Novel Structured Metal Bipolar Plates for Low Cost Manufacturing

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TreadStone Technologies, Inc.

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Project ID# : FC105

Project Overview

Timeline

- Project start date: Jan. 15, 2017
- Project end date: Jan. 14, 2018
- Percent complete: 15%

Barriers

- Barriers Addressed : Bipolar Plate Durability and cost
  - Cost: < $3/kW (2020)
  - resistivity < 10 $m\Omega \cdot cm^2$
  - corrosion < 1 $x10^{-6} A/cm^2$

Budget

- Total Funding Spent:
  as of 3/31/17: $63,000
- Total Project Value: $437,500
- Cost Share Percentage: 20%

Supporting Partner

- Strategic Analysis, Inc.
- Hawaii Natural Energy Institute, University of Hawaii.

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Objective of the Project

- Overall Objective: Develop lower cost metal bipolar plates to meet performance target and 2020 cost target (<$3/kW)
  - Develop large scale manufacturing process for the doped titanium oxide coating technology demonstrated in previous SBIR project.
  - Investigate the relationship between processing conditions and doped titanium oxide properties for production quality control system development.

Key Technical Targets

Characteristic	Unit	2011 Status	2017 Targets	2020 Targets
Cost	$ /kW	5-10	**3**	**3**
Corrosion	$\mu A/cm^2$	<1	**<1**	**<1**
Resistivity	$\Omega.cm^2$	<0.03	**<0.02**	**<0.01**

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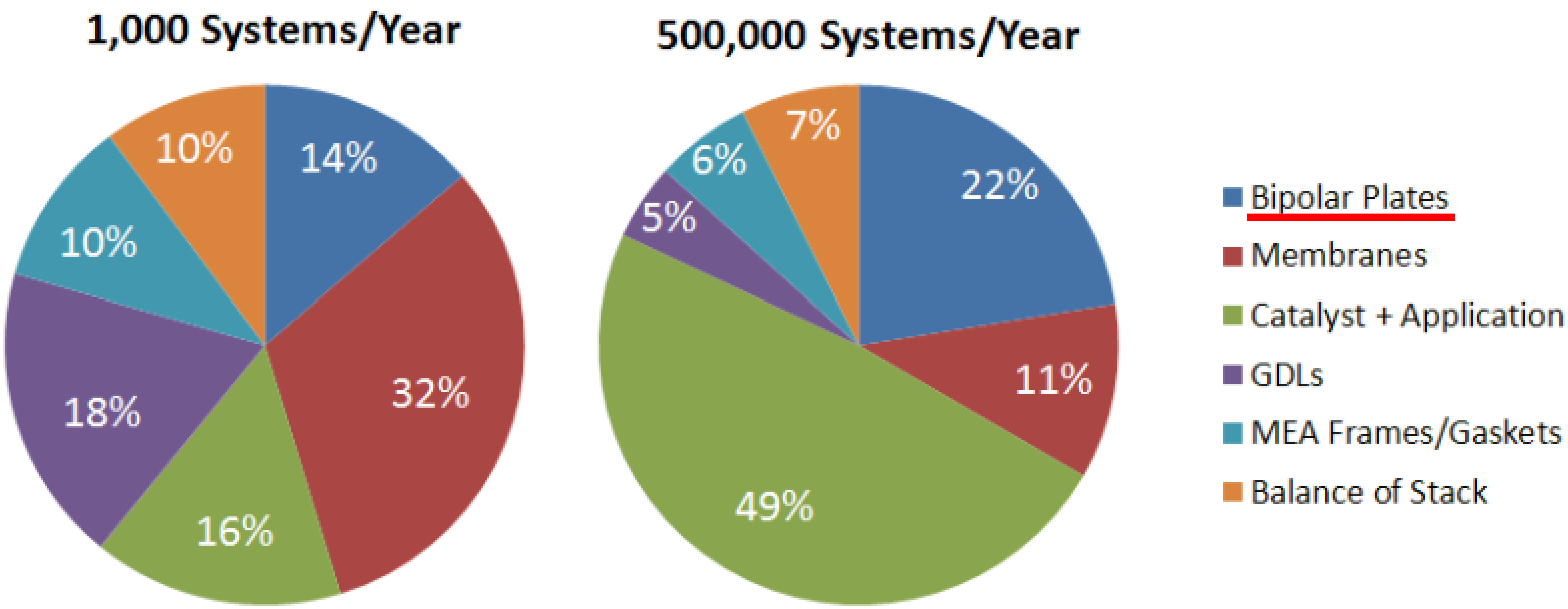
Relevance

