LumiShield

DE-FE0031659: Inexpensive and Sustainable Anti-Corrosion Coating for Power Generation Applications

Principal Investigator: Dr. John D. Watkins
LumiShield Technologies

NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Capture
2020 Integrated Review Webinar
October-5-7 2020

NETL/DOE Federal Project Manager Sai Gollakota

Program Overview

Objectives

1. Lab Scale Demonstration of Aluminum Oxide Primer Coating on Carbon Steel
   - Optimize coating process for acid resistance.
   - Test commercially available acid resistant top-coats for adhesion.
   - Form complete composite coating that shows good adhesion, acid resistance and temperature resistance.

2. Optimize Top-Coating Chemistry to Maximize Performance
   - Work with partners to develop next generation acid and amine resistant top-coats.
   - Optimize attachment of top-coats to LumiShield aluminum oxide surface treatment.

3. Characterize Coatings in Simulated and Realistic Flue Gas Conditions
   - Initial screening by in-house salt spray testing.
   - Simulated acid and base testing by liquid exposure testing.

4. Complete Cost-Benefit-Analysis
   - Calculate materials and process costs based on technology development.
   - Develop cost-benefit-analysis in partnership with AECOM to compare with existing coatings.

Program Overview

Proposed Budget

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 10/01/2019 – 03/31/2021				
Budget Period 2 Totals:	$400,444	$100,111	$500,555	46.5%
Project Totals:	**$860,490**	**$215,122**	**$1,075,612**	**100%**

Prime

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Subcontractor

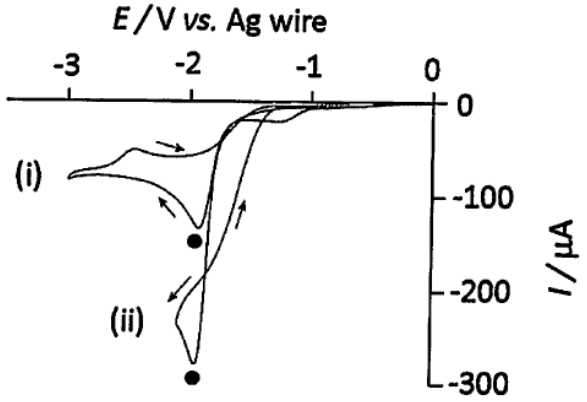
AECOM

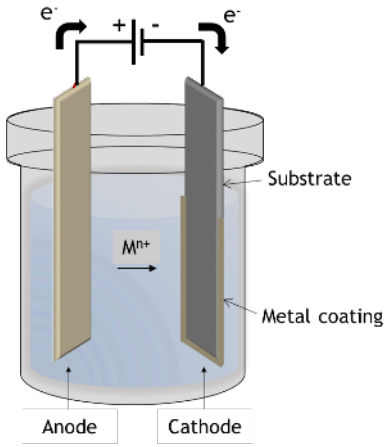
Technology Background

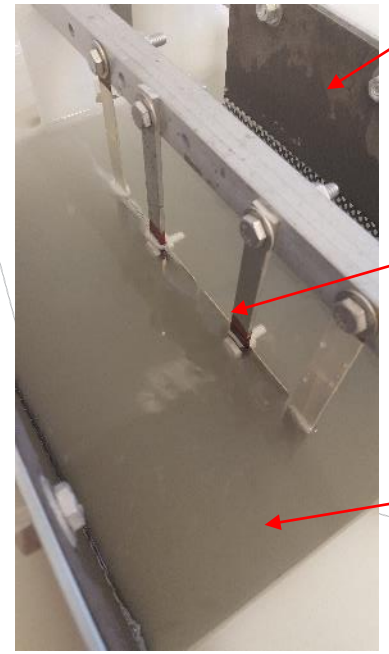
Key Idea: Use electrodeposited aluminum oxide as an adhesive pretreatment for organic coatings.

How Do Electroplated Coatings Work?

- Cathode (-ive) – Metal Plating.
- Anode (+ive) – Water Splitting.
- Solution:
  - Soluble metal salts.
  - Conductive electrolyte.
- Electrodeposition is voltage dependent.
  - Voltage = driving force.
  - Current = deposition rate.







Anode (+ive)

Cathode (+ive)

Water: Al^{3+} source + electrolyte

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Technology Background

2014 — Research Scale 10 – 1000mL

2017 — Development Scale 5 Gallon

2020 — Pilot Testing

Base Metal

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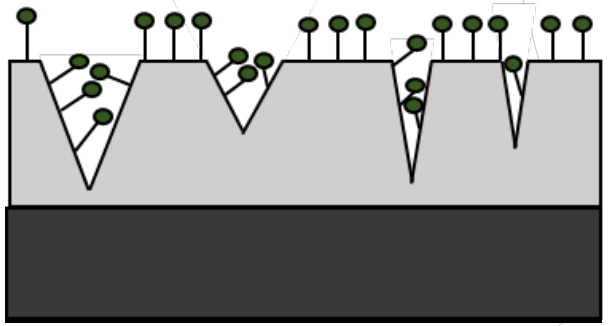
Technology Background

2014 — Research Scale 10 – 1000mL

2017 — Development Scale 5 Gallon

2020 — Pilot Testing

1. LumiShield Aluminum Oxide Plating



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Technology Background

2014 — Research Scale 10 – 1000mL

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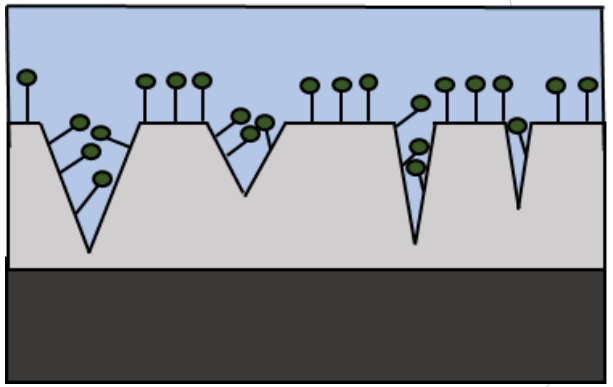

