Reduction of Methane Leaks through Corrosion Mitigation Pre-treatments for Pipelines with Field Applied Coatings (FE0031874)

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U.S. Department of Energy

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Resource Sustainability Project Review Meeting
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Project Dates, Funding, & Participants

- Originally 3 year project: 9/1/2020 to 8/31/2023
- 6 month NCTE on 8/2022: Amended end date 2/29/2024

- Direct cost (77%) to Principal Investigator
  - **DNV GL USA** $1,499,252
- Cost share Partners (23%)
  - **Enbridge**: pipeline field testing $300,000
  - **Lincoln Electric**: coupon fabrication $75,008
  - **DNV GL USA**: technical advisor, software $57,488
  - **MC Consult**: technical advisor $16,000

Project Total: $1,947,748

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Project Participant Organizations

- **DNV (Dublin, OH)**: Leading independent expert in risk management and quality assurance, including leading pipeline corrosion and welding expertise. Global HQ in Norway with 12,000 employees worldwide in 100+ countries.

(Cost Share)

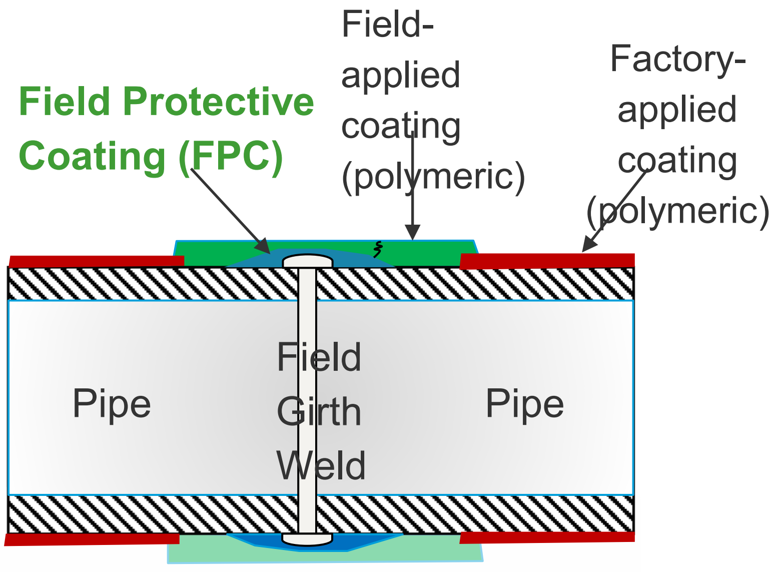
- **Lincoln Electric (Cleveland, OH)**: Leading world manufacturer of welding, brazing, and soldering alloys and robotic welding and cutting equipment, with 11,000 employees and 60 manufacturing locations worldwide

(Cost Share)

- **Enbridge (Houston, TX)**: Leading operator of oil and natural gas pipelines in North America, headquartered in Calgary, Canada. US operations has 23k miles of gas transmission and midstream pipelines in 30 states, transporting 19% of the natural gas consumed in the US (18 billion cubic feet per day).

Overall Project Objectives

1. Develop field protective coating over pipeline girth welds to mitigate corrosion under field applied coatings
2. Detail field applicability of the coating system
3. Develop guidance for application and technology transfer to industry



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Project Schedule & Milestones

Project Year	Task	Description
1	1.0	Project Management
	2.0	Select optimum coating composition
		Go/No-Go report
2	3.0	Lab tests of coating concept
	4.0	3-month lab & field tests
		Go/No-Go report
3	5.0	6-month field test
	6.0	Coating guidance document
		Final Report

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Natural Gas Transmission Pipelines

- **Length of Pipelines**

  300 thousand miles of gas transmission

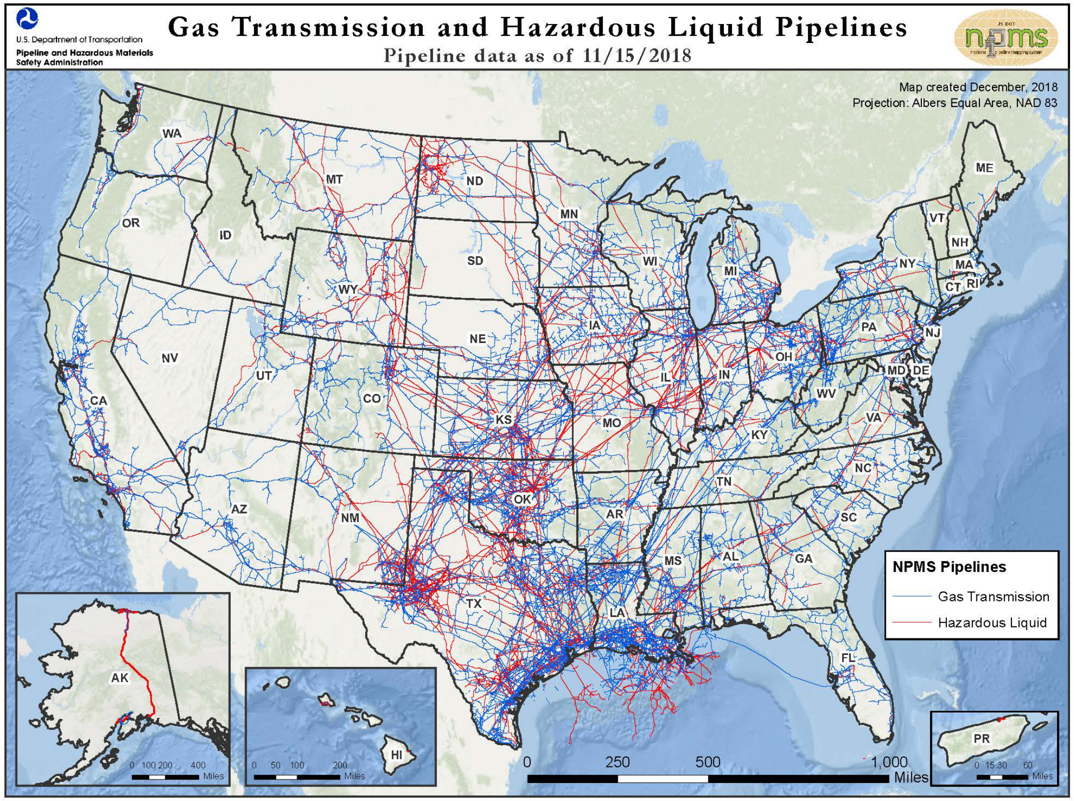
  2.2 million miles of gas distribution
  https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-mileage-and-facilities

- **Volume of Gas**

  28 trillion cubic feet delivered annually to 75 million customers (https://www.eia.gov/energyexplained/natural-gas/natural-gas-pipelines.php)

- **Gas Composition**

  70-90% methane by volume (pipeline quality gas)
  http://naturalgas.org/overview/background/



Natural Gas Transmission Pipelines

- **Pipe material: Steel**
  - Microalloyed, up to 80ksi min. yield strength
  - 12-42” diameter, ¼”-1” wall, manufactured in 40’-80’ length segments
- **External pipeline coating**
  - **Factory coating:** Fusion bonded epoxy (FBE) except for pipe ends, left bare for field welding
  - **Field FBE coating:** Applied over welds and pipe ends, often in adverse weather conditions (wind, rain, cold, etc.), and is usually lower quality and has higher failure rate

