AMMTO & IEDO JOINT PEER REVIEW

May 16th-18th, 2023

Washington, D.C.

A Digitalization, Automation, and Optimization Platform for Improved Resiliency and Consistency of Distributed Anaerobic Digestion for Wastewater Resource Recovery | IEDO

Jeffrey McCutcheon, University of Connecticut

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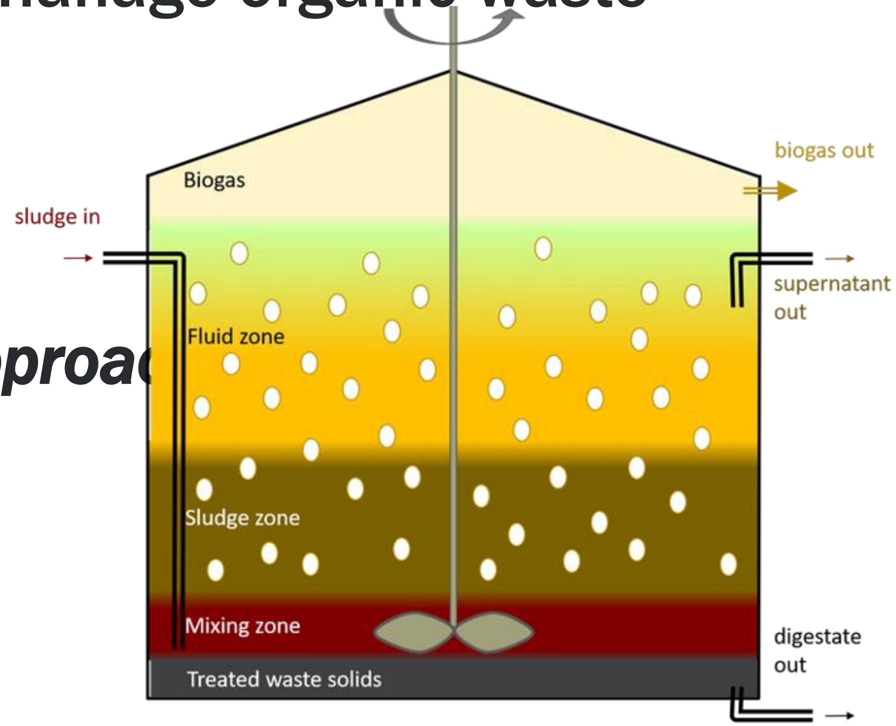
Project Overview

Anaerobic digestion offers a biological solution to manage organic waste

- Reduce waste volume
- Generate heat and/or electricity
- Capture resources (ammonia, VFAs, fertilizer)

We aim to develop a develop a ML aided control approac
performance over several performance metrics



Energy, Emissions, & Environment:	**Cost & Competitiveness:**
Maximize life-cycle benefits of AI controlled anaerobic digestion	Reduce cost barrier for installation through maximum value generation
Technical & Scientific:	**Other Impacts:**
Understand the internal workings of an anaerobic digester	CO_2 Footprint Reduction of organic waste

Project Outline

Innovation: Experimentally verified anaerobic digester digital twin for testing machine learning prediction and control

Project Lead: University of Connecticut

Project Partners: Greater Lawrence Sanitation District, Northeastern Biosolids & Residuals Association, Brown & Caldwell

Timeline: Start date: 10/01/2021, Progress: 50% complete as of March 31, 2023

Budget: $2,000,000 Federal, $500,000 cost share

End Project Goals: Demonstrate improved stability and predictable output of a digester through MLA-aided control strategy, demonstrate how improved performance can reduce WWT by up to 25%, define parameters for using MLA-aided AD to achieve net-zero WWT, integrate process model into WaterTAP

	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	0*	$458,000	$458,000	$2,000,000
Project Cost Share	0*	$157,396	$157,396	$500,000

*Please note that program started in Q1 of FY22

Challenge

Small to mid-sized anaerobic digesters have long suffered from operability problems, leading to poor stability and resilience

- Overloading of feedstock
- Fluctuation of feedstock composition
- Changes in temperature
- Microbial community inhibition
- Lack of micro/macronutrients
- Presence of toxic substances

Performance disruption can lead to "meltdown" or catastrophic failure of the digester.
Recovery from meltdown can take months.

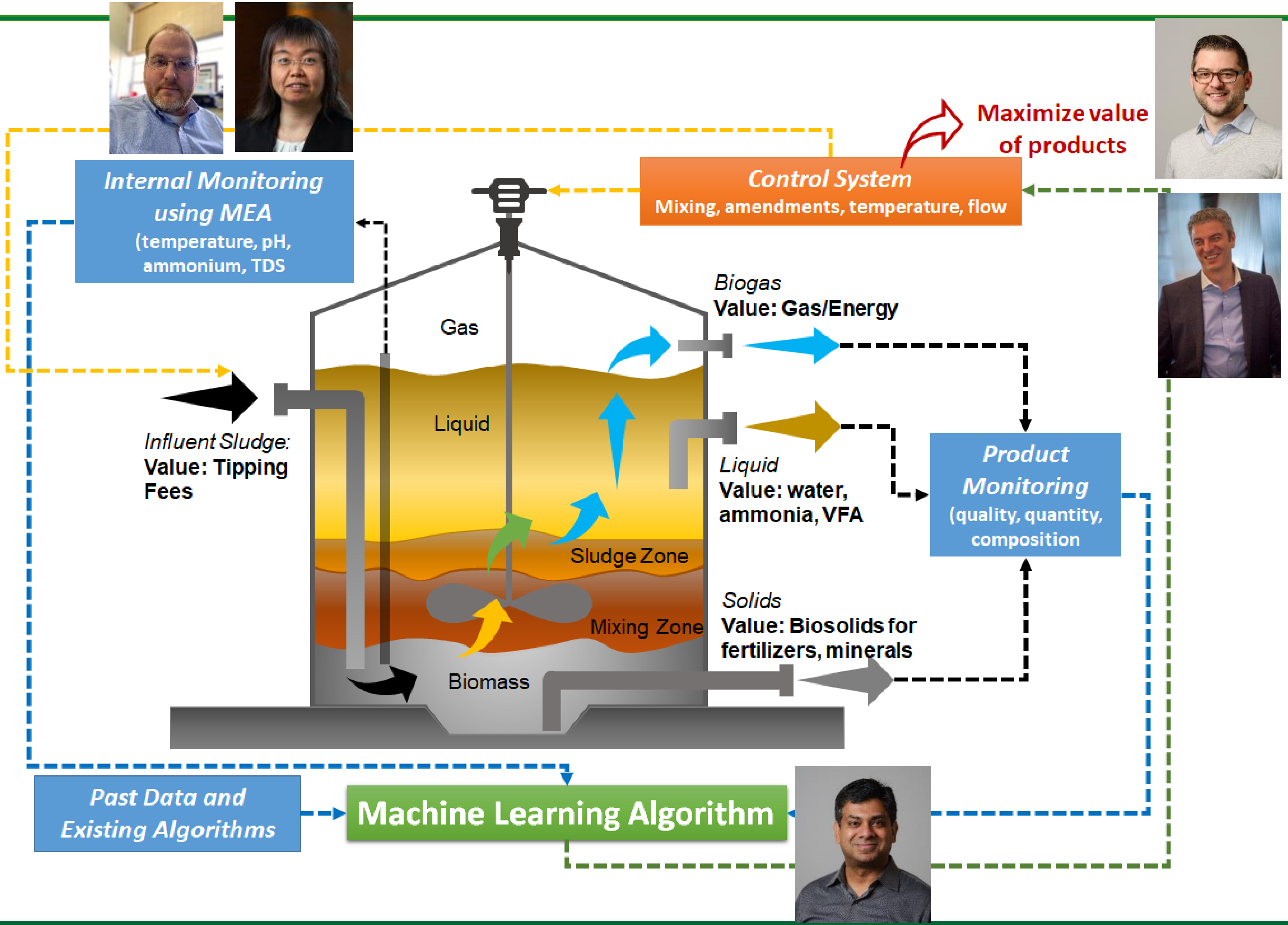
Economic incentives currently lacking for some operating ADs, with many digesters not even trying to capture value from their products.