1. LumiShield Aluminum Oxide Plating
2. Organic Seal Application

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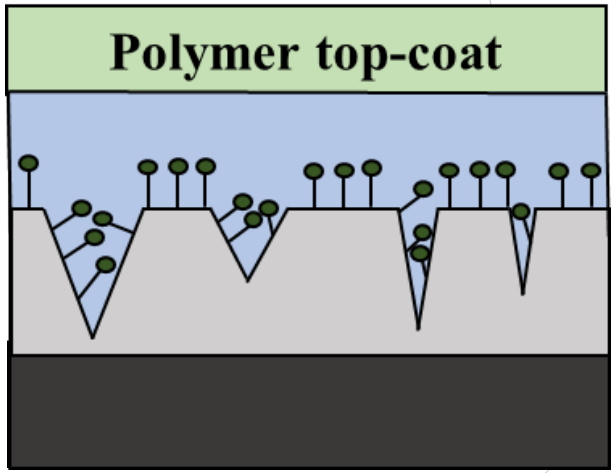
Technology Background

2014 — Research Scale 10 – 1000mL

2017 — Development Scale 5 Gallon

2020 — Pilot Testing



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

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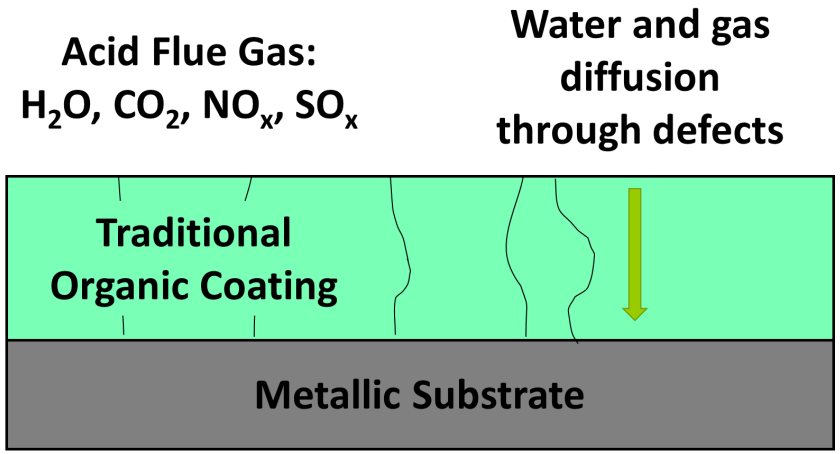
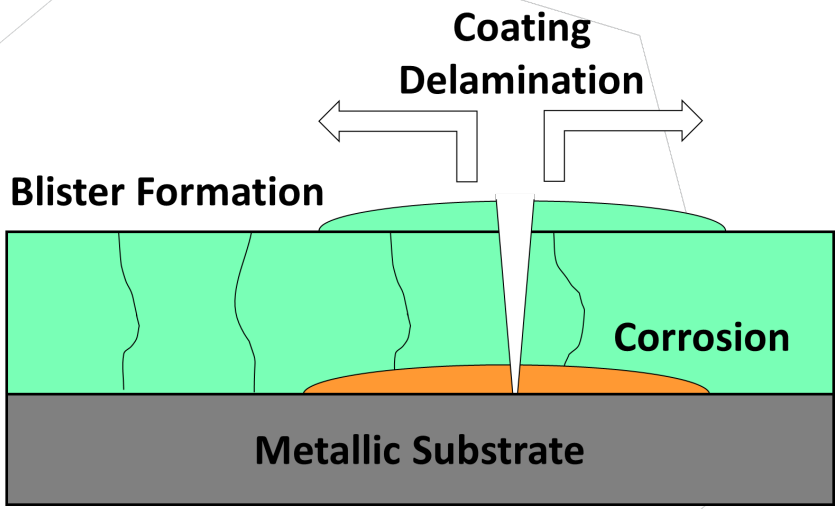
Technology Background





Stainless Steel
- Good corrosion resistance.
- High price.

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

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Technology Background

The LumiShield Coating is an Enabling Technology for Carbon Capture Systems, lowering capital and maintenance cost.

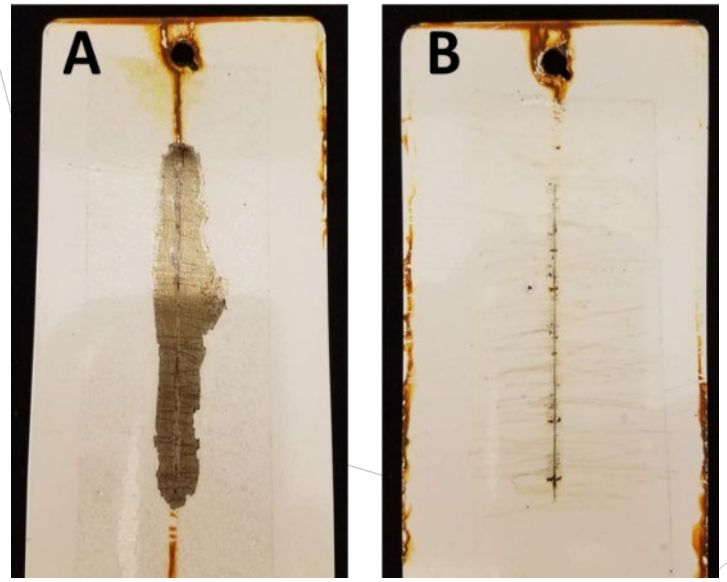
Advantages

- 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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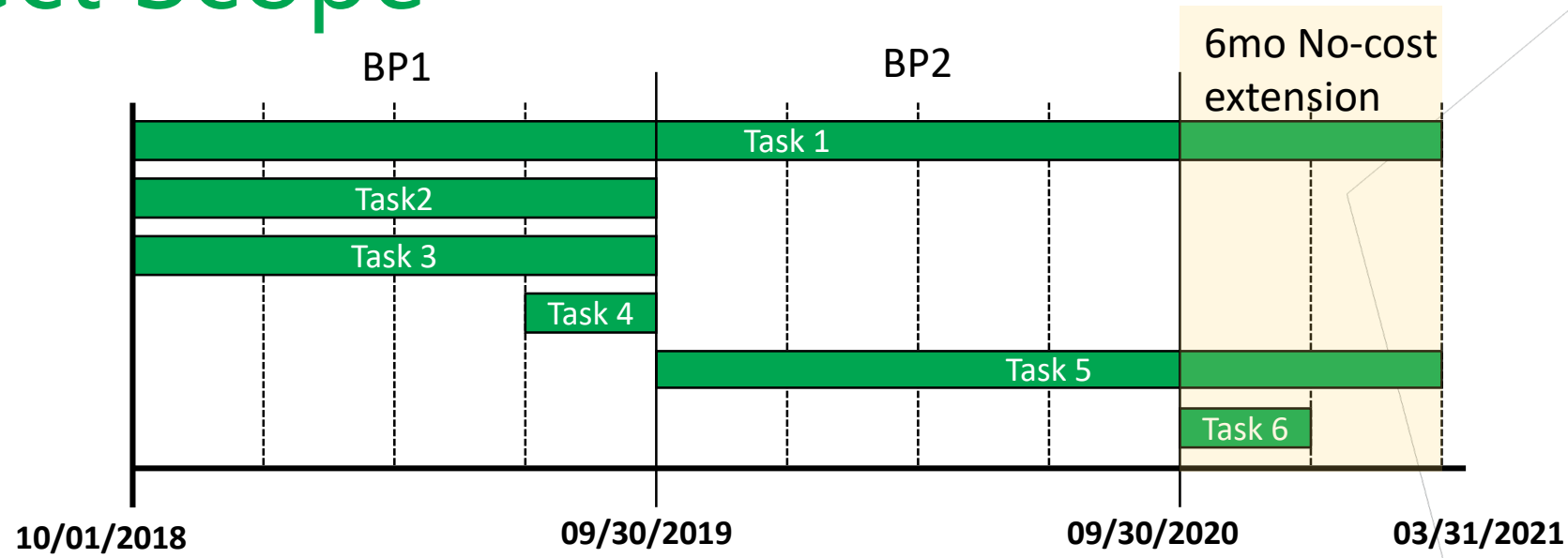
Project Scope