Pipeline Corrosion

- Corrosion protection: Pipelines are buried underground with polymeric pipeline coating and cathodic protection
- Corrosion is a leading cause of pipeline incidents
- Field coating issues identified by USDOT PHMSA below
  https://primis.phmsa.dot.gov/meetings/FilGet.mtg?fil=903

Field coating applied over dirt/debris

Construction damage of girth weld coating found by DCVG Survey during pipeline operation

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Reduction in Methane Emissions

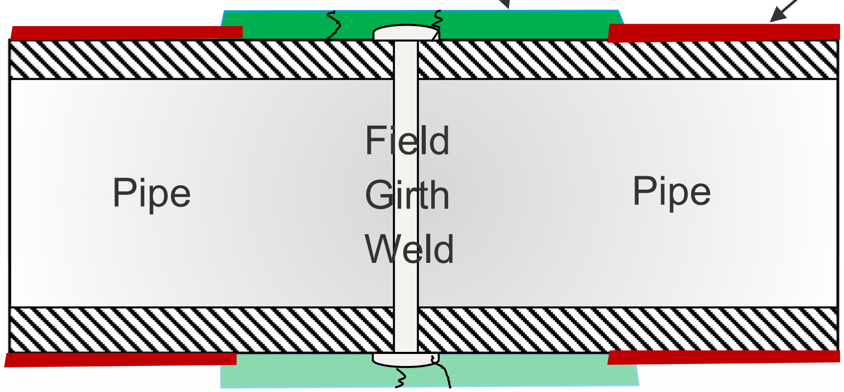
Reducing corrosion of natural gas pipeline welds lowers methane emissions by reducing: https://www.ingaa.org/File.aspx?id=34990&v=56603504

- **Controlled venting:** Depressurizing pipeline for maintenance, repairs, inspection, or hydrostatic testing, commonly for integrity management to meet federal pipeline safety regulations.
  - Example: 36” diameter, 800 psig pipeline blowdown for pipe replacement of a 30-mile segment (distance between mainline valves) results in natural gas emission of 60 million cubic feet http://blogs.edf.org/energyexchange/files/2016/07/PHMSA-Blowdown-Analysis-FINAL.pdf
- **Fugitive emissions:** Leaks and incidents during operations

Current Problem

Field-applied pipeline coating over pipe ends and field girth weld is:

- Usually **lower quality** than factory-applied pipe coating
- Results in more frequent **coating failures**



Axial cross-section of buried steel pipeline

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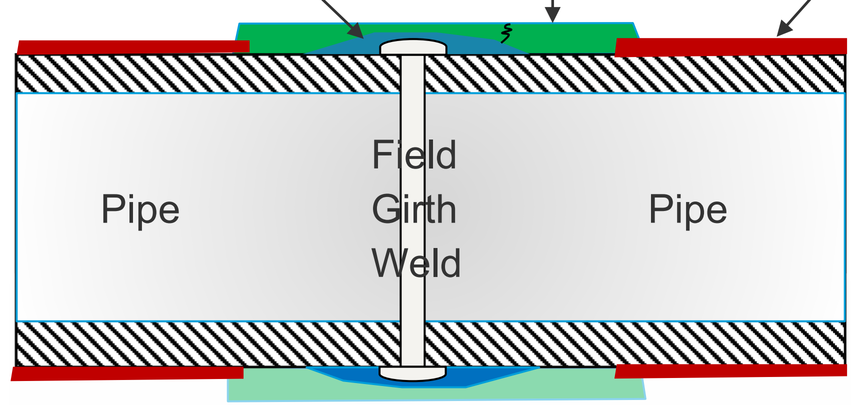
Proposed Solution

Field Protective Coating (FPC) provides extra layer of corrosion protection in girth weld region.

Especially when:

- Groundwater penetrates the field top coating
- Pipe is shielded from external CP



Axial cross-section of buried steel pipeline

Project Approach

- Optimize and select alloy(s) for field protective coating, using models and experiments
- Consider 2 types of alloys:
  - Corrosion resistant
  - Sacrificial
- Generate alloy coated pipe steel coupons
- Testing of corrosion coupons
  - Laboratory
  - Pipeline field site
- Document performance and draft guidance for field protective coating

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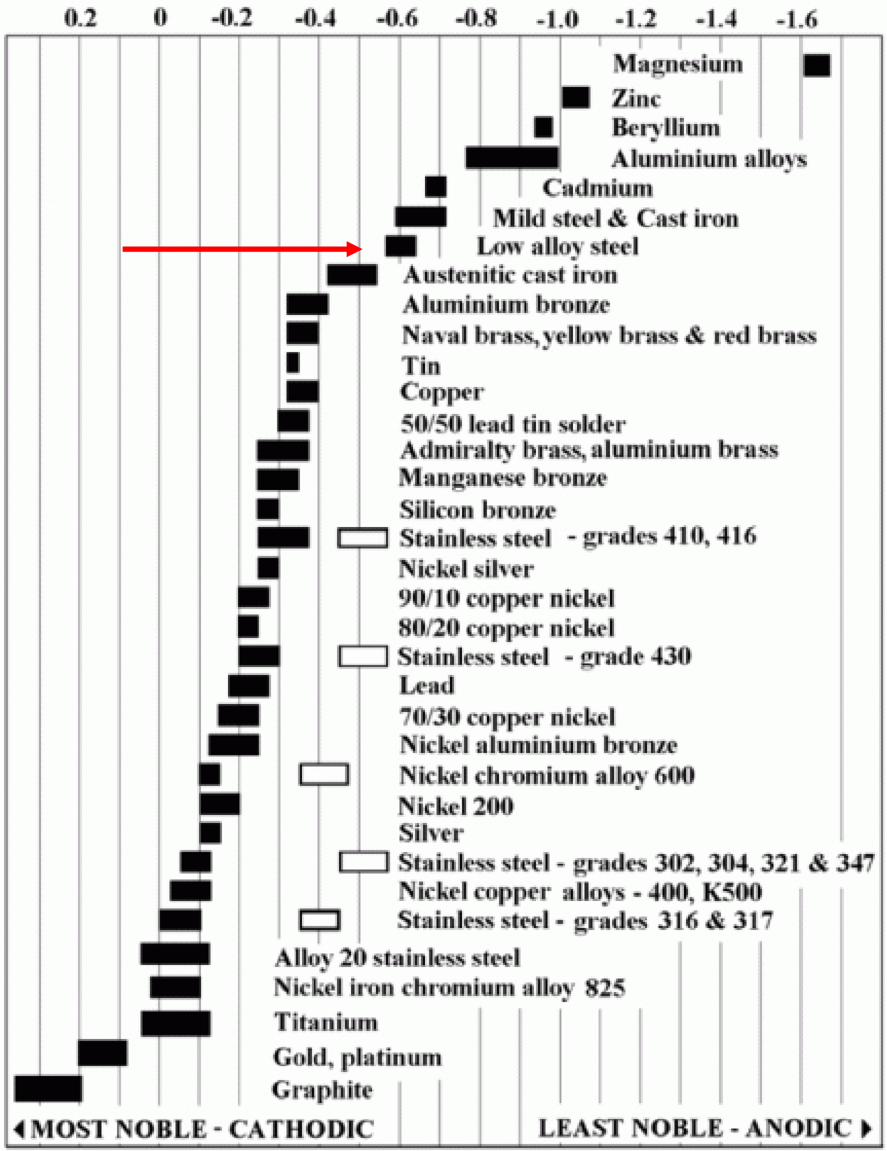
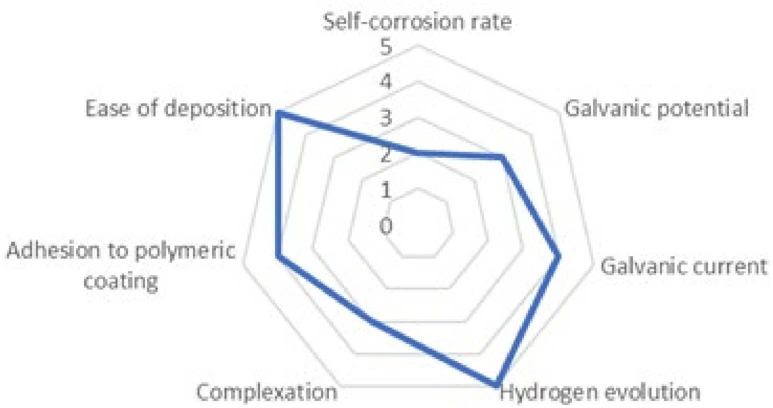
Alloy Overview & Selection





