LumiShield





Inexpensive and Sustainable Anti-Corrosion Coating for Power Generation Applications

09/27/2019

DOE Award # FE0031659

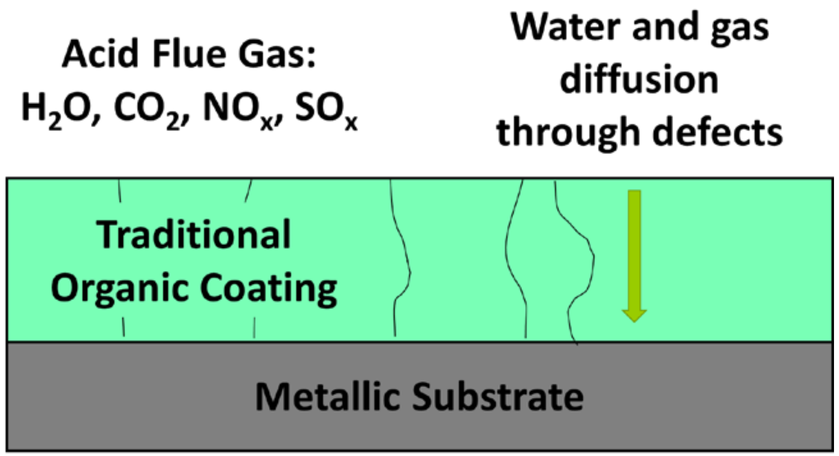
Dr. John Watkins, Principal Investigator

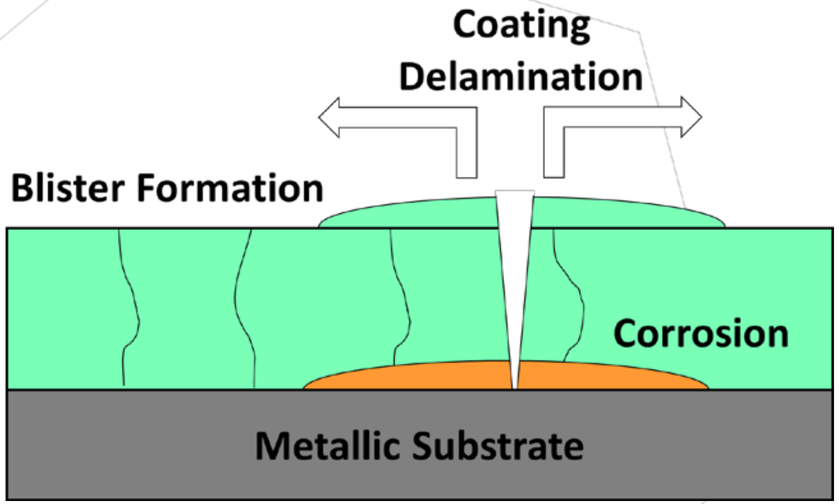
NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL/DOE Federal Project Manager Sai Gollakota

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

Motivation





Stainless Steel

- Good corrosion resistance.
- High price.

Mild Steel

- High strength, less material.
- Vulnerable to corrosion.
- Low price.

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Project Overview

Key Objectives:

1. **How much does the LumiShield coating improve corrosion resistance?**
   - ➢ Lab scale demonstration of aluminum oxide primer coating on carbon steel for carbon capture processes.
   - ➢ Optimize top-coating chemistry to maximize adhesion to LumiShield aluminum oxide coating, acid resistance and amine resistance.
   - ➢ Characterize coatings in simulated and realistic flue gas conditions.

2. **How much stainless steel is replaceable by mild steel with LumiShield coating?**
3. **How much does this alternative save in capital and operating costs?**
   - ➢ Complete cost-benefit-analysis for completed composite and compare with existing coatings and materials.

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Project Budget – By Category

Project Cost				
Project Task	**Government Share ($)**	**Recipient Share ($)**	**Total Cost ($)**	**% of Project Total**
Budget Period 1	**10/01/2018 – 09/30/2019**			
Budget Period 1 Totals:	$460,046	$115,012	$575,058	53.5%
Budget Period 2	**10/01/2018 – 09/30/2019**			
Budget Period 2 Totals:	$400,444	$100,111	$500,555	46.5%
Project Totals:	**$860,490**	**$215,122**	**$1,075,612**	**100%**

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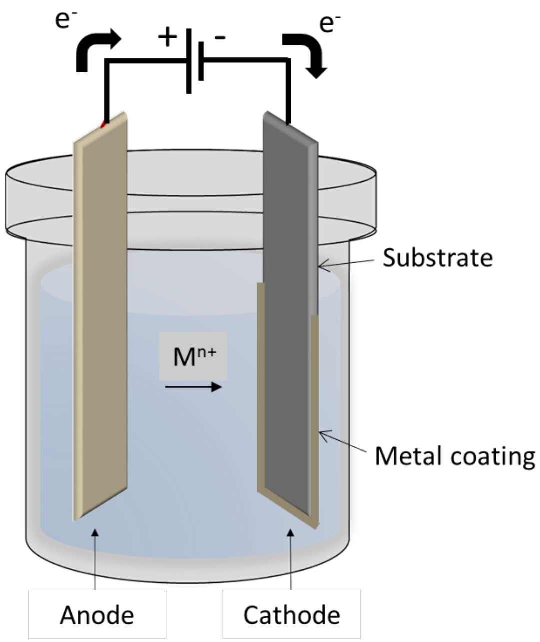
Background

<u>How Do Electroplated Coatings Work?</u>

- Cathode (part to be plated)
- Anode (donor metal or supporting process)
- Electrolyte (charge carrier)
- Electrical source (Reaction driver)



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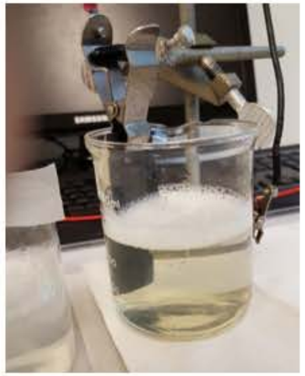
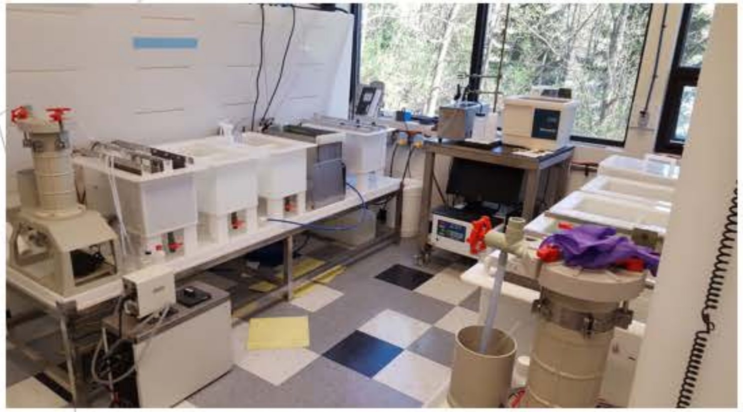
Background





