AMMTO & IEDO JOINT PEER REVIEW

May 16th-18th, 2023

Washington, D.C.

Integrated AnMBR electro-assisted fermentation for total resource recovery from diverse wastewaters| IEDO

Prathap Parameswaran, Kansas State University

DE-EE00009504 **|** October 2021 – March 2025

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Overview

- **Anaerobic Membrane Bioreactor (AnMBR)** with electro-assisted fermentation and a holistic process configuration for recovery of organic acids or biogas, nutrient products, and water for reuse

- This research project enables a **cross-sector technology platform** that enables decarbonization of agricultural (livestock) and municipal wastewater sectors, aligning with IEDO's mission statement

Energy, Emissions, & Environment:	**Cost & Competitiveness:**
• Reduce GHG emissions by 30% for swine wastewater treatment	• Use high value VFAs and nutrients to offset cost of swine wastewater treatment with 20% improvement in cost over current state-of-the-art technology
Technical & Scientific:	**Other Impacts:**
• Recovery of nutrients and high value VFAs from swine wastewater to lower lifecycle GHG emissions while minimizing energy footprint of the treatment process	• Circular bioeconomy for sustainable products and sustainable energy for enhancing rural and agricultural resilience.

Project Outline

Innovation: Valorization of livestock waste to resources in an integrated AnMBR platform

Project Lead: Dr. Prathap Parameswaran, Kansas State University

Project Partners: University of Kansas; University of Pittsburgh; Lawrence Berkeley National Lab

Timeline: October 2021 – March 2025, progress 35%

Budget:

	BP1 (Oct 21 – Sep 23)	BP2 (Oct 23 – Sep 24)	BP3 (Oct 24 – March 25)	Total Planned Funding
DOE Funded	$627,055	$511,697	$361,165	$1,499,917
Project Cost Share	$123,845	$92,637	$47,658	$264,140

End Project Goal: Demonstrate in the pilot scale integrated ANMBR system >50% Carbon conversion efficiency as methane, coupled with >30 g NH_4-N/kg clay and >90% P sequestration efficiency as well as greater than 50% reduction in fouling net energy requirement and enhanced energy generation (>0.6 KWh/m^3) through side stream co-fermentation along with final water meeting or exceeding discharge standards.

Background & Strategic Approach

The problem

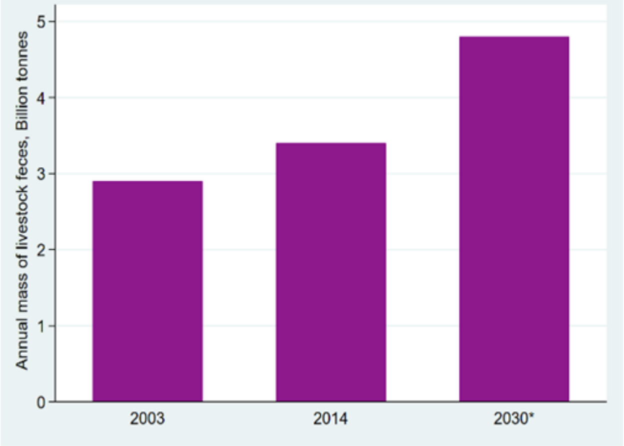


Figure 1: Forecasted mass animal waste
(40% increase from 2003 to 2030)

