Low-Cost Corrosion-Resistant Coated Aluminum Bipolar Plates by Elevated Temperature Formation and Diffusion Bonding

Zhiwei Yang (PI)
Raytheon Technologies Research Center

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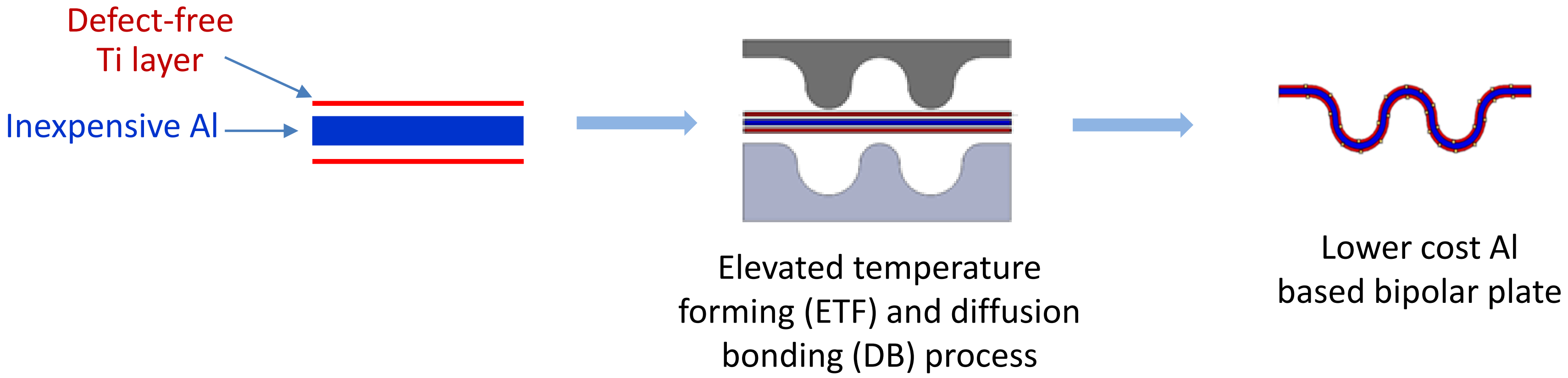
DOE Hydrogen Program
2022 Annual Merit Review and Peer Evaluation Meeting

Project ID: FC344

Raytheon Technologies
Pacific Northwest NATIONAL LABORATORY
TreadStone Technologies, Inc.

Project Goal

- Develop and test a simultaneous forming and defect-free coating process to fabricate low-cost corrosion-resistant coated aluminum for use as bipolar plates for PEM fuel cells.
- Fabricate full-size bipolar plates and demonstrate progress towards meeting HFTO 2030 technical targets for bipolar plates



Overview

Timeline and Budget

- Project Start Date: 12/01/2021
- Project End Date: 11/30/2024
- Total Project Budget: $1,565K
  - DOE Share: $1,252K
  - Cost Share: $313K (20%)
  - DOE Funds Spent*: $65K
  - Cost Share Funds Spent*: $10K

  * As of ~ 03/30/2022

Partners

- Pacific Northwest National Laboratory
  - Kenneth Ross, Christopher Smith
- TreadStone Technologies, Inc.
  - Conghua Wang
- Project lead: Raytheon Technologies Research Center
  - Zhiwei Yang, Rob Darling

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Relevance

- Bipolar plates are one of the crucial components of the PEM fuel cell stack, and significant contributor to the stack weight, volume and costs.
- Low-cost metal bipolar plates and fabrication technique(s) address barriers towards meeting HFTO 2030 cost target ($5/kW) and performance targets for heavy-duty applications.

Barriers	DOE Targets	Project Impact
Cost	5 $/ kW	• Develop Al based metal bipolar plates instead of SS or Titanium alone, and fabrication technique(s) to enable cost targets to be met
Durability	25,000 hrs	• Develop defect-free corrosion-resistant Ti coating and optimize DOTS technology (TreadStone) using carbon particles or gold to meet performance and durability targets
Performance	• Corrosion, Anode (μA/cm^2): < 1, no active peak • Corrosion, Anode (μA/cm^2): <1 • Electrical Conductivity (S/cm): > 100 • Contact Resistance (mΩ.cm^2 at 200 psi): 10	