Deer Island Wastewater Treatment Plant in Boston

Quantum Biopower Food Waste Digester in Connecticut

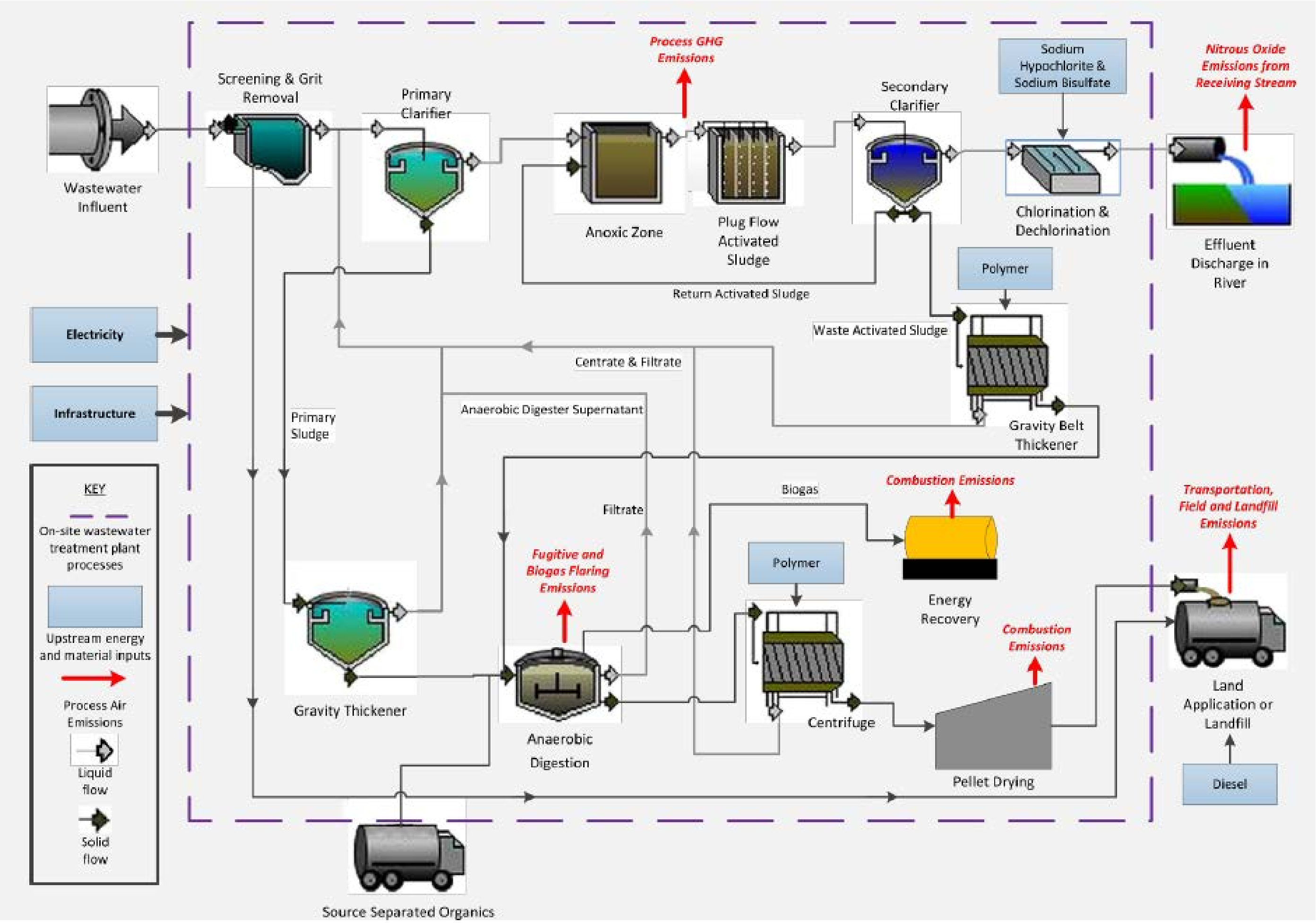
Approach

- Identify key TEA and LCA metrics for AD performance
- Install sensor network in operating digester for data collection
- Use MLA-aided process model to predict performance while optimizing across chosen DOE metrics



Municipal Partner

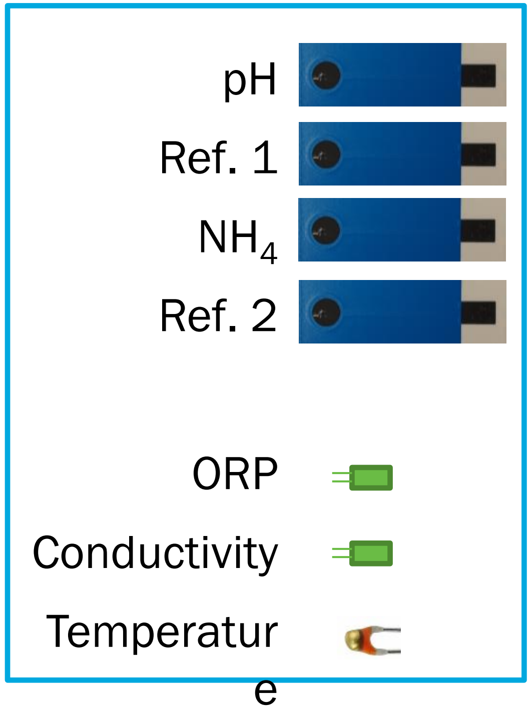
Greater Lawrence Sanitary District



Research Question, Hypothesis, and Objective

- **Research Question:** Can we better control small to mid-scale anaerobic digesters (ADs) in order to prevent failure and harness better economic and life-cycle benefits?
- **Hypothesis:** Using a machine learning algorithm (MLA) aided control strategy, we can improve co-digester performance across a number of metrics
- **Objectives:** Using a novel "milli-electrode array" platform, we will capture high fidelity data within an operating digester in order to train the MLA that will provide predictive . The MLA will be demonstrated on a newly developed AD digital twin that will enable quantification of performance improvement across a number of DOE defined metrics
- *Current metrics: Gas production, life cycle GHG reduction, solids volume reduction, revenue generation*