2014 **2016** **2019**

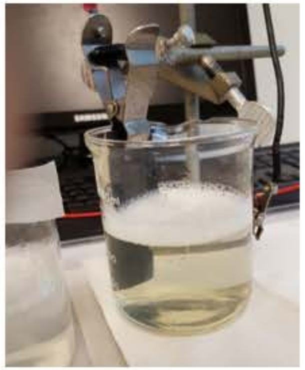
Research Scale 10 – 1000mL

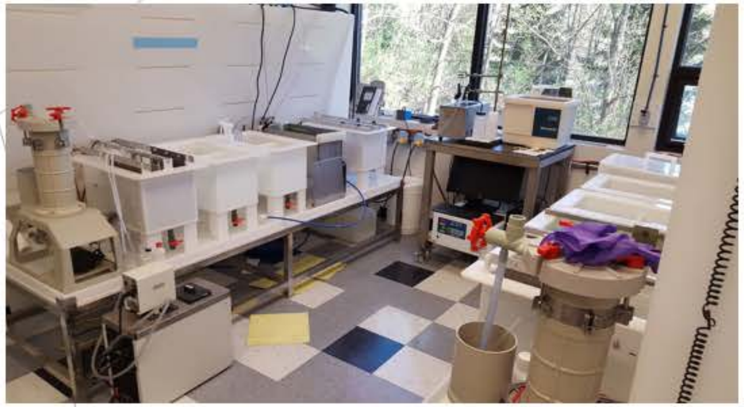
Bench Scale 3-5L

Development Scale 5 Gallon

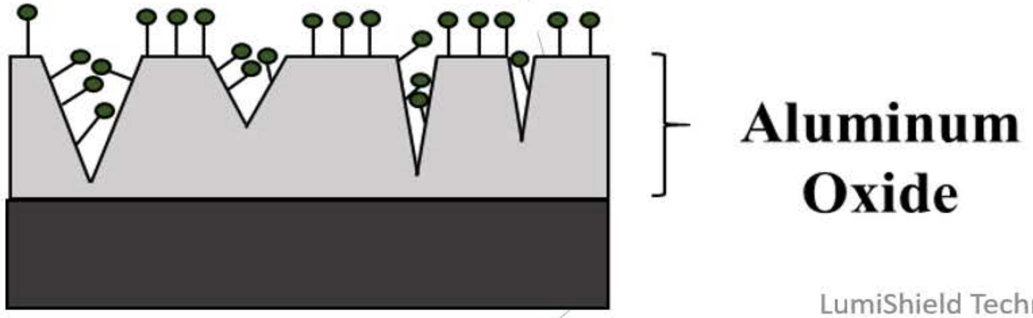
Base Metal

Background





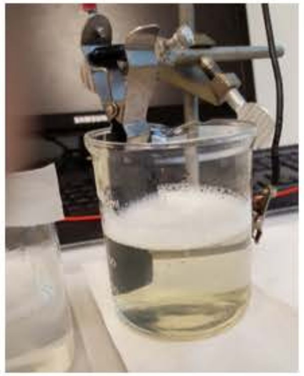
2014	2016	2019
Research Scale 10 – 1000mL	Bench Scale 3-5L	Development Scale 5 Gallon



1. LumiShield Aluminum Oxide Plating

LumiShield

Background

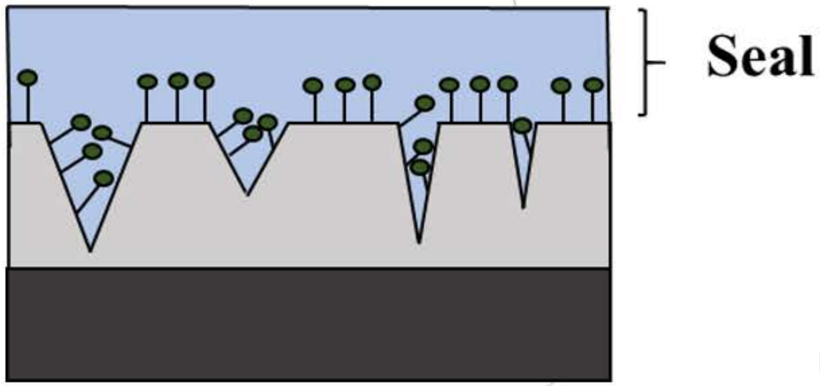


2014 → 2016 → 2019

Research Scale 10 – 1000mL

Bench Scale 3-5L

Development Scale 5 Gallon



1. LumiShield Aluminum Oxide Plating
2. Organic Seal Application

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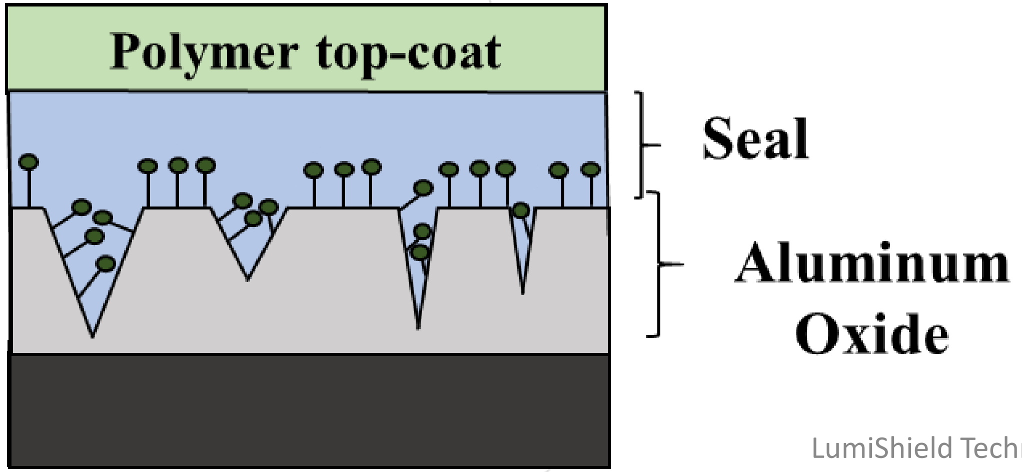
Background

2014	2016	2019
Research Scale 10 – 1000mL	Bench Scale 3-5L	Development Scale 5 Gallon