- Selection Criteria for an effective field protective coating
  - Minimal self-corrosion
  - Optimized galvanic potential and current
  - Mitigate hydrogen evolution
  - Avoid complexation
  - Adhesion to field applied polymeric coating
  - Weldability

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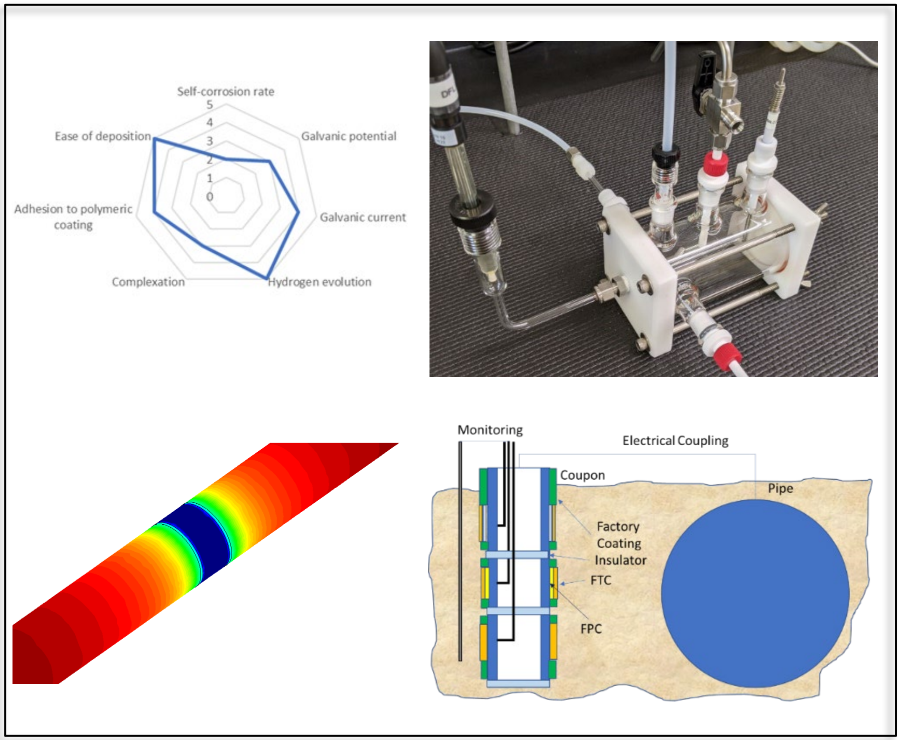
Research Approach



Materials overview and selection

- Modeling and data collection
- Candidate list of materials produced
- Downselect criteria developed

Electrochemical testing

- Polarization curves in soil simulant solutions

Finite element simulation of coating disbondment scenarios

Coated coupon studies

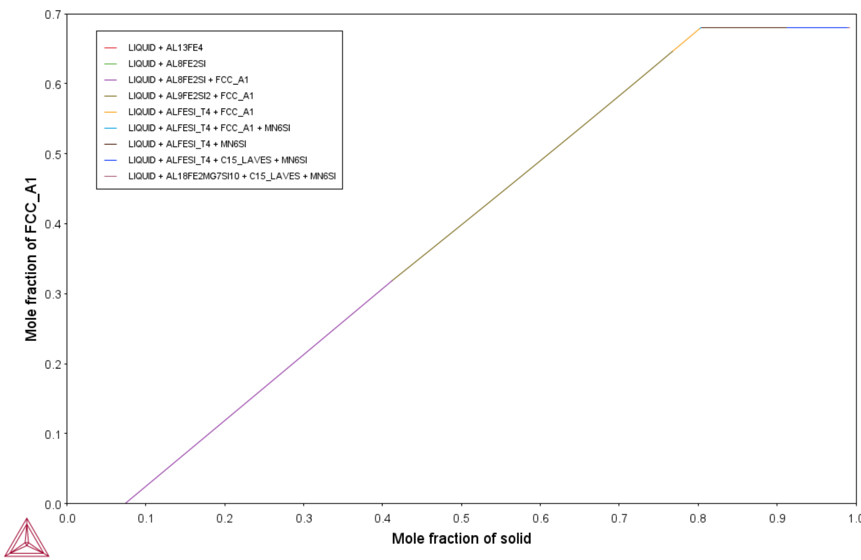
- Laboratory, electrochemical
- Field testing of coupons in soils

Final recommendations

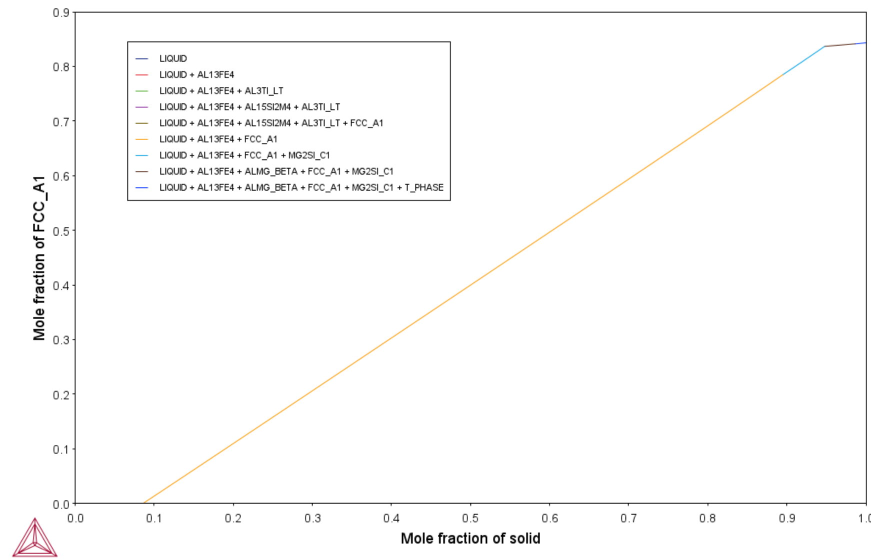
Primary Alloys Considered

- Commercially available, practical for field application
- Sacrificial Alloy – Aluminum
  - **4043** (Al-Si alloy): 4.5-6.0% Si
  - **5356** (Al-Mg alloy): 4.5-5.5% Mg
- Corrosion Resistant Alloy - Steel
  - **B2** (Fe-Cr-Mo alloy): 1.00-1.75% Cr, 0.45-0.65% Mo
  - **B3** (Fe-Cr-Mo alloy): 2.30-2.70% Cr, 0.90-1.20% Mo
  - **B9** (Fe-Cr-Mo-Ni-V alloy): 8.5-9.5% Cr, 0.85-1.10% Mo, 0.40-0.80% Ni, 0.15-0.25% V

