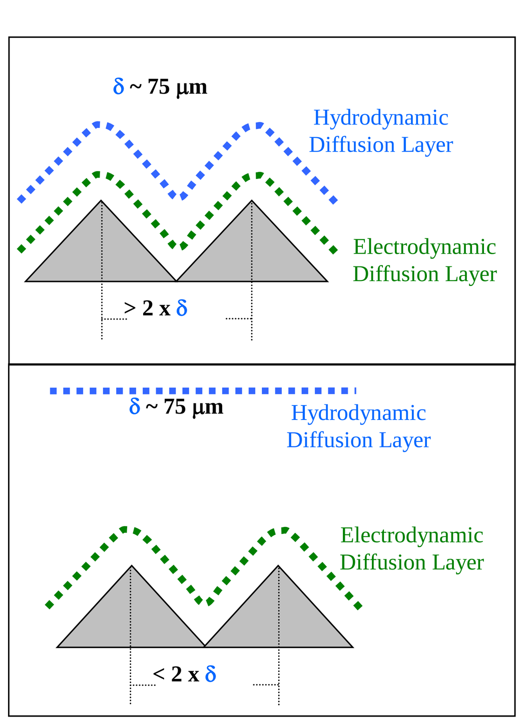
Reducing SOFC operating temperatures below 1000 ºC has permitted less resistive and expensive ferritic stainless steel interconnects to replace ceramic materials. However, even specially developed ferritic alloys operated at elevated temperatures for lengthy periods of time form a chromia scale that increases the interconnect resistance and results in chrome diffusion from the interconnect to the cathode that causes a reduction in cathode performance. One attractive method to resolve the chromia scale growth and diffusion issues is to electrodeposit a Mn-Co alloy coating onto the interconnect surface and subsequently convert it to a $(Mn,Co)_3O_4$ spinel.

Under funding from the Department of Energy, Faraday Technology and WVU are developing, optimizing and validating an electrodeposition process to apply Mn-Co alloy coatings to SOFC interconnects. The FARADAYIC® Electrodeposition Process is used to deposit a Mn-Co alloy that is subsequently oxidized to a spinel by thermal exposure at high temperatures in an oxidizing environment. Coatings exposed to extended thermal soaks exhibited relatively dense, crystalline microstructures that prevented chrome diffusion through the coating and maintained low area specific resistance. Faraday has scaled its process capabilities to industrial size SOFC interconnects with gas flow features.

Approach

The FARADAYIC® Electrodeposition Process





The appropriate waveform can alter the thickness of the pulsating diffusion layer and effectively focus or defocus the current distribution to create non-uniform or uniform deposition respectively.

← Macroprofile: Diffusion layer tends to follow the surface contour. Mass transport control results in a uniform current distribution or a conformal deposit during deposition.

← Microprofile: Diffusion layer thickness surface roughness. Mass transport control results in a non-uniform current distribution.