Installation & Operation Plan Objectives



- Placement of sensors, quantity
- Wiring from senor to data acquisition box
- Sensor mounting to a rod
- Securing rods to the digester
- Selection of data acquisition equipment

- Site operating requirements (site safety, PPE)
- Rod disposal

Sensor Test in GLSD Digestate

NH_4^+ Recalibration

Sensor Surface Conditioning

↓

Initial Calibration (1-128 mg/L)

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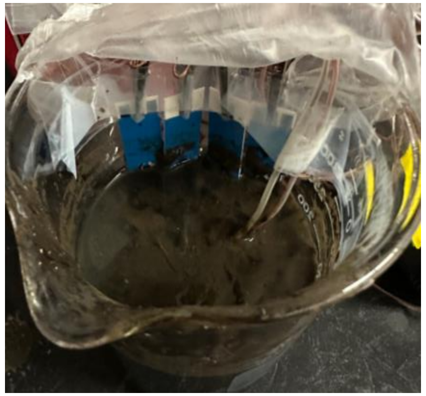
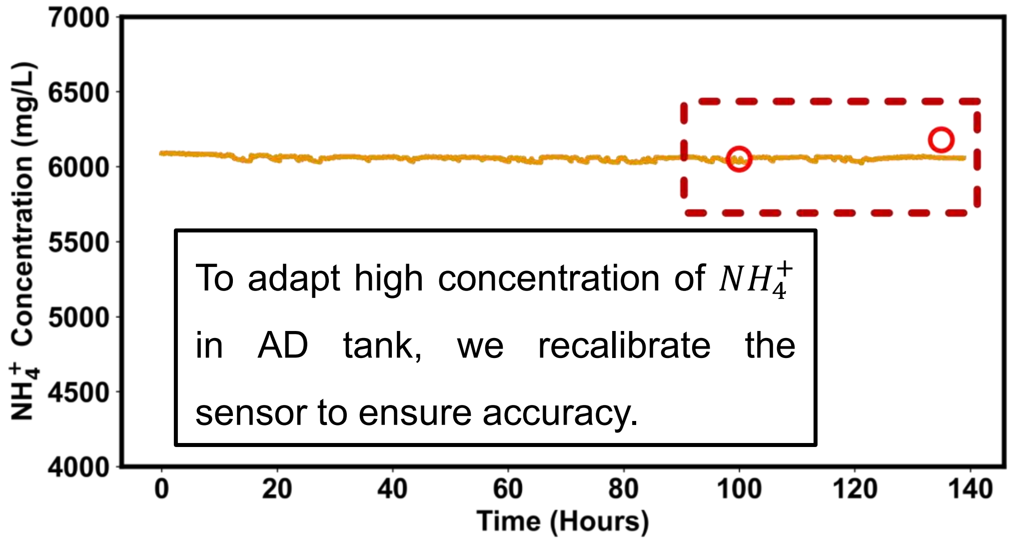
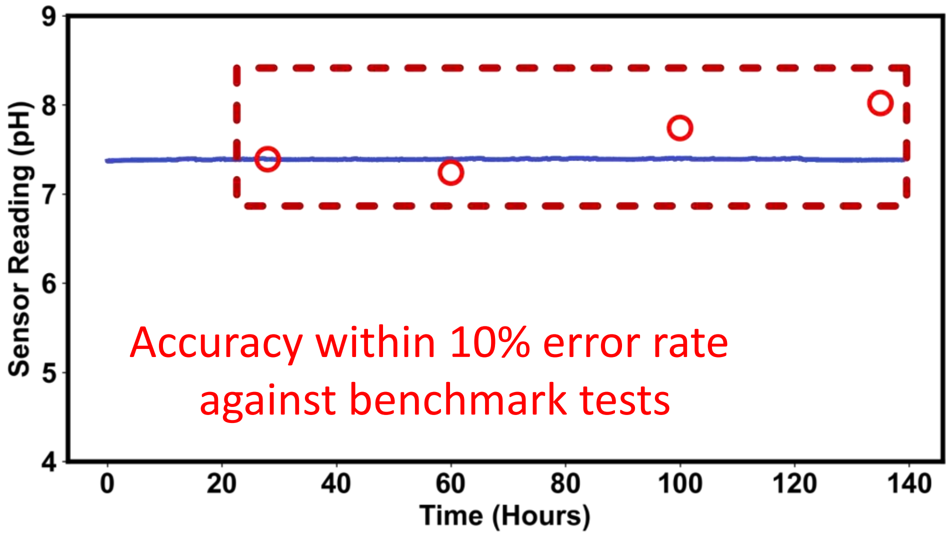
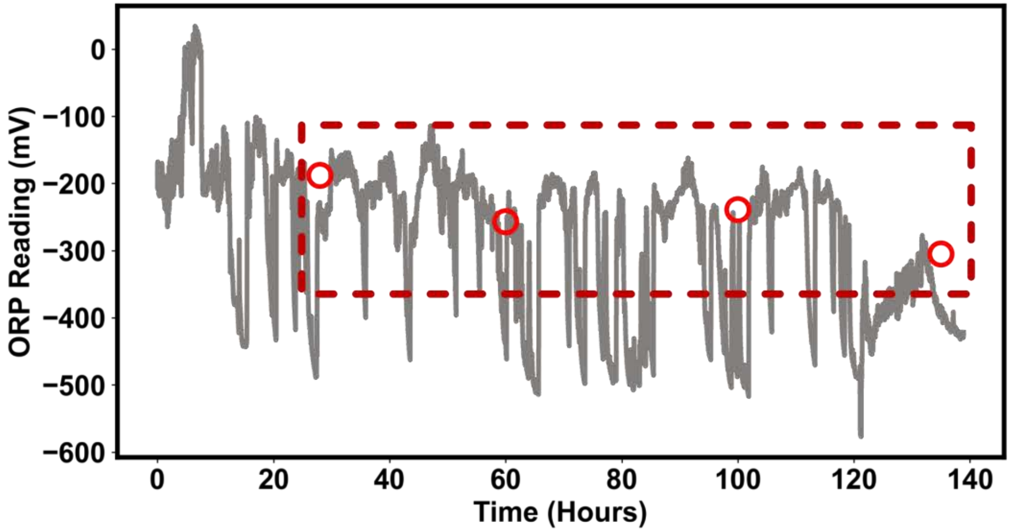
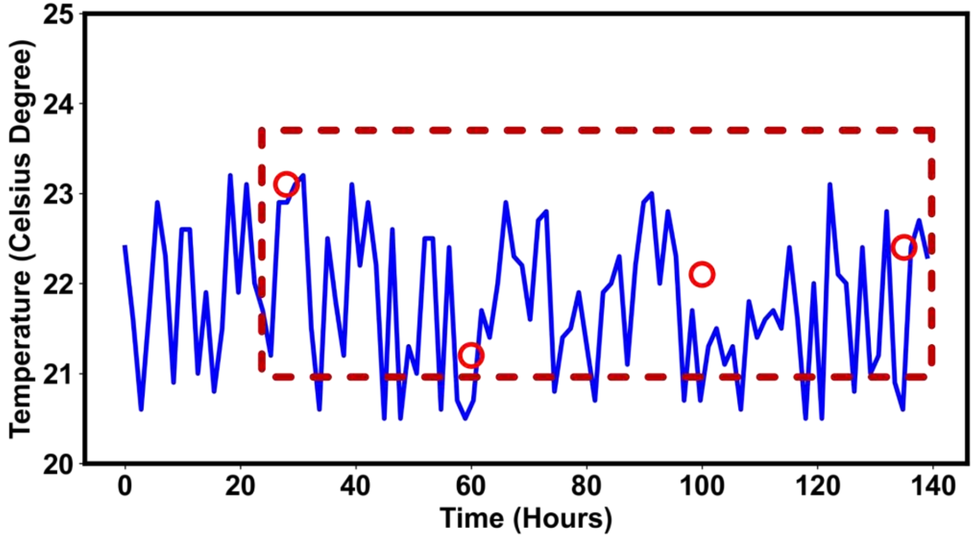
Recalibration (128-8192 mg/L)