	Success Criteria	
	BP1	**BP2**
Goal	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.	At least one of the coatings should result in a decrease in cost per tonne CO_2 of 1% or greater.
Status	**Success: 300 % increase shown using commercial epoxy powdercoat.**	**In Progress**

- COVID-19 shutdown lab for almost 2 months March – May 2020.
- Original Project end date 09/30/2020.
- With 6 month no-cost extension new end date 03/31/2021

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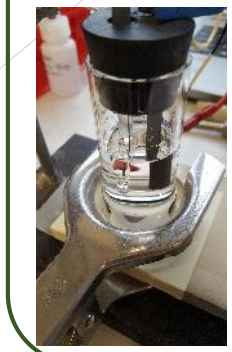
Technical Approach

Aluminum Oxide Optimization

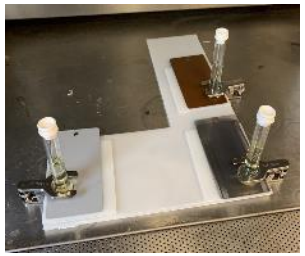
- Solution Parameters
- Process Parameters



- Microscopy
- Electrochemical Testing
- Corrosion Testing

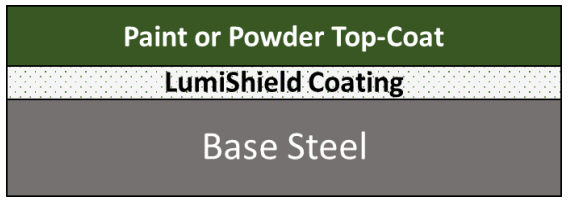
Top-Coat Optimization

- 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 Progress

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	10/24/18	Project Management Plan file
1	M-B	1	Kickoff Meeting	December 31, 2018	01/24/19	Presentation file
1	M-C	2	Select Optimal Fabrication Parameters for Preparation of Dense Base Coatings with High Surface Roughness	June 30, 2019	06/26/19	BP1 Q3 Report
1	M-D	3	Complete Preparation of 3 Benchmark Organic Coatings	March 31, 2019	03/31/19	BP1 Q2 Report
1	M-E	3	Complete Characterization of 3 Prototype Organic Coatings	June 30, 2019	06/26/19	BP1 Q3 Report
1	M-F	4	Complete Cost Benefit Analysis Development	September 30, 2019	09/26/19	BP1 Annual Report
2	M-G	5	Complete Screening of 9 Commercial Organic Coatings with Alumina Base Coat	March 31, 2020	06/12/20	BP2 Q3 Report
2	M-H	5	Evaluate 5 organic linker conditions for improved adhesion of organic top-coats to aluminum oxide base coating	March 31, 2021		Final Report
2	M-I	6	Update Cost Benefit Analysis with Optimized Coating Data	December 31, 2020		Final Report

Project delays due to COVID-19 closure, 6 month no-cost extension approved.

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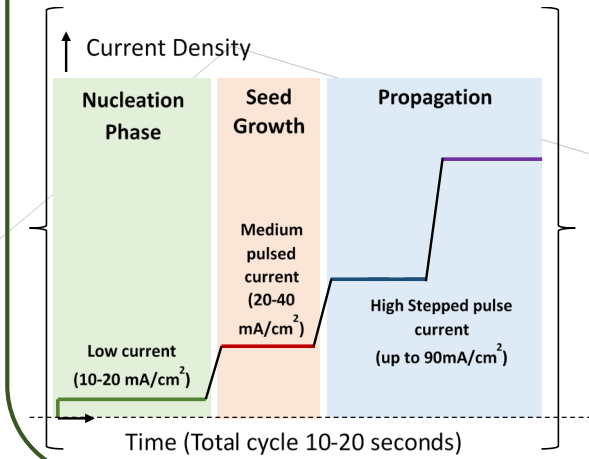
BP1 Summary

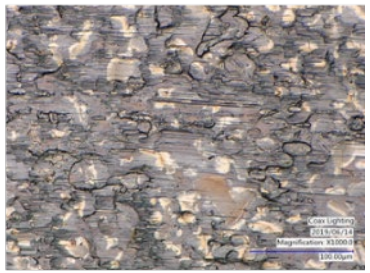
Task 2: Base Coating Optimization

Aluminum Oxide

Mild Steel

- Optimized Al oxide solution components and pH.
- Tested pulse timing and current conditions.
- Verified by electrochemical and accelerated corrosion testing.
- Partially cracked surface.





Task 3: Organic Coating Optimization

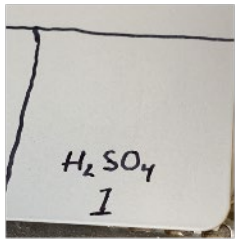
Top-Coat

Aluminum Oxide

Mild Steel

30% MEA, CO_2 sat. 60°C

1M H_2SO_4



- Using optimized pretreatments from Task 2, 3 paint classes tested, epoxy, phenolic and fluoropolymer.
- Fluoropolymer eliminated immediately due to poor adhesion.
- Epoxy had best combination of corrosion resistance, acid and amine resistance overall.
- 29% improvement in adhesion over iron phosphate.
- 300% increase in corrosion resistance.

