Ammonia Removal and Recovery During Food Waste Anaerobic Digestion Using Selective Membranes

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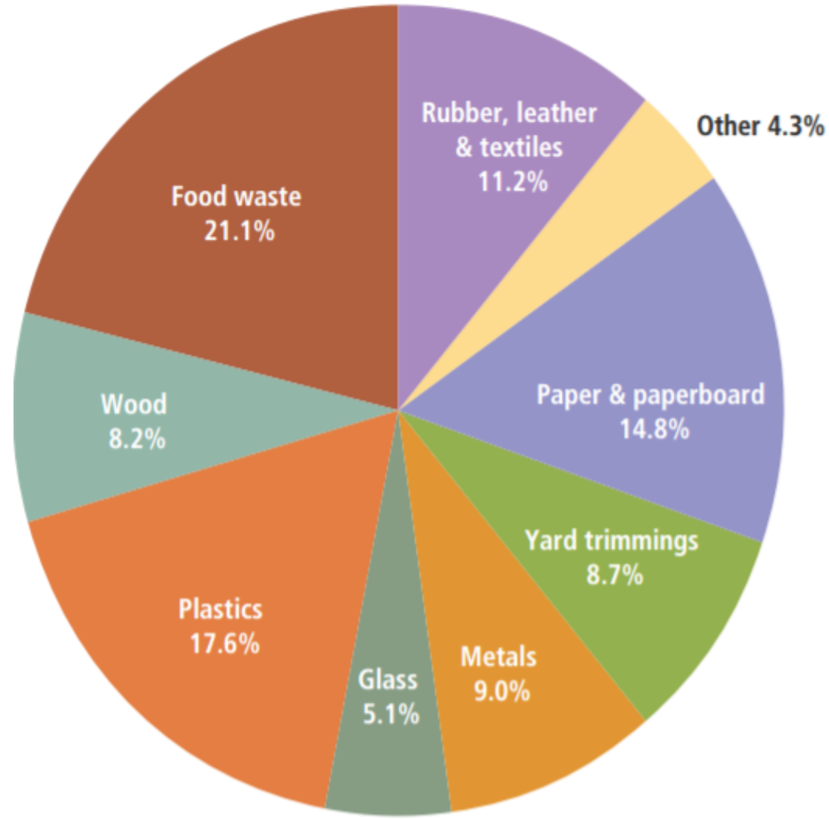
Clarkson UNIVERSITY defy convention ™

The Problem

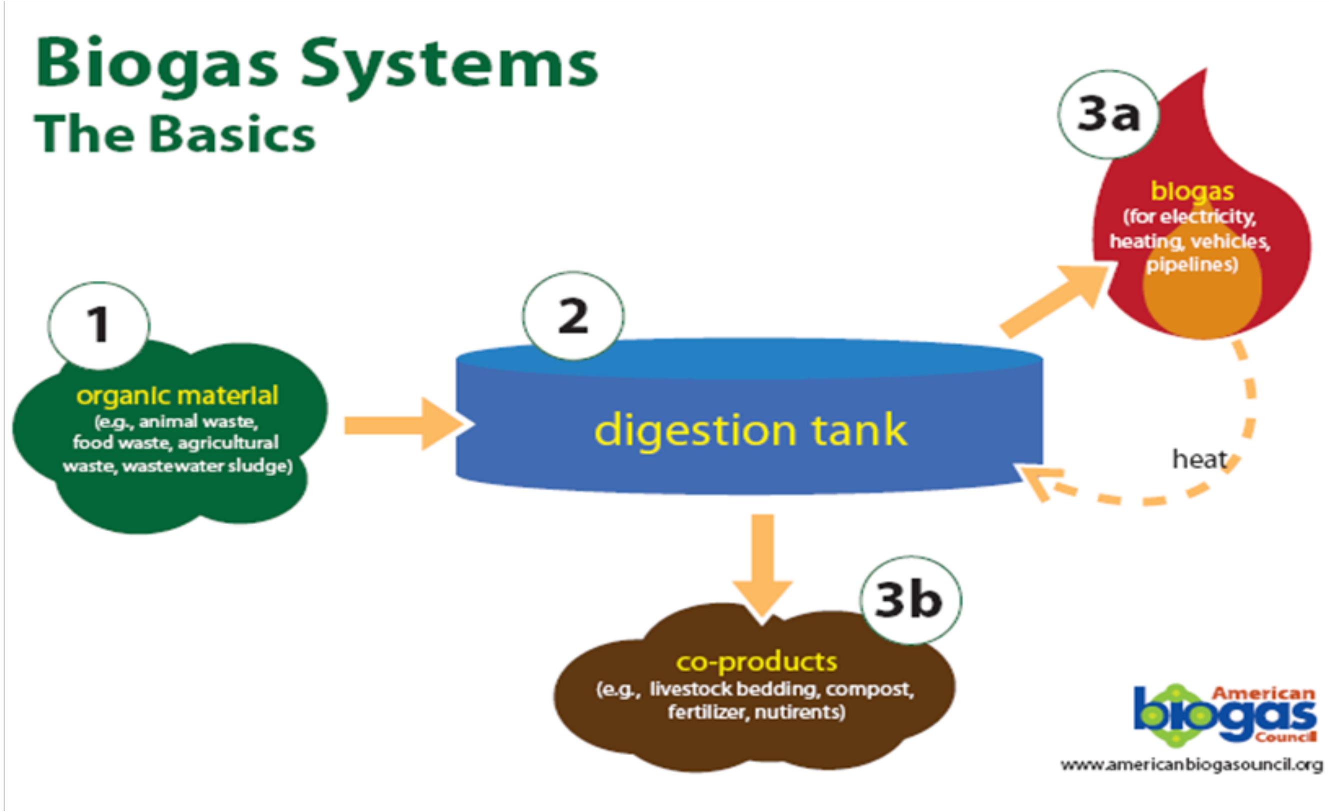
- US: 38 million tons of FW, 5.1% diverted from landfills[3]
- Worldwide: 1/3 of all food for human consumption is wasted (2011 FAO)[3]
- With limited oxygen, water, sunlight, and organisms food waste in landfills decomposes very slowly

10 year old carrots[2]