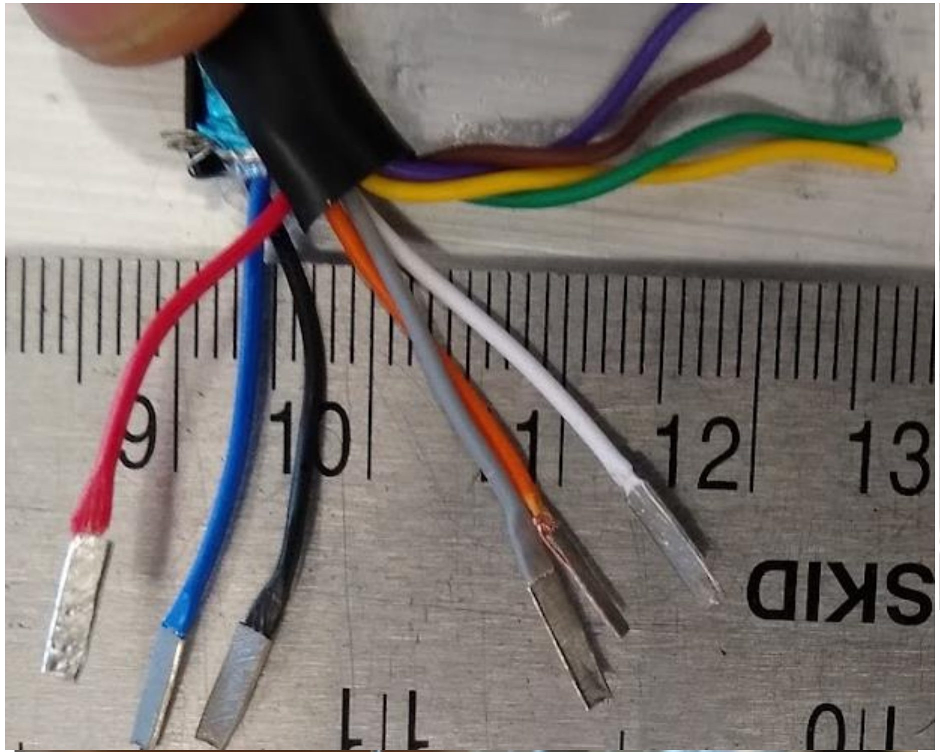


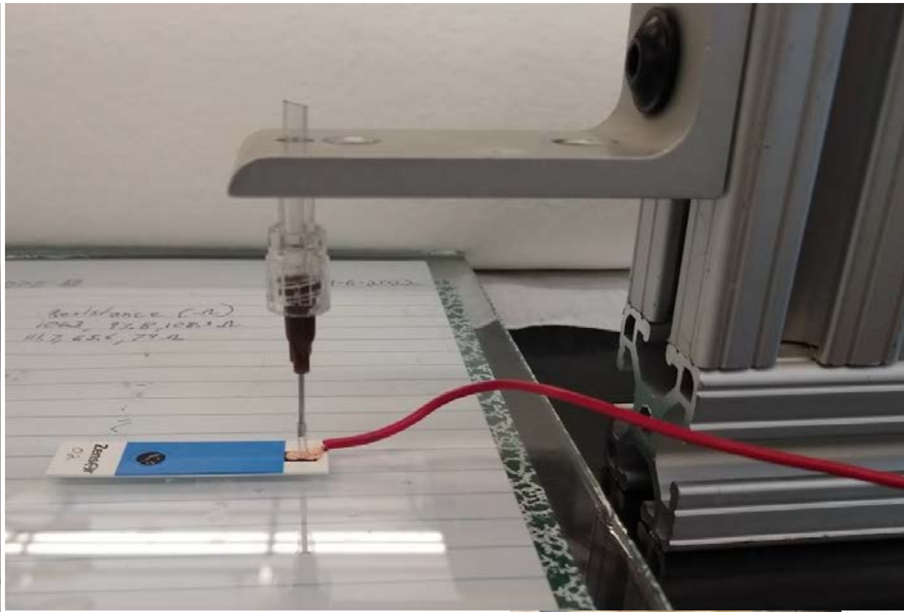


Sensor Wiring & Rod Attachment

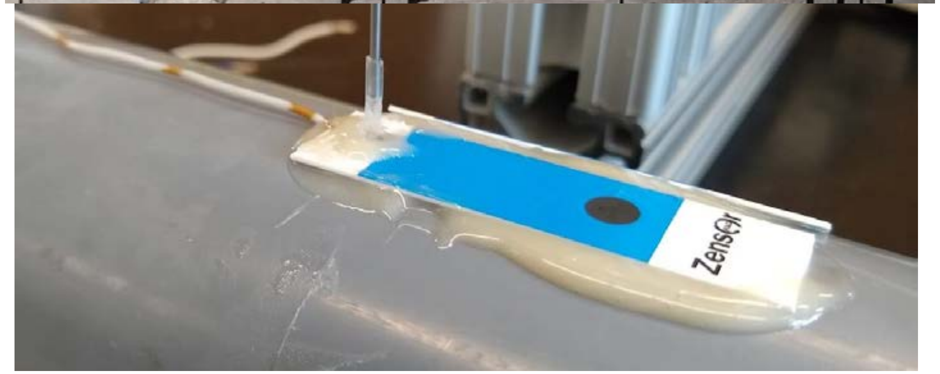
2” PVC
Sch 80
Pipe

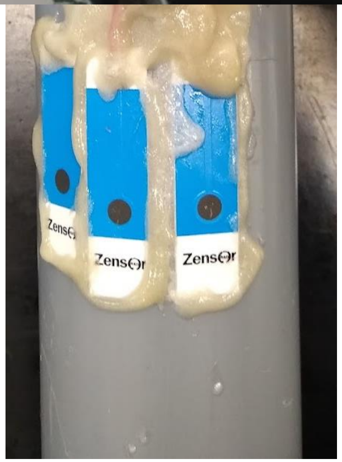
Epoxy sensor and hold electrical connection in place