Optimized Al oxide

Industry Standard

Patent Applied for - PCT/US2020/016356 “Methods and Compositions for Improved Adherence of Organic Coatings to Materials”

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BP1 Summary

Task 4: Initial Cost-Benefit Analysis

- AECOM sub-contract, 3 month effort.
- LumiShield estimates materials cost for aluminum oxide application at scale 0.07$/ft^2.
- Best potential components for replacement with power coated mild steel:

Stripper	17%
Absorber	13%
Piping	10-40% but offset by additional fabrication costs.

- “On balance, use of the LumiShield coating with a top coat in lieu of stainless steel for the absorber and stripper vessels may result in a reduction of $27M in total capital requirements for a carbon capture system achieving 90% capture for a 642 MWe (gross) coal-fired power plant.” AECOM, September 26, 2019.
- Some non-quantifiable benefits may also be realized as well as reduced maintenance costs.

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BP2 Progress

Task 5 – Organic Coating Development

- Screen 9 different epoxy powder coatings for adhesion, chemical compatibility and corrosion resistance.
- Test different post-plating treatments to further improve adhesion and corrosion resistance of coating system.

Supplier	Name	Description	Cost
Axalta	Alesta 61 Gray Epoxy	Standard Epoxy Powder Topcoat from Task 3	$5.00 / lb
Sherwin Williams	Powdura Pure Epoxy	Standard Epoxy Powder, generally used as primer. Indoor applications, poor weathering.	$7.00 / lb
PPG	Envirocron Epoxy Primer	Similar to Sherwin Williams Powdura. Industry standard epoxy primer.	$5.45 / lb
AkzoNobel	Interpon 100 Epoxy	Similar to PPG, Sherwin Williams. Epoxy coating for interior applications.	$6.42 / lb
AkzoNobel	ResiCoat PI	Interior Pipe Coating, resistant to acids, bases, and other chemicals.	$14.12 / lb

Supplier	Name	Description	Cost
AkzoNobel	ResiCoat RB-600	Fusion bonded epoxy, mostly for structural parts. Hard waring properties.	$5.91 / lb
TCI	Epoxy Primer	Standard MIL Spec 53022 epoxy primer for chemical resistance.	$5.89 / lb
TCI	OGF Hybrid Primer	Epoxy Polyester Hybrid. Used for higher adhesion and chemical resistance.	$4.16 / lb
TCI	TruZinc Epoxy	Epoxy primer containing Zinc for sacrificial protection of steel in corrosive environments.	$5.44 / lb

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BP2 Progress

Task 5 – Organic Coating Development

- Lifetime study for 67 consecutive plating runs.
- No variation in coating.


Run #1


Run #6


Run #15


Run #34


Run #41


Run #47


Run #53


Run #67

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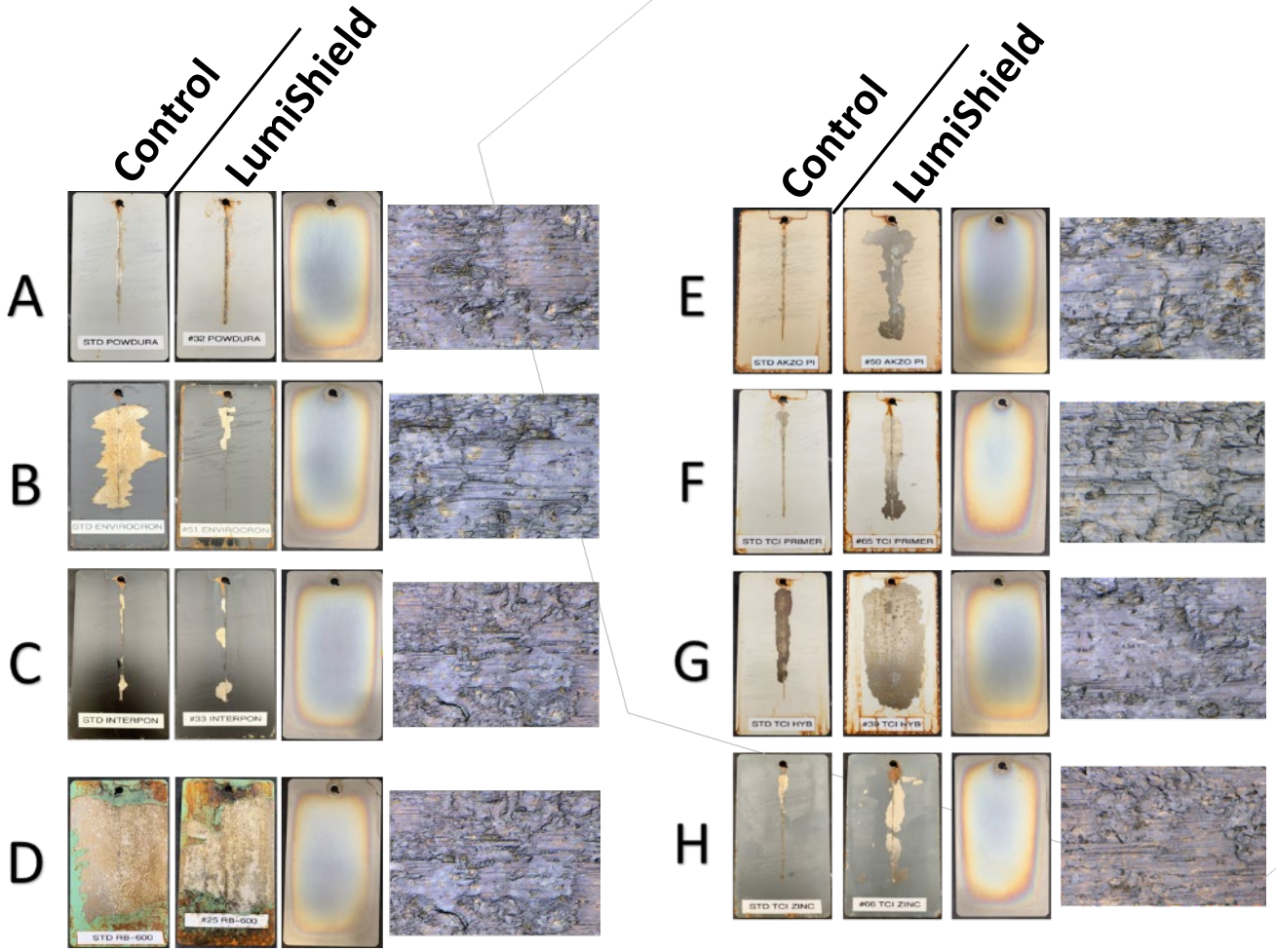
BP2 Progress

