Pacific Northwest
NATIONAL LABORATORY

Solid Phase Processing for Reduced Cost and Improved Efficiency of Bipolar Plates

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PNNL-SA-142441

Solid Phase PROCESSING

Overview

Timeline

Start date: October 2018

End date: September 2020

Barriers

B) Cost

C) Performance

A) Durability

Budget

Planned DOE funding for FY19: $500K

(includes 50K to industrial partner)

Planned DOE funding for FY 20:$500K

(includes 50K to industrial partner)

Industry cost share: $20K

Partners

Treadstone, Inc.

Arconic

Relevance

Directly Aligned with FCTO Multi-year plan

Primary Objective:

This work aims to develop and demonstrate methods to fabricate bipolar plates such that all 2020 technical targets for bipolar plates, including cost, are satisfied or surpassed.

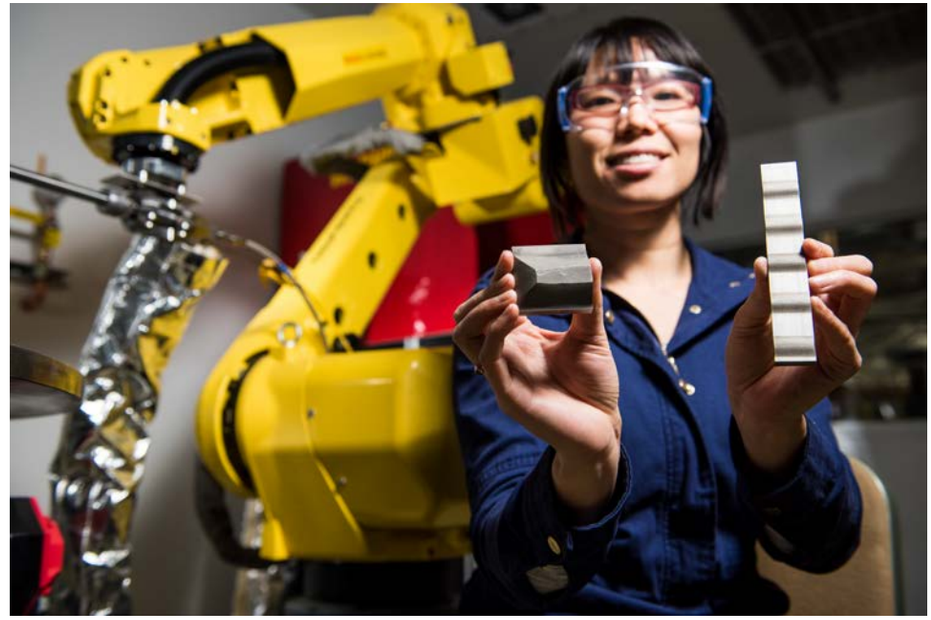
Barriers	Project Impact
B. Cost	Develop fabrication concept and execute techno-economic analysis to showing 2020 bipolar plate cost target is met (< 3 $/kW$_{net}$)
C. Performance	Develop fabrication concept and execute laboratory testing showing: Plate weight ≤ 0.4kg/kW$_{net}$; Plate H_2 permeation coefficient <1.3 x $10^{-14,f}$ @ 80°C, 3 atm 100% RH; Corrosion, anode < 1 µA / cm^2 and no active peak; Corrosion, cathode < 1 µA / cm^2; Electrical conductivity > 100 S / cm; Areal specific resistance <0.01 ohm cm^2; Flexural strength > 25 MPa; Forming elongation ≥ 40%.
A. Durability	Improved durability of bipolar plates. Reduced areal specific resistance and through plate electrical conductivity. This results in less thermal load which could be beneficial to durability of other components in the fuel cell

Project objectives and impacts are directly in-line with FCTO Fuel Cell Task 3 and 2020 Technical Targets.