ThermoCalc - Scheil Simulation for 5% Dilution with Fe: Content of intermetallics vs. α-phase



Alloy 4043



Alloy 5356

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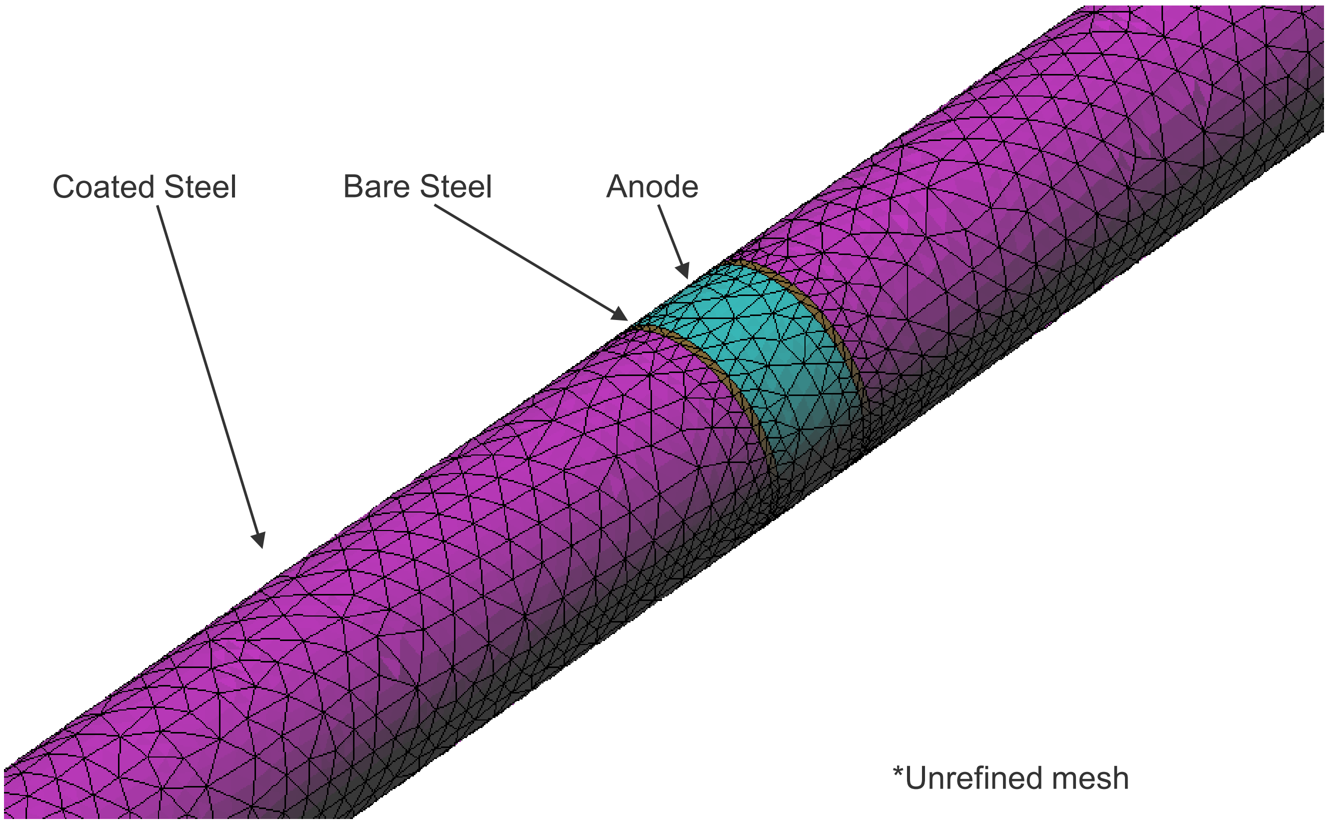
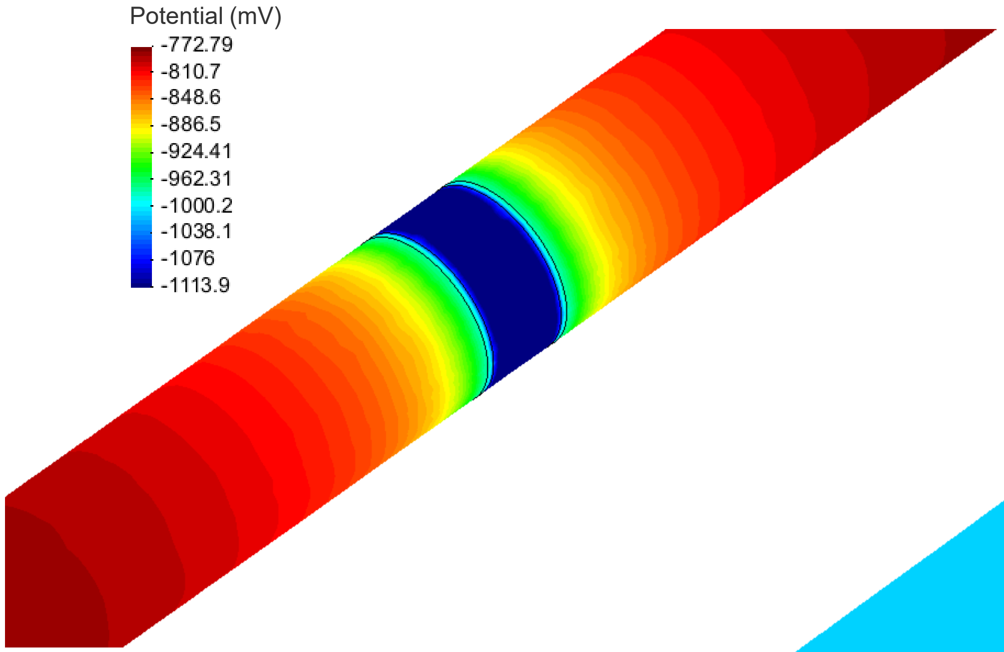
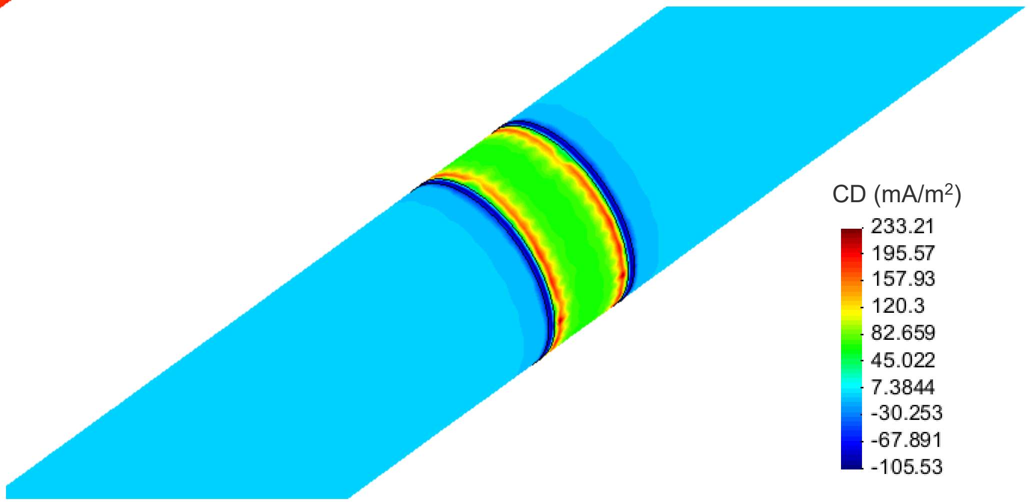
Corrosion/CP Modeling: BEASY Mesh