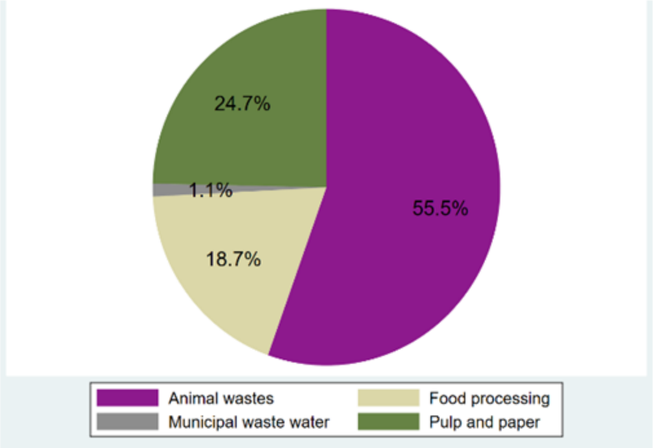
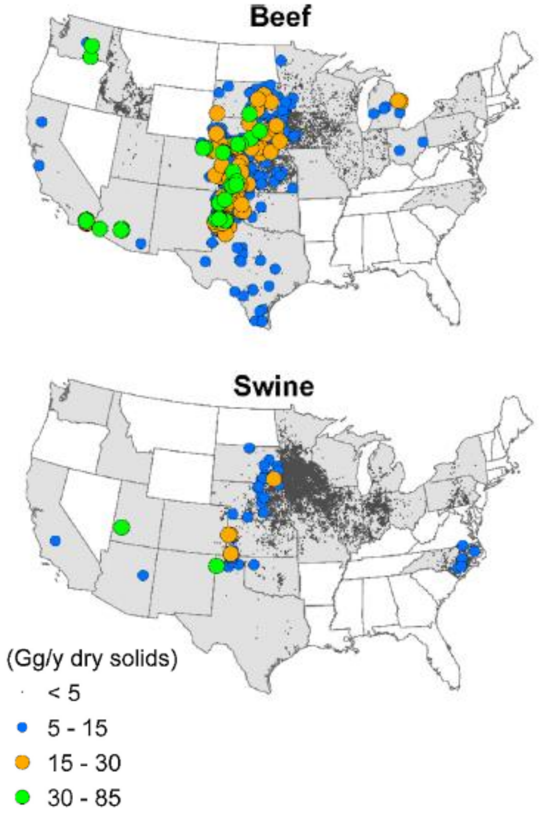


Figure 2: Biomass waste category by each source

Prevalence



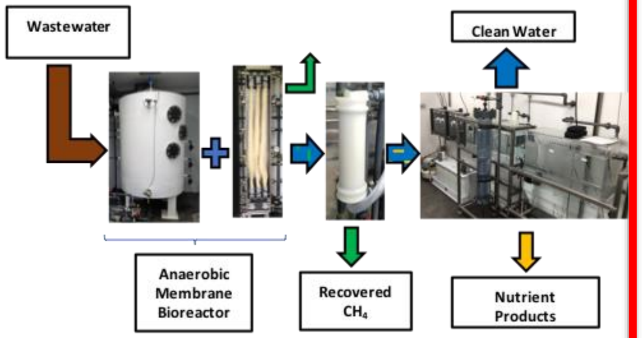
Localized concentration of animal wastes in the Midwest.