Project objectives and impacts are directly in-line with HFTO 2030 Targets

Relevance

- Aluminum is lightweight, formable, strong, conductive, and inexpensive but prone to corrosion.
- The proof-of-concept work at PNNL demonstrating the feasibility of elevated temperature forming (ETF) and diffusion bonding (DB) for the formation of dense, pinhole-free titanium coatings for aluminum (Figure 1), which exhibit high corrosion resistance (Figure 2)

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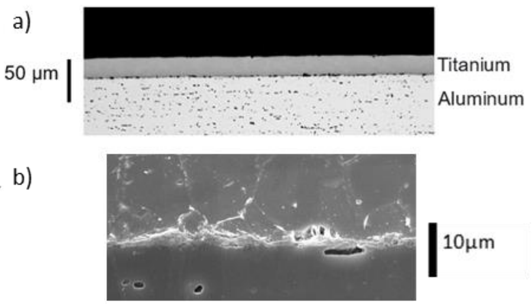


Figure 1. Diffusion bonded Ti to Al

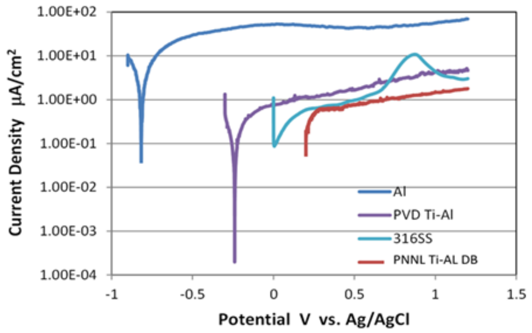


Figure 2. Anodic scan in pH 3 H_2SO_4 and 0.1 ppm HF solution at 80°C

- TreadStone has developed the DOTS technology using gold particles in a DOE funded project, and has used it for PEMFC and PEM electrolyzers applications for 10 years

TreadStone Technologies, Inc.

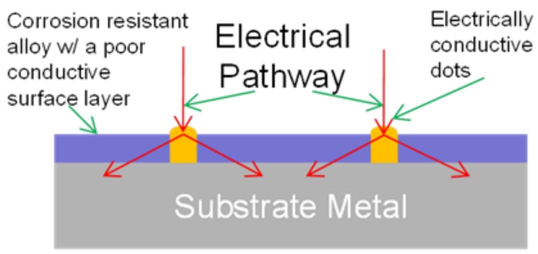


Figure 3. Schematic of DOTS deposition

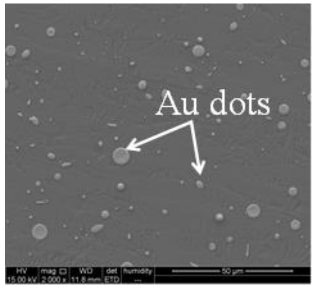


Figure 4. SEM of Au dots on stainless steel plate

Approach – Fabrication Process

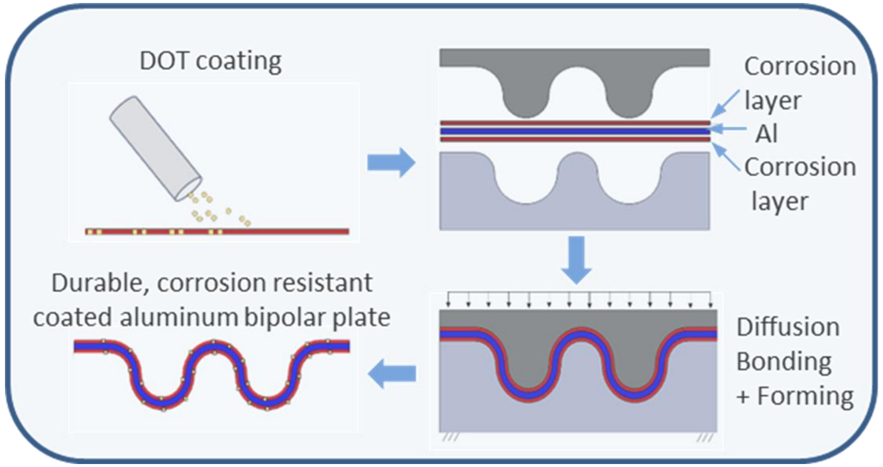
(A) ETF Optimization
- Optimize PNNL ETF process to minimize forming time, die wear, and geometry reproducibility

(B) ETF+DB Optimization
- Incorporate diffusion bonding process into ETF. Optimize for adhesion strength of DB.