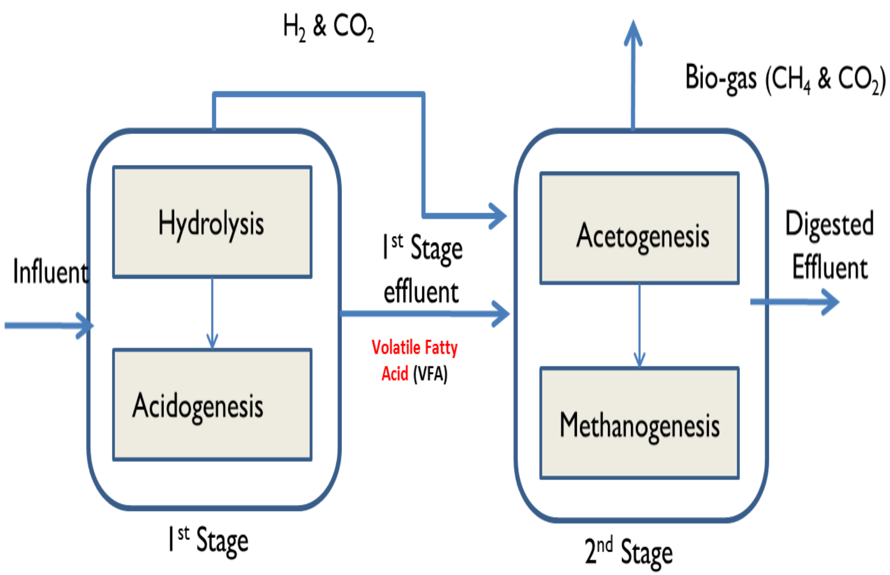
Solution: Anaerobic Digester

- Biogas: CH_4 & CO_2
- Effluent: High ammonia for fertilizer use



Clarkson's Anaerobic Digester

- Mesophilic two-phase pilot scale digester
- 30-60 day RT
- 300 lb/day loading (600 lb/day capacity)
- Biogas production is 30% higher than similar systems
- But can we do any better?



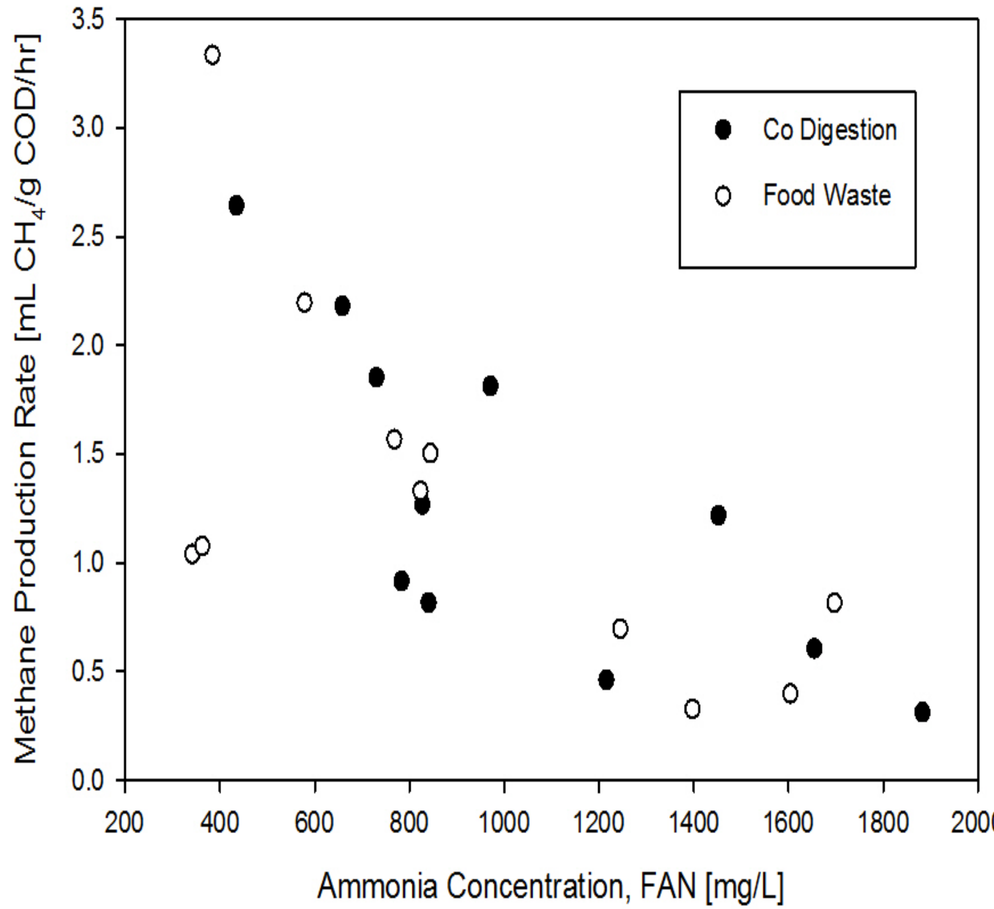
*K. Venkiteshwaran "Two-Stage Anaerobic Co-Digestion using crude glycerol or cheese whey with dairy manure to improve methane production"

Ammonia Toxicity

- Major cause of full-scale digester upset
  - Methanogens most susceptible
- Clarkson's food digester
  operates around 6 to 7 g/L TAN
- IWA-ADM1 model uses

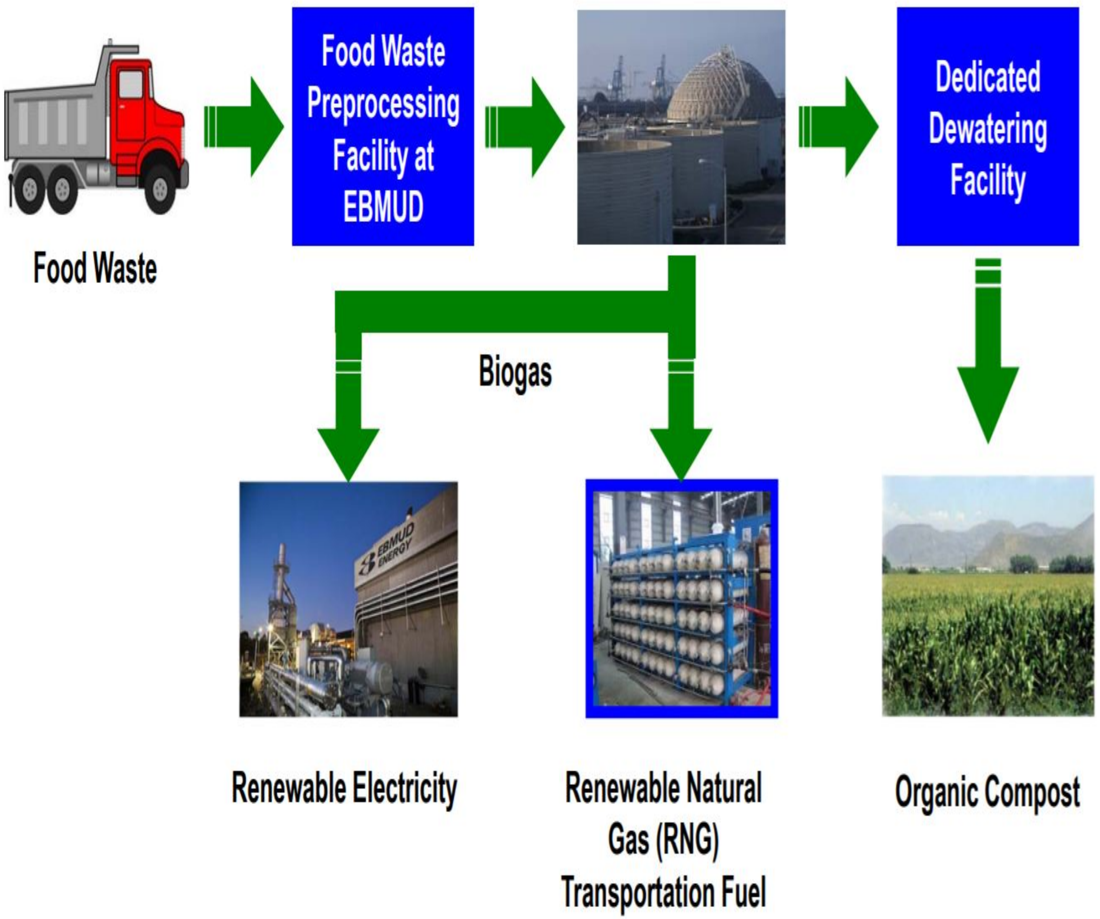
$$I = \frac{1}{1+\left(s_I/K_I\right)^4}$$