Current disposal

Feedlot runoff

Lagoons

Opportunity

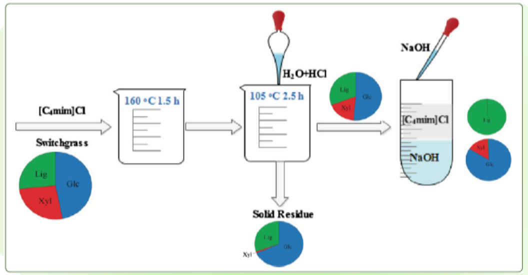


Anaerobic biotechnologies for total resource recovery

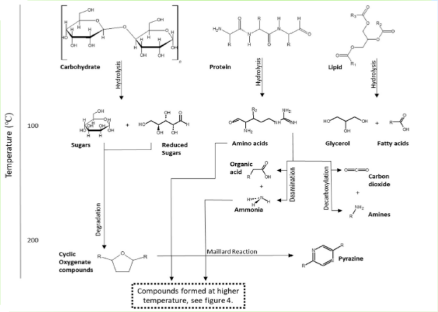
Background & Strategic Approach

Sustainable separation of organic acids using green techniques

LBNL

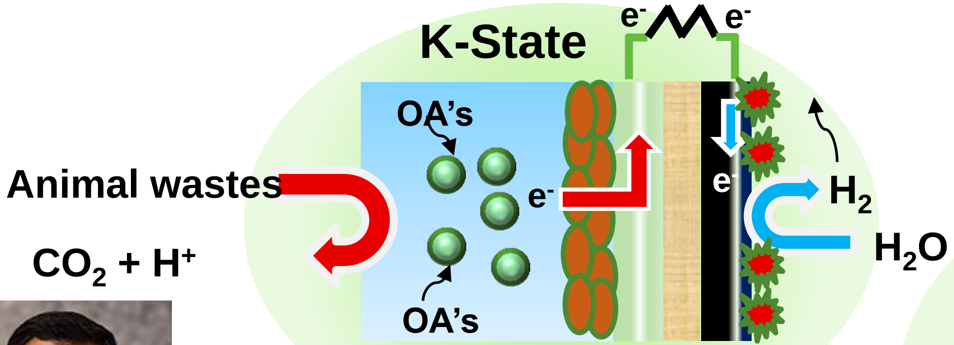


KU



Side stream Co-fermentation to augment energy recovery

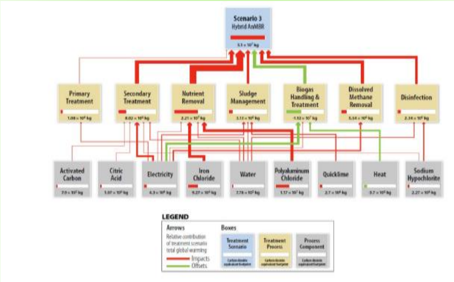
K-State



OA = Organic Acid

In-situ organic acid Conversion in integrated AnMBR-MEC + downstream Nutrient recovery

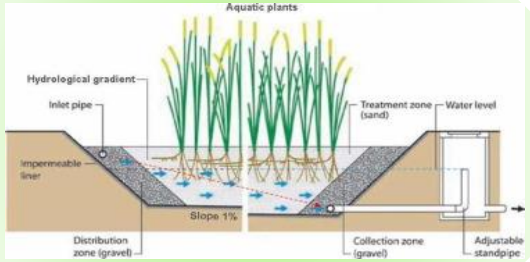
U Pitt/CDM Smith



Life-Cycle Analysis & Techno-Economic Analysis

Constructed wetlands For final effluent polishing

K-State



Background & Strategic Approach

Pilot AnMBR unit at K-State (1000 gpd)

Lab AnMBR (~110 L)

- The PI was an integral part of an **ESTCP project** (**ER-201434** – Anaerobic Membrane Bioreactor (AnMBR) for sustainable wastewater treatment) which was operated for >400 days at Ft. Riley, KS, treating municipal wastewater. Key accomplishments are summarized below:

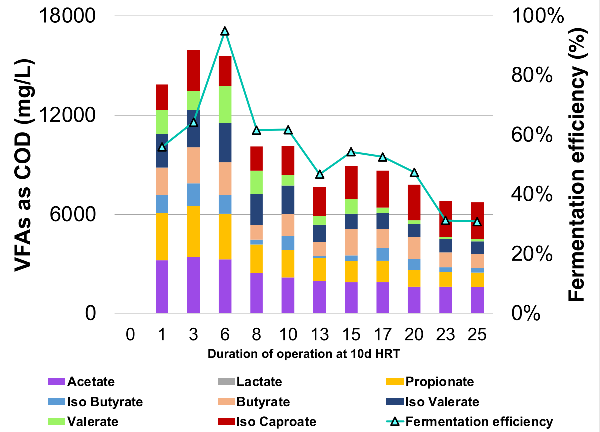
Parameter	Goal	Gas-Sparged
Effluent BOD_5 (mg/L)	≤ 30/10*	24±14
Effluent COD (mg/L)	≤ 60	53±16
HRT (h)	≤ 20	13±8
COD Loading (kg-COD m^{-3} d^{-1})	≥ 0.6	1.3±0.7
Energy Produced/Consumed	≥ 100%	74
Biosolids (g-VSS/g-COD_{loaded})	≤ 0.2	0.07±0.07
Net Flux (L m^{-2} h^{-1})	≥ 6	7.4±2.0
TMP (kPa)	≤ 30	13±9
Sulfide (mg/L)	≤ 0.1	< 0.14±0.08
Ammonia Removal (%)	≥ 90	99.8±0.2
Total Phosphorus Removal (%)	≥ 90	90±1
Dissolved Methane Removal (%)	≥ 90	6