(C) Conductivity Optimization
- Minimize contact resistance evolution with incorporation of tracers (PNNL) or DOTs/DuraC (TreadStone)

(D) Bipolar Plate Fabrication and Testing
- Manufacture full size plates and perform in-cell testing

Measurements:
- Channel Reproducibility
- Flexural Strength
- Forming Elongation
- Corrosion Testing
- Area Specific Resistance
- Interfacial Contact Resistance
- Accelerated Stress Testing
- Full scale 100-h Durability Test



Approach – Project schedule

			(A)				(B),(C)				(D)			
Task	Sub	Quarter	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
1	0	Project Management	M1											
2	0	ETF Optimization												
	1	DOE for ETF		M2.1										
	2	Patterned Coupon Fabrication			M2.2									
	3	Meet DOE mechanical property targets				M2.3								
	4	Fully optimize process for final process selection												
3	0	ETF+DB Optimization												
	1	DOE for ETF+DB					M3.1							
	2	Patterned Coupon Fabrication							M3.2					
	3	Fully optimize process for final process selection												
4	0	Bipolar Plate Development												
	1	Bipolar Plate Fabrication										M4.1		
	2	Deliver High Performance Plates to M^2FCT												M4.2
5	0	Specialized Coating Development												
	1	Optimize carbon-based DOT coating					M5.1							
	2	Feasibility assessment								M5.2				
	3	Support bipolar plate fabrication												
6	0	Component Testing												
	1	Initial corrosion testing				M6.1								
	2	Meet DOE technical targets including corrosion								M6.2				
7	0	Cell Testing												
	1	Finalize Cell Design									M7.1			
	2	AST Testing											M7.2	

(A) ETF Optimization, (B) ETF+DB Optimization, (C) Conductivity Optimization, (D) Bipolar Plate Fabrication and Testing

Approach – Y1 Milestones

Milestone Summary Table					
Task #	**Milestone #**	**Milestone Type**	**Milestone Description**	**Anticipated Quarter**	**status**
1	M1.1	Progress	Subcontracts Completed	Q1, 3/31/22	complete
2	M2.1	Progress	Complete statistical design of experiments for ETF process and initial techno-economic analysis for ETF and DB processes	Q2, 6/30/22	*In progress*
2	M2.2	SMART	Generate 10 single material subscale coupons where the generic bipolar plate channel feature is repeatable within ± 15 µm for scanned regions	Q3, 9/30/22	
6	M2.3	Go/No-go	Techno-economic analysis and initial test data establishes that coated or DB bipolar plates fabricated using ETF are projected to meet mechanical technical targets for heavy-duty bipolar plates	Q4, 11/30/22	
3	M6.1	Progress	Corrosion testing of DB subscale coupons fabricated using ETF	Q4, 11/30/22	

Go/No Go Decision Point #1 (Q4)

Techno-economic analysis and initial test data establishes that coated or DB coupons fabricated using ETF are projected to meet mechanical technical targets for heavy-duty bipolar plates. Techno-economic analysis will be performed using the same inputs and assumptions as that performed for automotive fuel cell bipolar plates by Strategic Analysis. The DB coupons will meet the following targets: flexural strength > 40 MPa evaluated per ASTM D790-10; and forming elongation of > 40% per ASTM E2448-18.