  - s_I -ammonia concentration
  - K_I -inhibition parameter of ammonia
- Suggests that any ammonia concentration would result in some inhibition
- Removal of ammonia should increase in methane production



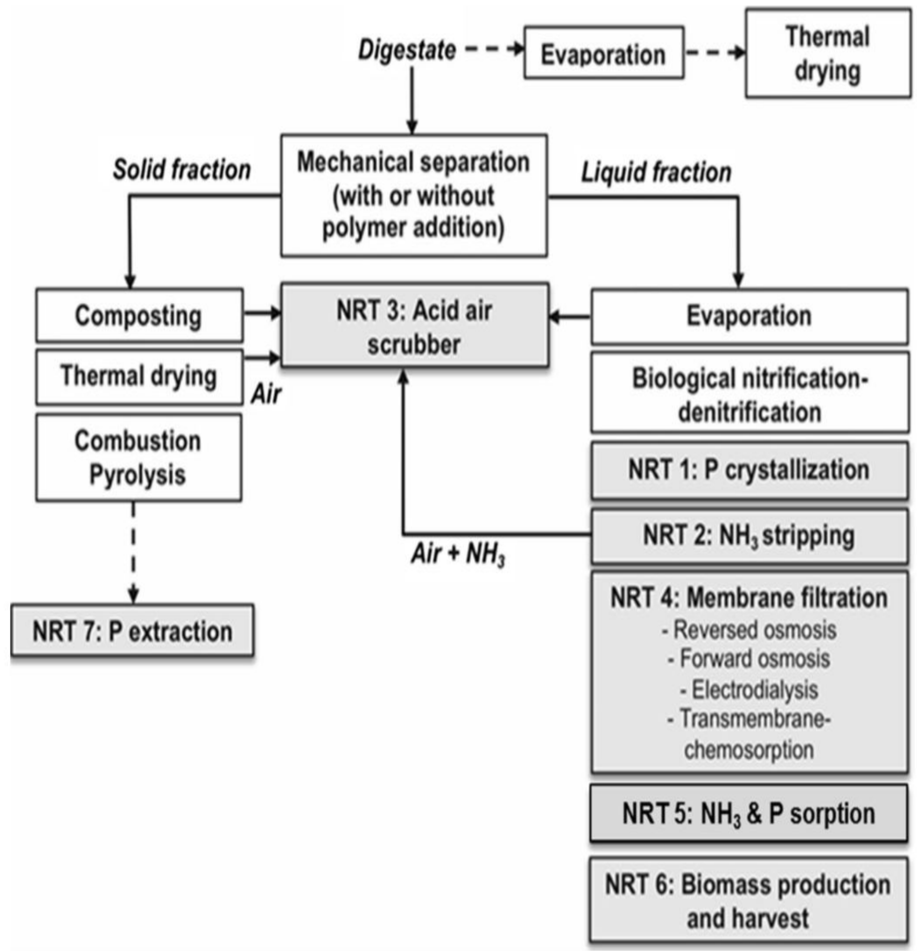
Relevance to Municipal WWTPs

- Ammonia toxicity not significant in conventional wastewater digesters
- Co-digestion gaining more prominence
- Food waste as a co-substrate:
  - Easily degradable
  - High COD → High energy yields
- Ex: East Bay Mud, CA
  - 0.6 MGD (≤ 1% of their avg flow)
- Co-digestion of FW could lead to ammonia inhibition



Purpose & Objectives

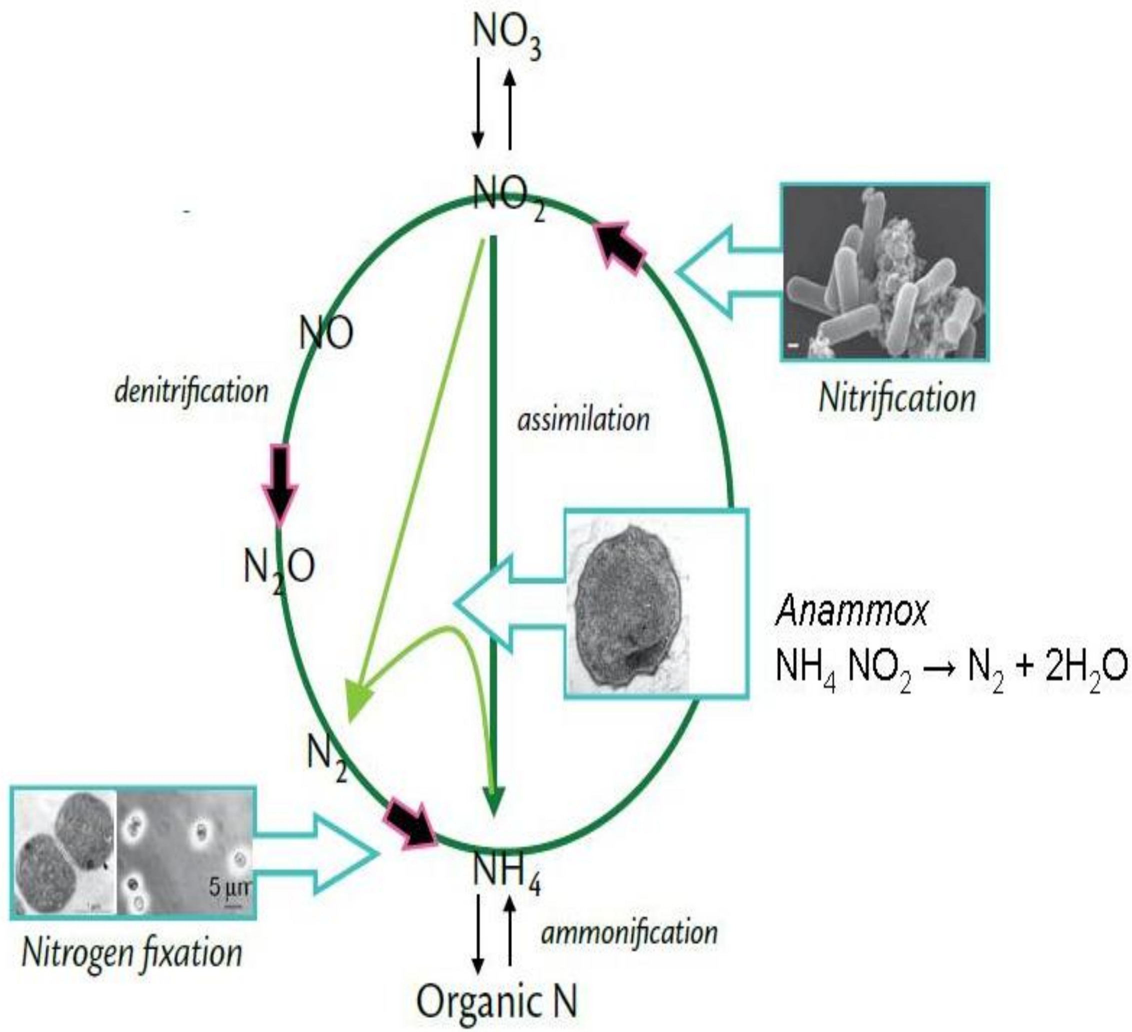
- Ammonia is inhibitory[5-8]
- Requires ammonia removal system to increase carbon recovery
- Ammonia loss may result in loss of effluent fertilizer potential
- Design an ammonia removal and ***recovery*** mechanism
    - Selective membranes