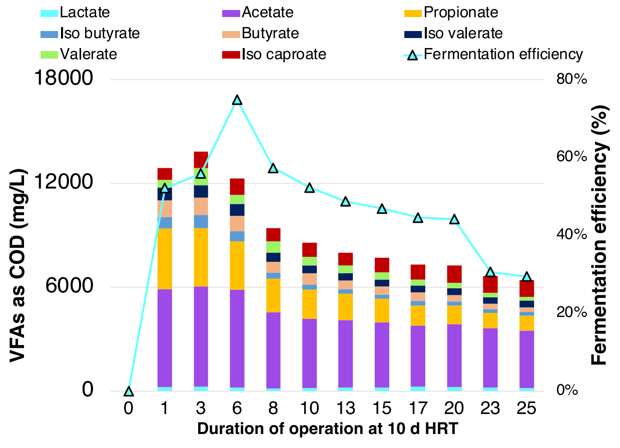
Met

Met

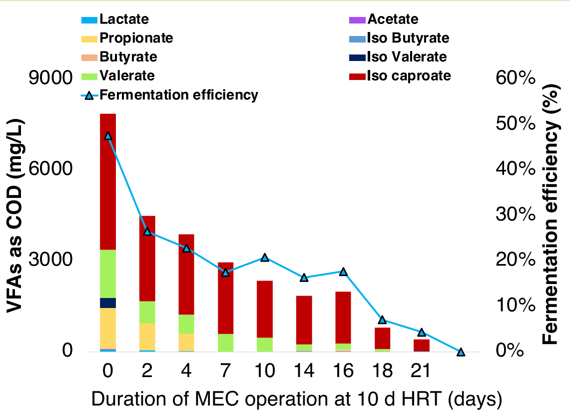
Results and Achievements

Task 1: Swine waste fermentation with or without a microbial anode



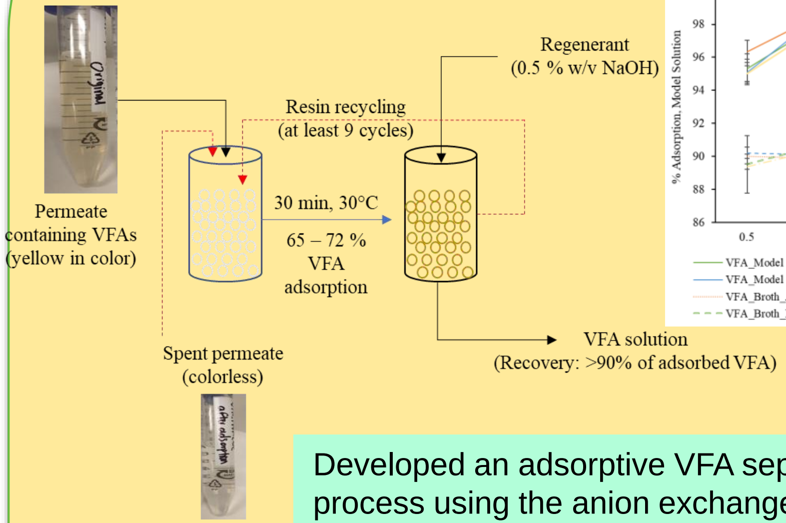


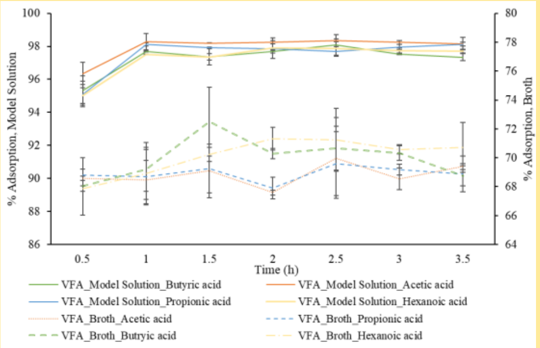
pH 5 & 9 fermentation profiles and carbon conversion efficiency



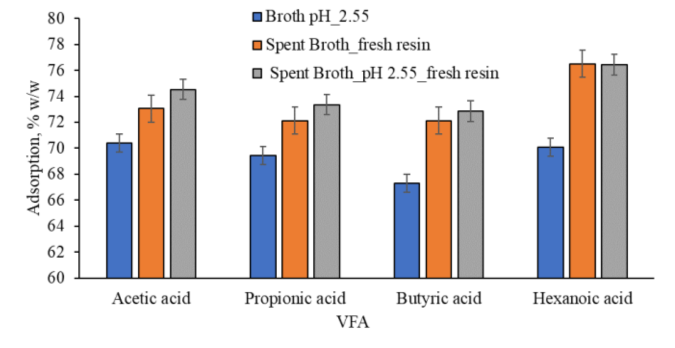
- Fermentation efficiency > 50% was achieved for both pH 5 & 9 with swine wastewater as feedstock.
- Higher VFAs selectively accumulated during MEC fermentation (iso-caproate was highest), albeit with loss of acetate leading to a lower fermentation efficiency.