Approach

Unique design strategy, material sets and fabrication methods

- Multi material design ***must*** be used to meet conflicting technical and cost targets
  - This includes, but is not limited to, a base material and a corrosion barrier coating.
- Use lower cost, high performance material
  - Aluminum coated with a thin titanium layer is an example of a material combination with improved performance and dramatically reduced cost relative to current methods for bipolar plate fabrication
- Superior manufacturing processes
  - Cold spray, a sold phase process (SPP), can apply metal coating orders of magnitude faster than currently used vapor deposition techniques
  - Improved forming methods are faster and lower cost



Background: PNNL's high velocity cold spray system
Foreground: PNNL researcher with cold sprayed coupons.

Aluminum 6061 substrate coated with commercially pure nickel using PNNL cold spray equipment

Approach

High Velocity Cold Spray is a superior coating process

- Cold spray is a solid phase deposition process
- ~5 - 45µm particles are propelled at Mach 1-4
- Carrier gas is nitrogen or helium
- Impact energy causes extreme plastic deformation creates grain refinement and metallurgical bonds
- Deposition rates up 8kg/hour+ depending on material and equipment per nozzle
- Cold spray enables superior economics through higher deposition rates and lower material costs

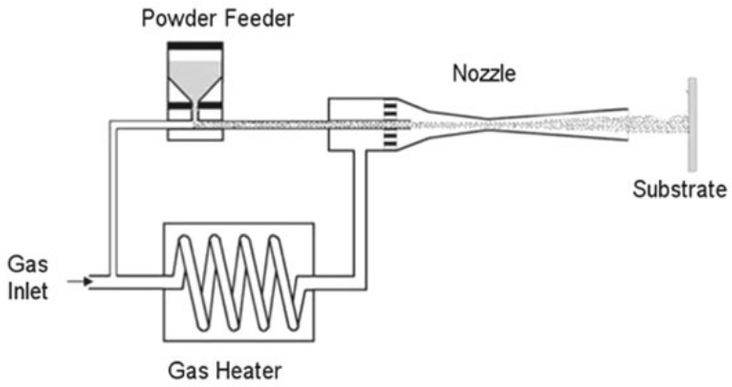


Image courtesy of the Army Research Lab
https://www.arl.army.mil/www/default.cfm?page=370

Approach

Project Plan is focused on 2020 bipolar plate technical targets

Project Plan Summary:

- Identify the fabrication concepts with the greatest potential to meet or surpass 2020 technical targets, including cost, for bipolar plates.
- Iterative coupon level development is done iteratively to ensure design criteria is met
- Development is repeated at subscale to ensure design criteria are met for complex channels
- Fabricate and test a full scale prototype plates using developed concept
- Show via laboratory testing and techno-economic analysis that developed methods to meet or surpass 2020 technical targets, including cost, for bipolar plates.

- Tasks

1. Parametric Cost Analysis and Concept Scoring Tool 2. Process Development- coupon level 3. Process Characterization 4. Subscale Forming Study	FY 19
5. Subscale Characterization 6. Full Scale Forming Study 7. Full Scale Characterization 8. Final Report and Publication	FY 20

Approach

Progress is measured against well defined performance indicators

#	Name	Criteria	Due date
1	Selection of fabrication concepts	FCTO project managers approval of the tool and selected fabrication concepts	1/31/2018 Done
2	Coupon Generation	Coupons are provided to the mechanical and environmental test lab at PNNL	3/31/2019
3	Forming tolerance verification	Channel profile on 10 coupons are within +/15μm as measured using optical profilometry.	6/30/2019
4	Technical basis established for achieving technical targets for bipolar plates	Forming elongation ≥ 32% per ASTM E8 (80% of the 2020 target) at temperatures and strain rates representative of the forming processes. Fabricated coupons will also demonstrate electrical conductivity > 80 S/cm (80% of the 2020 target).	9/30/2019 Go/No-Go
5	Completion of subscale forming study	Fabricated subscale plates are provide to the mechanical and environmental test lab at PNNL	12/31/2019
6	Completion of full scale forming study	Fabricated full scale plates are provide to the mechanical and environmental test lab at PNNL	3/31/2020
7	Bipolar plates targets achieved	Test data and analysis reported showing all 2020 technical targets (except cost) are met.	6/30/2020
8	Business/economic analysis	Final report submitted to FCTO that includes the analysis supporting compliance with the 2020 technical targets (including cost)	9/30/2020