Vaneeckhaute et al., 2016

Anammox

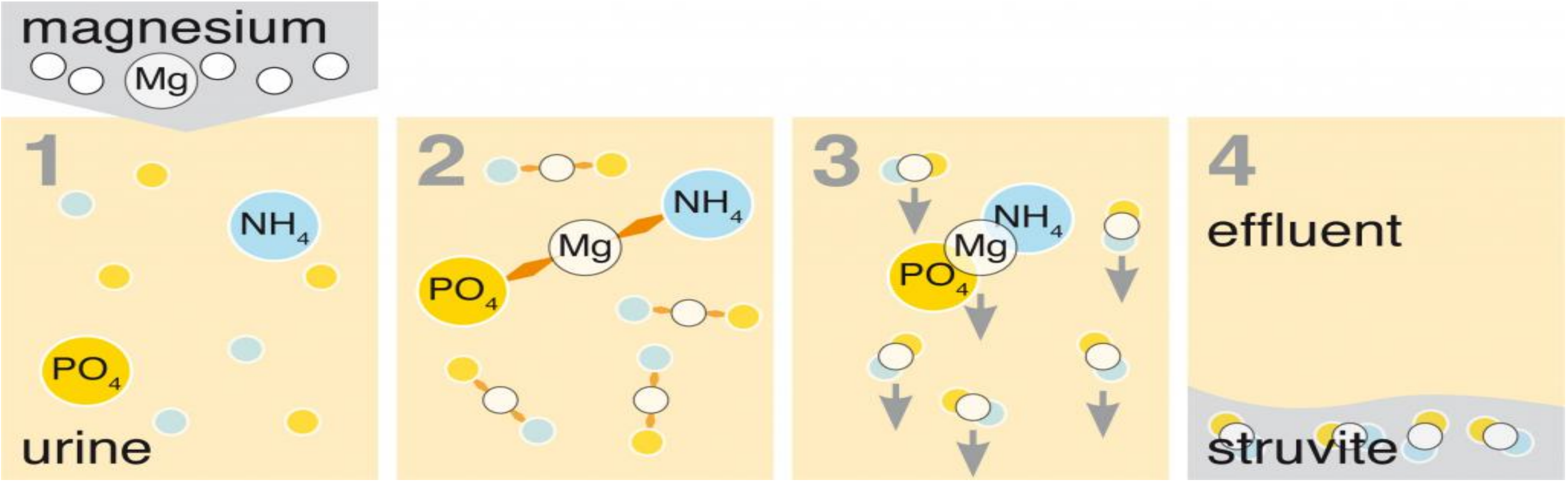
- Autotrophic bacteria
- Oxidizes ammonium with nitrite to N_2 gas
- Implemented at several WWTPs
- Long start up times
- Lacks potential for recovery



Ward et al. (2011)

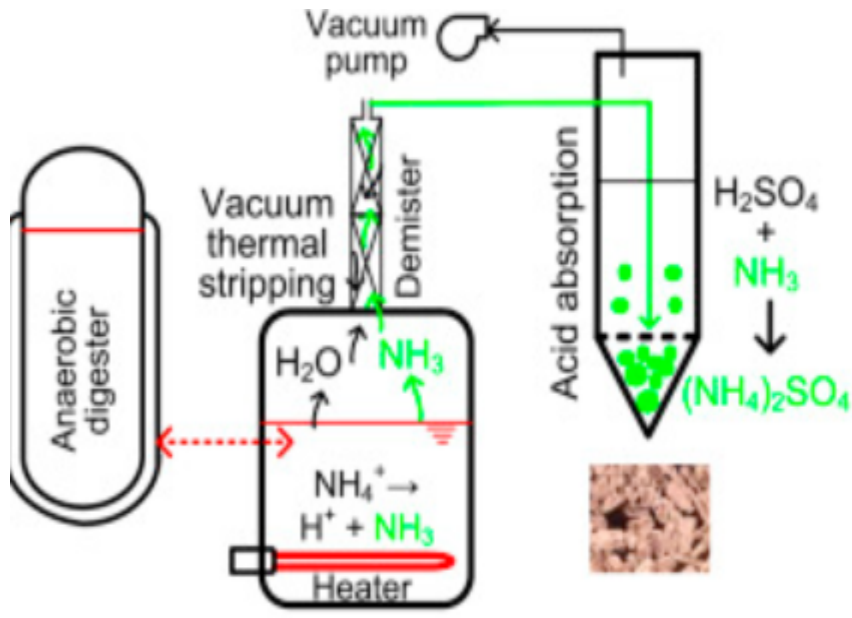
Struvite

- Magnesium ammonium phosphate (kidney stones)
- General Reaction: $Mg^{2+} + NH_4^{+} + PO_4^{3-} + 6H_2O \longrightarrow MgNH_4PO_4 \cdot 6(H_20)$
- Solubility increases with pH; (target 8.5)
- Used as slow release ammonia fertilizer
- Clarkson Digestate: 8 to 1 N:P