Approach – Y2/Y3 Milestones

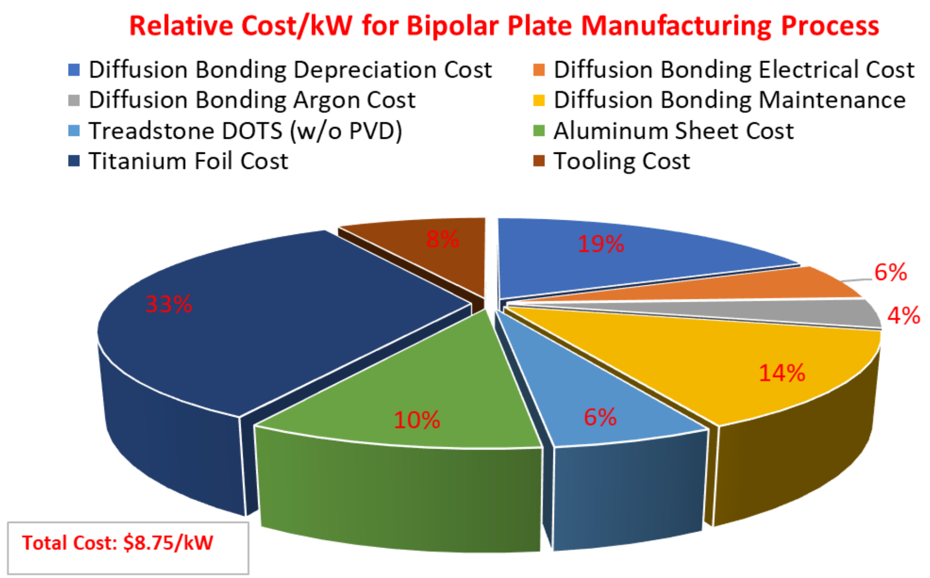
Milestone Summary Table				
Task #	**Milestone #**	**Milestone Type**	**Milestone Description**	**Anticipated Quarter**
3	M3.1	Progress	Complete statistical design of experiments for ETF+DB process	Q5, 3/31/23
5	M5.1	Progress	Optimize DOT coating of carbon-based conductive material and integrate with ETF process	Q6, 6/30/23
3	M3.2	SMART	Generate 10 multi material subscale coupons where the generic bipolar plate channel feature is repeatable within ± 15 µm for scanned regions	Q7, 9/30/23
5	M5.2	Progress	Finalize determination of feasibility and optimal approach of integration of advanced coating into bipolar plate forming process.	Q8, 11/30/23
6	M6.2	Go/No-go	Techno-economic analysis and corrosion testing establishes that fabricated bipolar plates are projected to meet technical targets for heavy-duty bipolar plates	Q8, 11/30/23
7	M7.1	Progress	Finalize design of full-size test cell for fuel cell testing	Q9, 3/31/24
4	M4.1	Progress	10 full size bipolar plates are provided for coating and testing	Q10, 6/30/24
7	M7.2	SMART	Accelerated stress testing of subscale fuel cells and full-size cell testing for 100 h with ICR increase of < 1 mΩ cm^2	Q11, 9/30/24
4	M4.2	Final	Final report submitted to HFTO including a detailed assessment of the cost and manufacturability of the bipolar plates and 6 subscale plates provided to M2FCT for independent testing and evaluation	Q12, 11/30/24

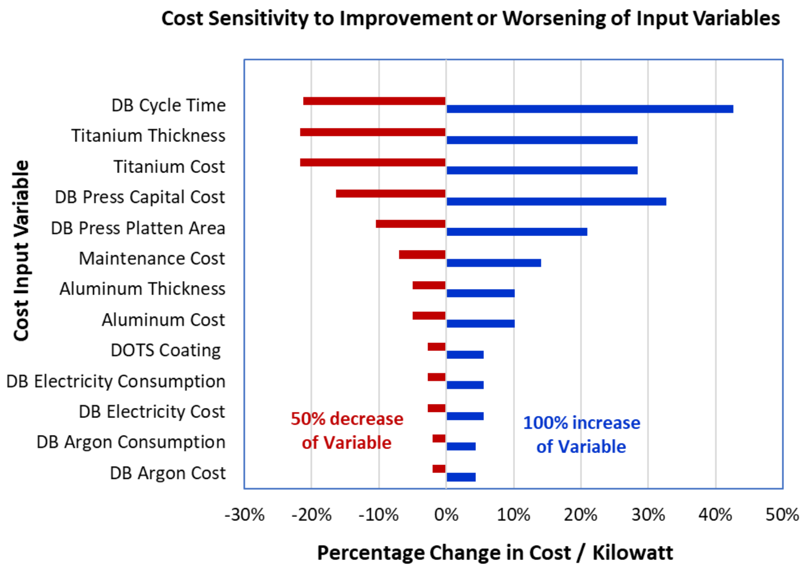
Go/No Go Decision Point #2 (Q8)

Techno-economic analysis and test data establishes that formed bipolar plates meet technical targets for heavy-duty bipolar plates. Techno-economic analysis will be performed using the same inputs and assumptions as that performed for automotive fuel cell bipolar plates by Strategic Analysis. In addition to the technical targets met in M2.3, the bipolar plates will meet the following technical targets: anode corrosion of <1 $\mu A/cm^2$ and no active peak under the testing conditions described in Task 6; cathode corrosion of <1 $\mu A/cm^2$ under the conditions for cathode corrosion testing described in Task 6; and area specific resistance of <0.01 $\Omega\ cm^2$.