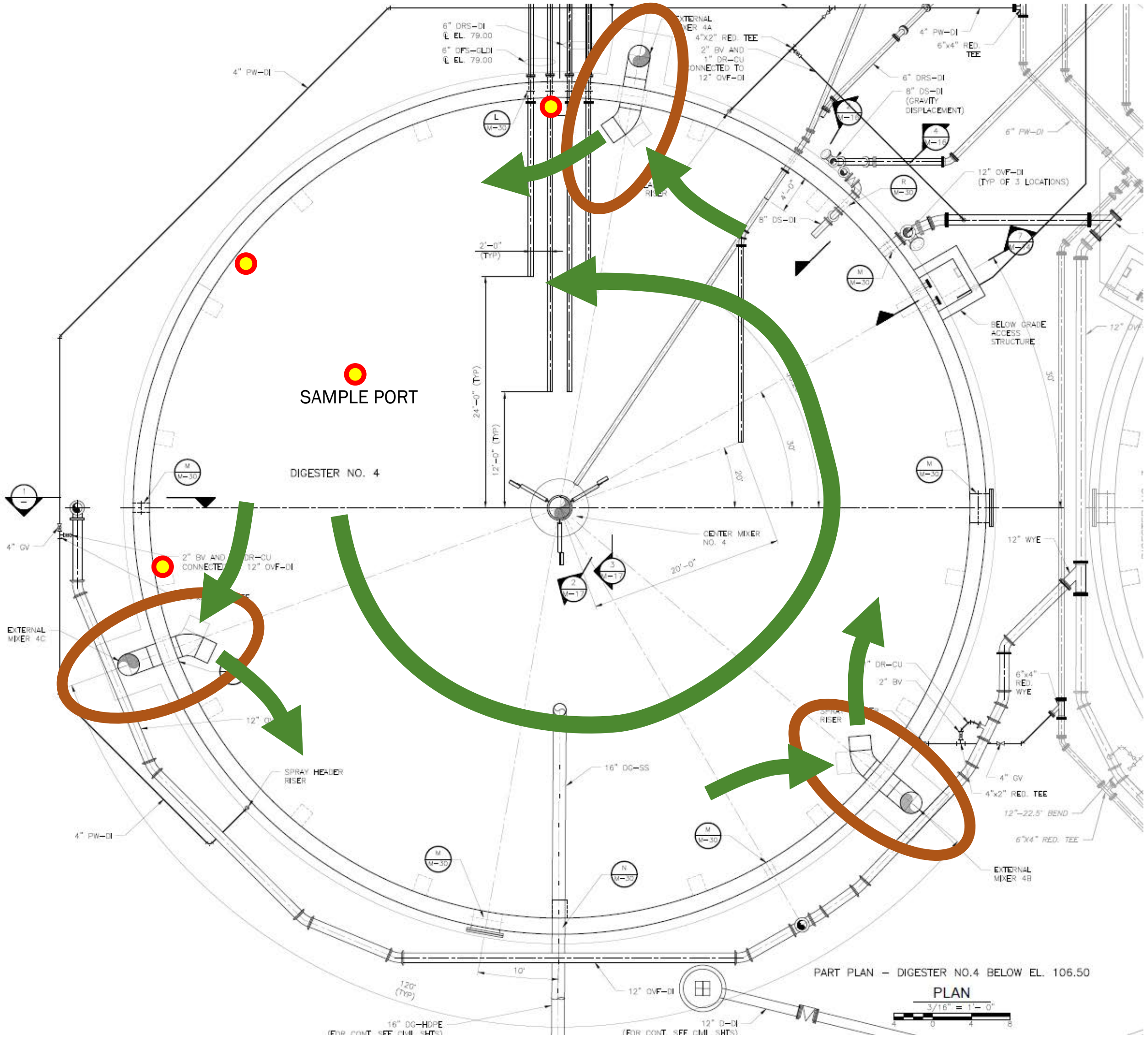
Epoxy electrical connection





Sensor Placement: Tank Top View

- Proposed rod locations
- Circulators



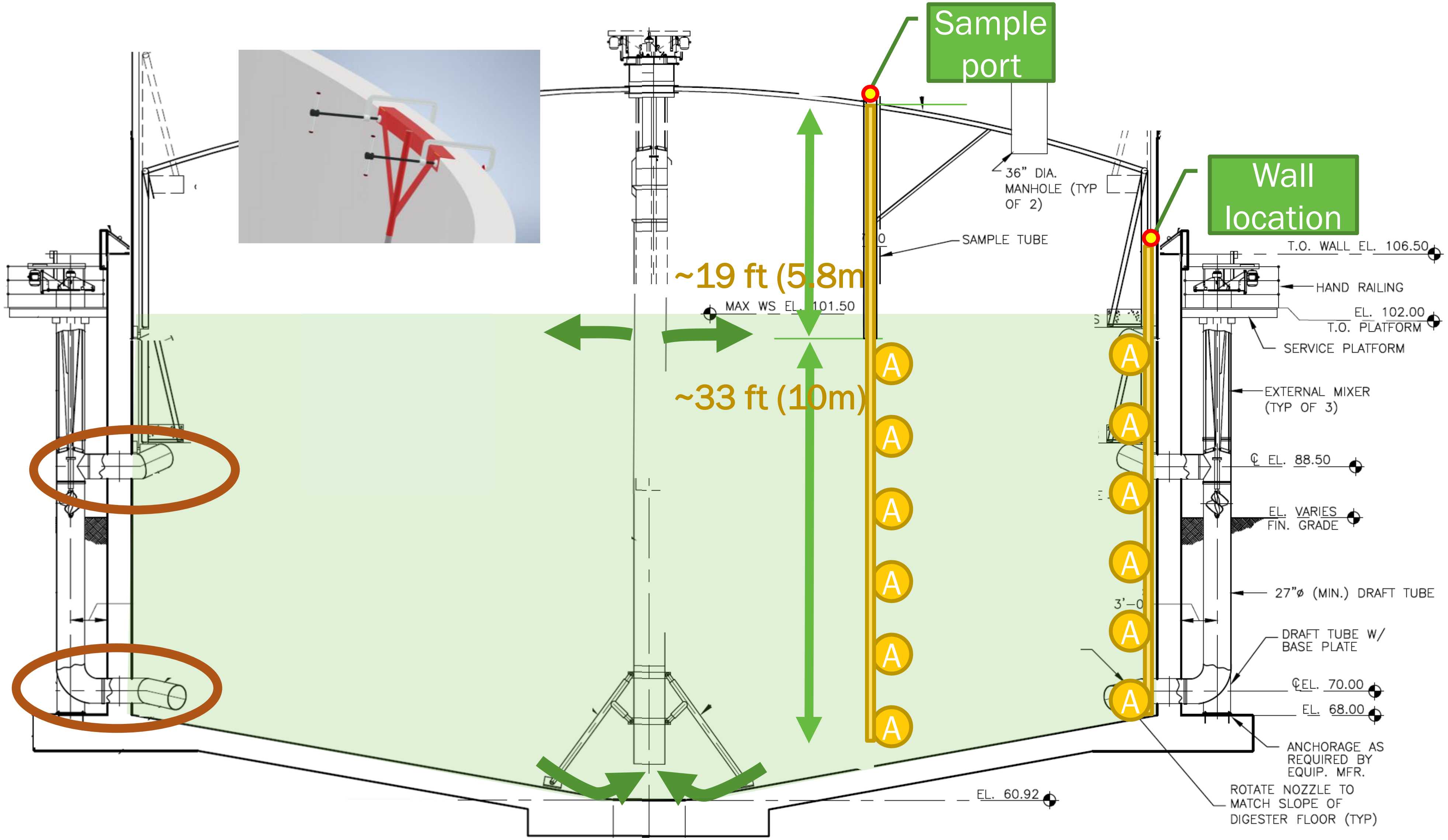
Sensor Placement: Tank Side View

- Proposed rod locations
- Circulators

Tank at its max height

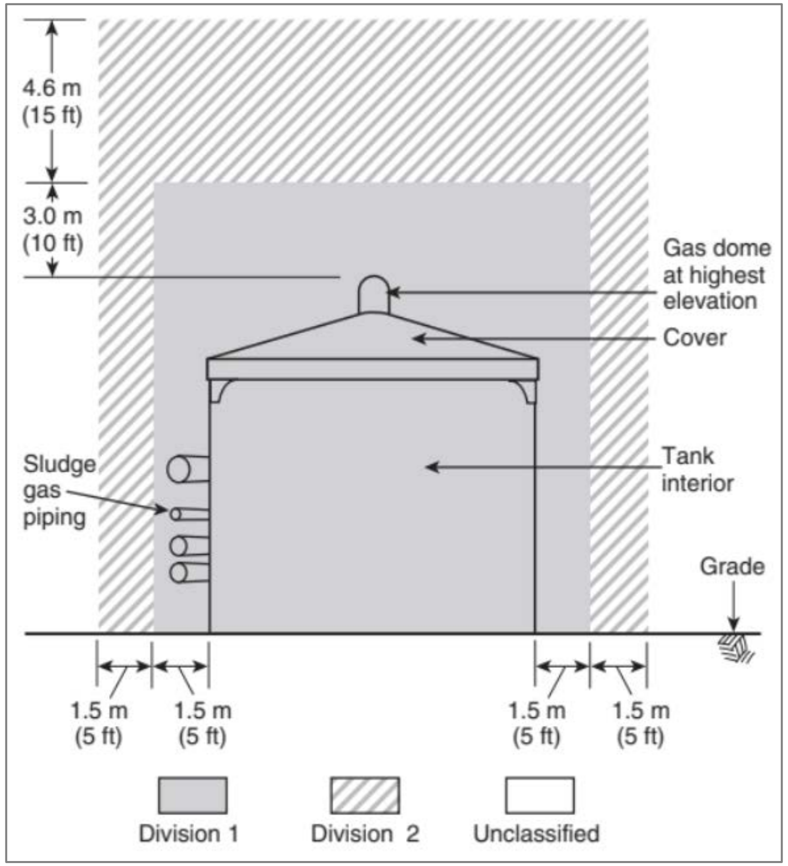
Array of Sensors

Sensor array every 5ft (1.5m) depth



We had a problem

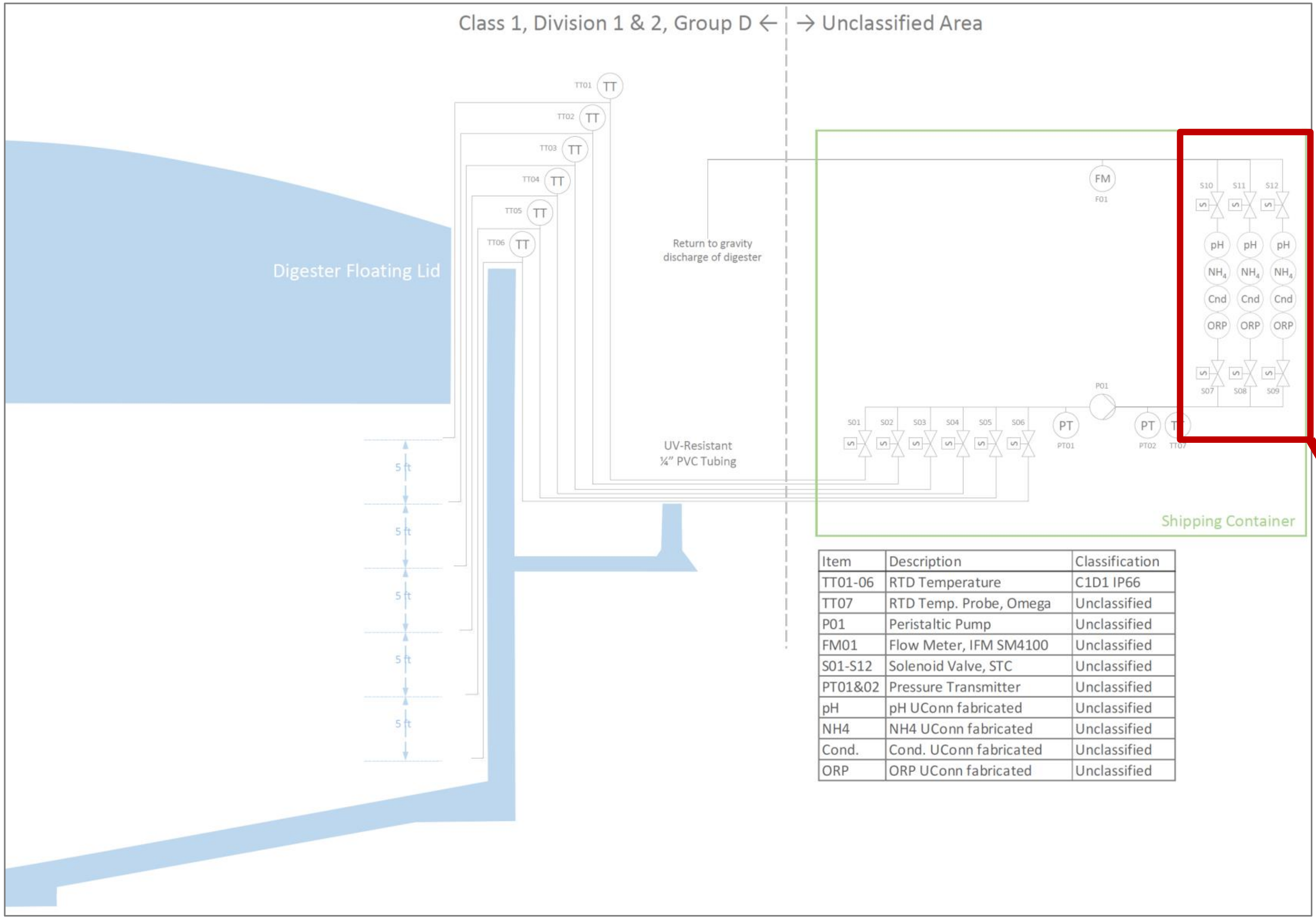
Classified Environments



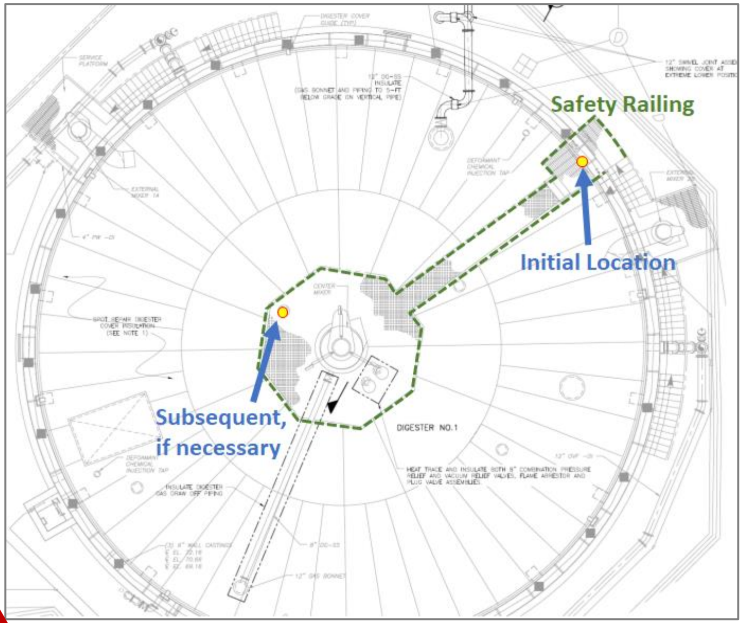