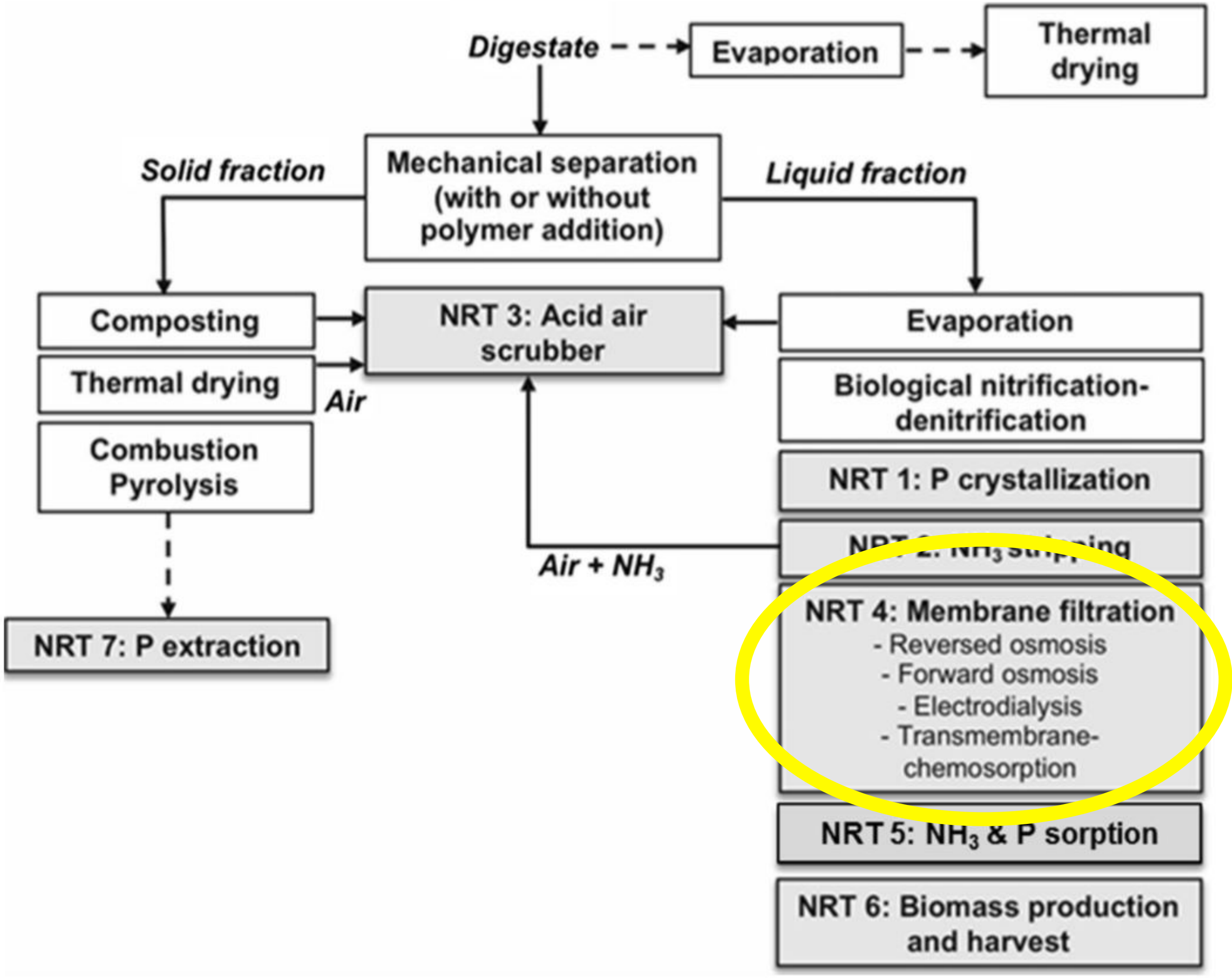


Air Stripping

- Physical transfer of NH_3 in the aqueous phase to gas phase
  - $NH_4^+ (aq) \leftrightarrow NH_3 (aq) + H^+$
  - $P_{NH_3} = H \cdot [NH_3]$
  - pH dependent; requires elevated pH
  - $pK_a = 9.25$ @ $T = 298\ K$
- Usually coupled with an acid scrubber
- Ammonia salts generated can be used as fertilizer
- High energy inputs
- Clarkson's digestate: strongly buffered → high chemical inputs



Ukwuani et al. (2016)



Digestate
Evaporation
Thermal drying
Mechanical separation (with or without polymer addition)
Solid fraction
Liquid fraction
Composting
Thermal drying
Combustion Pyrolysis
NRT 3: Acid air scrubber
Air
Evaporation
Biological nitrification-denitrification
NRT 1: P crystallization
Air + NH_3
NRT 4: Membrane filtration
- Reversed osmosis
- Forward osmosis
- Electrodialysis
- Transmembrane-chemosorption
NRT 5: NH_3 & P sorption
NRT 6: Biomass production and harvest
NRT 7: P extraction

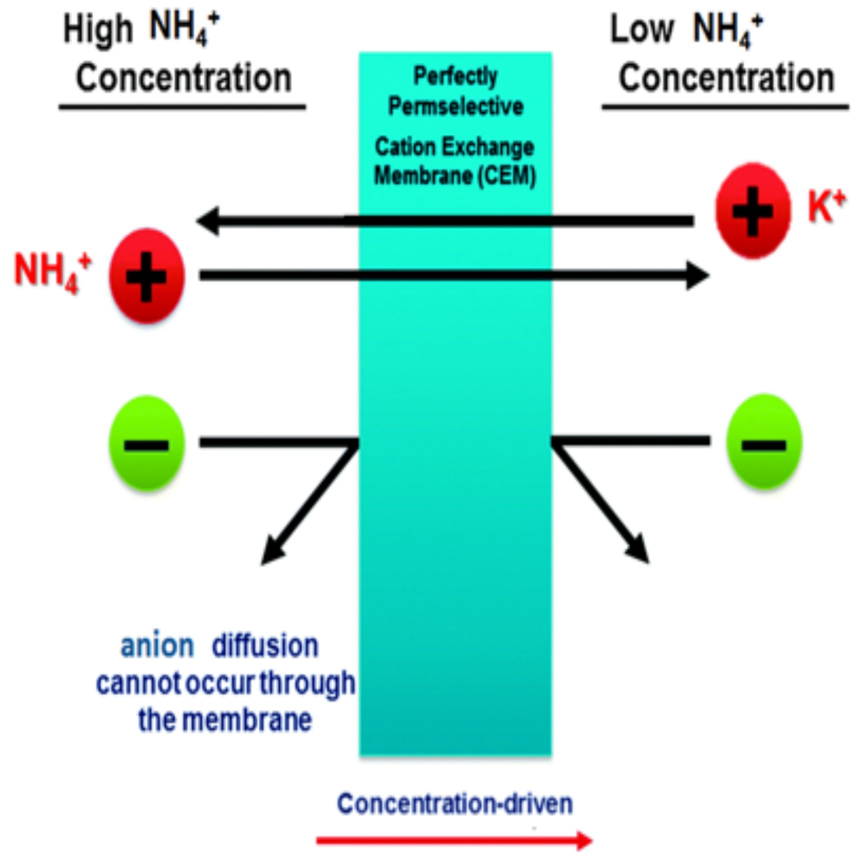
Process Mechanims

Cation Exchange Membranes

- Selectively-permeable
- Molecular passage based on ionic charge
- Concentration gradient driven
- NH_4^+ permeates through membrane
- Exchanging with cation (H^+ or K^+)

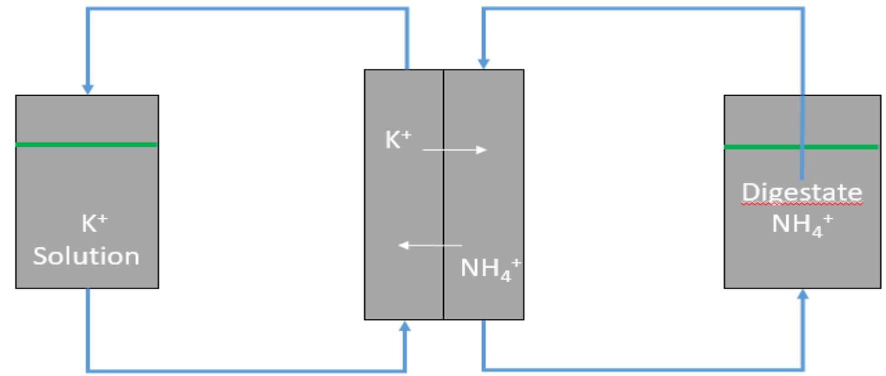
Why?