1. LumiShield Aluminum Oxide Plating
2. Organic Seal Application
3. Powder or Paint Top-Coat Application

Background

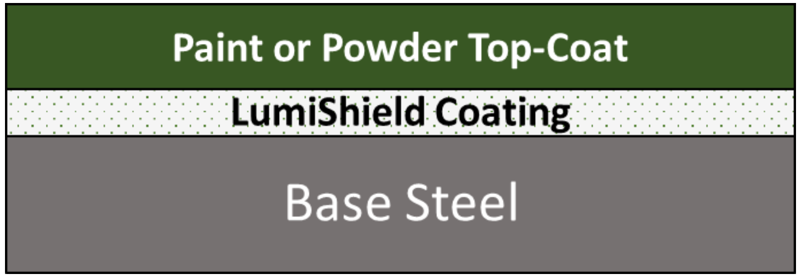
The LumiShield Coating is an Enabling Technology for Carbon Capture Systems

Advantages

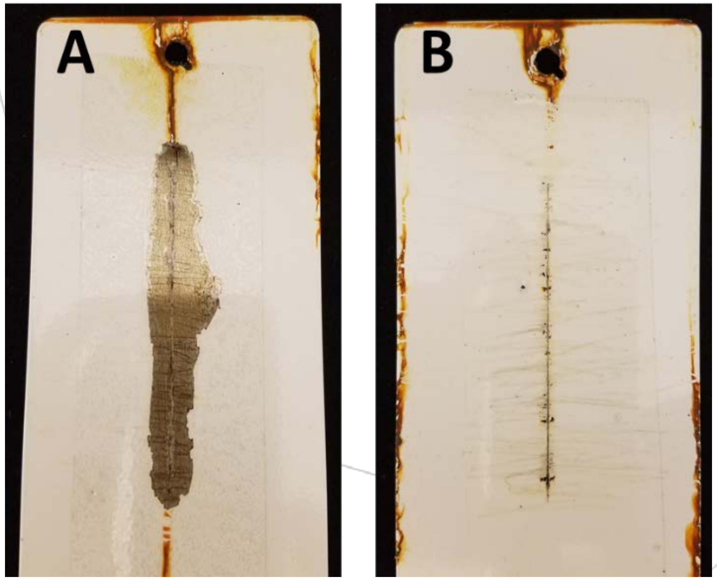
- Can be made acid and amine resistant with suitable top-coats.
- Cost effective coating to replace stainless steel construction.
- Non-toxic coating to replace heavy metal-based processes.

Challenges

- Electroplated coating best for fabrication but can be challenging as point of use technology.



500 Hours of Salt Spray Exposure



Phosphate + Epoxy Primer

LumiShield Coating

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Project Scope

BP1 – 10/01/2018 – 09/30/2019	BP2 – 10/01/2019 – 09/30/2020
Task 1 Project Management and Planning	
Task 2 Base Coating Optimization	**Task 5** Organic Coating Development
Task 3 Proof-of-Concept Testing	**Task 6** Final Cost Benefit Analysis and State Point Data Table
Task 4 Preliminary Cost Benefit Analysis and State Point Data Table	

Success Criteria	
At least one of the prototype coatings should show a 10% increase in equivalent salt spray hours in the presence of the alumina base coat.	**BP1**
At least one of the coatings should result in a decrease in cost per tonne CO_2 of 1% or greater.	**BP2**

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Technical Approach

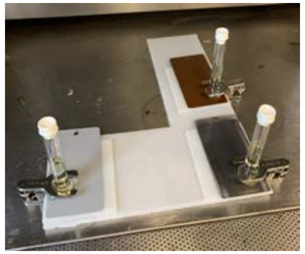
Aluminum Oxide Optimization

- Solution Parameters
- Process Parameters

- Microscopy
- Electrochemical Testing
- Corrosion Testing

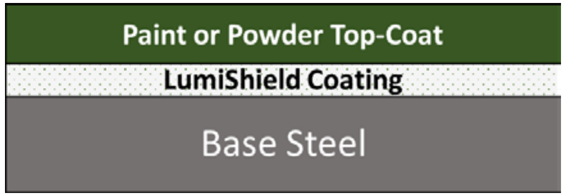
Top-Coat Optimization

- 3 top-coat classes
  - Epoxy
  - Phenolic
  - Fluoropolymer
- Test on steel vs. LumiShield coated steel.



Composite Optimization

- Optimized aluminum oxide coating mixed with best top-coat.
- Iterations of different top-coat compositions tested.
- Real flue gas exposure testing for different composite coatings.



Cost Benefit Analysis

- Collaboration with AECOM.
- Preliminary cost benefit analysis and state point data table after BP1.
- Updated at the end of BP2.
- Consider materials, labor and lifetime costs vs existing materials and coatings.

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Project Milestones

Budget Period	ID	Task Number	Description	Planned Completion Date	Actual Completion Date	Verification Method
1	M-A	1	**Updated Project Management Plan**	**October 30, 2018**	**October 24, 2018**	**Project Management Plan file**
1	M-B	1	**Kickoff Meeting**	**December 31, 2018**	**January 24, 2019**	**Presentation file**
1	M-C	2	**Select Optimal Fabrication Parameters for Preparation of Dense Base Coatings with High Surface Roughness**	**June 30, 2019**	**June 26, 2019**	**BP1 Q3 Report**
1	M-D	3	**Complete Preparation of 3 Benchmark Organic Coatings**	**March 31, 2019**	**March 31, 2019**	**BP1 Q2 Report**
1	M-E	3	**Complete Characterization of 3 Prototype Organic Coatings**	**June 30, 2019**	**June 26, 2019**	**BP1 Q3 Report**
1	M-F	4	Complete Cost Benefit Analysis Development	September 30, 2019		BP1 Annual Report
2	M-G	5	Complete Screening of 9 Commercial Organic Coatings with Alumina Base Coat	March 31, 2020		BP2 Q2 Annual Report
2	M-H	5	Evaluate 5 Phenolic Materials Produced with Different Cross-linker Species as Organic Coatings	September 30, 2020		Final Report
2	M-I	6	Update Cost Benefit Analysis with Optimized Coating Data	September 30, 2020		Final Report

BP1 Progress

Task 2 – Base Coating Optimization: Solution

Plating Chemistry Optimization

Variable
Solution pH
Nickel strike undercoating
Metal concentration
Temperature

Bath	[Al(LS)]	[Zr(LS)]	$[NH_4Cl]$ Electrolyte /M	pH
1	High		0.5	3.0
2	Medium		0.5	3.0
3	Low		0.5	3.5

Result

- Ni not required for thin paint adhesion coatings. Removes processing step.
- Low temperature gives better, denser coatings.
- Low pH better but pH lower than 3 unstable.
- Low [M] better but lower than 0.3M unstable.