Anaerobic Digester Division specifications, NFPA 820, 2020 edition, Annex A, p44.

- Everywhere within 10 feet of the digester was a classified environment (Class 1/Div 1 or Class 1/Div 2)
- This meant that all electronic devices (including cords) would have to be rated for use in a classified environment or be considered a “simple apparatus”
- Our sensors could not be rated as either
- Commercial classified sensors were too expensive, and non were rated for submersion

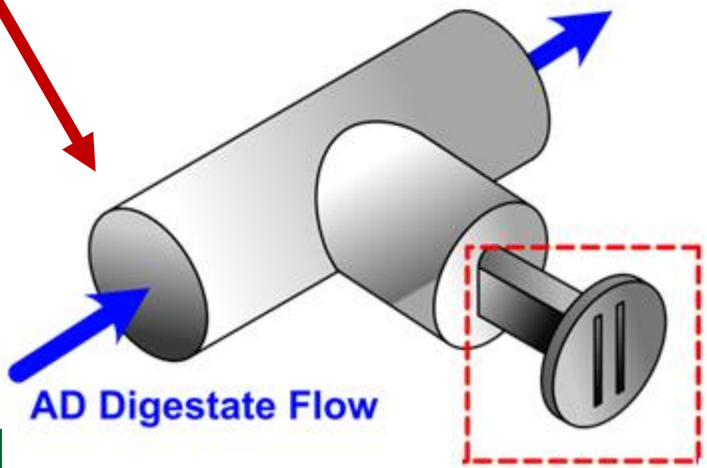
Alternative installation



Item	Description	Classification