The FARADAYIC® Electrodeposition process…

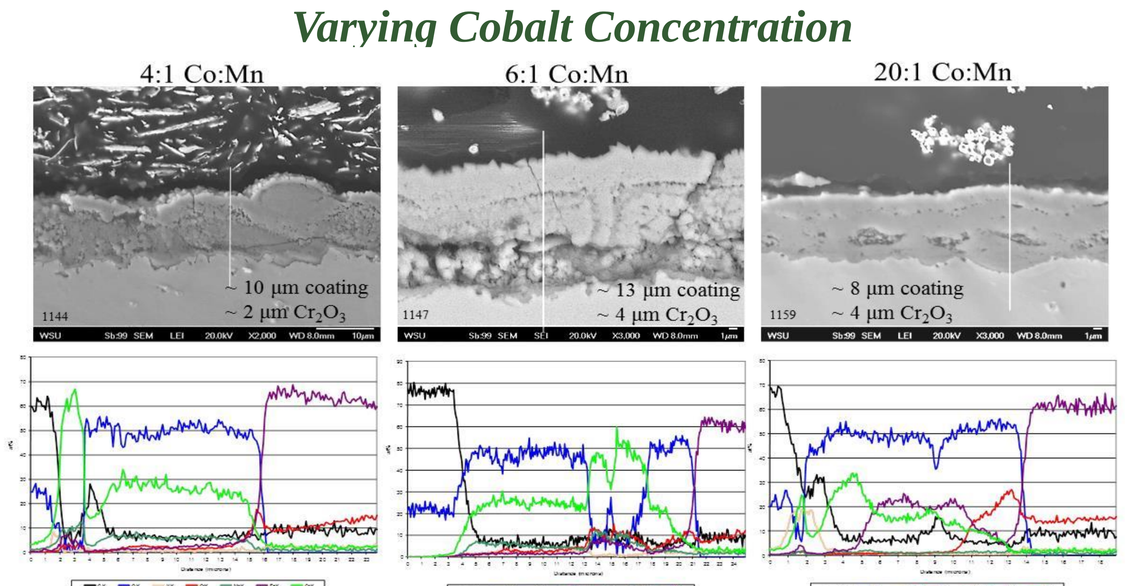
- Enables alloy composition control
- Enables control of coating uniformity for flow field patterns
- Maintains fast processing times to enable high throughput manufacturing
- Is an inexpensive manufacturing process for SOFC interconnect coatings

Milestones

Fiscal Year	Title	Planned Completion	Percent Complete
2011	1. Design/modification of 10" x 10" electrodeposition cell	May 2011	100%
2012	2. Long-term high temperature, thermal evaluation	September 2012	100%
2012	3. Process development for 4"x4" planar interconnects	May 2012	100%
2013	4. Process development for 4"x4" pattern interconnects	June 2013	100%
2013	5. Long-term on-cell performance evaluation	August 2013	100%
2013	6. Qualification/demonstration of IC in single cell test rig	September 2013	50%

