Fouling-resistant, chlorine-tolerant zwitterionic membranes for treatment of produced water in the Permian Basin

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Presentation Outline

- Technology status
- Techno-economic analysis status
- Summary project accomplishments to date
- Lessons learned
- Synergy opportunities
- Project summary and next steps

Technical Status

- ZwitterCo has introduced an innovative new zwitterionic superfiltration technology that provides nanometer-scale selectivity and is virtually immune to oil and grease fouling
- Potential to provide pretreatment for downstream desalination processes such as membrane distillation
- In a recent landfill application pilot study, **ZwitterCo superfiltration increased overall freshwater recovery** in the combined treatment train **from 60% to >85%**
- Project is currently in Phase II, preparing for pilot-scale deployment to begin trials with actual produced water samples

Technical Status

– ZwitterCo has demonstrated a bench-scale ability to filter & pretreat simulated Permian Basin produced water

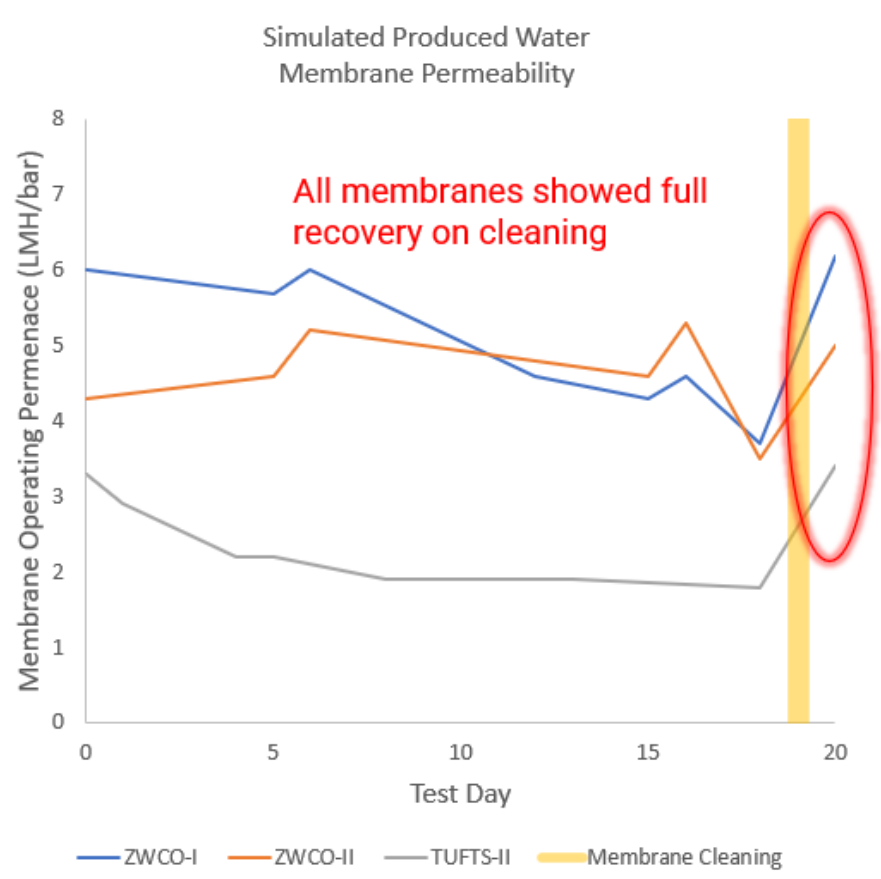
Day 18

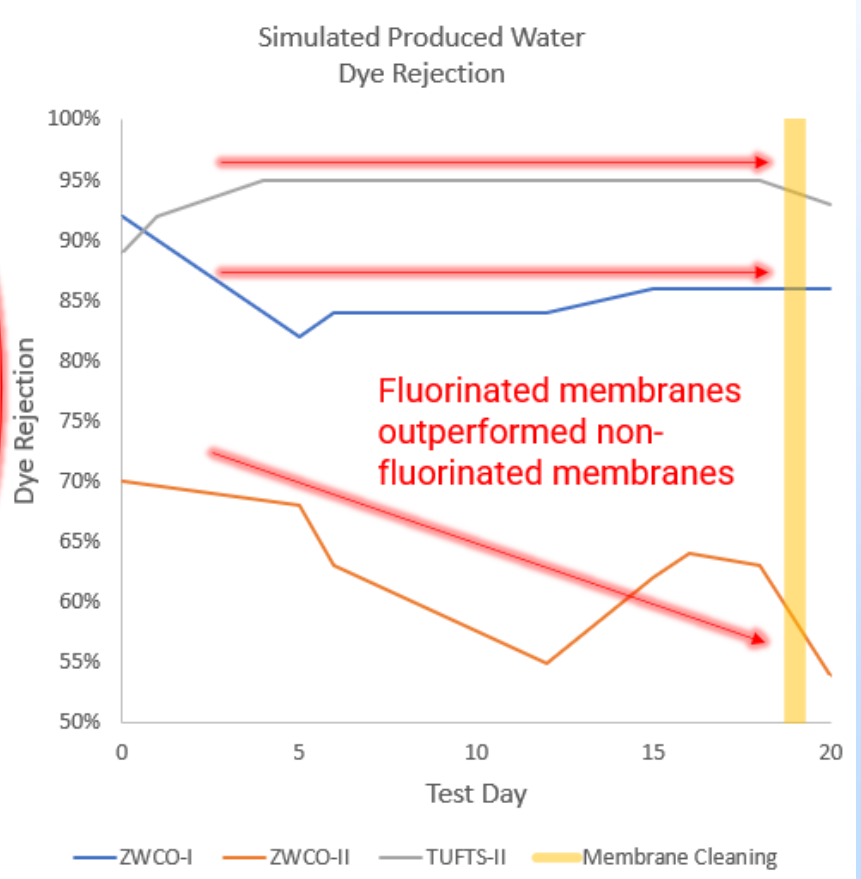
After Rinse

After CIP

Technical Status

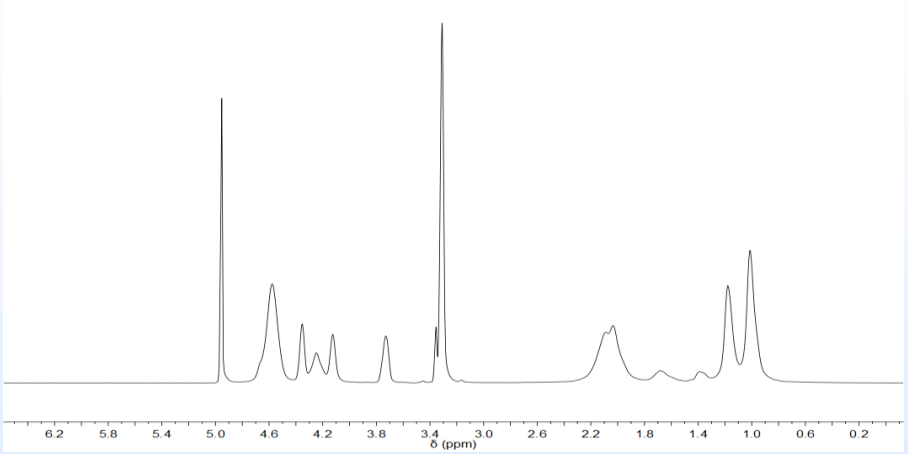
– Multiple variations of membrane chemistry were evaluated for compatibility with produced water and permeate quality