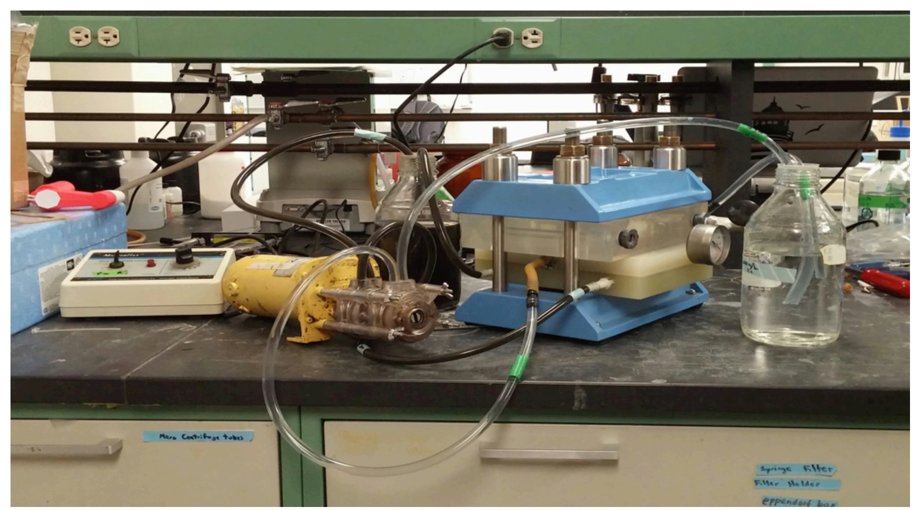
- Removal and Recovery



Experimental Methods: Membrane Test

- Nafion 117
- Pump and tubing set up
  - Flow rates: ~ 2 gpm each
- Leak/mixing test ~ 30 minutes
- Duration: 1-2 days
- Analysis: TN Analyzer, pH, 5 mL samples



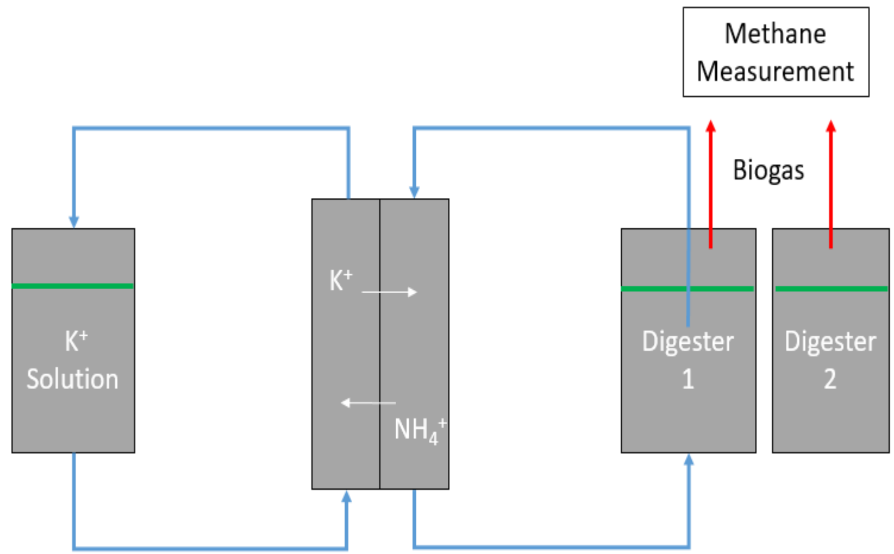


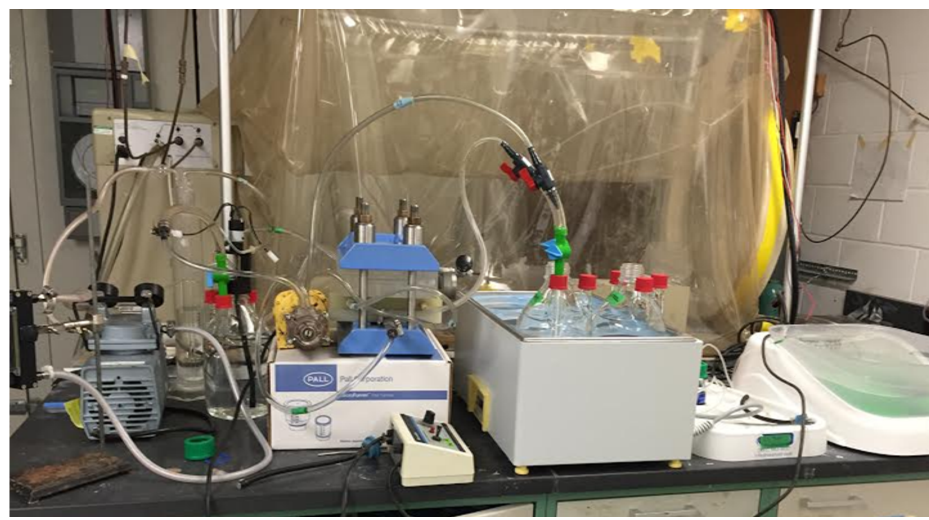
Results: Membrane Test

Trial	Membrane	Ammonia-Rich Solution	Draw Solution Composition	Flux mol/d/m^2
1 & 2	Nafion® 117	Ammonium Chloride NH_4Cl	Sulfuric Acid pH<2	92.0±8.5
3	Nafion® 117	Stage 2 Digestate Filtered	Sulfuric Acid pH<2	22.8±10.2
4 & 5	Nafion® 117	Stage 2 Digestate Unfiltered	Sulfuric Acid pH<2	14.3±1.04
6	Nafion® 117	Stage 2 Digestate Unfiltered	Potassium Sulfate K_2SO_4	10.7±1.9
7	Neosepta® CMX	Stage 2 Digestate Unfiltered	Potassium Sulfate K_2SO_4	3.71
8	Ultrex™ CMI-7000S	Stage 2 Digestate Unfiltered	Potassium Sulfate K_2SO_4	11.2±8.8