Previous Accomplishments

Varying Cobalt Concentration

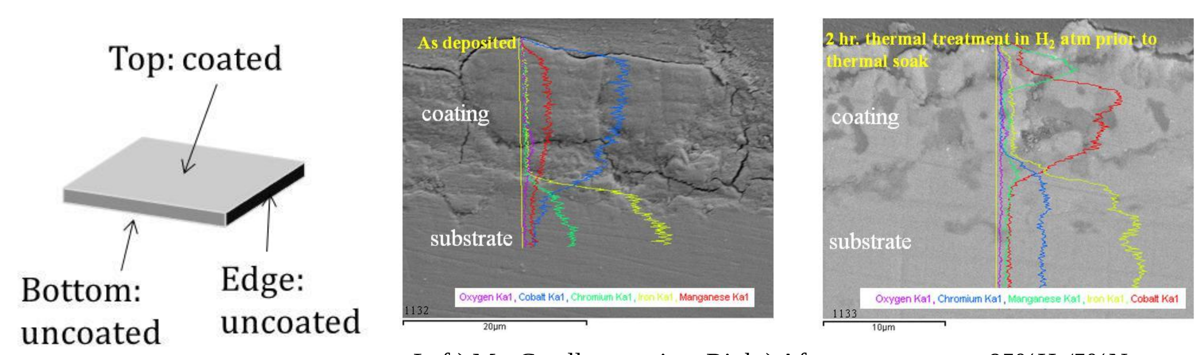


- Minor Cr diffusion
- Minor Fe diffusion

- Minor Cr diffusion
- Some Fe diffusion

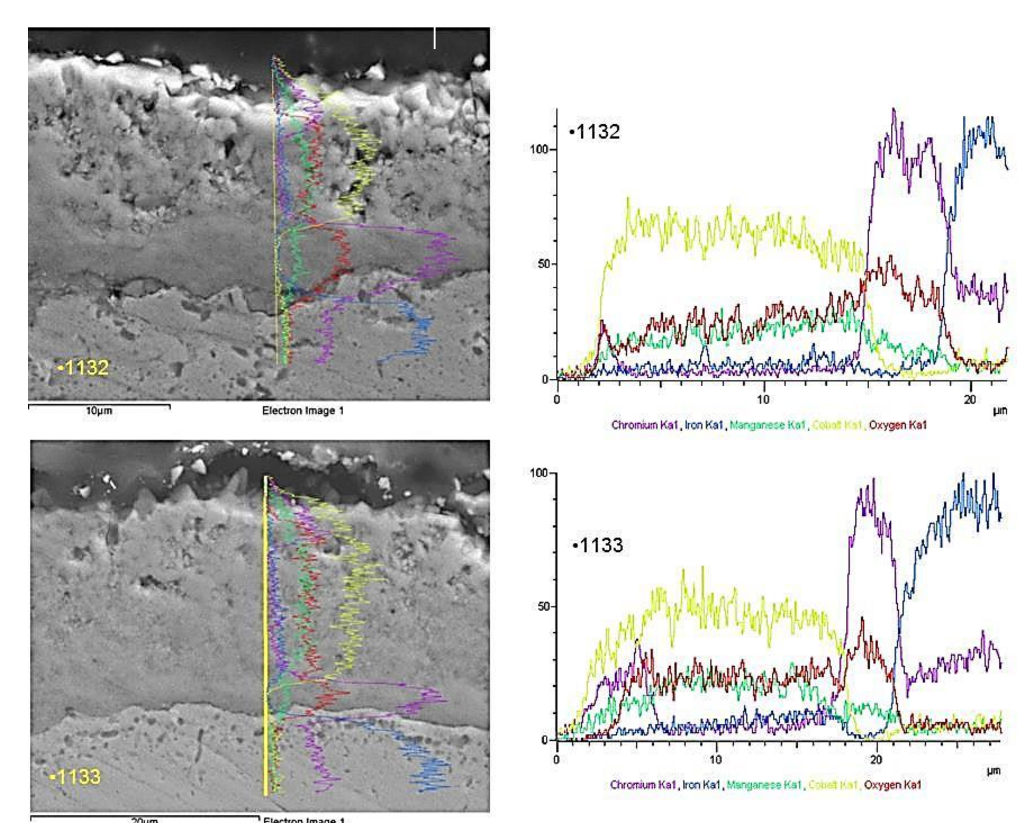
- Negligible Cr diffusion
- Fairly significant Fe diffusion

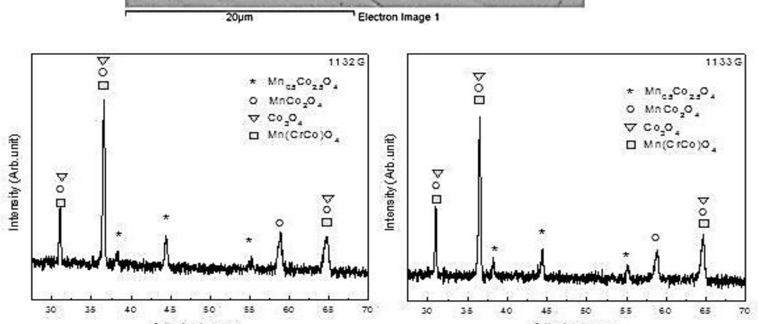
2000 Hour Thermal Soak



Left) Mn-Co alloy coating, Right) After exposure to a $95\%H_2/5\%N_2$ atmosphere for two hours at 800 °C with a 4 °C min^{-1} ramping & cooling rate & a $50\% H_2/50\%N_2$ ramping & cooling atmosphere

Sample No.	2 hour thermal soak pre-treatment	Mn-Co coating thickness (µm)	Chromia scale thickness (µm)	ASR ($m\Omega$ cm^2)
1132H	H_2	12	5	27.6
1133H	Air	17	4	29.1
1135H	Air	14	5	30.6
1136H	H_2	16	6	21.6
1137H	Air	15	5	26.0