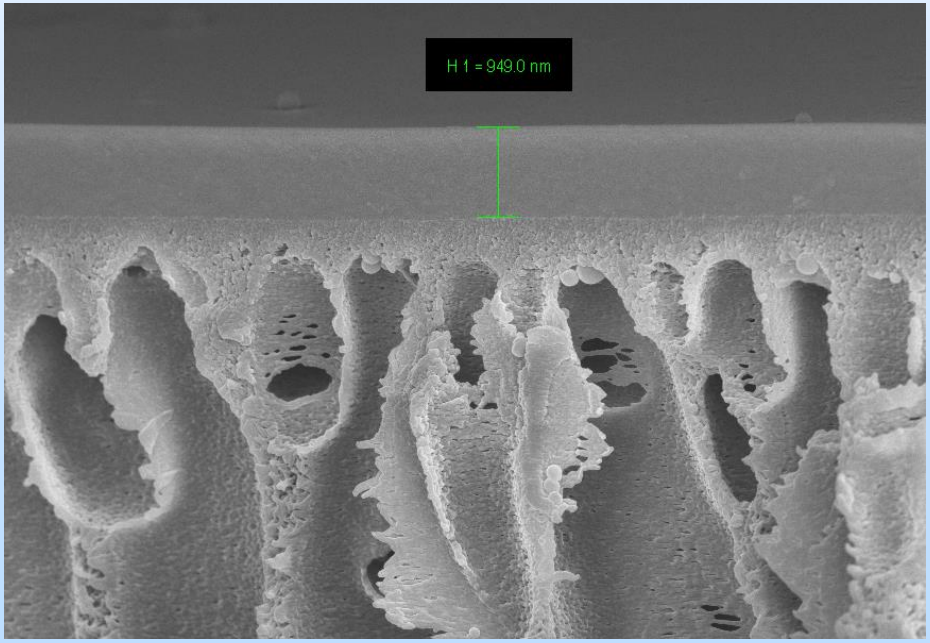


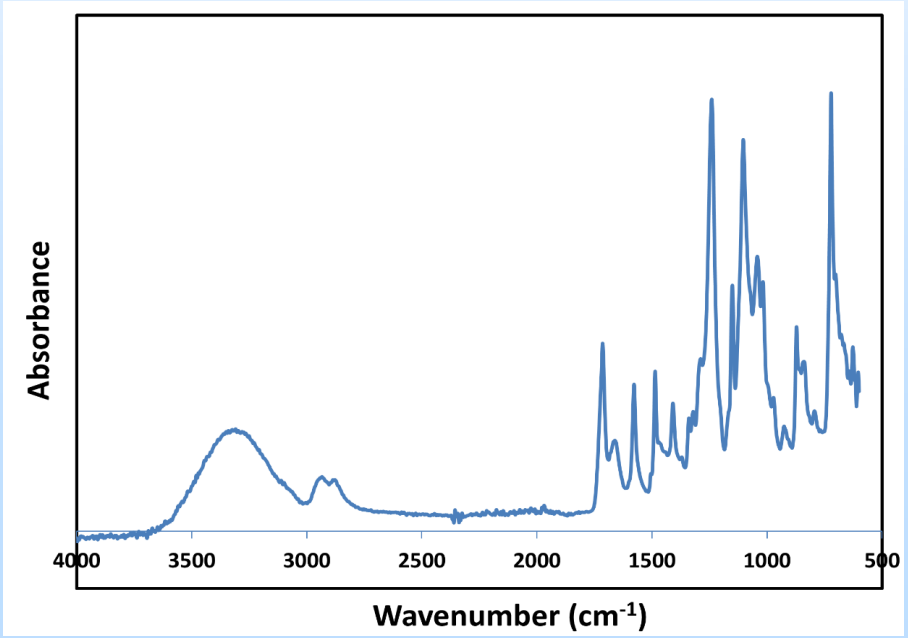


Technical Status

With support from Tufts University, complete characterization of the prototype produced water membranes was been performed, including NMR, ATR-FTIR, and SEM.