Task 2: Volatile Fatty Acids (VFA) separation





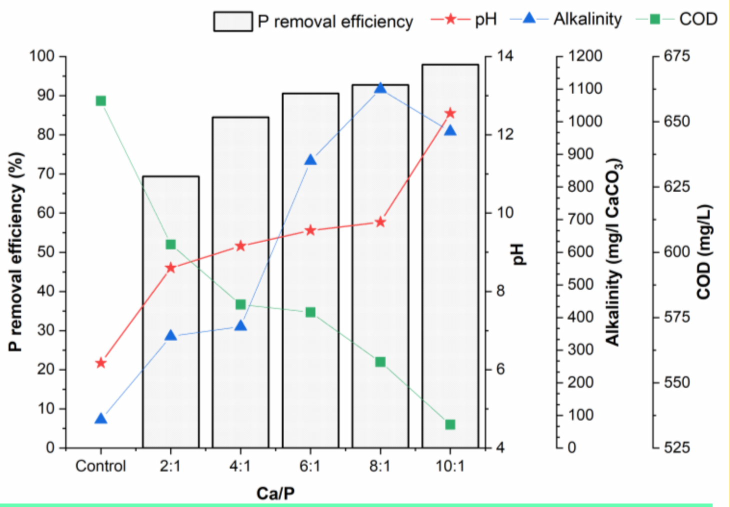
Developed an adsorptive VFA separation and recovery process using the anion exchange resin: Relite RAM2 with a tertiary amine functional group



- VFAs' adsorption depends strongly on the pH of the substrate
- 65-72% VFAs were adsorbed from fermentation broth using the selected resin
- The resin was recycled for 9 successive adsorption/ desorption cycles without a loss of efficiency

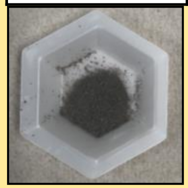
Results and Achievements

Task 3: Nutrient Recovery (ammonia-N and Phosphorus) from swine permeate

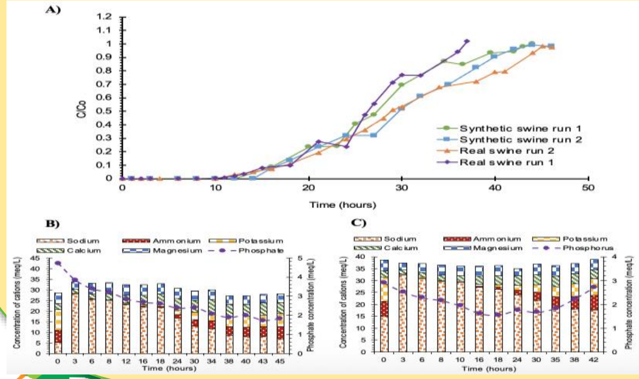


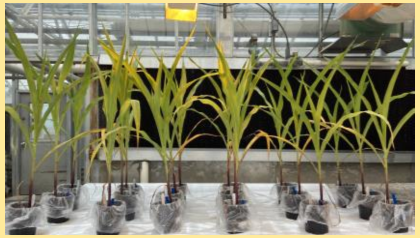
Product Ca : P dose ratio	Total P (%)	2% Citric acid solubility (% total P)
2:1	11.8	10.9
4:1	10.9	11.4
6:1	11.2	9.3
8:1	10.6	10.4
10:1	7.5	2.1

CO_2 redistribution from permeate greatly aids with efficient P removal and capture.



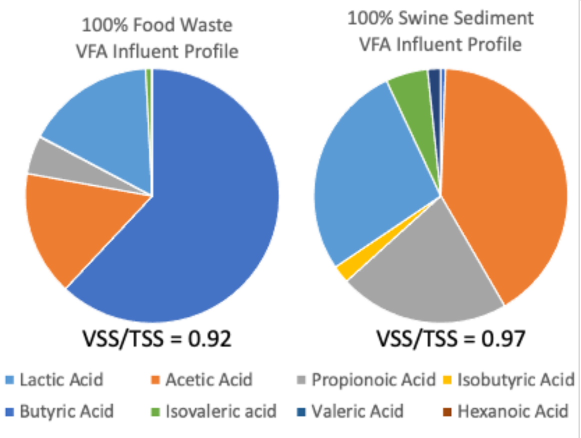
CaP product recovery. Provisional patent submitted (63/407,936)