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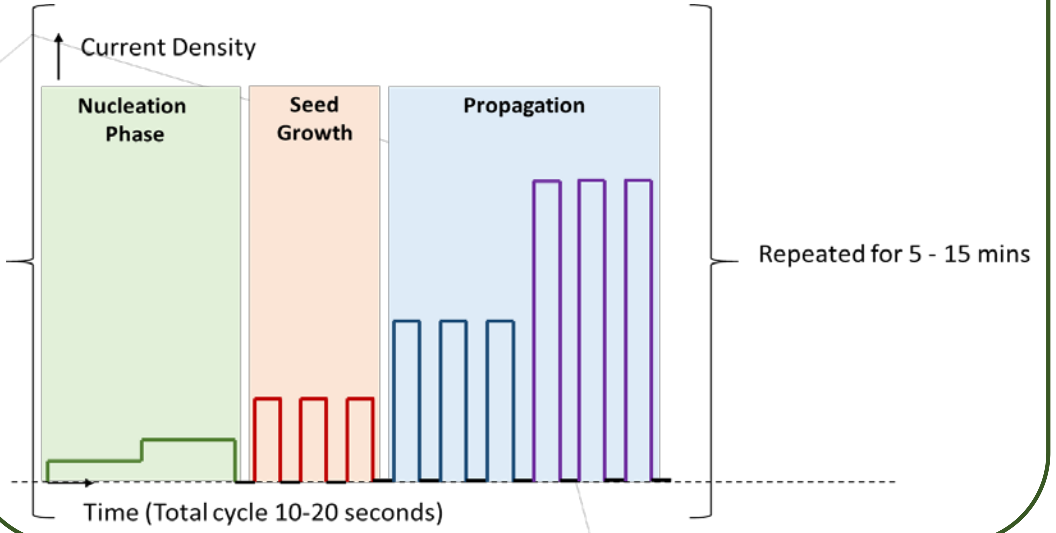
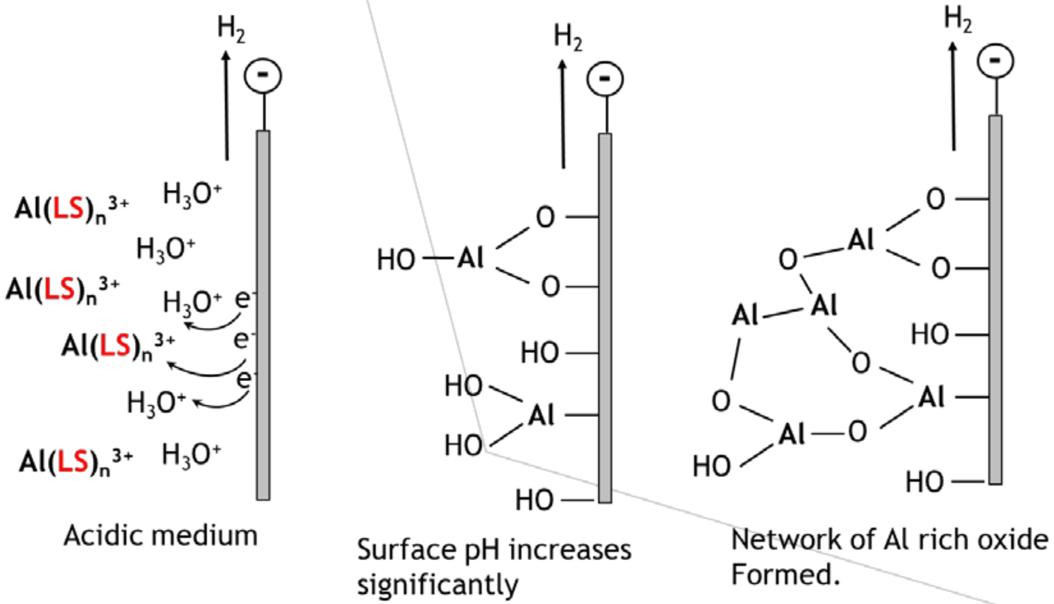
BP1 Progress

Process Variables

Variable	Limits
Pulse Scheme	DC, Pulsed
Peak Current Density / mA/cm²	Low - high
Pulse timing / s	0 – 0.2





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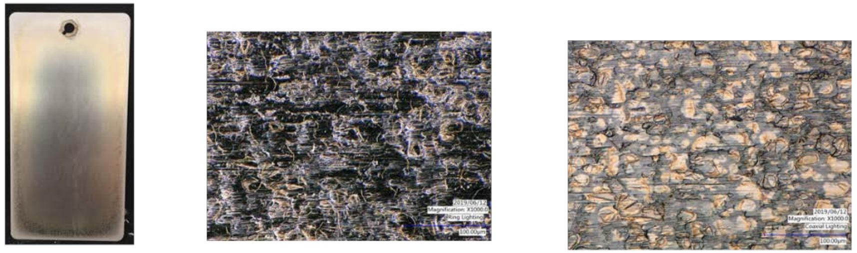
BP1 Progress

Task 2 – Base Coating Optimization: Process

Sample Generation

Run #		Ring Light 1000x	Coaxial Light 1000x

2



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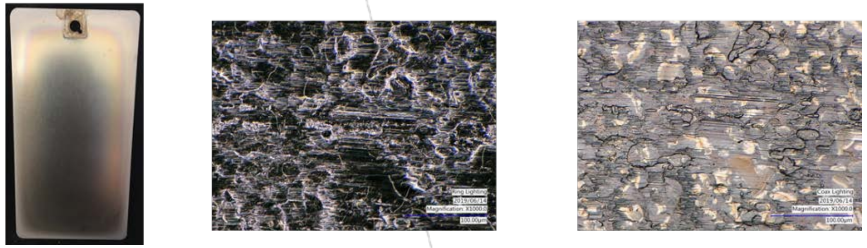

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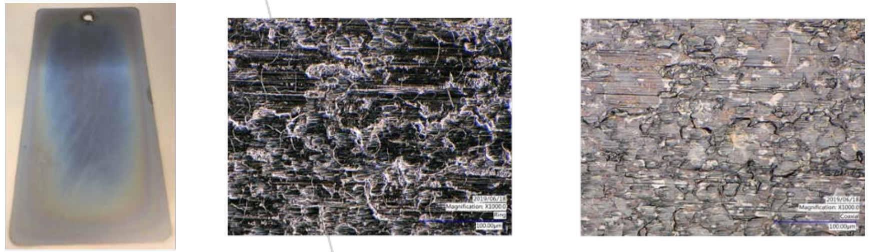