Bipolar Plate Cost is a Major Portion of Stack Cost



J. Spendelow, J. Marcinkoski, "Fuel Cell System Cost – 2013"
DOE Fuel Cell Technology Office Record # 13012

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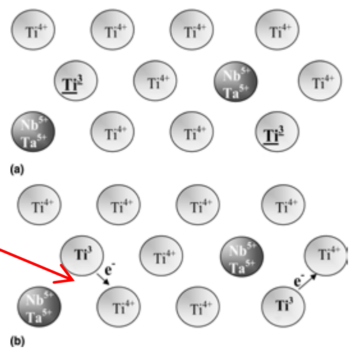
Approach: Coating Material for SS Plates

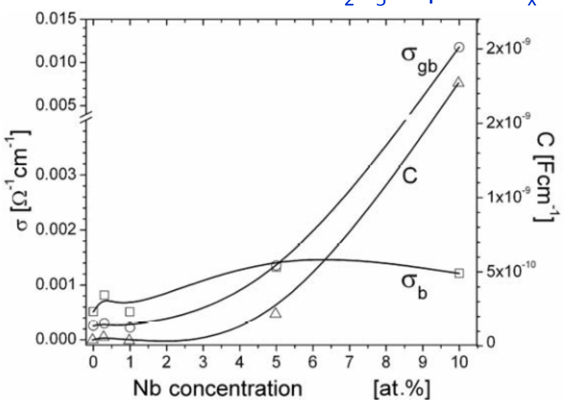
--- Semiconductive Doped TiO_x

Doping TiO_2 with +5 valence elements enforce the formation of Ti^{+3} in TiO_2 lattice structure, and result in the higher electronic conductivities.

Electron hopping between Ti^{+3} & Ti^{+4} sites



Electrical conductance of Nb_2O_5 doped TiO_x



A. Trenczek-Zajac, M. Rekas, Materials Science-Poland, Vol. 24, No. 1, 2006

Challenges to use doped TiO_x coating:

1. Doped TiO_x is semi-conductive. The electrical conductivity is not high enough.
2. The week bonding of doped TiO_x to metal substrate surface.

TreadStone's approach:

- Coat stainless steel substrate with Ti-Nb or Ti-Ta alloy. Then, grow the doped TiO_x surface layer on the Ti alloy coating layer.

1. The doped TiO_x on Ti alloy surface is thin and reliable.
2. Ti alloy coating has excellent adhesion on metal substrate (stainless steel or aluminum).

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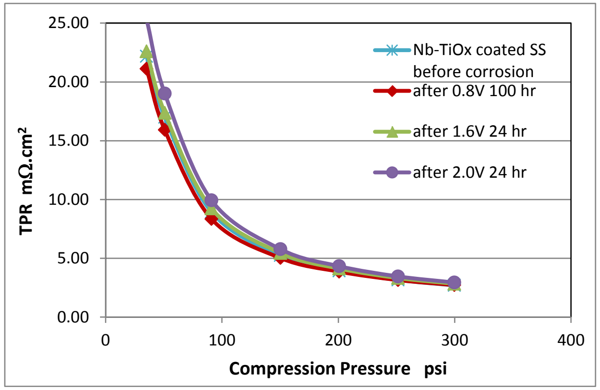
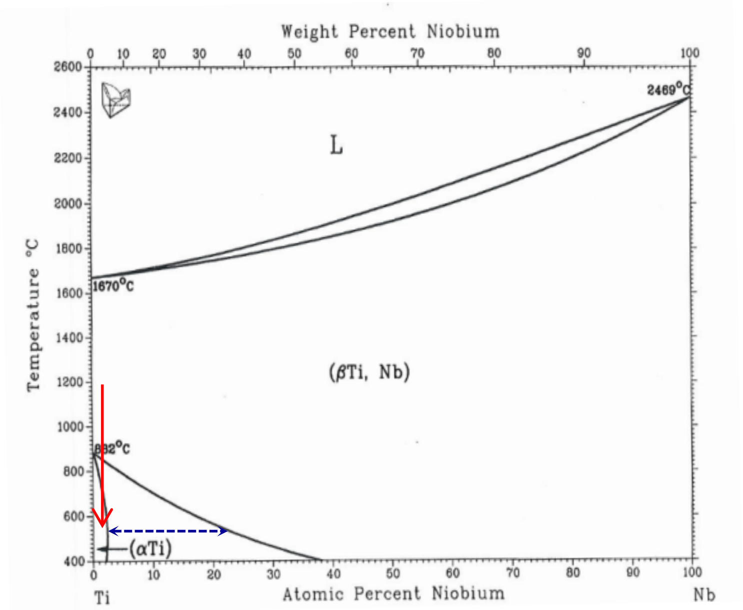
Achievements and Challenges