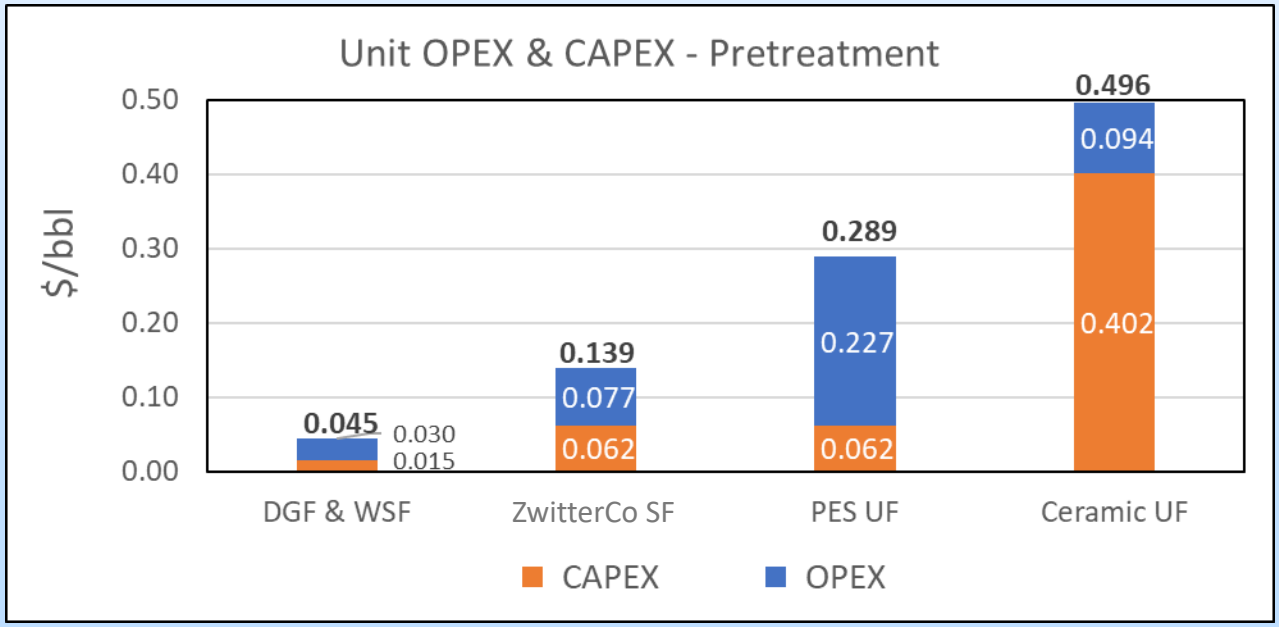




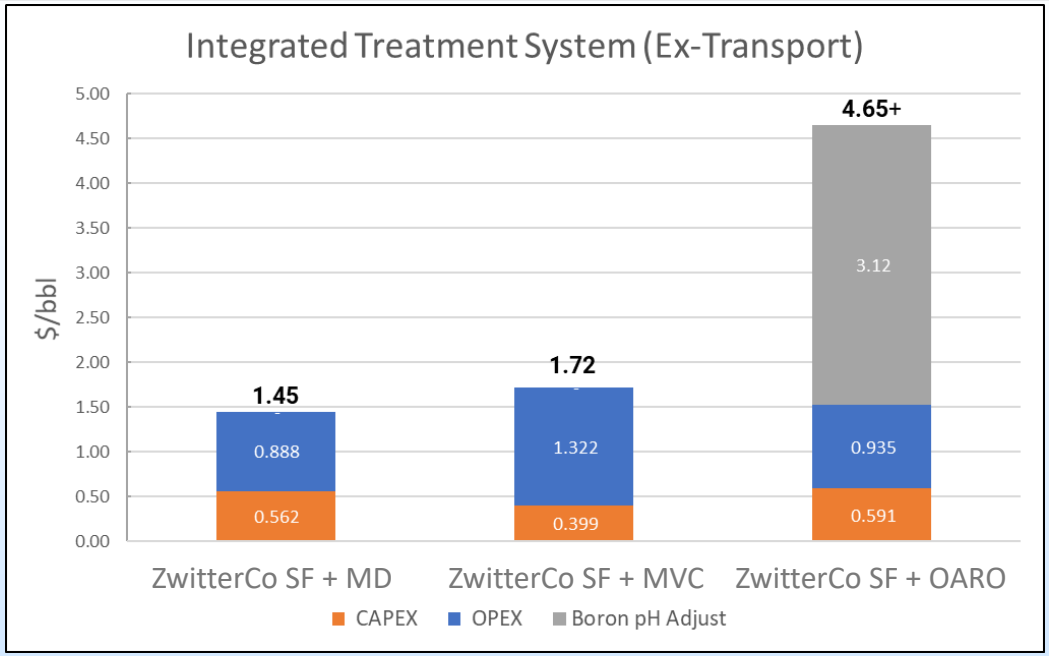


Technical Status

- ZwitterCo SF offers the lowest total pretreatment cost ($0.14/bbl) while achieving effluent quality suitable for desalination
- Dissolved gas flotation (DGF) and walnut shell filtration (WSF) are suitable for oilfield reuse of produced water but not as pretreatment to desalination