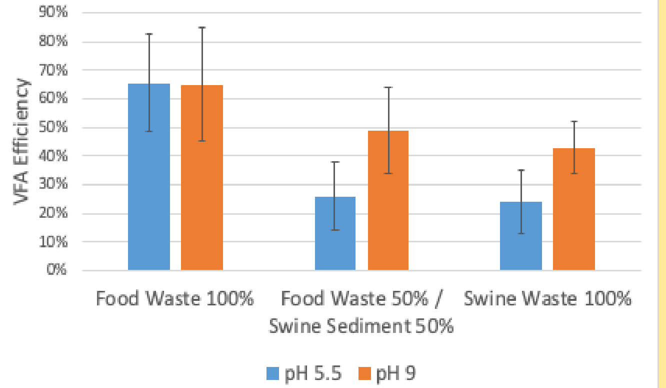


Plant N uptake with 80% urea + 20% swine recovered ammonia was on par with the urea treatment

Task 4: Side-stream cofermentation of swine sediments with food waste

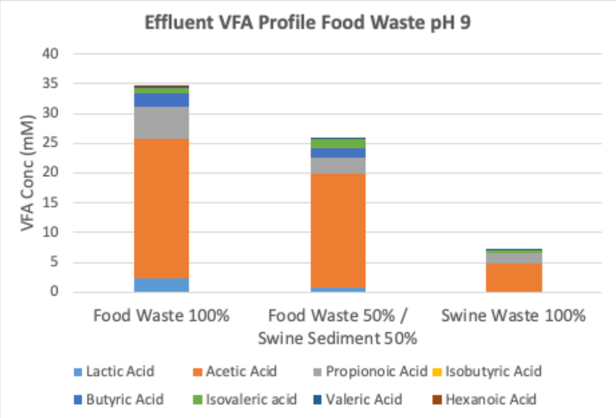


pH 5 & 9 carbon conversion efficiency



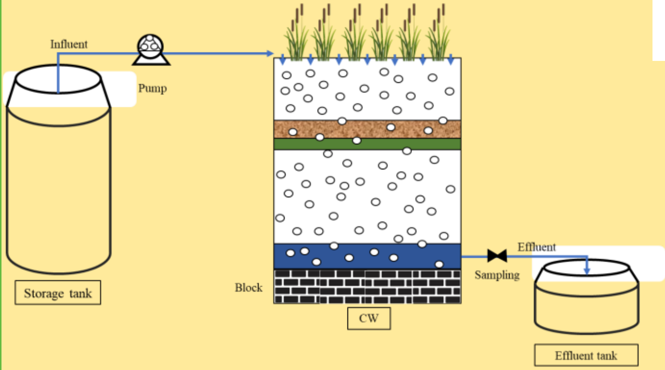
Food waste and swine sediment fed to fermenters in three ratios

- Fermentation efficiency > 65% for both pH 5.5 & 9 with food waste as feed.
- Fermentation efficiency > 43% achieved with swine sediment feedstock at pH 9
- Swine sediment feedstock reduced conversion efficiency



Results and Achievements

Task 5: Constructed wetlands for final effluent water polishing



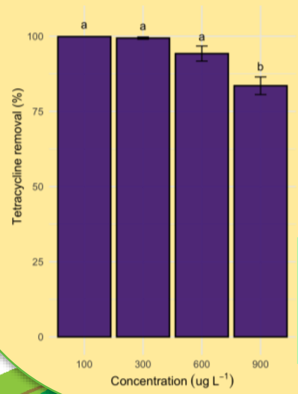
AnMBR permeate (after N& P capture)

CWs effluent

Constructed wetland design with cattail as the primary plant species

Permeate quality after N & P capture

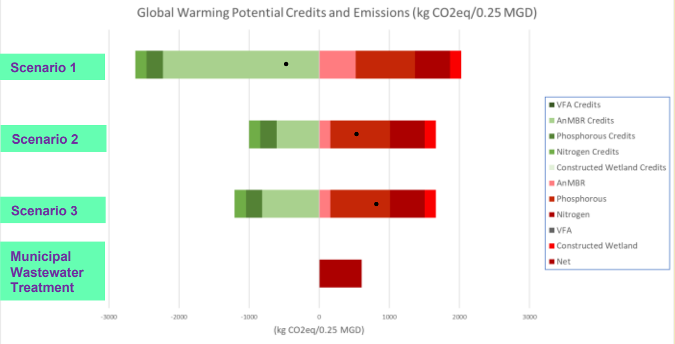
Parameter	Value
Total N (mg N/L)	17.7
Total P (mg P/L	1.99
Total coliforms (CFU/mL)	2.19 x 10^5± 30,500
Fecal coliforms (CFU/mL)	0