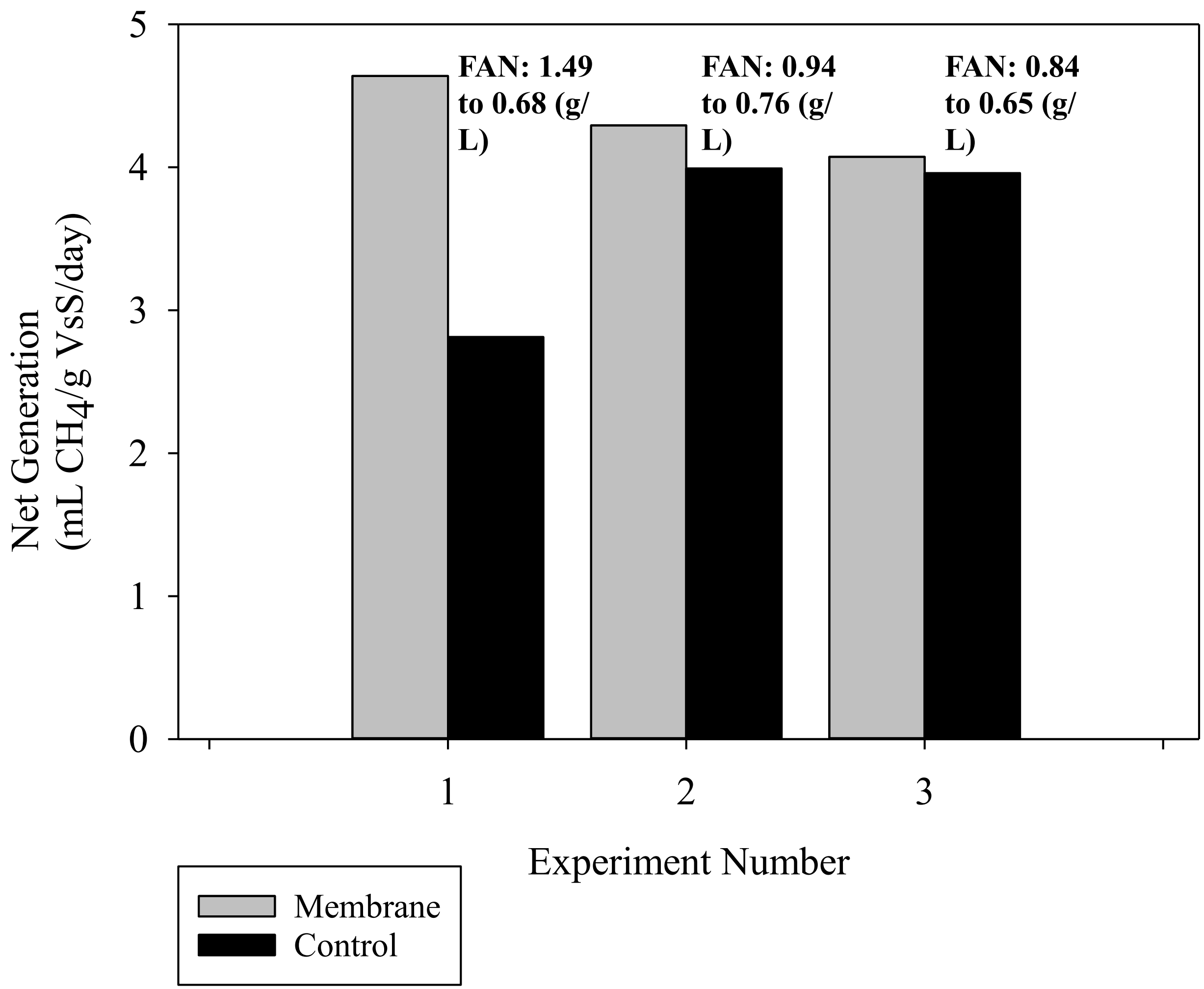
Experimental Methods: BMP Test

- Nafion 117
- Leak/mixing test ~ overnight
- 2.1 L volumes
- Draw Solution:
  - 17,000 mg/L K+
  - 0.1M Phosphate buffer: pH 8
- Control and Membrane Cell digesters:
  - Pre-consumer FW from CU kitchens
  - Stage 2 Digestate
  - 1:1 ratio based on VS
- Methane measured using AMPTS II
- 6 mL samples collected once a day
  - TN, COD, pH
- Duration: 10-15 days





Results: BMP Test



Results

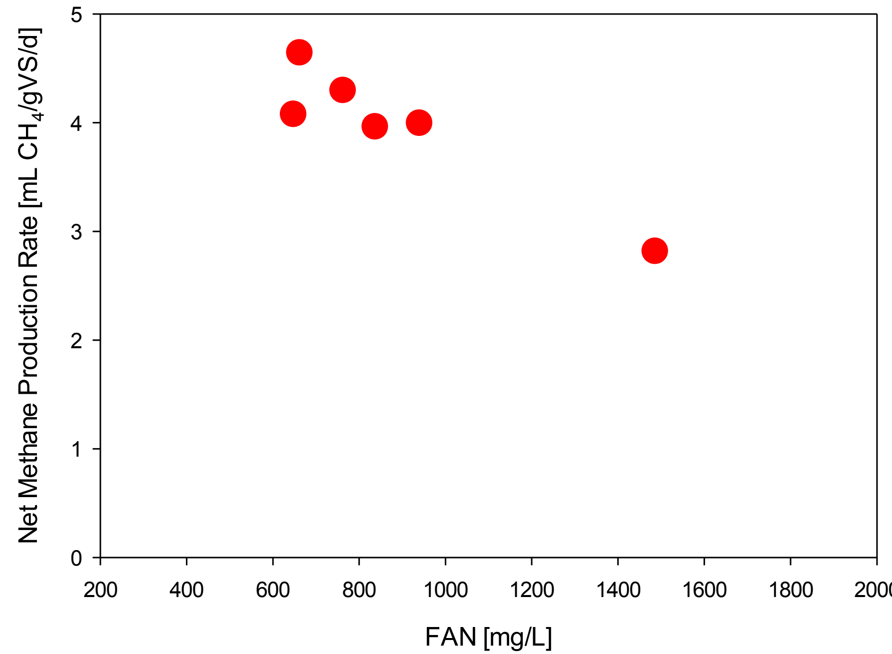
- ADM1 model uses

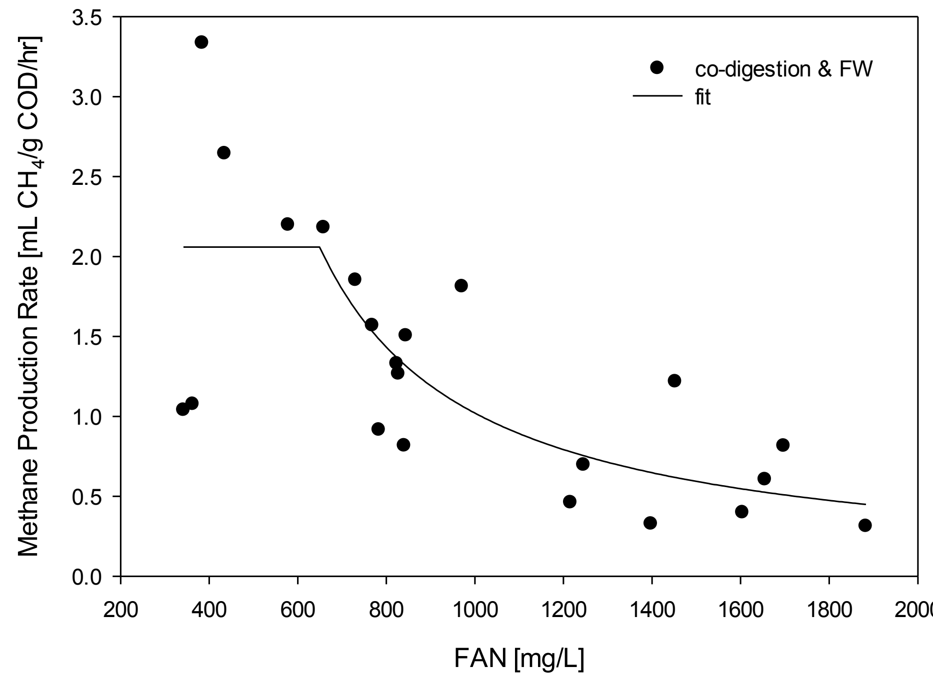
$I=1/1+s\downarrow I\ /K\downarrow I \quad 4$

  $S\downarrow I$ -ammonia concentration

  $K\downarrow I$ -inhibition parameter of ammonia

- Threshold model predicts methane rate constant below specific concentration[6,7,10-15]
  - Threshold concentration: 650 ± 196 (95% C.I.) mg/L FAN
  - Threshold should be microbial culture dependent.