TT01-06	RTD Temperature	C1D1 IP66
TT07	RTD Temp. Probe, Omega	Unclassified
P01	Peristaltic Pump	Unclassified
FM01	Flow Meter, IFM SM4100	Unclassified
S01-S12	Solenoid Valve, STC	Unclassified
PT01&02	Pressure Transmitter	Unclassified
pH	pH UConn fabricated	Unclassified
NH4	NH4 UConn fabricated	Unclassified
Cond.	Cond. UConn fabricated	Unclassified
ORP	ORP UConn fabricated	Unclassified

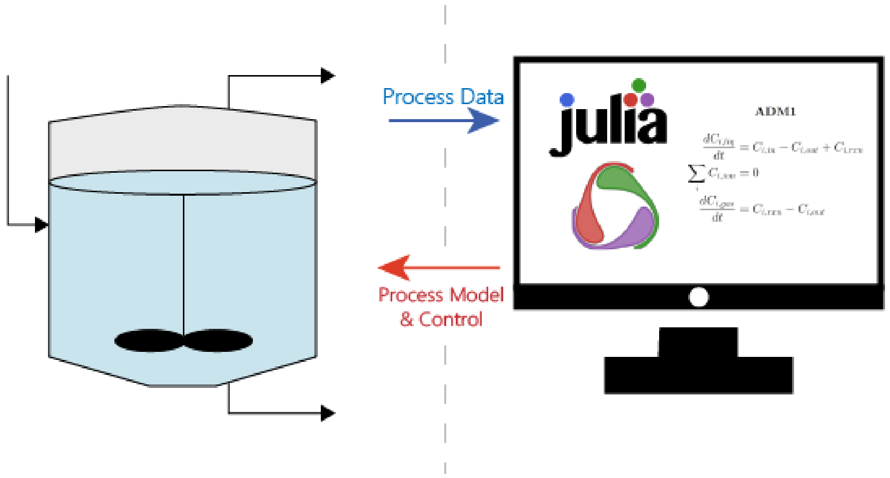


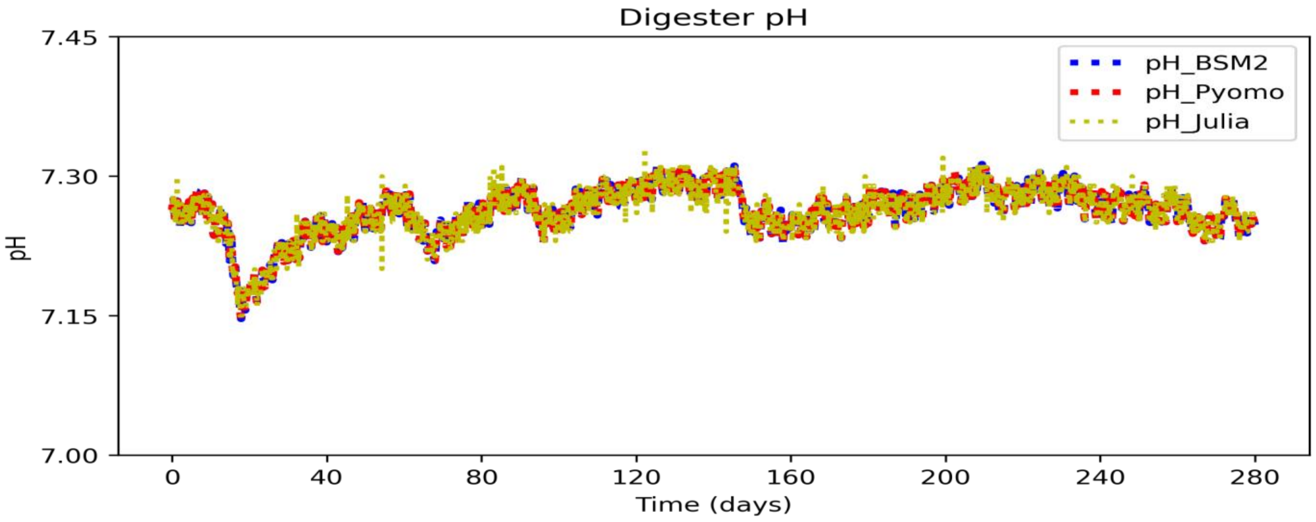
Top view of digester with sample locations available within safety railing