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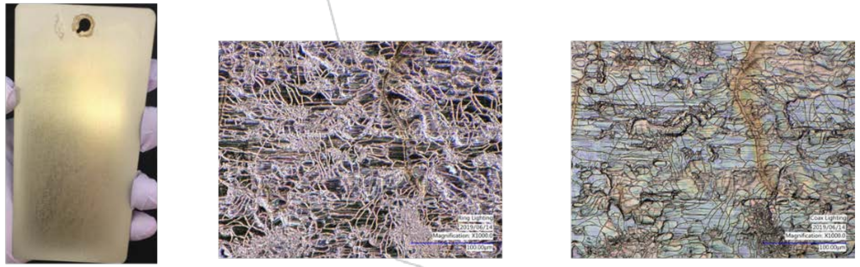

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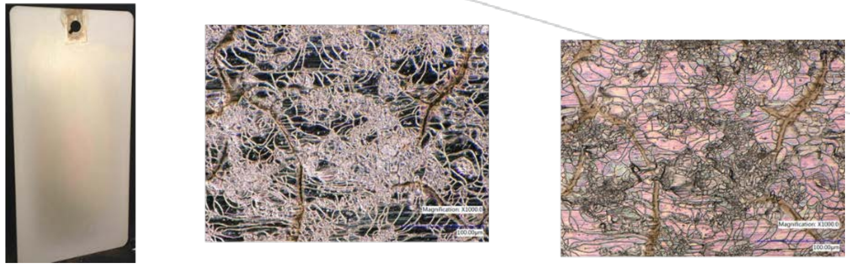

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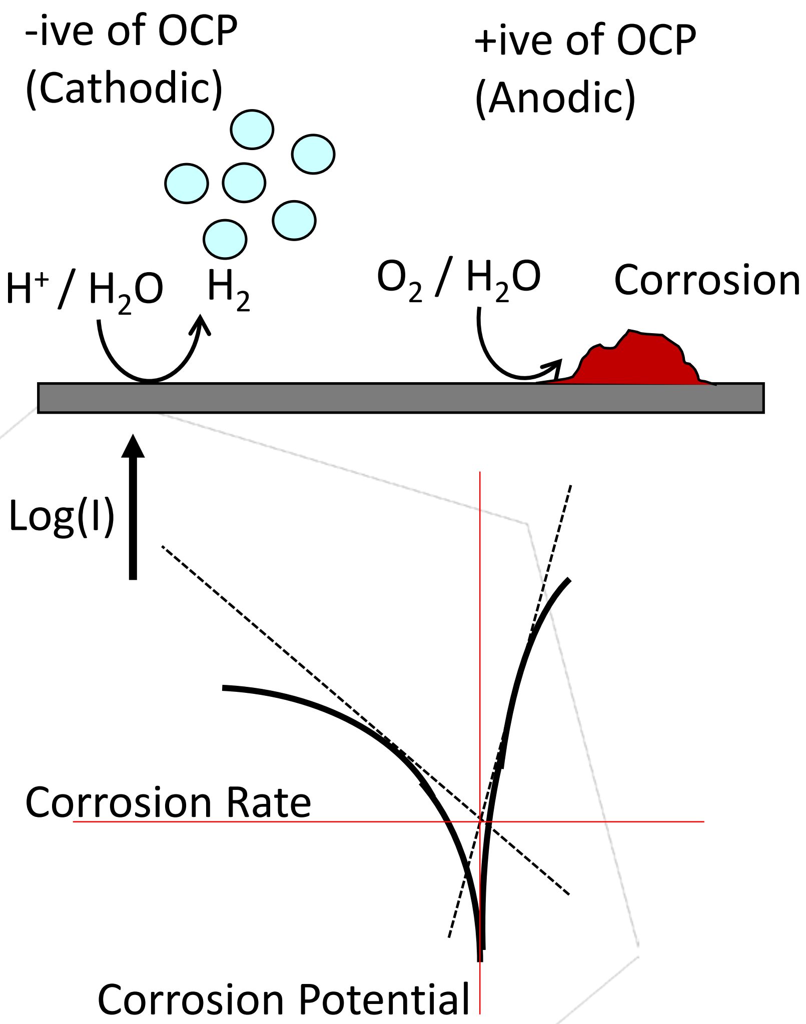
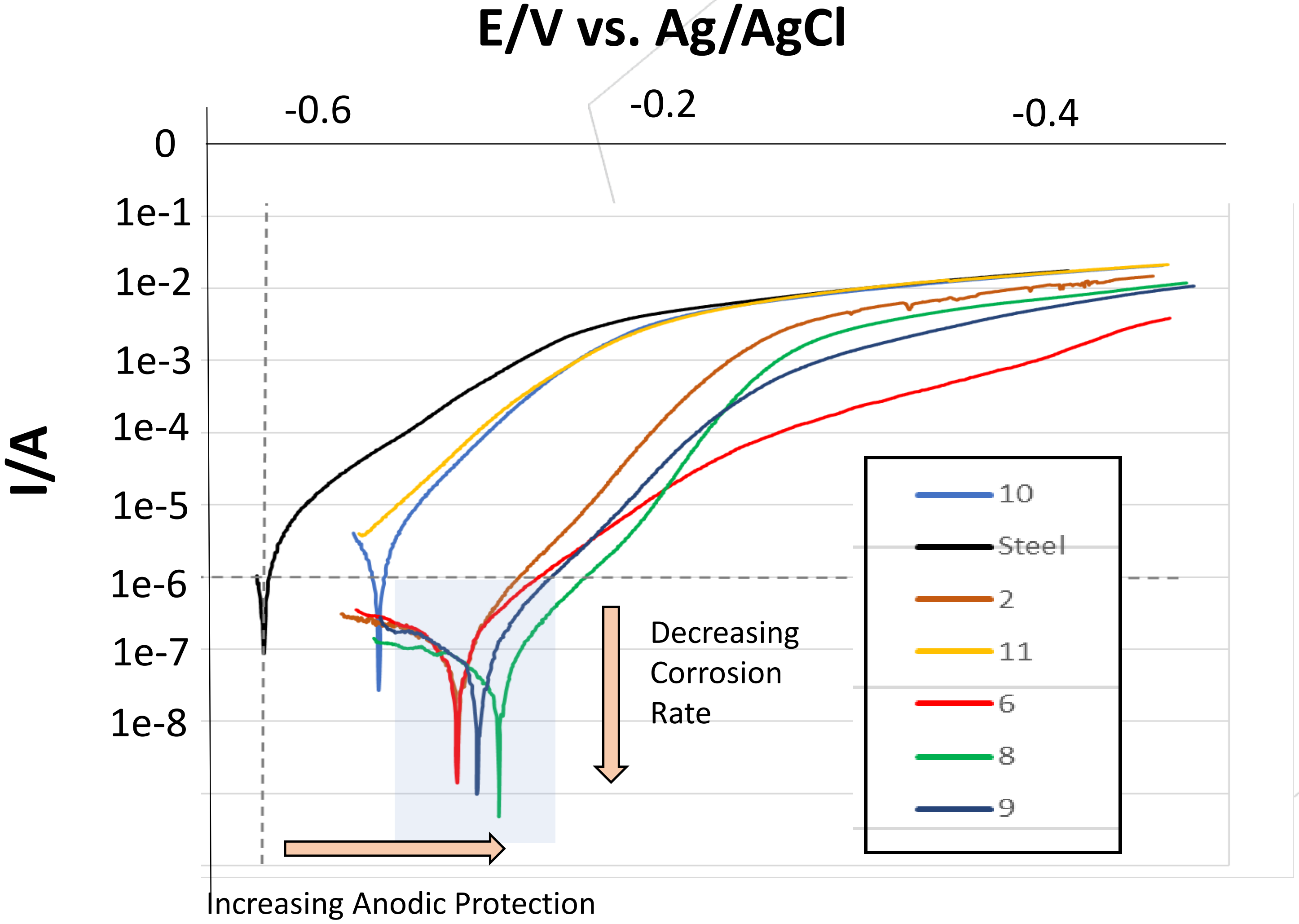
BP1 Progress