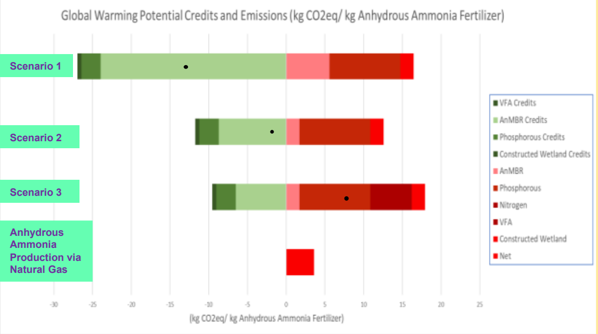


Eastern red cedar biochar (incorporated in the CWs) sorption of the final water indicated removal of Tetracycline; a common antibiotic used in swine nutrition

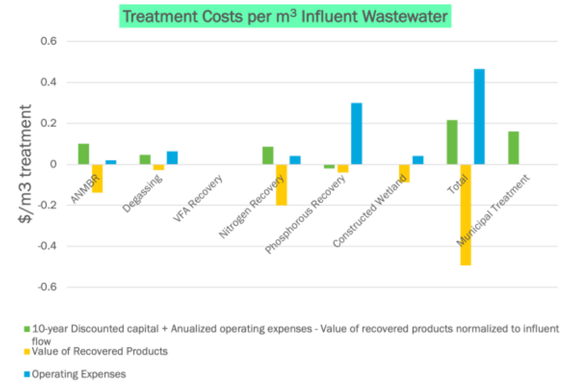
Task 3: Life Cycle Assessment and Techno-Economic analyses of the integrated AnMBR

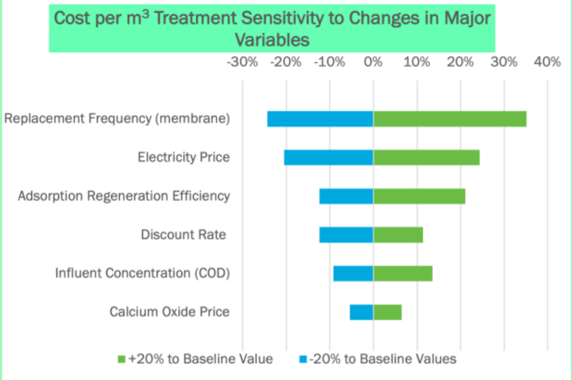
Scenario 1: Degasser with CH_4 for electricity. **Scenario 2:** Degasser with CH_4 for flaring
Scenario 3: No dissolved CH_4 recovery.





Initial LCA results show that in scenarios including degassing the GHG emissions are reduced to more than 30% compared to baseline treatment





- Initial TEA results show cost of influent swine wastewater AnMBR treatment is comparable to treatment cost of municipal wastewater

Future Work, Technology Transfer, & Impact

Future Work:

- Integrated AnMBR-MEC experiments at pH 9 to maximize selective higher organic acids generation, with a targeted fermentation efficiency > 50%
- Optimization of VFA separation with real AnMBR swine permeate from electro-assisted MEC operation.
- Greater fouling control on the AnMBRs with proactive solids wasting based on colloidal organics and smart sparging through bubble dynamics control, with a target of lowering energy requirement to < 0.6 KWh/m^3
- Prepare pilot AnMBR for operation under methanogenic mode with nutrient recovery and water for reuse.

Technology Transfer:

- Patent follow up and filing for nutrient recovery applications (brushite and struvite recovery) and work with interested entities (Carollo, Monsanto, ADM)
- Membrane fouling control novel method development with modified cleaning protocol with wastewater derived peroxide (Veolia)
- Microbial chain elongation at pH 9 in the integrated AnMBR-MEC using a novel microbial consortium (proof of concept stage)

Impact:

- The AnMBR platform presents a viable opportunity for resource recovery from livestock, other agricultural, and municipal waste streams towards a circular bioeconomy, with the product portfolio ranging from organic acids, biogas, fertilizer products, and water for reuse.

Questions?

- Integrated AnMBR electro-assisted fermentation for total resource recovery from diverse wastewaters| IEDO

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