Task 5 – Organic Coating Development

500 Hours

500 HOURS SALT FOG	Scribe Delamination / cm				Coating Performance
	Control 1	Control 2	Panel 1	Panel 2	
(A) S.W. Powdura	Fail	0.32	0.18	0.09	57.8% Increase
(B) PPG Envirocron	4.08	3.4	0.95	0.45	81.3% Increase
(C) AkzoNobel Interpon	0.1	0.24	0.46	0.38	59.5% Decrease
(D) ResiCoat RB-600	Fail	Fail	Fail	Fail	Total Panel Failure
(E) ResiCoat PI	0.05	0.15	2.2	1.95	95.2% Decrease
(F) TCI Primer	0.35	0.2	1.1	1.6	79.6% Decrease
(G) TCI Hybrid	0.34	1	4.2	4.45	82.2% Decrease
(H) TCI TruZinc	0.3	0.35	1.4	1.05	73.5% Decrease



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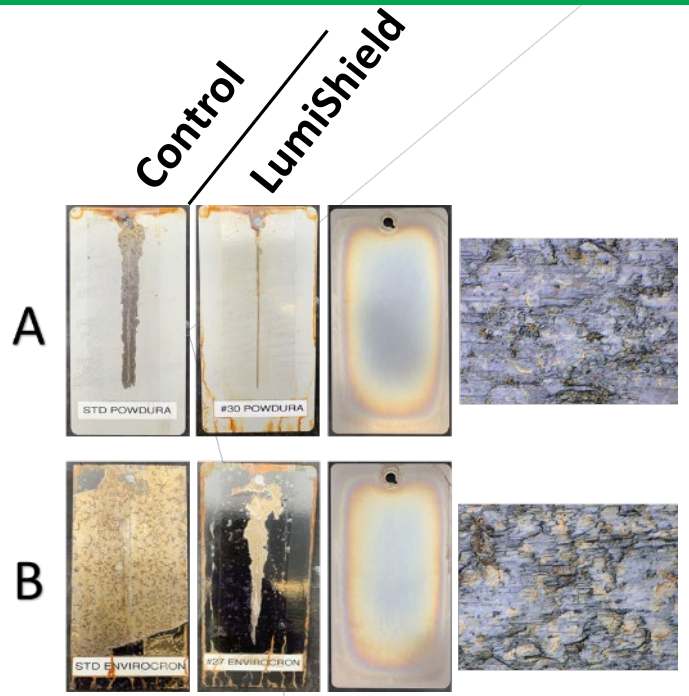
BP2 Progress

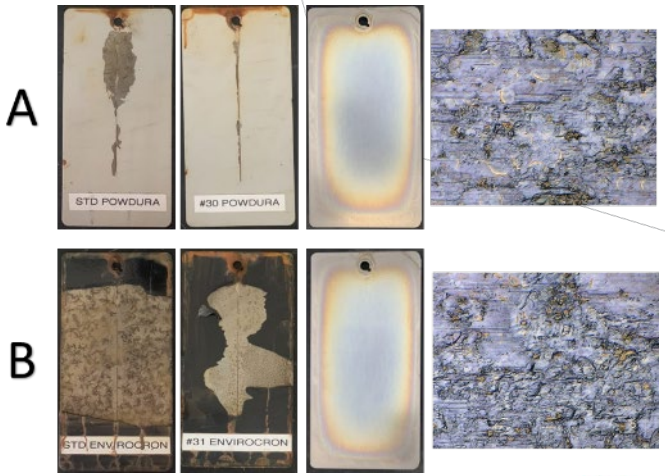
1000 Hours

1000 HOURS SALT FOG	Scribe Delamination / cm				Coating Performance
	Control 1	Control 2	Panel 1	Panel 2	
(A) S.W. Powdura	1.35	1.18	0.1	0.5	76.4% Increase
(B) PPG Envirocron	Fail	Fail	0.67	1.05	Not Calculable
(C) AkzoNobel Interpon	1.28	0.98	2.98	2.14	55.9% Decrease
(D) ResiCoat RB-600	Fail	Fail	Fail	Fail	Total Panel Failure
(E) ResiCoat PI	0.25	0.72	3.16	4.58	87.4% Decrease
(F) TCI Primer	0.4	0.55	0.92	1.76	64.6% Decrease
(G) TCI Hybrid	0.92	0.9	5.1	3.96	79.9% Decrease
(H) TCI TruZinc	0.95	0.88	2.95	4.28	74.7% Decrease



1500 Hours

1500 HOURS SALT FOG	Scribe Delamination / cm				Coating Performance
	Control 1	Control 2	Panel 1	Panel 2	
(A) S.W. Powdura	1.25	4.98	0.25	0.80	83.1% Increase
(B) PPG Envirocron	Fail	Fail	4.78	3.82	Not Calculable
(C) AkzoNobel Interpon	1.95	2.08	2.25	4.05	36% Decrease
(D) ResiCoat RB-600	Fail	Fail	Fail	Fail	Total Panel Failure
(E) ResiCoat PI	0.38	0.5	4.36	5.12	90.7% Decrease
(F) TCI Primer	5/18				Incomplete
(G) TCI Hybrid	0.15	0.12	6.45	5.98	97.8% Decrease
(H) TCI TruZinc	5/18				Incomplete