Task 2 – Base Coating Optimization:





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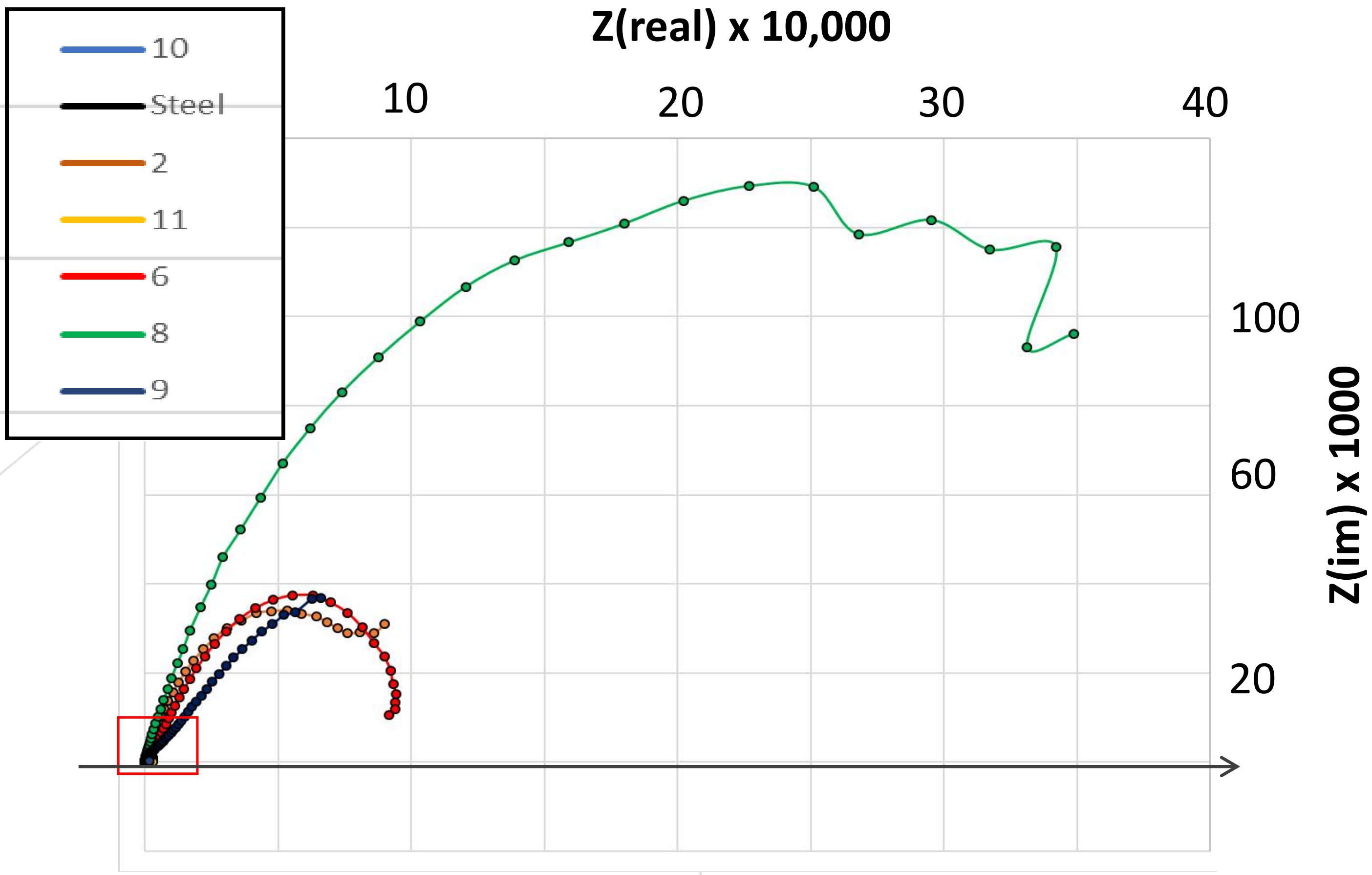
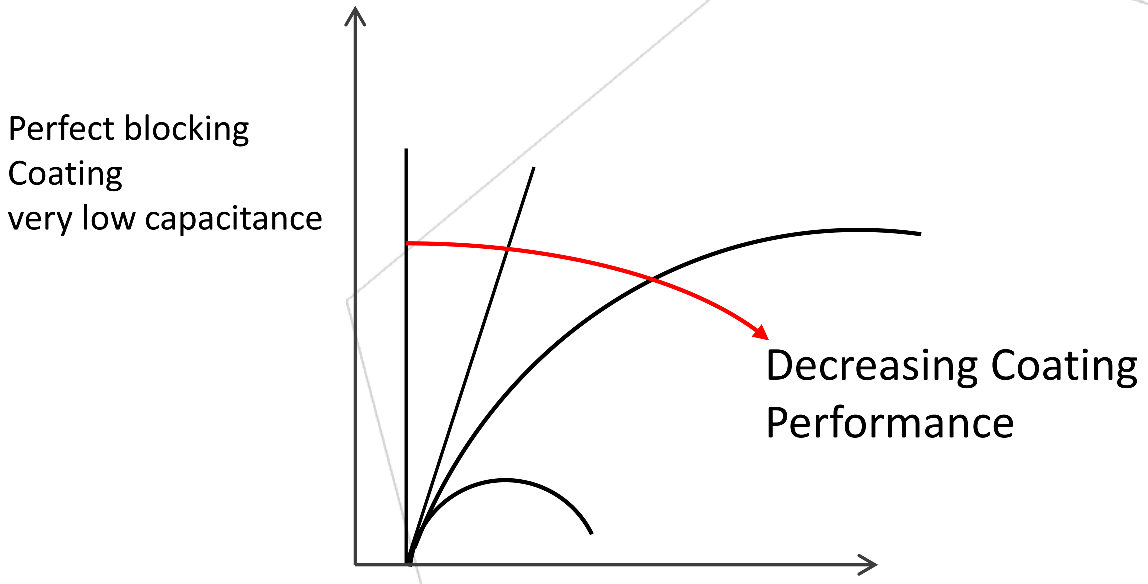
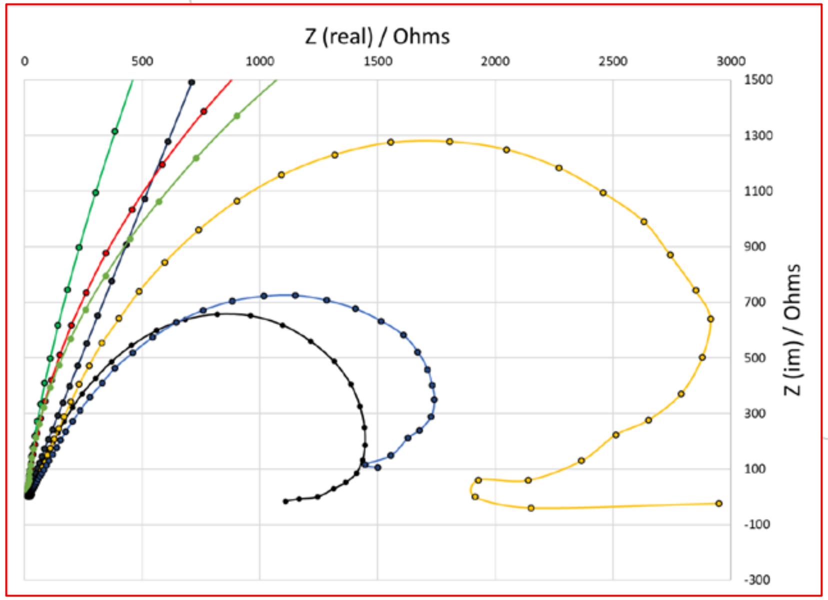
BP1 Progress