Mixture of spinel phases

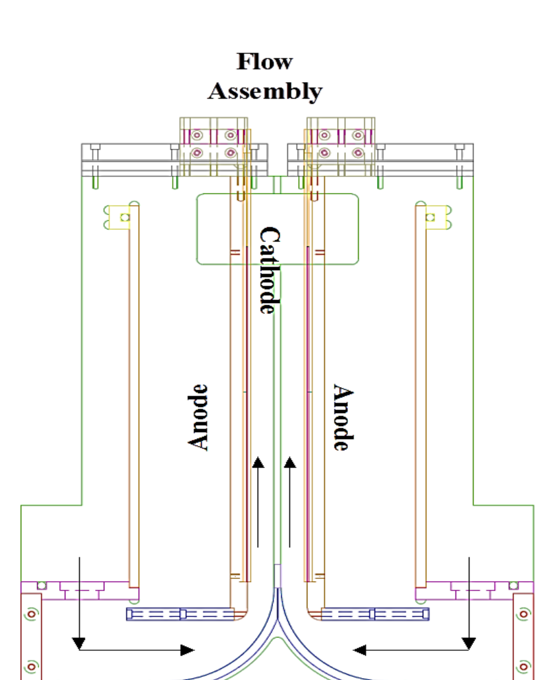
- $Mn_{0.5}Co_{2.5}O_4$ and $MnCo_2O_4$
- Co_3O_4
- $MnCrCoO_4$
  - Believed to form from Cr contamination in furnace due to uncoated areas of samples

Negligible differences observed between samples

Processing Equipment

Electrochemical Cell

Based upon Faraday's electrochemical cell design that facilitates uniform flow across the surface of a flat substrate (US patent #7,553,401; 7,947,161; 8,226,804)



FARADAYIC® Electrodeposition Cell Features:

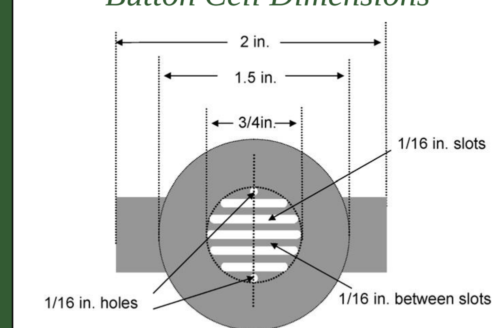
Cathode side only or cathode and anode side coatings

Interconnect coatings of various shapes and size ranging from 6.5 cm^2 – 645 cm^2

Technical Results

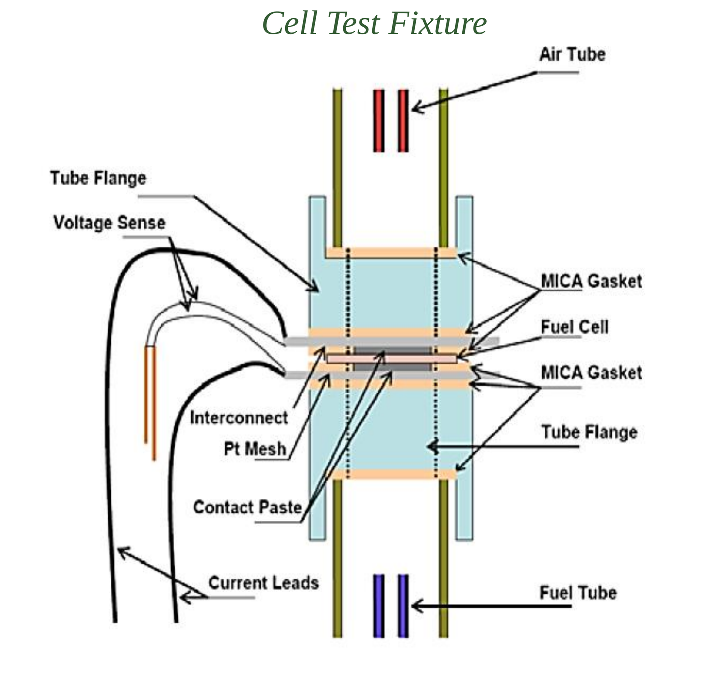
Long-term On-cell Performance Evaluation