Results

- Threshold model

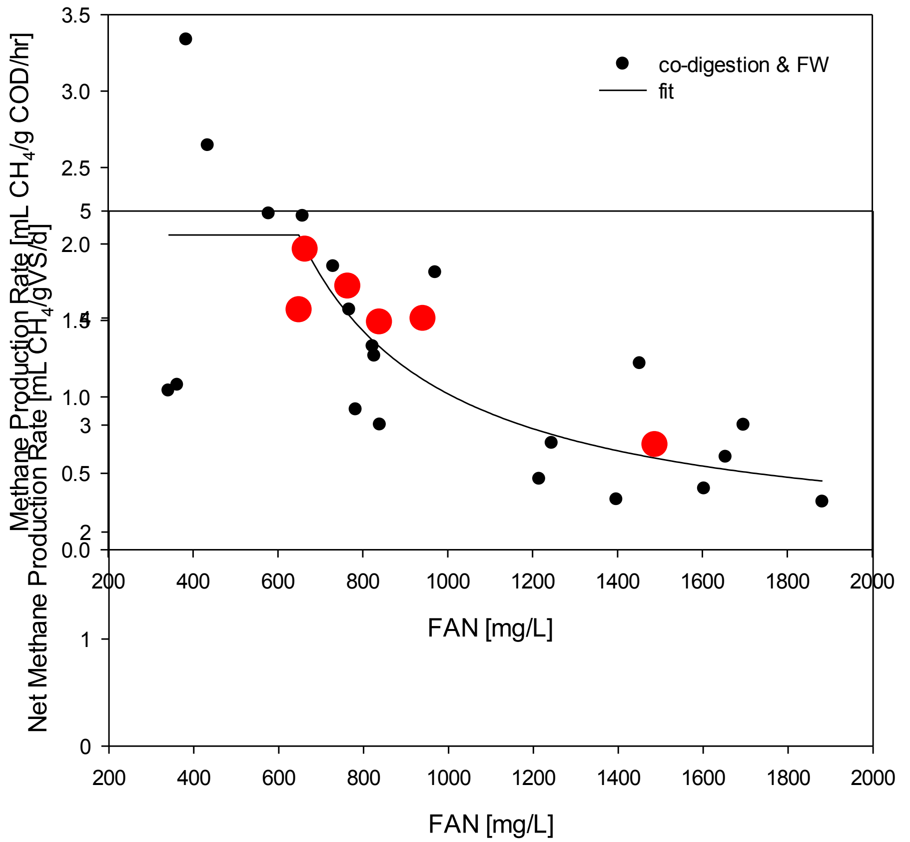
$I = 1\,;\qquad S_I < T_s$

$I = 1/1 + S_I - T_s/K_I\;;\qquad S_I > T_s$

S_I -ammonia concentration

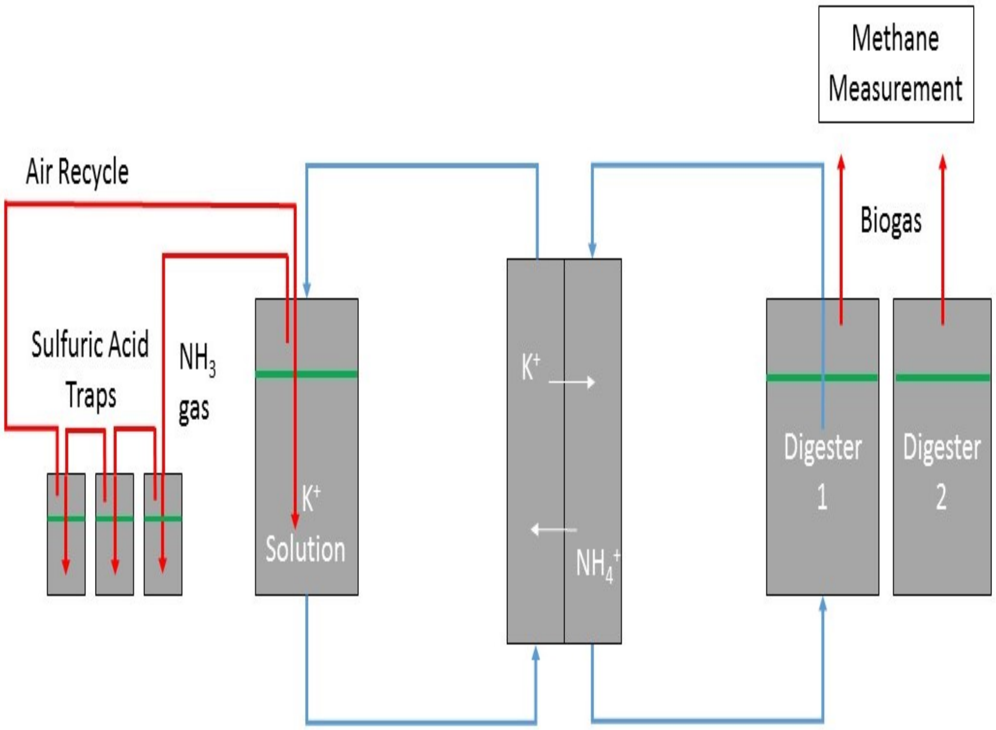
K_I -inhibition parameter of ammonia

T_s – threshold concentration



Summary

- Membrane System has been operated for 2.5 months without significant flux decline
- Membrane system allowed for increased methane production at concentrations well above threshold concentration (650 ± 196 (95% C.I.) mg/L FAN for our seed culture from campus food digester).
- As expected at FAN concentrations close to threshold concentration no increased methane production was observed. Thus a membrane system would have limited value.
- Ammonia recovery in form of ammonium sulfate



Conclusions and Future Work

- Membrane easily achieves removal and recovery of ammonia
- The membrane system allows for blending ammonia with digester effluent to balance nutrient composition of effluent
- Threshold model may better describe ammonia inhibition for food waste digestate
- Further experimentation at higher FAN concentrations to confirm inhibition model
- Characterize digester microbial community
- Scale up for Clarkson's food digester system

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NYS P2I New York State Pollution Prevention Institute

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