--- from previous SBIR project

- Low contact resistance and superior corrosion resistance have been demonstrated using the doped TiO_x coating on SS substrate for PEM fuel cell applications.
- Challenges:
  - Processing technology has to be optimized to obtain the desired structure of surface oxide layer.
    - Segregation of Nb or Ta alloy element from the coating surface leads to the pure Ti surface oxide layer of the sputtering coated surface.
  - Need to determine the optimized coating composition.
  - Understand the relation of the processing condition with the surface oxide layer structure.





The objective of this project is to develop technical solutions to overcome these challenges..

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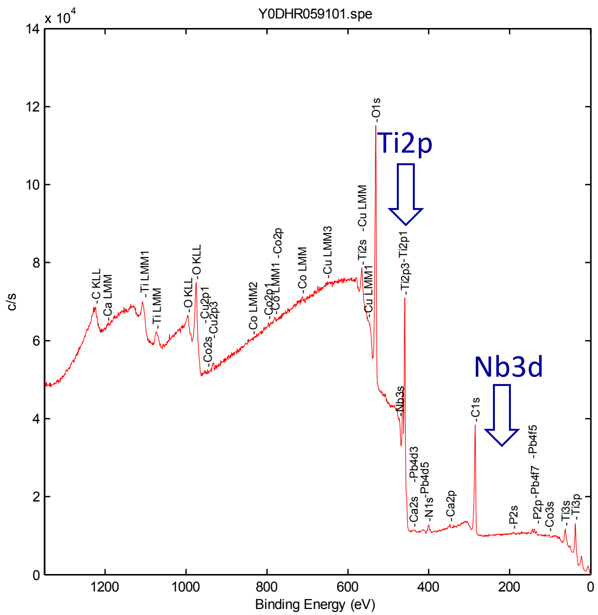
PVD Process Condition Optimization

--- Minimizing Surface Layer Alloy Element Segregation

- Previous Processing Condition

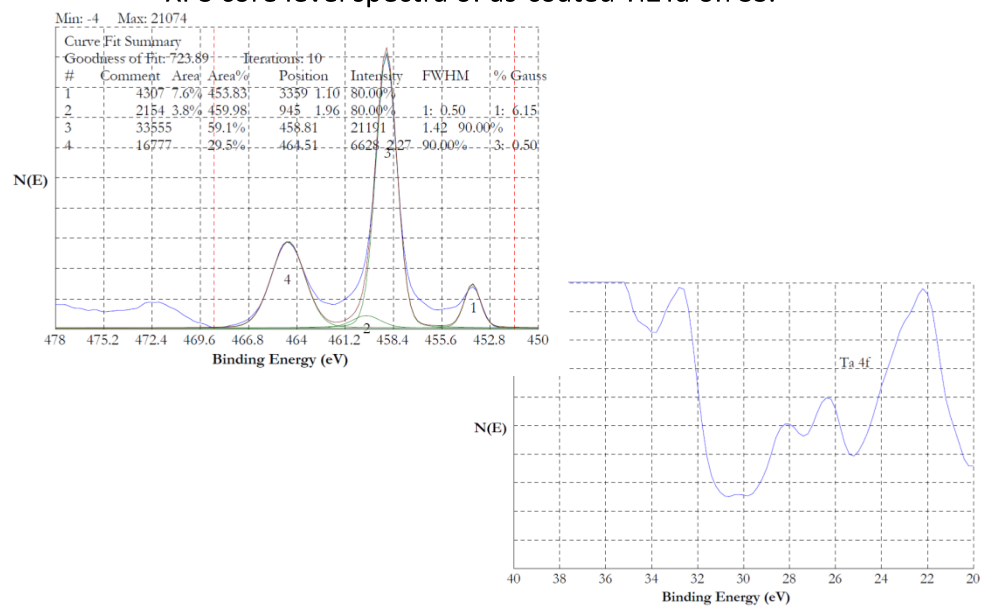
XPS survey spectrum of as-coated Ti3Nb on SS.