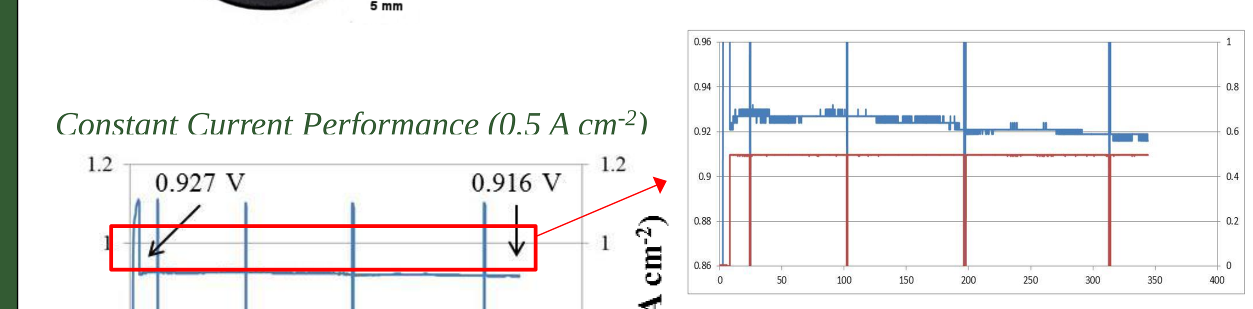
Button Cell Dimensions



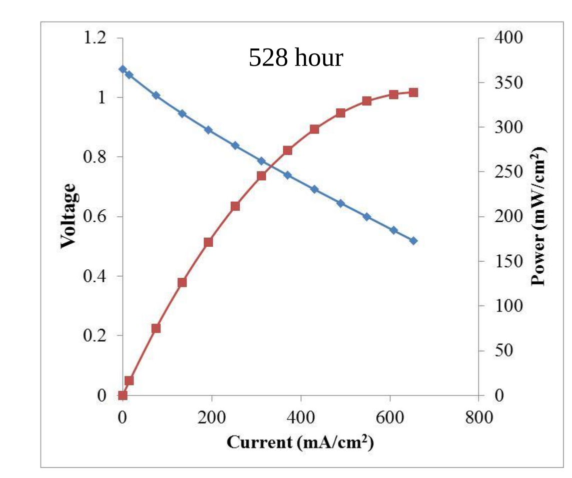
$(Co,Mn)_3O_4$ coated 441 stainless steel button cell

Cell Test Fixture





1.2 % voltage decay after 344 hr.

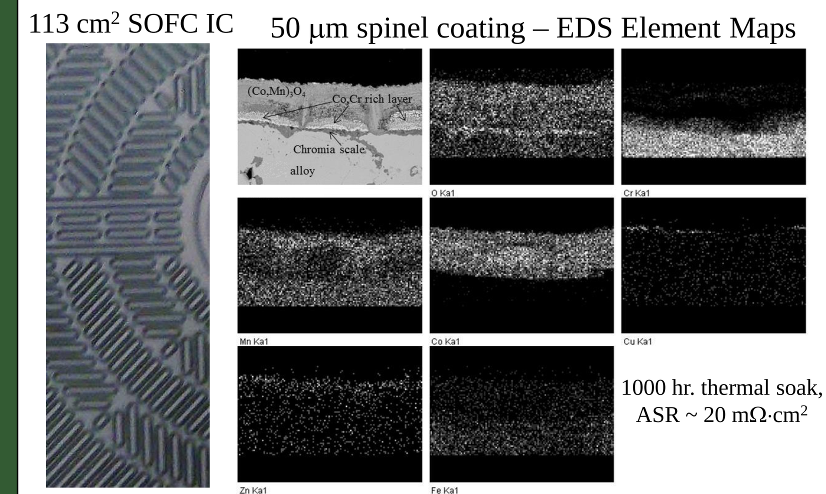


Power and current density as a function of cell voltage.