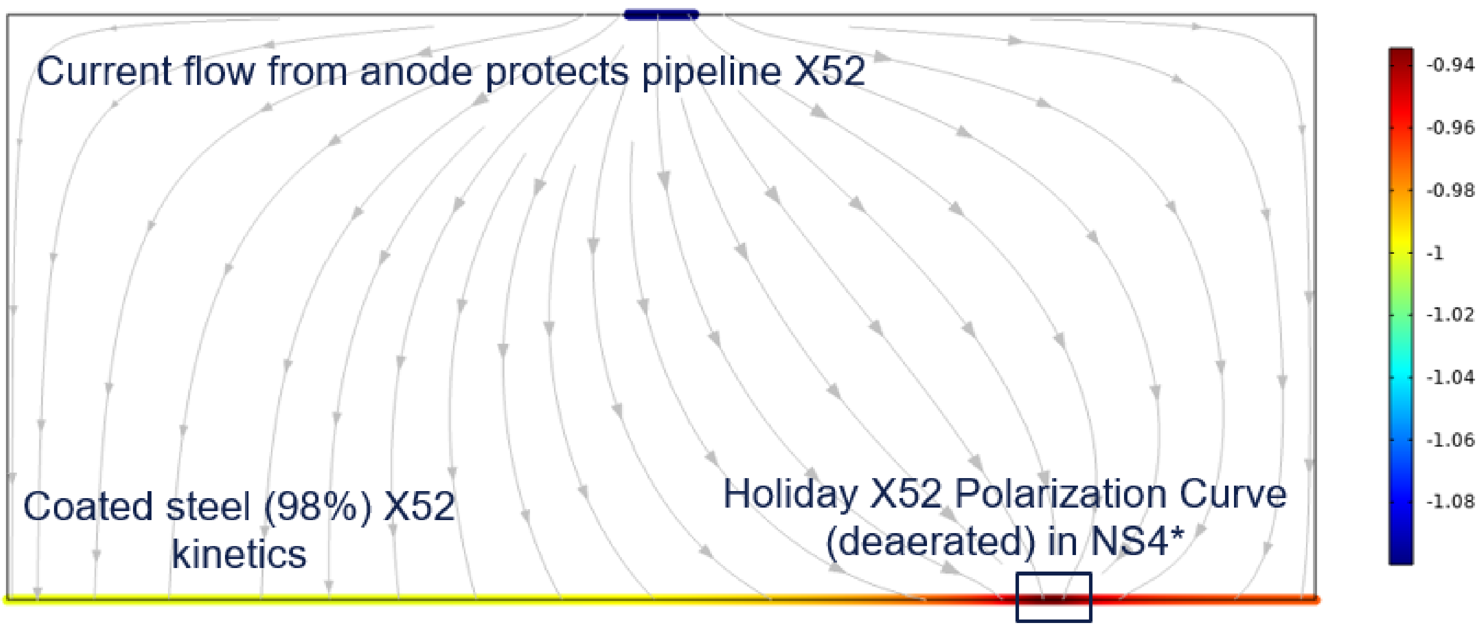


BEASY Results

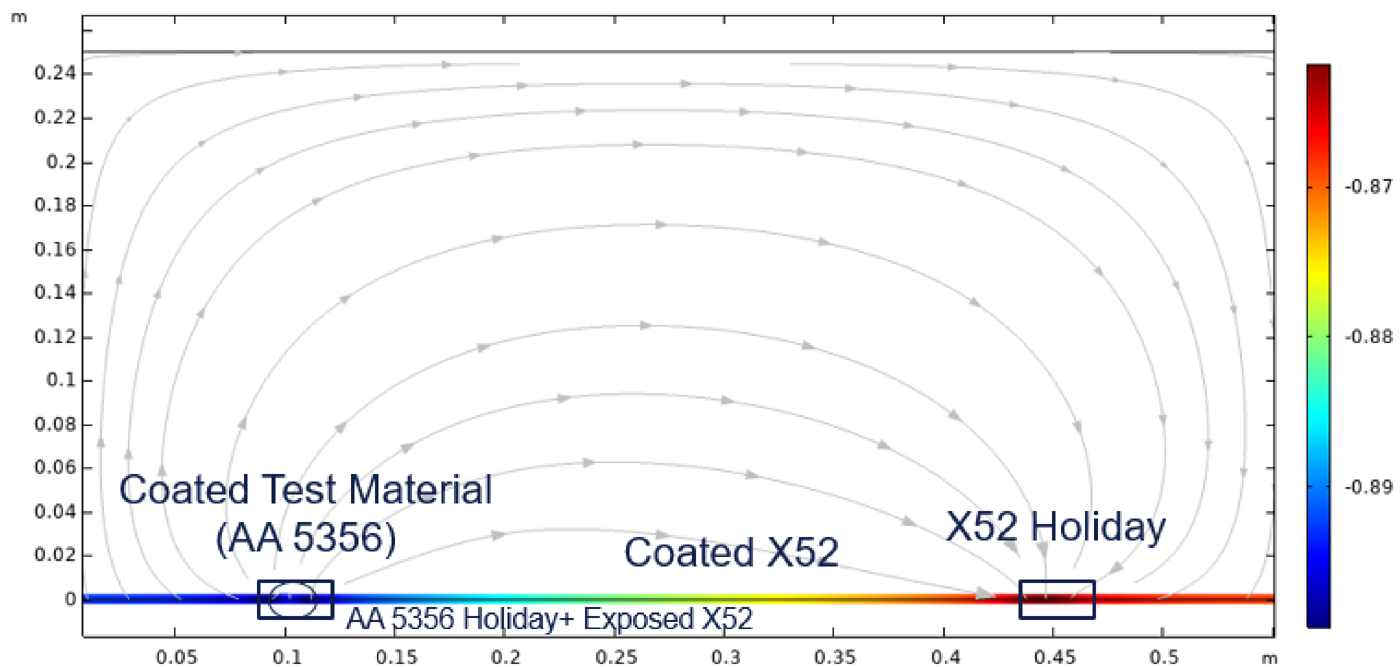




Example COMSOL Simulation #1: Baseline with CP



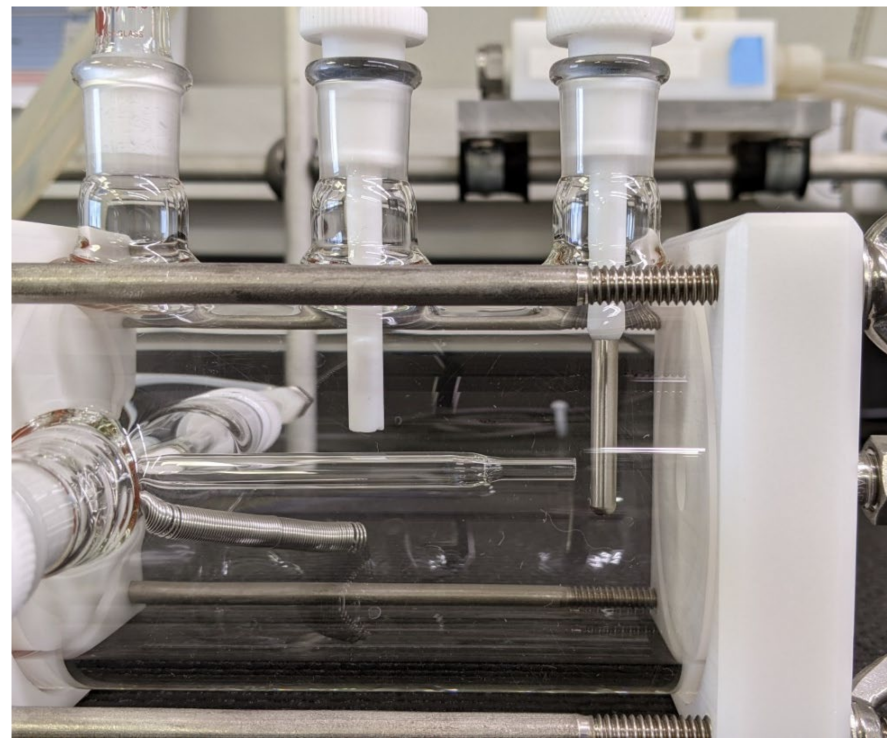
Example COMSOL Simulation #2: Without CP and Sacrificial Coating



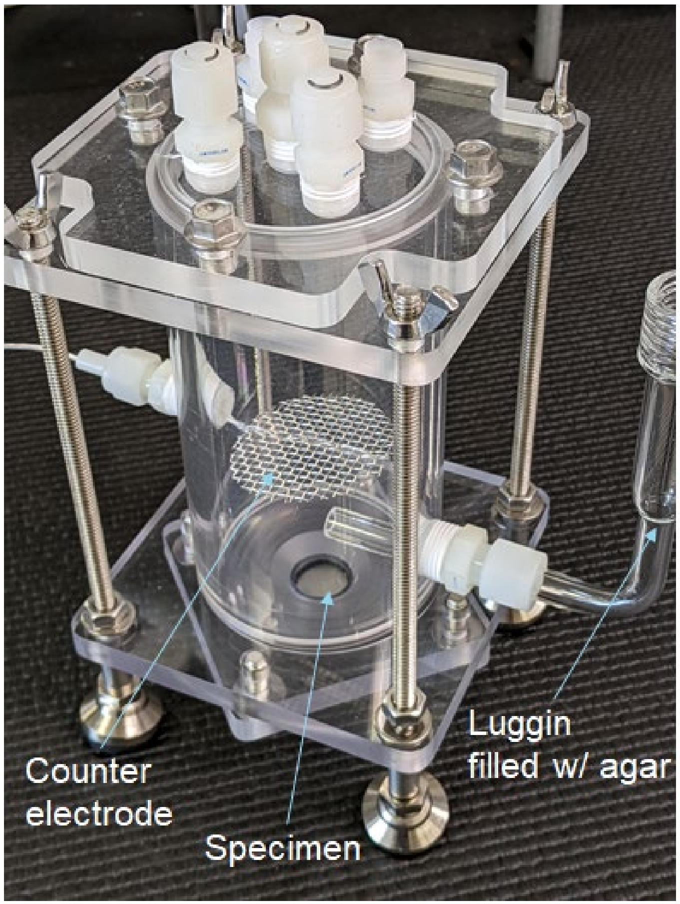
Electrochemical Testing

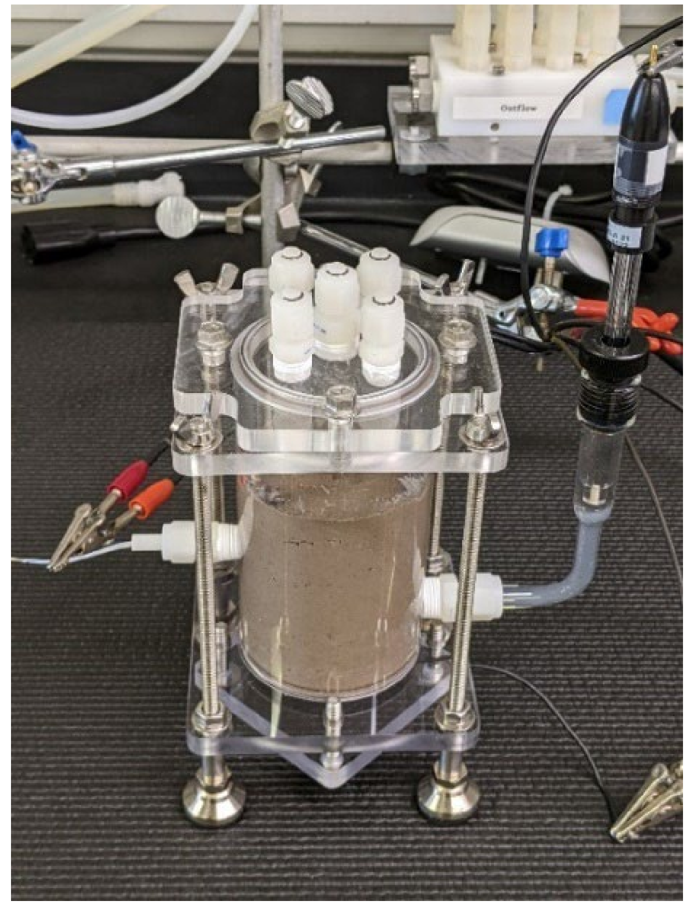
- Sacrificial FPC:
  - Materials provided by project partners in weldable TIG rods of 4043 and 5356 aluminum
- Corrosion resistant FPC:
  - B2, B3, B9 steel alloys
- Flat cell Luggin capillary, soil simulant solution

Reagent	g/L
KCl	0.122
$NaHCO_3$	0.483
$CaCl_2.2H_2O$	0.181
$MgSO_4.7H_2O$	0.131



Electrochemical Testing





Test cell and electrode configuration used for electrochemical testing in soil

BP1 Go/No-Go Metrics

1. Composition should be commercially available, or developed with relatively minor modifications of existing commercial alloys;
2. Alloy should be capable of being deposited using methods suitable for pipeline field conditions; and
3. Alloy should be amenable to field application of polymer coating
4. Sacrificial Alloy
   - Galvanic potential should be in the range of -950 to -850 mV SCE
   - Corrosion rate of sacrificial alloy should be low (e.g. for 0.1 inch thick coating to last 20 years, corrosion rate should be < 5 mils per year)
5. Corrosion Resistant Alloy
   - Corrosion rate of the alloy should be low, and at least an order of magnitude lower than unprotected steel
   - Galvanic effect between the corrosion resistant material and steel should be relatively low