No Nb (or Ta using Ti-Ta alloy target) was detected on the coating surface

- Modified Processing Condition

XPS core level spectra of as-coated Ti2Ta on SS.



Surface layer Ta to Ti ratio is 0.4% : 99.6% (using Ti2Ta target)

The modified processing condition has brought Ta to the surface. Further optimization is needed to increase its concentration.

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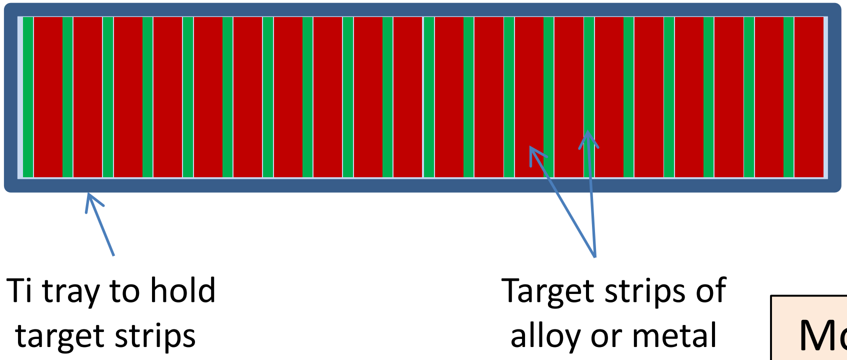
Coating Composition Optimization

- Need to prepare targets with various compositions.
  - Challenge: the cost and lead time for custom composition targets.
    - Typically $2,000 – $3,000, 6-8 weeks for one target.
- Conventional co-deposition: using several targets, alternately deposit from each target to control the bulk composition of the coating by the sputtering time of each target.
  - The coating is nano-scale layer by layer structure, not the atomic scale mixing. The surface oxide composition (several nm thick) could only contain the element of last layer of the coating.
- "Mosaic" target approach for coating composition optimization.



- ➢ The coating composition can be controlled by the width of each target strip.
- ➢ The distance from the target to the substrate has to be long enough for sufficient mixing of vapors.

Mosaic target approach makes it feasible for composition optimization in this project.