Accomplishments and Progress

- RTRC and TreadStone completed a subcontract on 12/16/21.
- The kick-off meeting with DOE was held on 2/7/22.
- RTRC delivered a Hydrogen Safety Plan to DOE on 2/25/22.
- PNNL completed the validation die design and the initial TEA.





- The initial techno-economic analysis shows the main cost factors include materials (43%, with 0.5mm Al and 0.025 mm Ti foil), machine depreciation (19%) and maintenance (14%).
- The sensitivity analysis indicates that the total cost can be significantly reduced by improving diffusion bonding cycle time and using thinner/lower-cost Ti & Al.

Responses to Previous Year Reviewer's Comments

- This project was not reviewed last year.

Collaborations

Company	Role	Logo
Raytheon Technologies Research Center	• Project lead • Corrosion Testing • Electrical Testing • Accelerated Stress Testing • 100-Hr full-cell durability test	Raytheon Technologies
Pacific Northwest National Laboratory	• ETF+DB Process Optimization • Bipolar Plate Fabrication • Mechanical Testing	Pacific Northwest NATIONAL LABORATORY
TreadStone Technologies, Inc.	• DOTs Optimization	TreadStone Technologies, Inc.

Remaining Challenges and Barriers

- **Challenge:**
  - Engineering challenges associated with die design and forming process development for extremely small tolerances and complex geometries needed for next generation bipolar plates
  - The proposed plates have not yet been operated within a fuel cell. Issues may exist that were not exposed by prior testing and analysis.

- **Planned Resolution:**
  - Much of the key technical risks of this technology have been addressed through the proof-of-concept work performed by PNNL. The remaining risk is mitigated by PNNL's leading expertise in solid-phase processing.
  - This risk is mitigated by the expertise in fuel cell design, testing and failure analysis brought by RTRC, and experience in the development of corrosion barriers for metal bipolar plates brought by TreadStone.

Proposed Future Work

a) **ETF Optimization (Q1-Q8)**
   - iterative tooling design and experimental processes optimization to minimize forming time, die wear and variation in channel geometry

b) **ETF+DB Optimization (Q3-Q10)**
   - the simultaneous ETF and DB process optimization

c) **Bipolar Plate Development (Q9-Q12)**
   - process development and fabrication of full-scale bipolar plates for testing and evaluation

d) **Specialized Coating Development (Q1-Q12)**
   - develop low-cost coating technology to reduce the surface contact resistance of the aluminum based bipolar plates using DOTS

e) **Component Testing (Q3-Q8)**
   - corrosion testing of ETF, ETF-DB, and DOT-coated ETF-DB test articles

f) **Cell Testing (Q9-Q12)**
   - subscale and full cell fuel cell testing using cells constructed with bipolar plate test articles.

Summary

- **Objective**: Develop and test a simultaneous forming and defect-free coating process to fabricate low-cost corrosion-resistant coated aluminum for use as bipolar plates for PEM fuel cells

- **Relevance:** This project addresses fuel cell cost and durability by developing low-cost corrosion-resistant coated aluminum bipolar plates and fabrication techniques. The project is directly in-line with HFTO 2030 Targets.

- **Approach:** The project will leverage RTRC's world-class expertise in PEM fuel cell development and testing with PNNL's leading expertise in solid-phase processing, and TreadStone's experience in the development of corrosion barriers for bipolar plates to rapidly develop Al based bipolar plates that aims to meet the HFTO 2030 technical and cost targets for bipolar plates.

- **Accomplishments:** completed subcontracts, PNNL completed the validation die design and the initial TEA.

- **Collaboration:** RTRC, PNNL and Treadstone are working together and will engage others within the fuel cell and manufacturing communities as appropriate.

Technical Backup and Additional Information

Technology Transfer Activities

- RTX has an established history of licensing PEMFC technology to others. This is expected to continue, so any IP generated during this project by RTRC could be made available to automotive OEMs.
- The team for this project includes TreadStone, world leader in metal bipolar plate corrosion resistant coating technologies. TreadStone has scaled up and commercialized the DOTS technology for fuel cell and electrolyzer applications. The success of the proposed project will further reduce the cost of the metal plate coating technology for broad commercial markets that TreadStone has been focused on. It is expected that TreadStone will bring this technology to market in 2023-2024.