Approach

Best practices of product design applied to select fabrication concepts

- This first objective of this project is to identify the fabrication concepts with the greatest potential to meet or surpass 2020 technical targets for bipolar plates.
- This was accomplished by creating a simplified cost analysis and concept scoring tools
  - Cost analysis
    - ✓ uses simplified cost model from Strategic Analysis Inc.[1]
    - ✓ Is an input to the concept scoring tool
  - Concept scoring
    - ✓ A best practice for product development and design
    - ✓ employs simplified models and best estimates to down selecting the most likely concepts to succeed from a multitude of ideas
    - ✓ baseline design is the Dots-R coating of SS 316 by TreadStone Technologies, Inc.[2]
    - ✓ enables scoring and ranking of concepts based on weighted selection criteria

1 Huya-Kouadio, Jennie Mariko, Brian David James, and Cassidy Houchins. “Meeting Cost and Manufacturing Expectations for Automotive Fuel Cell Bipolar Plates.” *ECS Transactions* 83, no. 1 (January 4, 2018): 93–109. https://doi.org/10.1149/08301.0093ecst.

2 https://www.energy.gov/sites/prod/files/2017/05/f34/fcto_biploar_plates_wkshp_wang.pdf

Accomplishments

Creation of tool to rank concepts relative to FCTO Technical Targets

- Cost values are estimated using the simplified cost model
- Ratings are improvement relative to the baseline value

Note: user inputs are shown in **blue**

		Category 1				Categ			
		Concept 1A		Concept 1B		Concept 2A		Concep	
Selction Criteria	Criteria Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	W
Low Cost	30.0%	1.92	0.58	1.52	0.46	2.45	0.74	1.01	
Light weight	7.5%	3.20	0.24	3.20	0.24	1.00	0.08	3.20	
Low Plate H2 Permeation Coefficient	7.5%	1	0.075	1	0.075	1	0.075	1	
Corrosion resistance	15.0%	1	0.15	1	0.15	1	0.15		
Electrial Conductivity	10.0%	2	0.2	2	0.2	1	0.1		
Low Areal Specific Resistance	15.0%	2	0.3	2	0.3	1	0.15		
Flexural Strength	7.5%	1	0.075	1.5	0.1125	1	0.075		
Forming elongation	7.5%	2	0.15	2	0.15	2	0.15		
	Total Score	1.77		1.68		1.51			
1.00	Rank	5		6		9			

3 Fabrication Concepts Selected

- 3 fabrication categories emerged from top scoring concepts. Concepts within each category represent variations of an overarching fabrication strategy.
  - Category 1: Novel forming process followed by cold spray coating
    - ✓ Low technical risk
  - Category 2: Cold spray coating prior to a novel forming process
    - ✓ Lower technical risk and higher probability of exceeding cost targets
  - Category 3: Proprietary
    - ✓ Moderate technical risk but has the highest potential to exceed cost and technical targets
    - ✓ Enables improved process intensification and enables improved multi-material designs
- Details on concepts scoring and design concepts will not be presented at in AMR due to business sensitivity around evolving IP. Please contact the PI for additional information.

Response to Previous Year Reviewer's comments

Project was not reviewed last year

Project Team

Company	Role	Logo
Pacific Northwest National Laboratory	• Project lead, responsible for execution of project tasks and coordinating with collaborators • Provides leadership in: Advanced manufacturing, materials and design • Executes experimental work	
TreadStone Technologies (Formal Collaborator)	• Has a sub contract to support this effort and are providing cost share • Execute corrosion barrier development with PNNL • provide industrial guidance	
Arconic (Formal Collaborator)	• Provide industrial guidance and feedback • Provide high volume material costing • Arconic will provide access to subject matter experts for materials or production processes of interest	
Strategic Analysis (Informal collaborator)	Provided simplified cost model and assisted with PNNL modifications for use with concept scoring	

PNNL and Treadstone

PNNL role

- Project lead, responsible for execution of project tasks and coordinating with collaborators
- Provides leadership in: Advanced manufacturing processes, product design, multi-material design, dissimilar material joining and relevant testing techniques. The bulk of the experimental work will be done in PNNL's Solid Phase Processing Lab.