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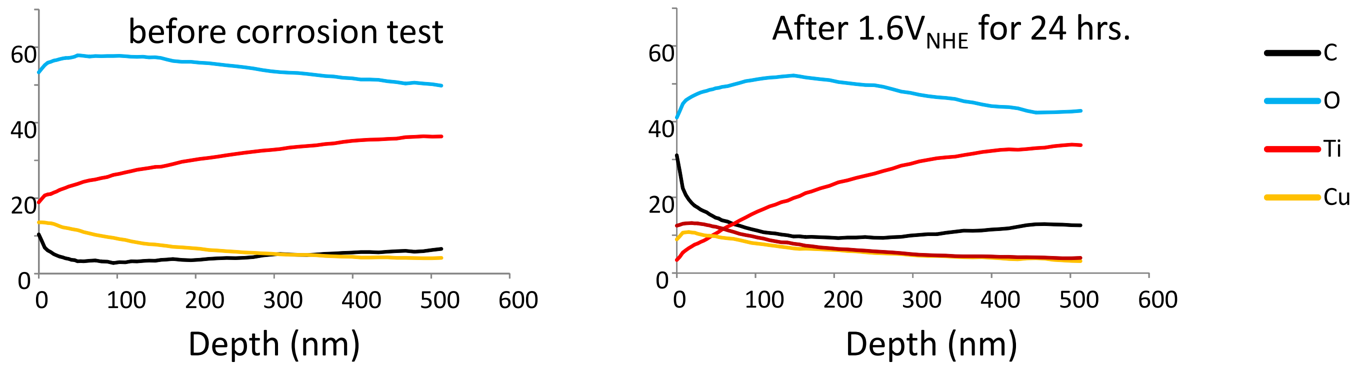
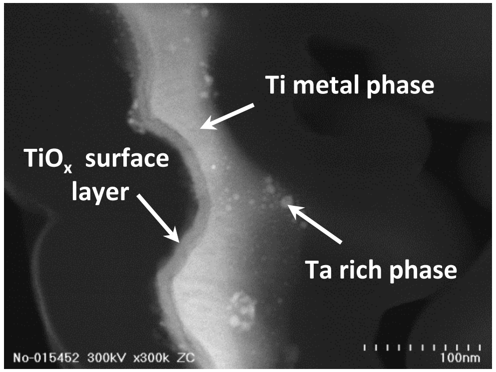
Surface Oxide Layer Characterization

- Previously, X-Ray Photoelectron Spectroscopy (XPS), Auger Electron Spectroscopy (AES) and Rutherford Backscattering Spectroscopy (RBS) have been used to characterize the surface oxide layer.
  - ➢ The rough surface topography makes the analysis difficult.
  - ➢ The thickness of the surface layer are relative (typically to SiO_2)..

XPS depth profile of Ti2Ta coated SS



- FIB/STEM is more suitable method for the surface layer analysis.



- The TiO_x surface oxide layer is 15-20 nm.
- There is Ta rich phase in the Ti2Ta coating layer.
- The small amount of the β phase can not be detected by XRD.

The data was from a DOE SBV project, teaming with LANL and ORNL.

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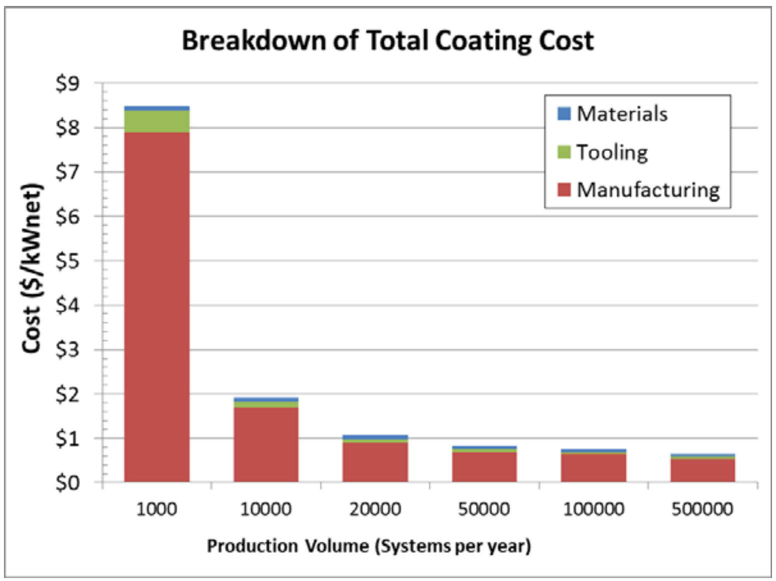
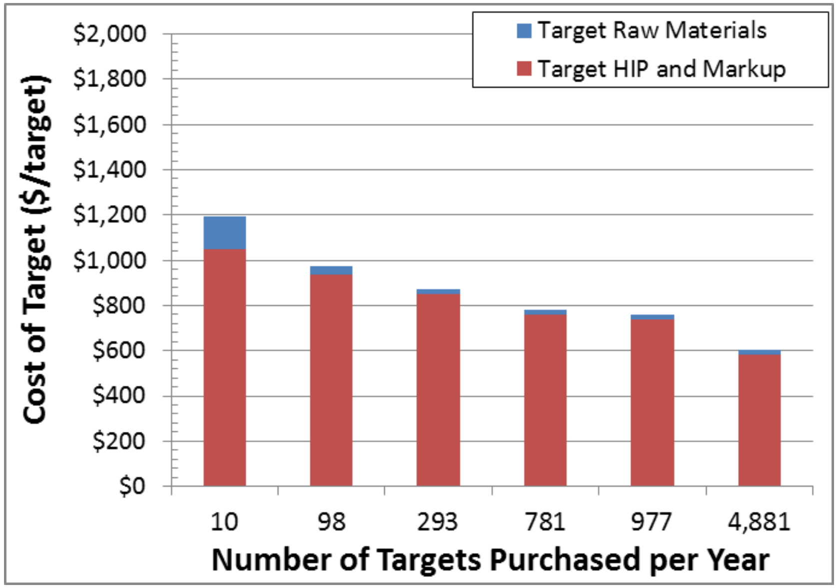
Fabrication Cost Analysis