Technical Status



- ZwitterCo SF + membrane distillation (MD) offers the lowest total cost of treatment
- Osmotically assisted reverse osmosis (OARO) was determined to be infeasible as a desalination option due to the pH adjustment required to remove the Permian's high levels of boron to concentrations acceptable for off-field reuse

Accomplishments to Date

- Completed preliminary TEA, establishing target economics of <$1.50/bbl overall treatment cost and <$0.15/bbl ZwitterCo membrane system cost
- Completed inventory and risk assessment of water demand centers within basin geography
- Membrane characterization of 6 variations of ZwitterCo chemistry adapted for use in produced water
- Bench-scale performance validation using high TDS synthetic produced water
- Completed chemical resistance study to rate membrane for exposure to BTEX, oxidizers, acid and base

Lessons Learned

- Project experienced significant delays in connection with ongoing pandemic; additional spending to parallelize some aspects of the project closed some of the gap.
- Material of construction (MOC) selection is of extreme importance, even for auxiliary equipment
- Ionic strength impacts on membrane properties are notable at extreme TDS levels (in this case, for the better!)

Bench-scale filtration cell destroyed by BTEX exposure

Synergy Opportunities

- As requested by FOA, ZwitterCo project focused on pretreatment only, not TDS removal. However, TEA has revealed that the most promising reuse cases will require TDS removal.
- ZwitterCo's permeate provides ideal feed quality for desalination unit operations – **interested in collaborating with emerging desalination technologies** to quantify cost-savings and technical advantage conferred by this pretreatment

Project Summary

- ZwitterCo membranes successful in reducing oil and grease, silt density index, and total iron loads in simulated produced water to levels needed for desalination
- ZwitterCo membranes unaffected by >250k ppm-hrs of BTEX and chlorine exposure
- No irreversible fouling from oil and grease seen
- Next steps:
  - Prepare equipment and membrane prototypes for field testing
  - With project partners, secure Permian Basin produced water samples for testing campaign
  - Finalize operational plans and site preparation

Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

- This project seeks to advance the DOE's goal of diverting produced water from deep well injection.

- The project will demonstrate that ZwitterCo's membrane technology out-competes conventional pre-treatment on the fully burdened cost per barrel, thereby economically removing the constituents that would otherwise handicap further treatment efforts like ion exchange, electrocoagulation, and membrane or thermal desalination. For desalination, a prerequisite for recycling produced water in most non-oilfield applications, ZwitterCo pre-treatment could enable cost-efficiencies seen in mature zero liquid discharge (ZLD) applications, accelerating the adoption of these technologies in the oilfield and the standardization of beneficial reuse.