Task 2 – Base Coating Optimization:







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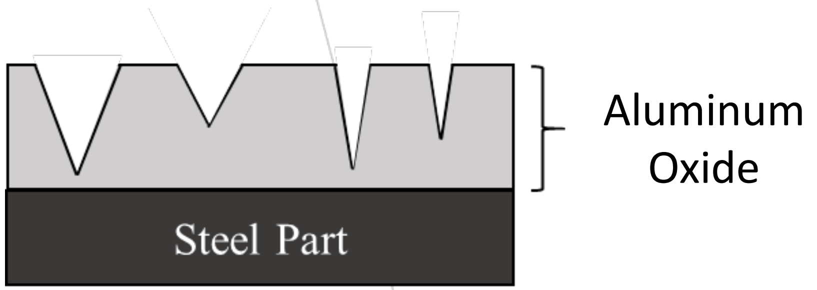
BP1 Progress

Task 2 – Base Coating Optimization:

Current

- Thin, rough, adherent coating successfully developed.
- Conditions optimized to favor layers suitable for paint adhesion (**M-C complete**).



Porous oxide ready for modification

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BP1 Progress

Task 3 – Proof-of-Concept Testing:

Subtask 3.1: Benchmark Organic Coating Preparation

Epoxy

Fluoropolymer

Phenolic

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BP1 Progress

Task 3 – Proof-of-Concept Testing:

Subtask 3.2: Benchmark Organic Coating Characterization

- Aim: Characterize physical and chemical properties of complete coatings.

Phenolic

Epoxy

Fluoropolymer

BP1 Progress

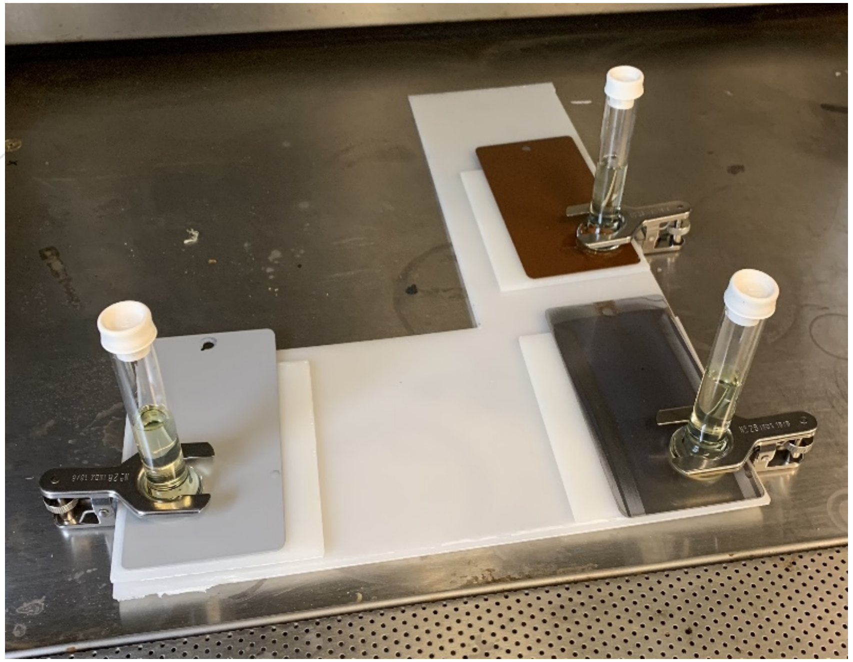
Task 3 – Proof-of-Concept Testing:

Subtask 3.2: Benchmark Organic Coating Characterization

- Aim: Characterize physical and chemical properties of complete coatings.