--- Conducted by Strategic Analysis, Inc.

- 377 BPP assemblies per stack, 1095 mW/cm^2 power density,
- The target material cost is dominated by the manufacture cost. It could be reduced with lower cost manufacture method.
- Total cost of doped TiO_x coating is roughly $0.14/welded pair of plates ($0.85/kW) at 500k sys/year. The largest contributor is the PVD capital cost.





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STRATEGIC ANALYSIS

Planned Future Work

- PVD Process Development
  - Using the methods developed in the project, conduct a detailed investigation of the process conditions and coating layer structure to enable a reliable manufacturing process for large scale production
    - Working with two PVD companies for the process development.
- Doped TiO_x Surface Oxide Characterization
  - Using FIB/STEM, investigate the relation of the surface oxide thickness/composition to the processing condition and its stability under PEM fuel cell operation conditions.
    - Having user agreement with IAC, Princeton University for the access to their facility. Their new equipment, installed last summer, is capable for the task.
- Durability Evaluation
  - *ex-situ* and *in-situ* tests of the doped TiO_x coating for PEM fuel cell applications will be conducted at TreadStone and HNEI, U. Hawaii

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Milestones

- **Milestone 1.1:** *Manufacture Cost Analysis.* By the end of 3rd month, the manufacture cost analysis is finished.
- **Milestone 1.2:** *PVD Process Development.* By the end of 6th month, the target material is prepared and the initial metal plate coating process for has been demonstrated.
- **Milestone 1.3:** *PVD Process Development.* By the end of 9th month, the optimized metal plate coating process development will be finished.
- **Milestone 2.1:** *Doped TiO_x surface layer properties determined*. By the end of 9th month, the properties of the doped TiO_x surface will be determined.
- **Milestone 2.2:** *Compatibility with bipolar plate stamping process characterized.* By the end of 12th month, the feasibility of the doped TiO_x coating on low cost 304 [and 202] stainless steel substrates and as the pre-stamping coating is evaluated.

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Summary

- ***Objective:***
  - Develop low cost fabrication process of the doped TiO_x coating for PEM fuel cell applications.
  - Investigate the relation of the properties of doped the doped TiO_x surface layer with processing condition and its durability in PEM fuel cell operation environment.
- ***Relevance:*** Reducing the metal bipolar plate cost to meet FY20 requirements.
- ***Approach:*** Using doped TiO_x coating on metal plates surface for fuel cell applications.
- ***Accomplishment:***
  - Identified processing factors for the coating layer surface composition control.
  - *Developed a low cost method for coating composition optimization.*
  - Manufacturing cost analysis indicates that the cost of this precious metal free coating technology is lower than other competing technologies.
- ***Future Work:***
  - Detailed development of the PVD process for the optimized coating properties.
  - Investigation the relation of the surface oxide layer properties with processing conditions and its durability.
  - Conduct *ex-situ* and *in-situ* tests to demonstrate the performance of the coating processed with low cost fabrication process.

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Acknowledgements

- DOE EERE Fuel Cell Team.
- DOE SBIR Program.
- Supporting Partners.
    - Strategic Analysis, Inc.
    - HNEI, U. Hawaii

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