Industrial Scale Activities

113 cm^2 SOFC IC

50 µm spinel coating – EDS Element Maps



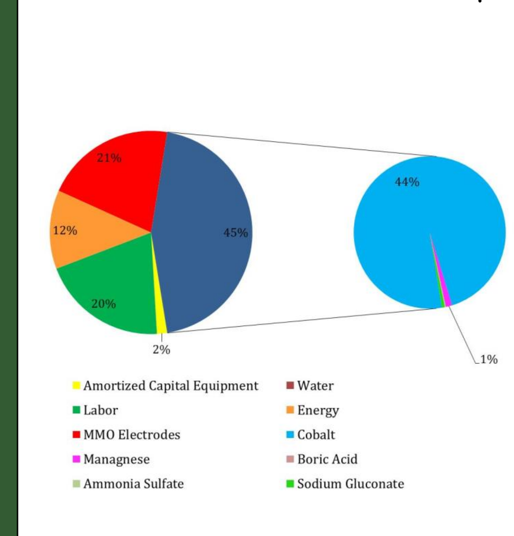
1000 hr. thermal soak, ASR ~ 20 $m\Omega{\cdot}cm^2$

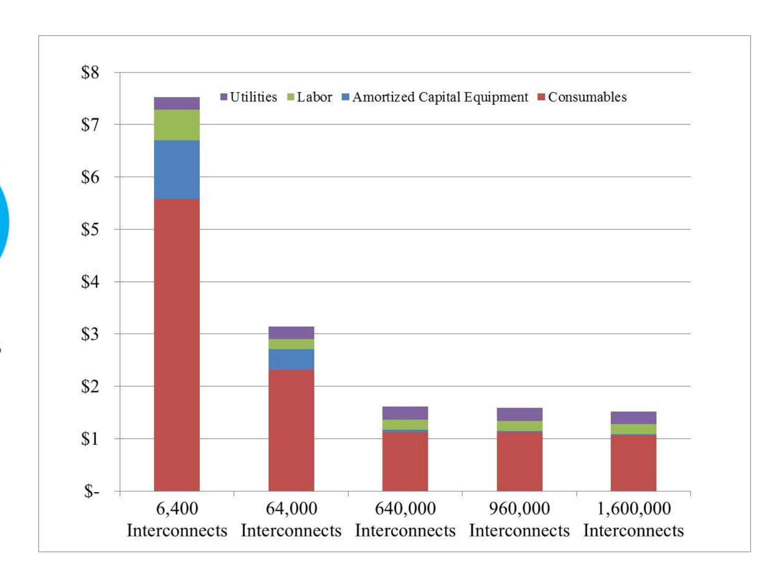
- Planar and patterned interconnects ranging from 100 – 225 cm^2
- Stainless steel alloy & proprietary alloys
- Coatings from a few microns to 50 µm
- Contained proprietary flow fields
- Varying ratios of Co:Mn
- Have received reports of good adhesion and ductility for the oxide coatings
- ASR reported in the range of 10 – 20 $m\Omega$ cm^2
- Stack testing next

Economic Analysis

Current cost analysis of coating process based upon batch manufacturing of 1,600,000 plates per annum at a cost of ~\$0.98 per 625 cm^2 coated interconnect.

10 µm thick cathode coating*





Cost is ~\$1.72/IC for cathode and anode side coating

Accomplishments/Future Work

FY 2013 Accomplishments

- Completed long-term on-cell performance evaluation of button cells
- Updated economic cost evaluation
- Delivered coated interconnects to commercial partners for performance evaluation via SOFC stack testing

Future Work

- Qualification/demonstration of interconnect coating in single cell test rig under ideal SOFC operating conditions by potential commercial partners

Acknowledgements

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Principal Investigator: Heather McCrabb, Company Name: Faraday Technology, Inc., Address: 315 Huls Drive, Clayton, OH 45315, Phone: 937-836-7749, E-mail: heathermccrabb@faradaytechnology.com, Company website: faradaytechnology.com