1.	30% MEA in water, CO_2 sat. 60 ^oC
2.	1M H_2SO_4 Room Temp

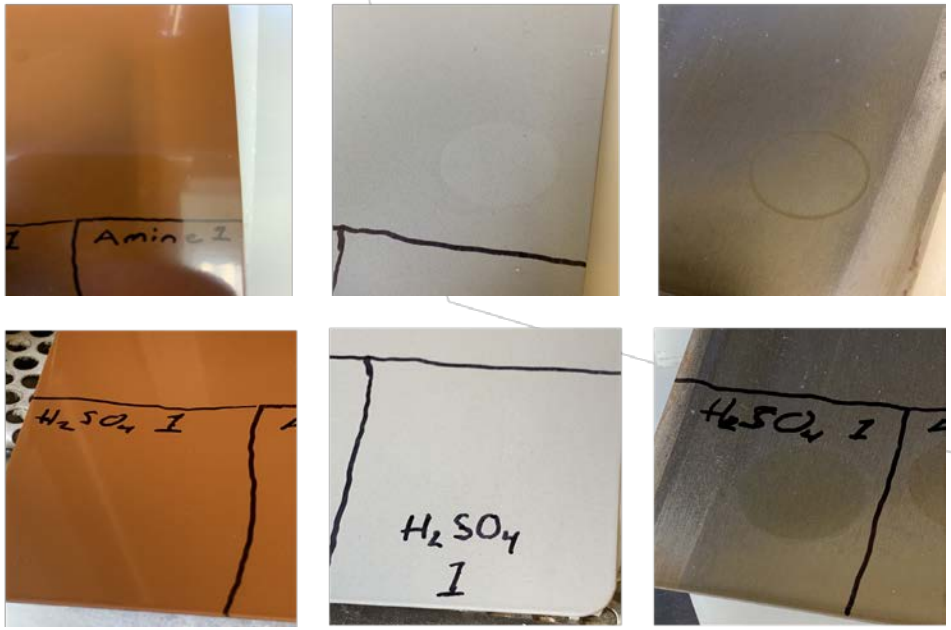
Chemical Exposure Testing



Phenolic | Epoxy | Fluoropolymer

1.

2.



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BP1 Progress

Task 3 – Proof-of-Concept Testing:

Subtask 3.2: Benchmark Organic Coating Characterization

Phenolic

Epoxy

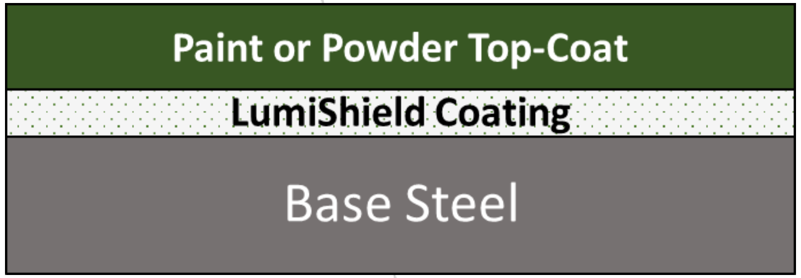
Fluoropolymer

BP1 Progress

Task 3 – Proof-of-Concept Testing:

Current

- Baselines established for each polymer class for corrosion resistance, adhesion and scribe creep (**M-D and M-E complete**).
- Initial testing of LumiShield coating with each polymer top-coat shows initial compatibility.
- Improvement in corrosion resistance of 10% met with LumiShield coating in initial testing.



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BP1 Progress

Initial Results for LumiShield Coating

	Scribe creep at 1000 Hours of Salt Spray				
	Industry Standard		**Aluminum Oxide Coated Steel**		
	Average creep / mm	max creep / mm	Average creep / mm	max creep / mm	Improvement
Epoxy	1.08	1.6	0.77	1.1	**29%**
Phenolic	1.12	1.8	0.89	1.3	**21%**

	Salt Spray Hours Initial Testing to Failure		
	Industry Standard	**Aluminum Oxide Coated Steel**	Improvement
Epoxy	500	1500	**300%**
Phenolic	500	1000	**200%**

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Future

Budget Period 1 – Ending 09/30/2019	
Task 2	• Correlate electrochemical characterization with salt spray results. • Validate optimized pulses with top-coat addition.
Task 3	• Comparison of optimized base coatings with polymer top-coats to verify Task 2 coatings and compare with baseline.
Task 4	• Complete preliminary cost benefit analysis and state point data table in collaboration with AECOM.

Budget Period 2 – 10/01/2019 – 09/30/2020	
Task 5	• Screen multiple types of chosen top-coat class to maximize corrosion and chemical resistance. • Develop novel top-coats with best compatibility with LumiShield aluminum oxide while improving performance parameters. • Test composite coatings in simulated and realistic flue gas conditions.
Task 6	• Complete final cost benefit analysis and state point data table in collaboration with AECOM.

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Future

Scale-up

- LumiShield coating will be scaled from 5 gallon to 25 gallon in the next 6 months.
- Demo plating with plating partners to begin in 2020 with sites being sought for 50 – 200 gallon.

Next Steps

- Two customers interested in piloting LumiShield technology with specific modifications to their specific paints.
    - Automotive company interested in high temperature paint adhesion for heat shields.
    - Expansion of oil and gas program towards other markets and corrosion sites using heavy brine solutions.
    - Interest in compatibility with other corrosive amines for chemical industry.

Acknowledgements

NETL	
Project Manager	Sai Gollakota
Contract Specialist	Jacqueline Wilson

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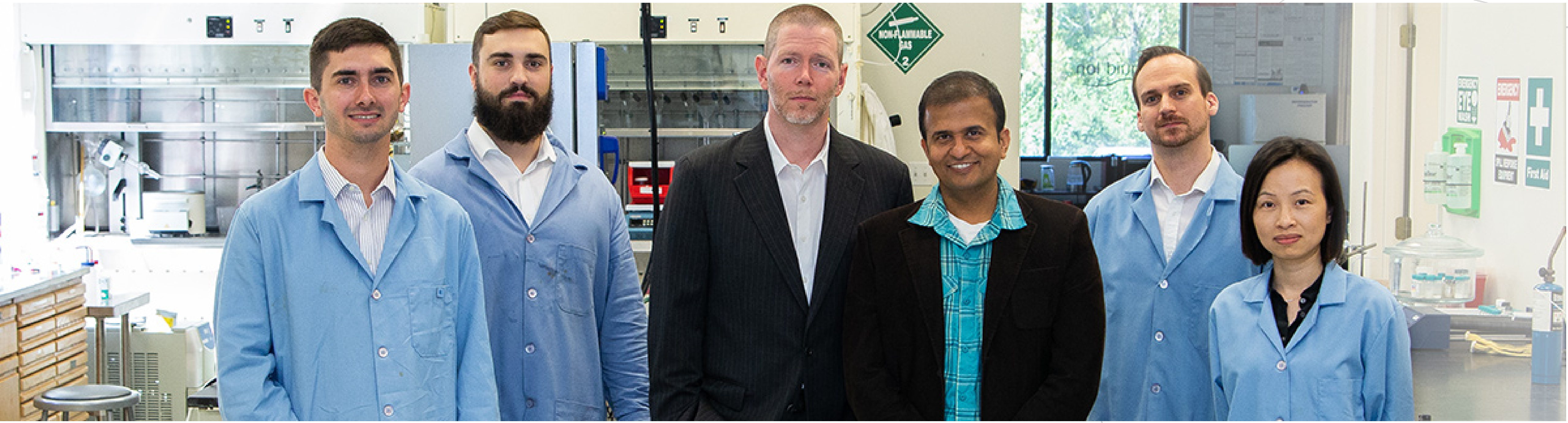

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Supported by the National Energy Technology Laboratory
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