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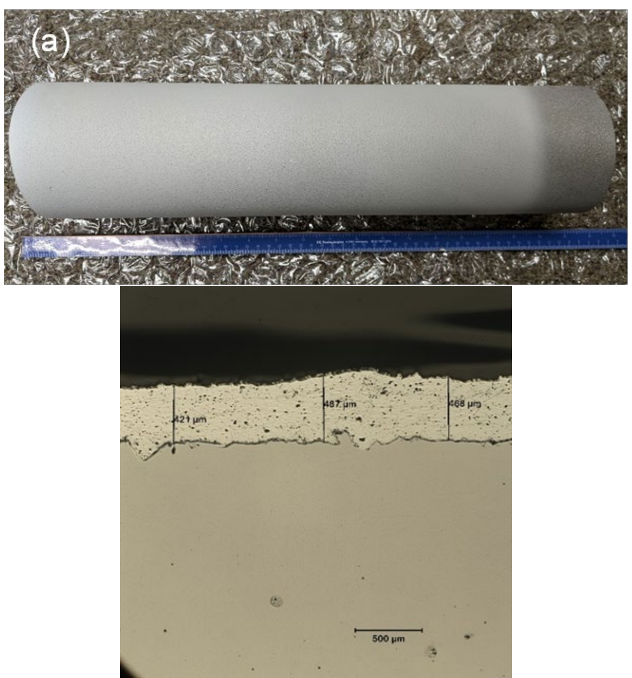
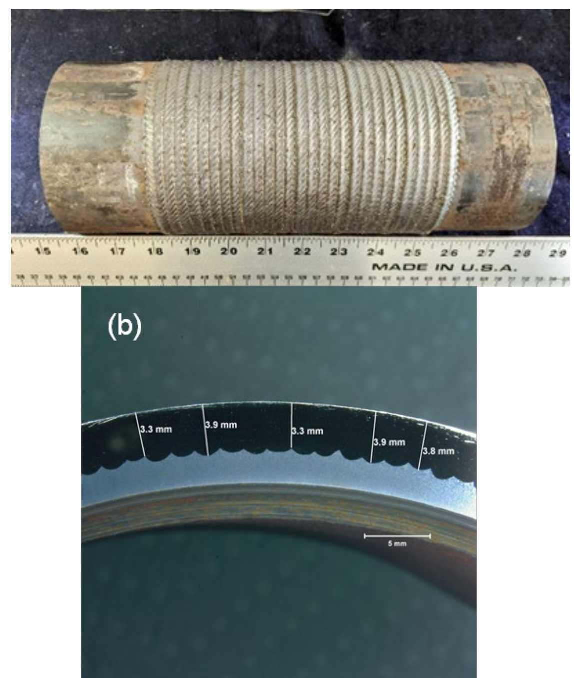
Alloys Selected

- Sacrificial Alloy: Aluminum 5356
  - Flame sprayed to avoid brittle intermetallics
- Corrosion Resistant Alloy: Steel B9
  - Gas metal arc welded on 4.5” dia. X42 pipe





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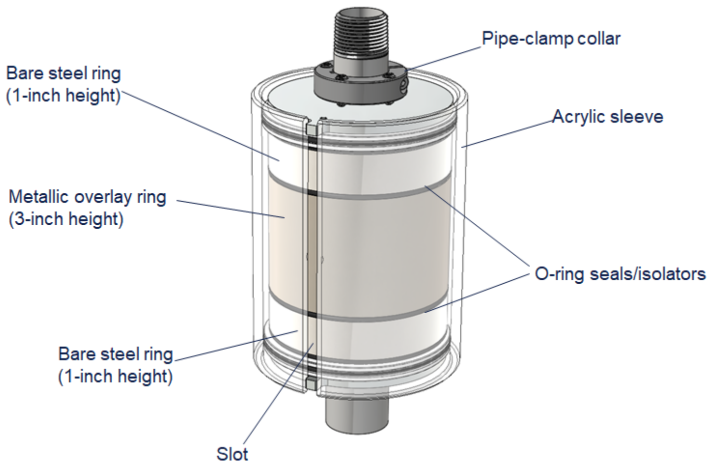
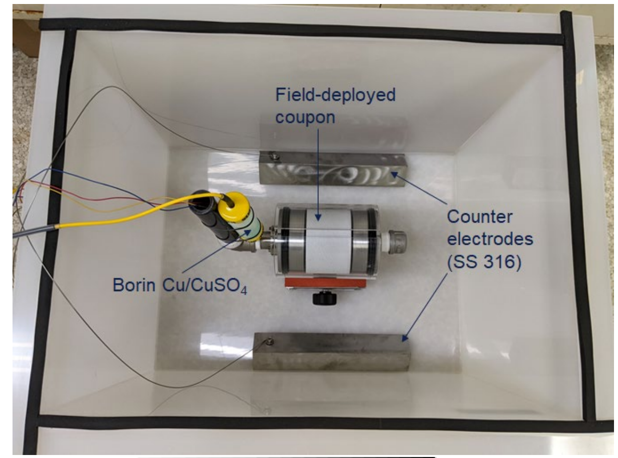
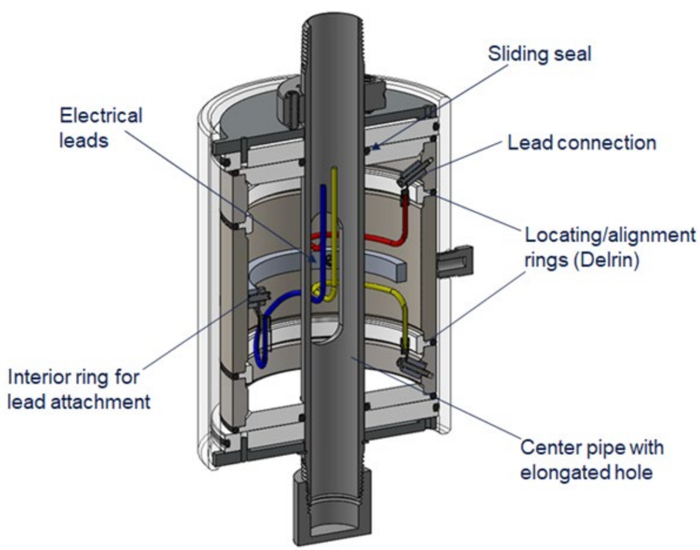
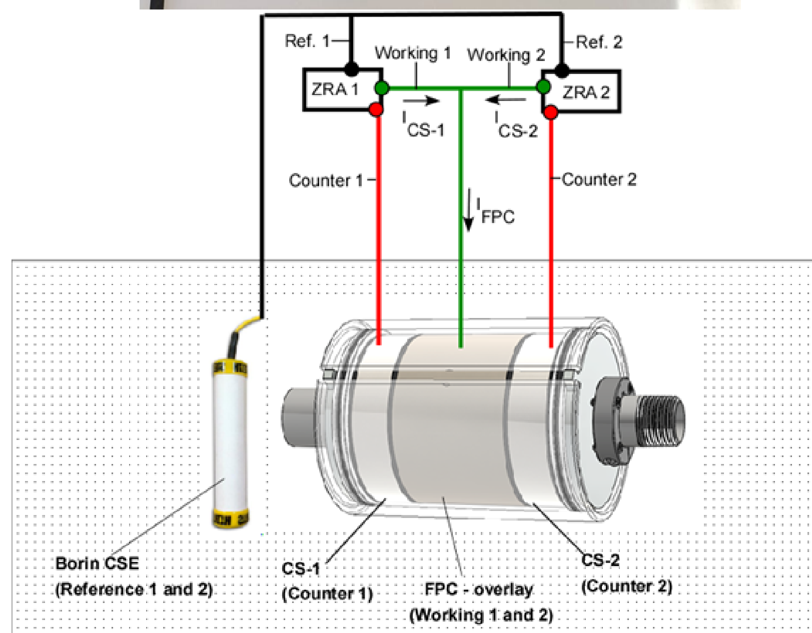
Field Coupon









3-Month Field Test

- Enbridge site: Natural gas pipeline compressor station in San Jacinto County, TX
- Coupons are electrically coupled to the pipeline to simulate CP conditions that a pipeline undergoes.
- The corrosion rate is monitored using linear polarization resistance and impedance methods after periodically disconnecting the pipe connection.