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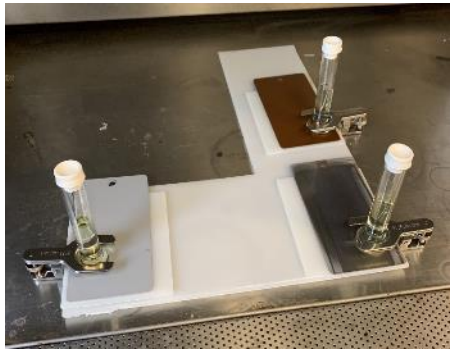
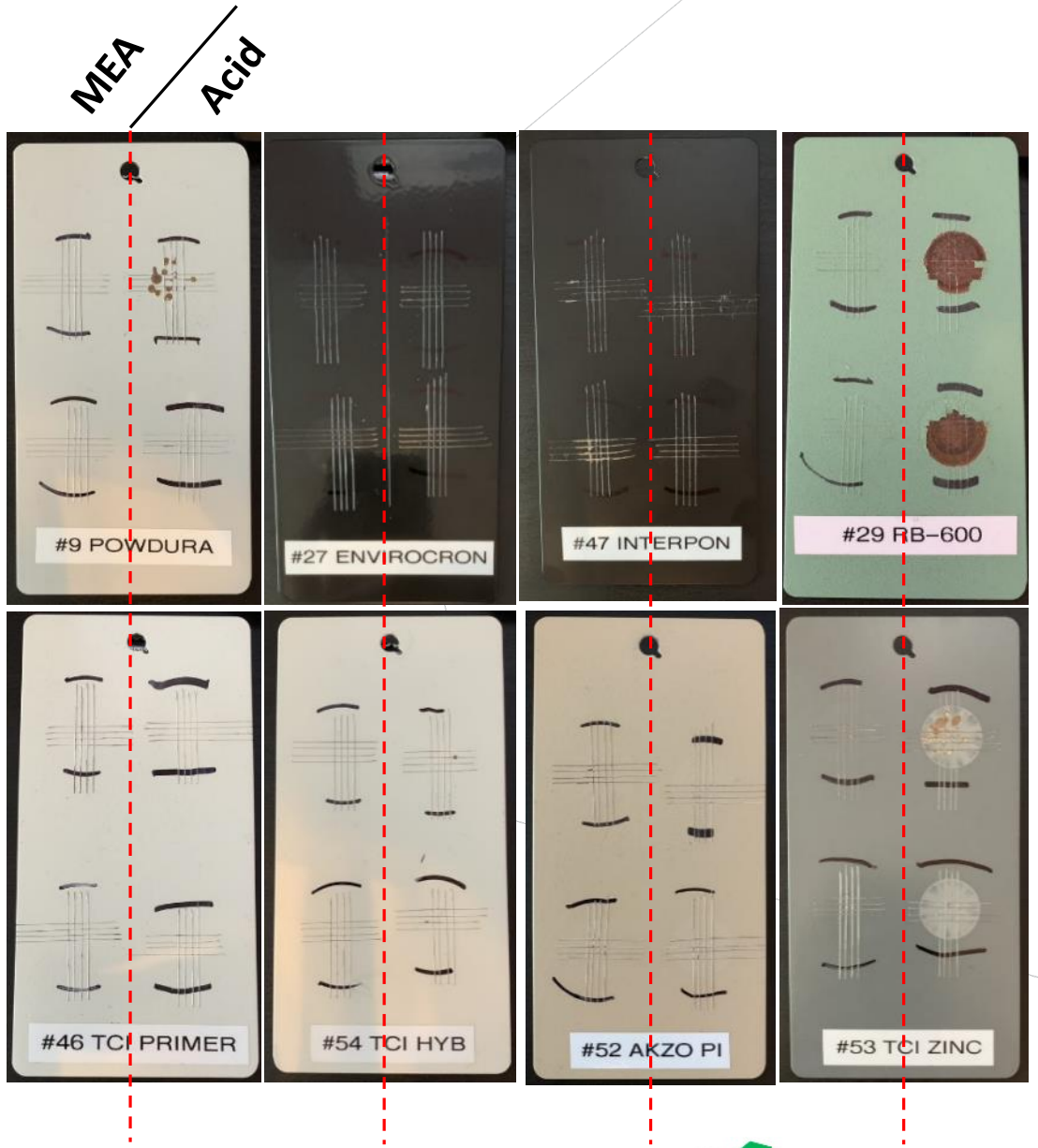
BP2 Progress

CROSS HATCH ADHESION	Acid site 1	Acid site 2	Amine site 1	Amine site 2
S.W. Powdura	5B	-	5B	5B
PPG Envirocron	5B	5B	5B	5B
AkzoNobel Interpon	5B	5B	3B	3B
ResiCoat RB-600	0B	0B	5B	5B
ResiCoat PI	5B	5B	4B	4B
TCI Primer	5B	5B	4B	4B
TCI Hybrid	5B	5B	5B	5B
TCI TruZinc	2B	2B	5B	5B
Interpon 100	5B	5B	3B	3B

- Exposure testing for:
  - Left = 30% MEA, CO_2 sat. 60°C, 6 days.
  - Right = 1M H_2SO_4 room temp, 6 days.
- Adhesion test on exposure site.
- Powdura, Envirocron, Interpon 100, TCI primer, TCI hybrid and AK PI epoxy all passed both tests.





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Future

Budget Period 1 – Ending 09/30/2019 - COMPLETE	
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 – 03/31/2021	
Task 5	✓ Screen multiple types of chosen top-coat class to maximize corrosion and chemical resistance. • Test sealant treatments on aluminum oxide to better improve adhesion to epoxy top-coat.
Task 6	• Complete final cost benefit analysis and state point data table in collaboration with AECOM.

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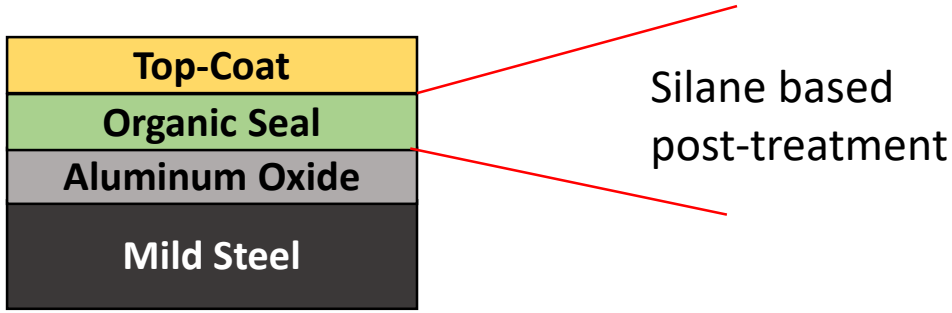
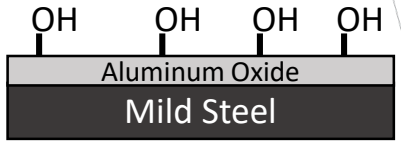
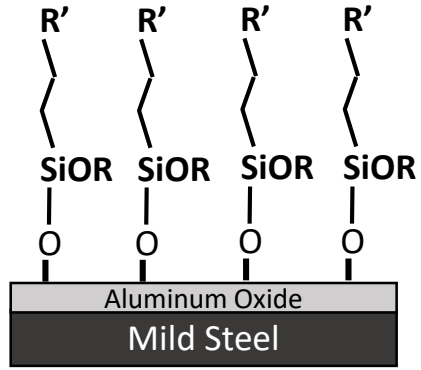
BP2 Future

Task 5: Investigation of organic linker conditions on epoxy adhesion.