Treadstone Technologies: Formal Industrial collaborator

- Has a sub contract to support this effort and are provide cost share and
- Execute corrosion barrier development with PNNL
- provide industrial guidance

PNNL provides advanced manufacturing and materials leadership

TreadStone provides corrosion barrier expertise and is a bipolar plates industry stakeholder

Arconic and Strategic Analysis

Arconic: Formal Industrial collaborator

- Provide industrial guidance and feedback
- Provide high volume material costing
- Arconic will provide access to subject matter experts for materials or production processes of interest
- Fabrication of titanium and aluminum components for aerospace and automotive core competencies of Arconic

Strategic Analysis: Informal industrial collaboration

- Provided simplified cost model and assisted with PNNL modifications for use with concept scoring

Arconic has access to pricing and strategy around mass production using materials of interest and is an industrial stakeholder for automotive manufacturing

We are leveraging work done by Strategic Analysis

Existing project plan

Remainder of FY19

- Iterative coupon level development is for the three selected fabrication concepts
- Go/No-Go: Technical basis established for achieving technical targets
  - ✓ demonstrate forming elongation ≥ 32% per ASTM E8 (80% of the 2020 target) at temperatures and strain rates representative of the forming processes.
  - ✓ Fabricated coupons will also demonstrate electrical conductivity > 80 S/cm (80% of the 2020 target).

FY 20

- Development is repeated at subscale to ensure design criteria are met for complex channels
- Fabricate and test a full scale prototype plates using developed concept
- Show via laboratory testing and techno-economic analysis that developed methods to meet or surpass 2020 technical targets, including cost, for bipolar plates.

Any proposed future work is subject to change based on funding levels.

Proposed Future Work

Reduced risk through developing multiple concepts in parallel

- Milestone 4: Technical basis established for achieving technical targets for bipolar plates
  - Go/No Go Due on 9/30/2019
  - demonstrate forming elongation ≥ 32% per ASTM E8 (80% of the 2020 target) at temperatures and strain rates representative of the forming processes.
  - Fabricated coupons will also demonstrate electrical conductivity > 80 S/cm (80% of the 2020 target).
  - This milestone is critical because it justifies or refutes continuation of this project

Risk Mitigation

- Concept generation and scoring yielded multiple paths to achieving performance criteria required by milestone 4.
- Multiple fabrication concepts are being developed in parallel to reduce risk

Any proposed future work is subject to change based on funding levels.

Multiple Provisional Patents Applications in Preparation

- Provisional patents in process relative to
  - Material selection
  - Design strategies
  - Fabrication techniques

Summary Slide

Objective: Develop and demonstrate methods to fabricate bipolar plates such that all 2020 technical targets for bipolar plates are satisfied or surpassed

Relevance: This project directly addresses fuel cell cost, durability and performance through improved bipolar plate materials and fabrication techniques. This project aims to achieve all technical targets and tasks related to bipolar plates in the FCTO multi-year plan

Approach: This project will leverage multi-material design strategies and relevant manufacturing processes. Concepts are generated and ranked using best practices of product design and development. Processes development is done for top ranked concepts and coupons are tested to validate performance. Full scale prototypes are fabricated, tested and economic analysis is done to validate achievement of cost and performance targets

Accomplishments: Identified concepts with the highest likelihood to meet targets and started process development.

Collaboration: PNNL and industry collaborators, Treadstone and Arconic, are working together and engaging others within the fuel cell and manufacturing communities as appropriate.