Outreach

- CORRISION 2021 (April 22, 2021)
  - Christopher Taylor presented “Enhanced Protection of Pipeline Field Joints Using Field Protective Metallic Coatings”, Research in Progress symposium, virtual conference, Association for Materials Protection and Performance (AMPP) [formerly called NACE International]

Questions?

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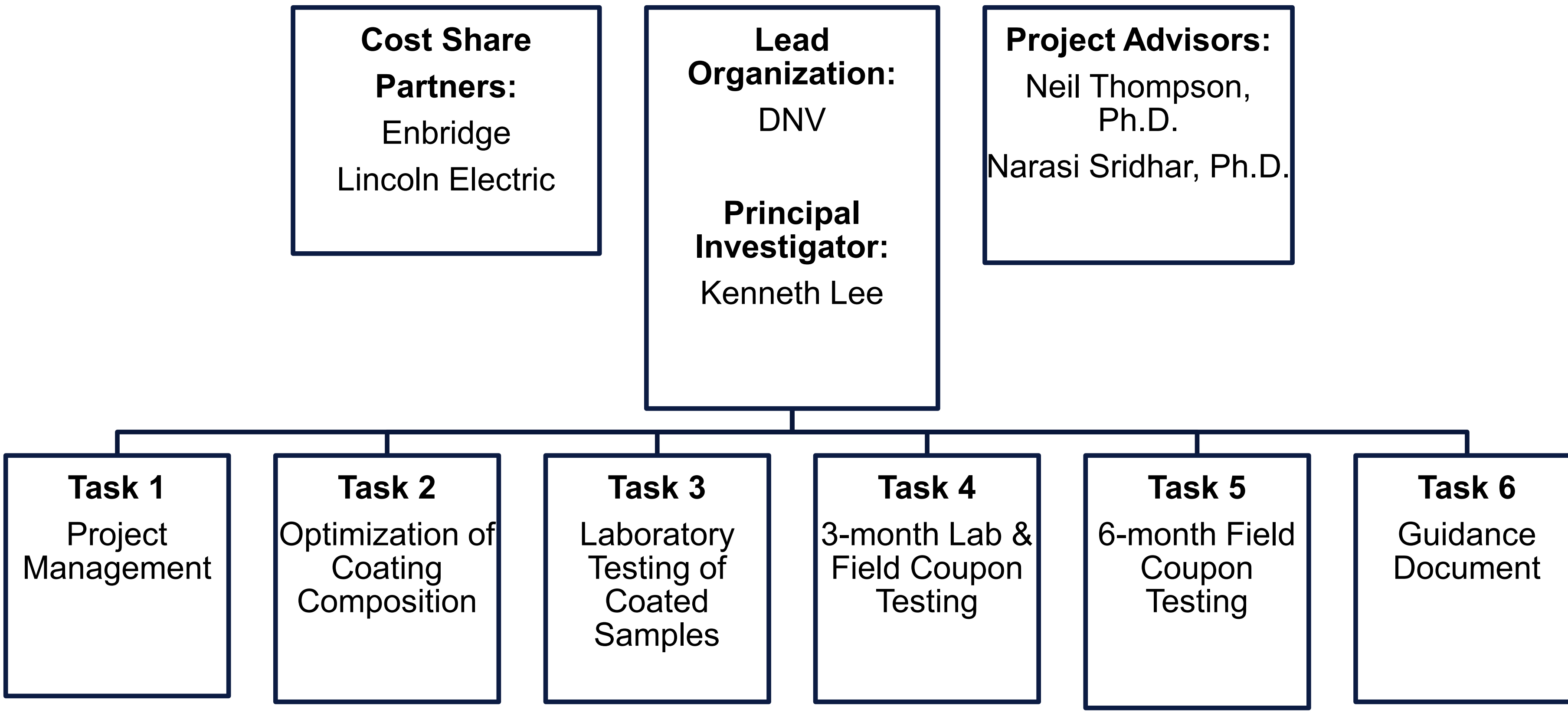
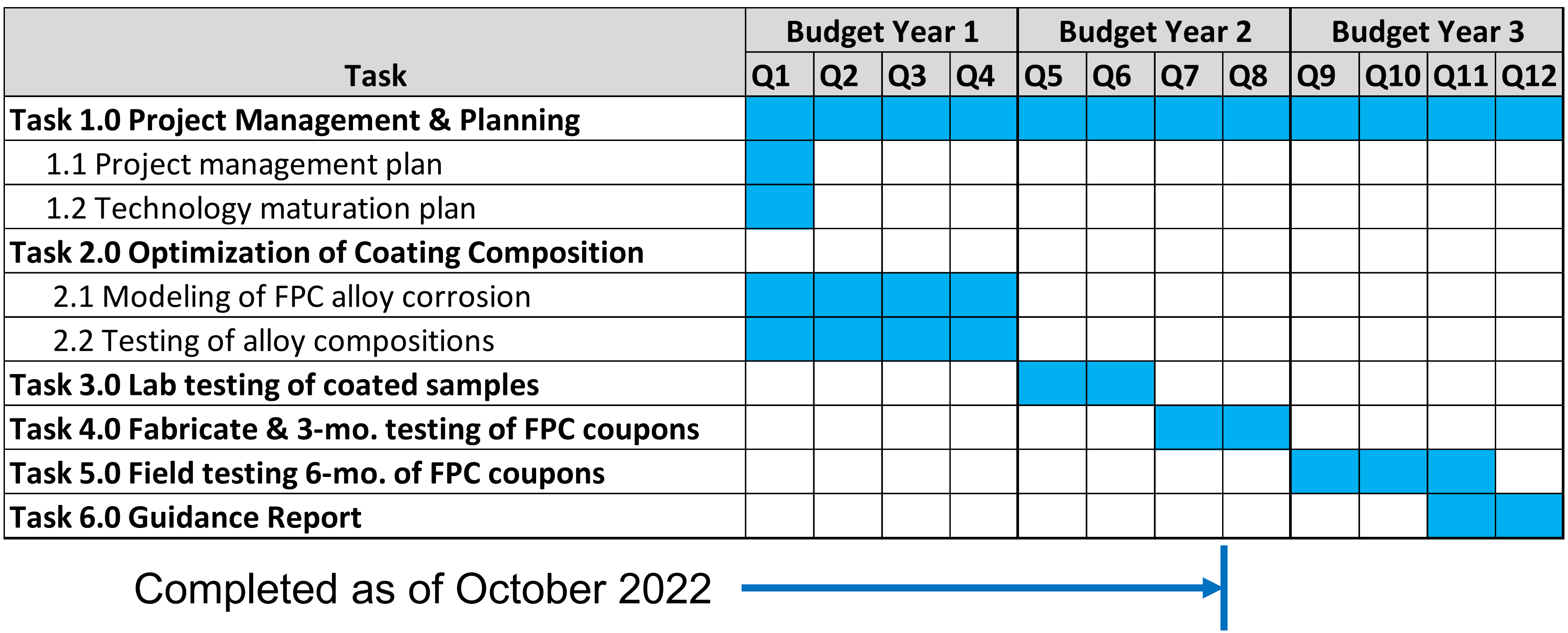
Appendix

Organization Chart



Gantt Chart



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