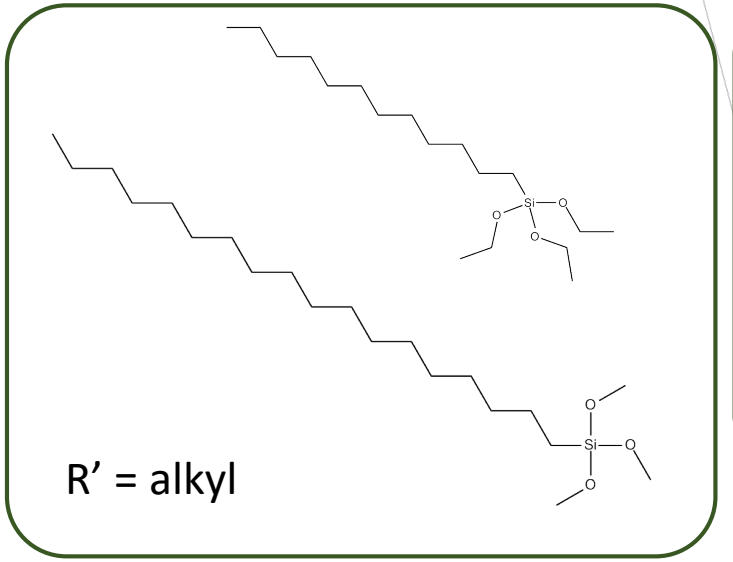
Native Surface

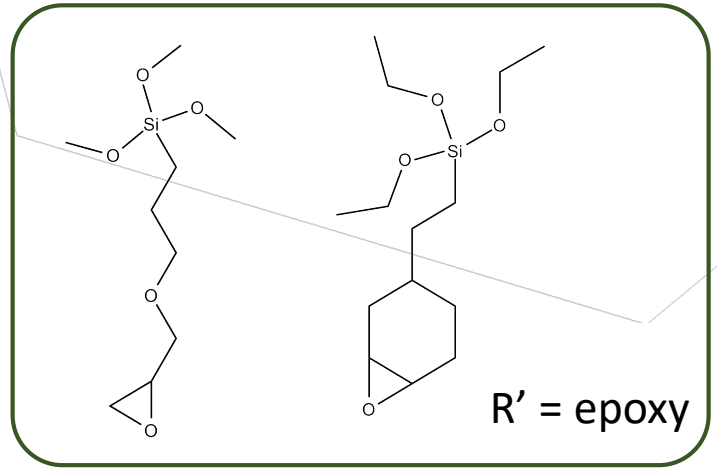


Modified Surface

R' can be alkyl or epoxy ring

- Hydroxide surface of aluminum oxide already favorable for epoxy chemical binding.
- Functionalized silanes can be used to modify hydroxide groups of aluminum oxide layer to further improve adhesion to epoxy.





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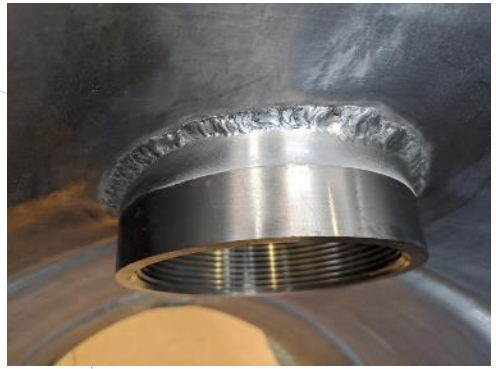
Future Development

Scale-up Potential

- LumiShield process successfully scaled up to 100 gallons in partnership with an oil & gas customer.



LumiShield Next Steps

- LumiShield looking to adapt coating as a corrosion resistant paint adhesion layer on other surfaces.
  - AA2024 – Aerospace and Air Force / NAVAIR
  - AA7075 – Navy and ocean facing applications
  - Nickel plated – Automotive
  - Zinc coated – structural applications
- Water handling adaptation for optimized coatings in brine treatment and pipe parity.

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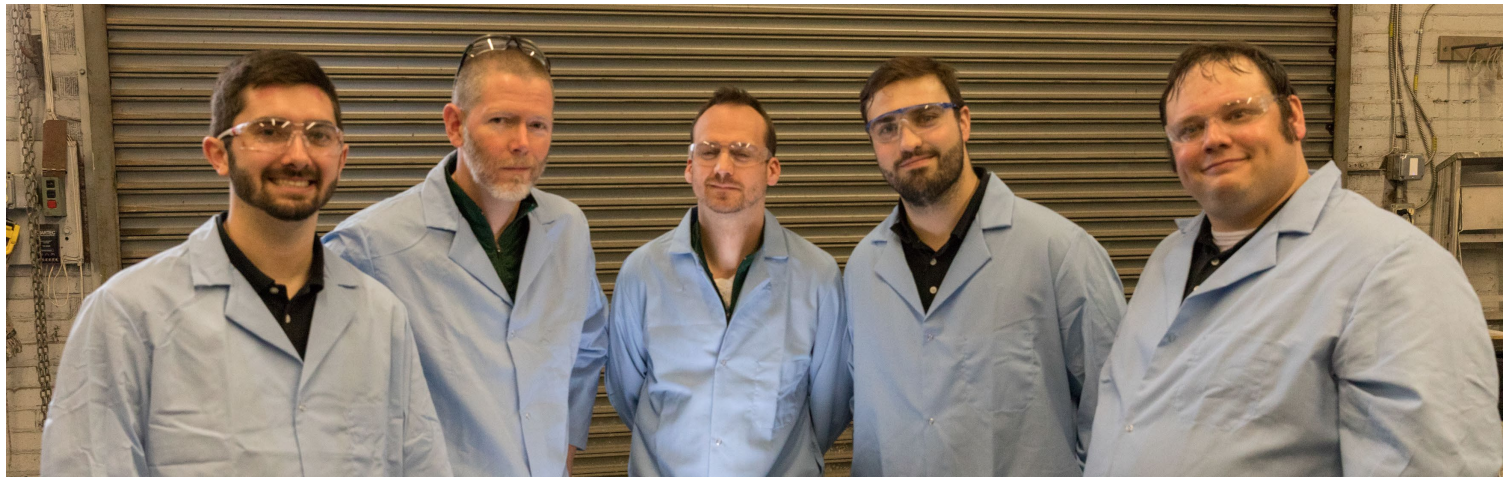
Acknowledgements