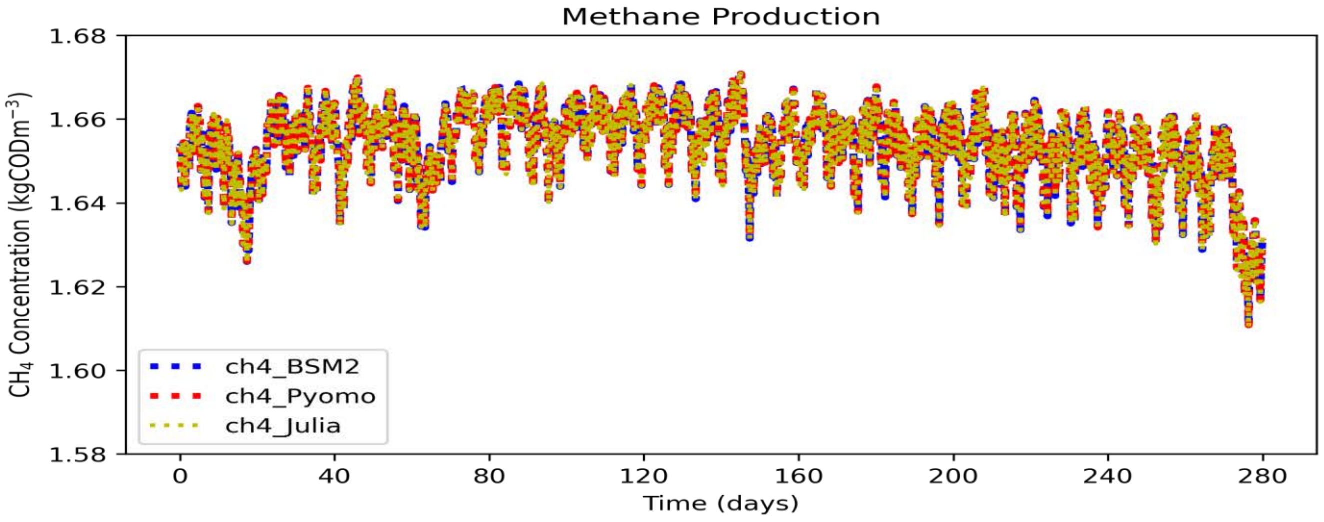


Validation of ADM1 in Pyomo and Julia

- **BSM2 represents Benchmark Simulation Model No. 2**
- **Verifies ADM1 implementation numerical accuracy**
- **Data contains varying input conditions.**
- **Julia offers transient behavior prediction**

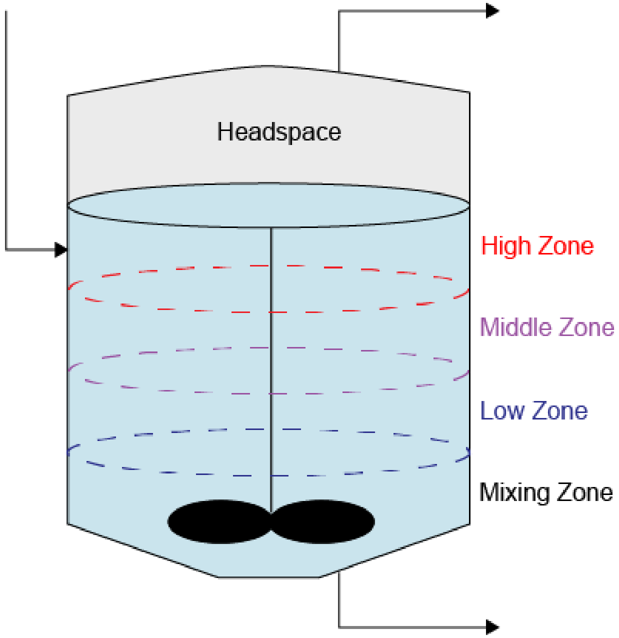






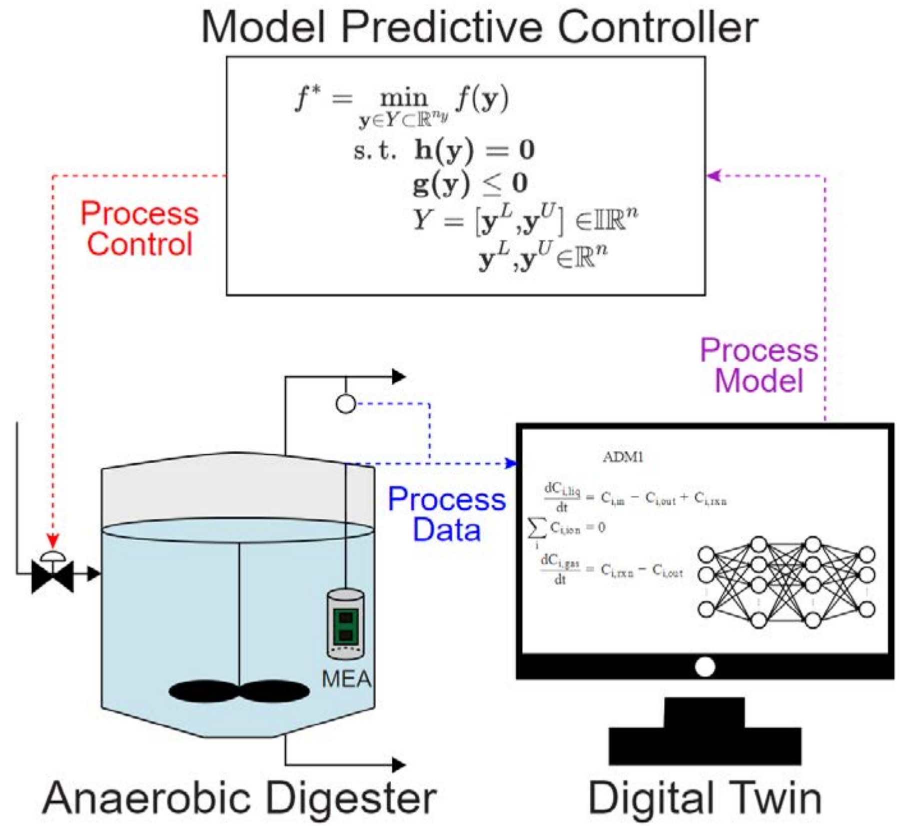
High Fidelity Modeling and Predictive Control

High Fidelity Modeling



- Establish spatial heterogeneity using compartment modeling
- Map common wastewater parameters to ADM1 state variables and parameters
- Establish temperature dependency / energy balance within model
- Develop low complexity surrogate for model to accelerate model predictive control

Develop and Simulate Anaerobic Digester Controls



- Develop control strategy to prevent digester upsets
- Implement model predictive control using Julia optimization framework to implement control strategies

Future Work, Technology Transfer, & Impact

Future Work:

- Consultant review of sensor installation plan (Brown & Caldwell Contract In Progress)
- Continued sensor development

Technology Transfer:

- We are considering commercialization of the sensor platform (providing sensors as a service for wastewater plants)

Impact:

- Reduction of WWT operating cost by 25%
- Net Zero Energy WWT
- Reduced life cycle GHG emissions

Questions?

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Jeffrey McCutcheon, University of Connecticut
Email: jeffrey.mccutcheon@uconn.edu
Website: www.ccast.uconn.edu

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North East Biosolids & Residuals Association

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