Project Overview

Goals and Objectives

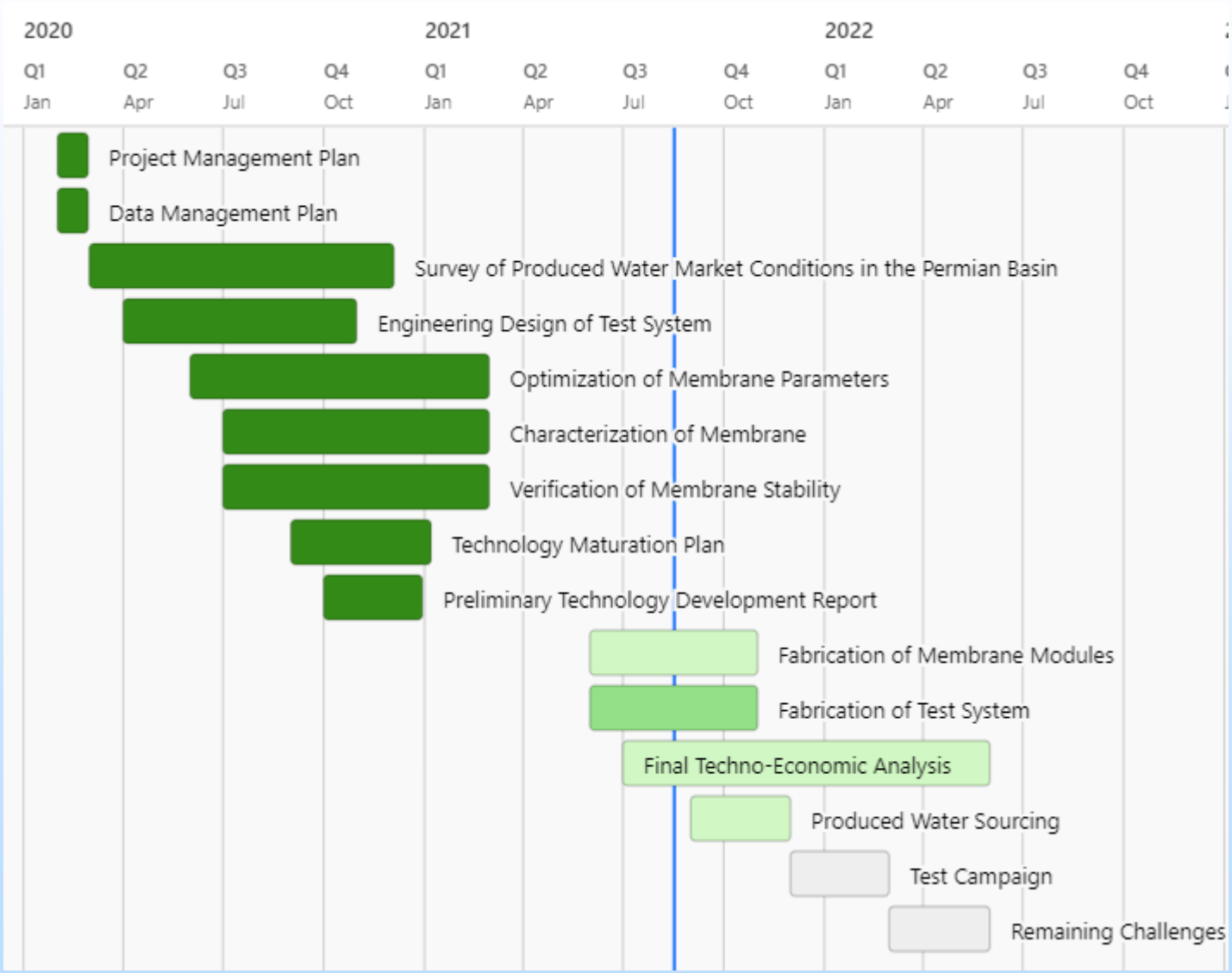
- The goal of the project is to advance the development of a novel membrane technology based on zwitterionic copolymers that can provide cost-effective pretreatment for produced water and maintain immunity to detrimental and irreversible membrane fouling. If successful, this project will demonstrate that produced water can be treated to levels supporting economic beneficial reuse of the water.

1. Project Management, including a Technology Maturation Plan
2. Technology Development, including optimizing the membranes for produced water, characterizing them, and verifying chemical compatibility
3. Preliminary Techno-Economic Analysis, including a survey of produced water market conditions in the Permian Basin, engineering design of the test system, and identification of water demand centers
4. High-fidelity testing, including fabrication of modules and test system, sourcing of produced water, and a testing campaign
5. Final project report, including the finalized TEA and next steps

Organization Chart

- ZwitterCo, Inc.
  - Christopher Drover, PI
  - Chris Roy
  - Project management and all functions not performed by other partners
- Tufts University
  - Dr. Ayse Asatekin
  - Scientific support in polymer formulation, technology development, and characterization of new and used membranes
- Worley Advisian
  - Dr. John Walsh
- Michael Dunkel

Gantt Chart


2020
2021
2022
Q1 Jan
Q2 Apr
Q3 Jul
Q4 Oct
Project Management Plan
Data Management Plan
Survey of Produced Water Market Conditions in the Permian Basin
Engineering Design of Test System
Optimization of Membrane Parameters
Characterization of Membrane
Verification of Membrane Stability
Technology Maturation Plan
Preliminary Technology Development Report
Fabrication of Membrane Modules
Fabrication of Test System
Final Techno-Economic Analysis
Produced Water Sourcing
Test Campaign
Remaining Challenges

Bibliography

- No peer-reviewed publications have yet been generated by this project.