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Thank you

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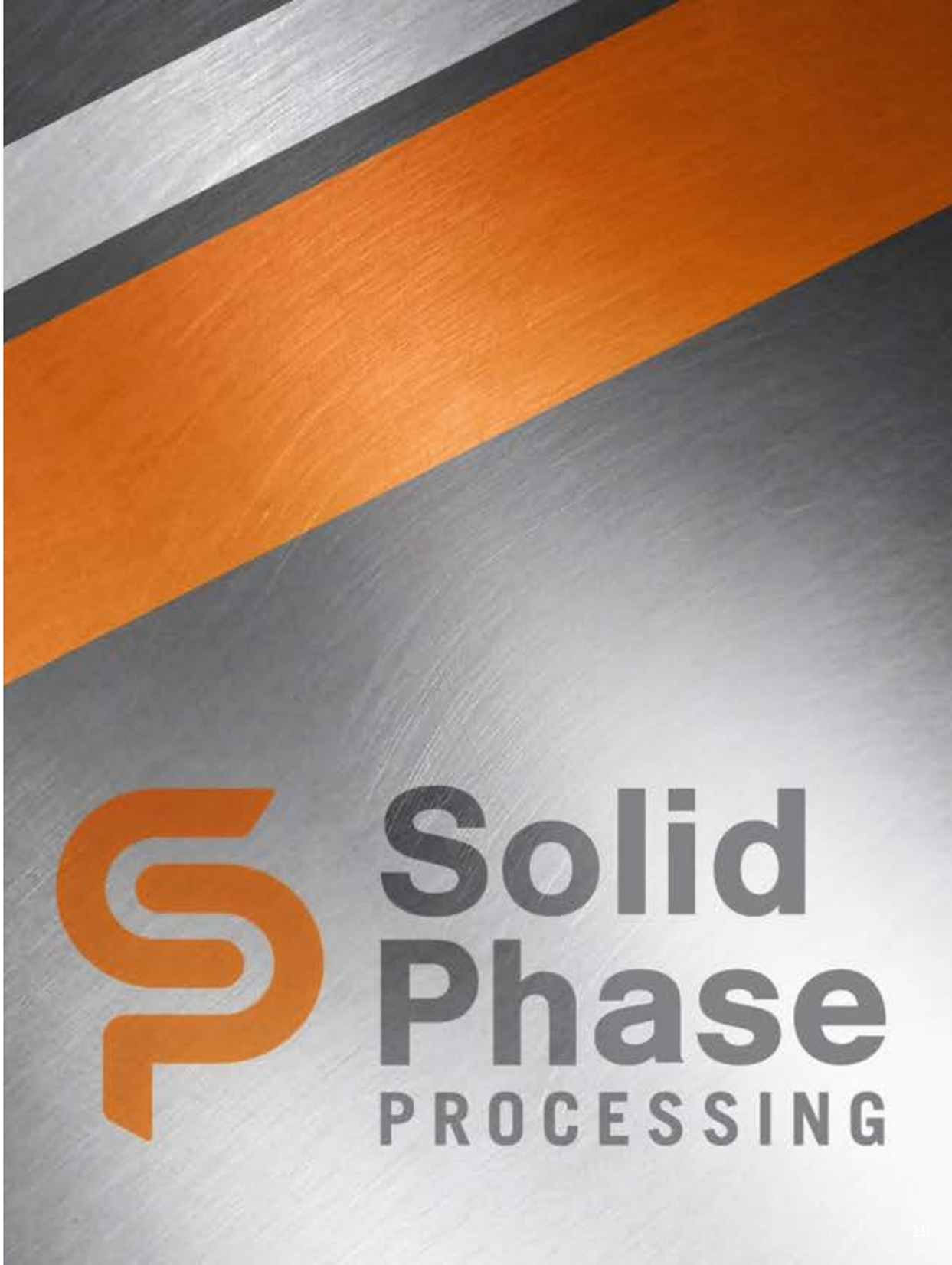

Critical Assumptions and Issues

- Note: This slide is for the use of the Peer Reviewers only; it is not to be presented at the AMR. These Reviewer-Only slides will be included in the file made available to reviewers.

Critical Assumptions and Issues

- Due to evolving IP details about developed concepts cannot be disclosed in this presentation.
- The PI is working to appropriately protect IP around developed concepts sufficiently for it to be disclosed later this FY.