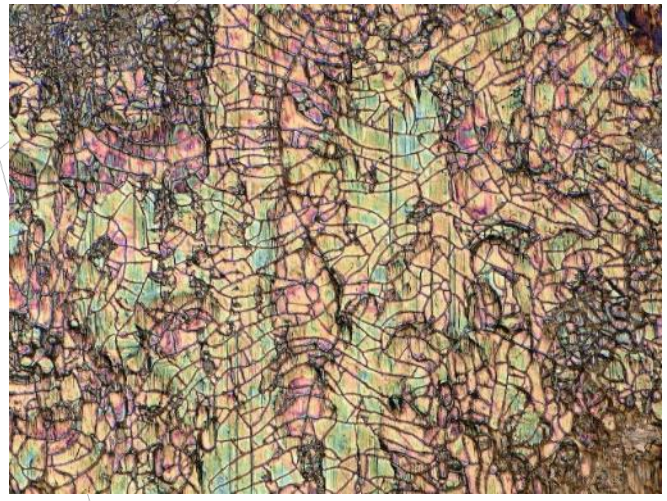
NETL	
Project Manager	Sai Gollakota
Contract Specialist	Jessica Adams

This material is based upon work supported by the Department of Energy under Award Number DE-FE0031659.

Summary



Microscope Image of Aluminum Oxide coating.



Tasks 3/5: Powder Coated Epoxy - Powdura

Task 5: Optimized Organic Linker – **In Progress**

Task 2: Optimized Aluminum Oxide

Remaining:

1. Organic Linker Conditions.
2. Realistic Flue Gas Exposure Test.
3. Final Cost-Benefit Analysis and State Point Data Table.

Supported by the National Energy Technology Laboratory
Project: DE-FE0031659

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Appendix

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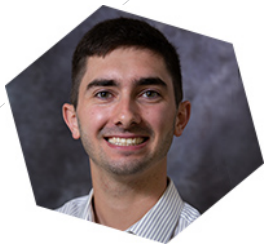
Organization Chart

Management Team

PI:
John Watkins

Business Contact:
Dave Luebke

Project Team



Zach Kaufman

Blake Woodyard

Ben Davis

John Larson

Spiro Karoubalis

Project Support

AECOM

Tasks 4 and 6
Cost-Benefit Analysis

Pittsburgh Powder Coat

Tasks 3 and 5
Application of epoxy powder coatings to aluminum oxide test samples

Consultants

Hunaid Nulwala
Polymer SME
Advice for optimization of top-coat in Tasks 3 and 5

Prof. Stanko Brankovic
Electrodeposition SME
Electrodeposition Advice for Tasks 2 and 5

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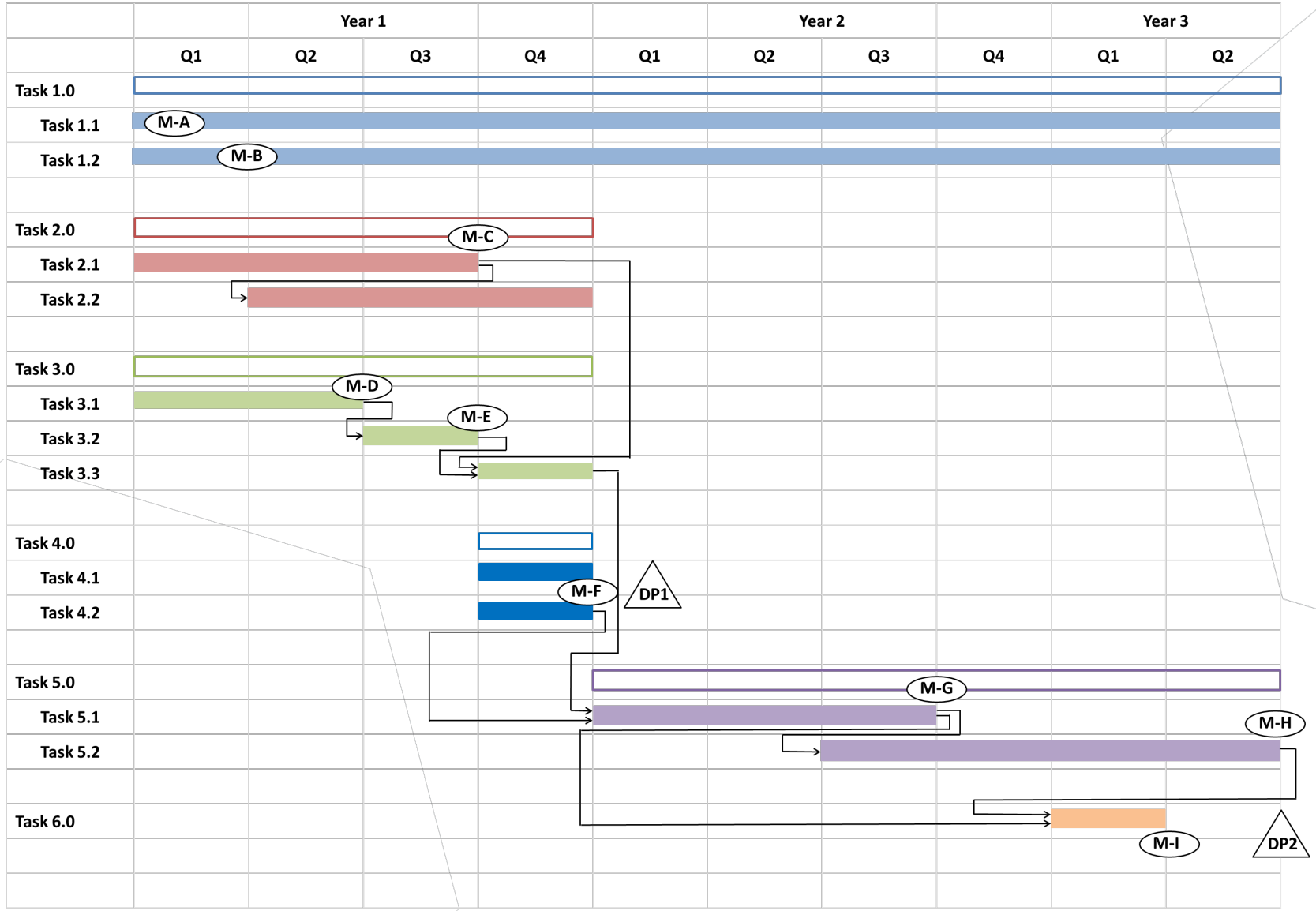
Gantt Chart



M = Milestone

DP = Decision Point

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