Using Mathematical Modeling to Predict Microbial Electrochemical Cell (MxC) Performance Using Primary Sludge Feedstock

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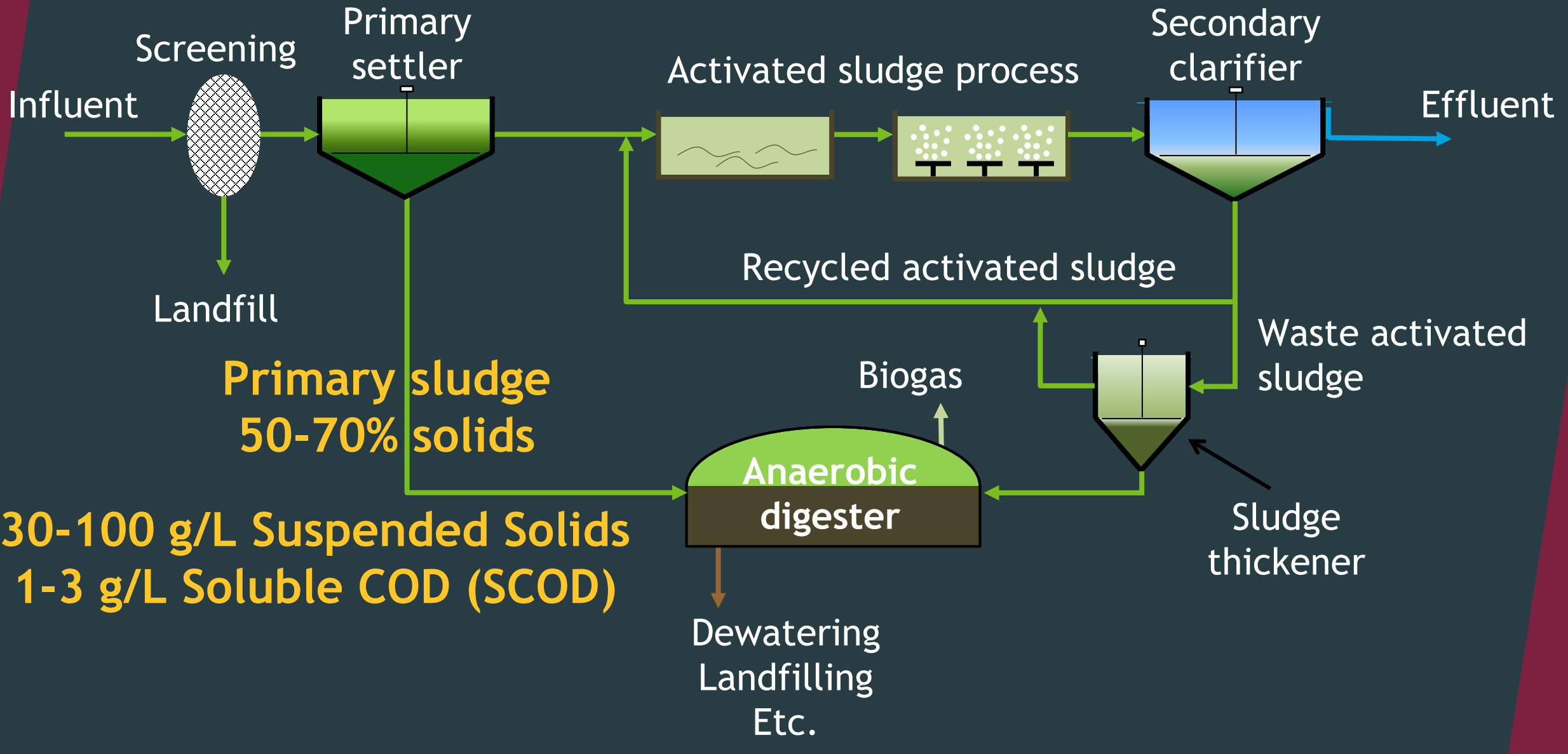
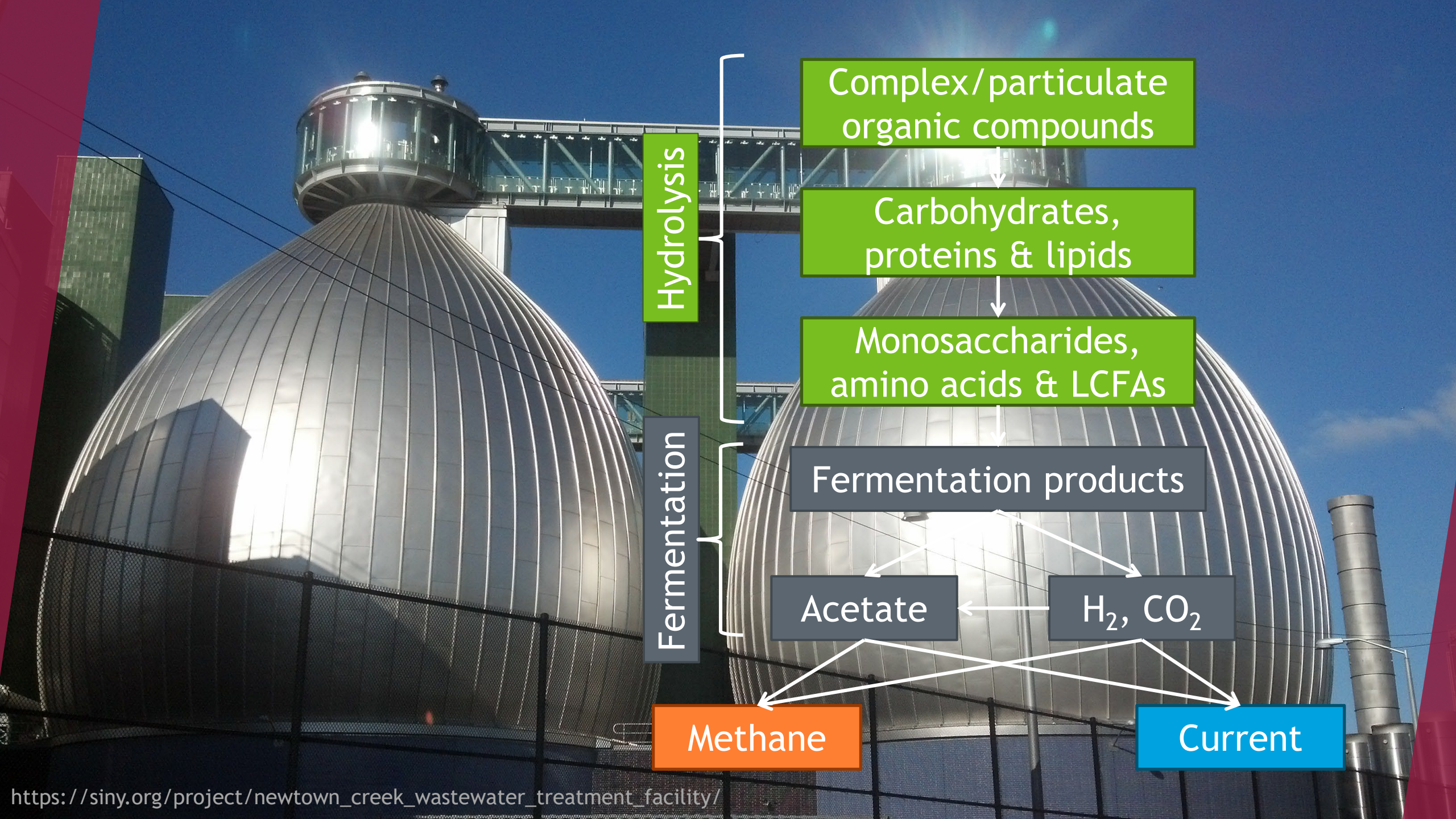
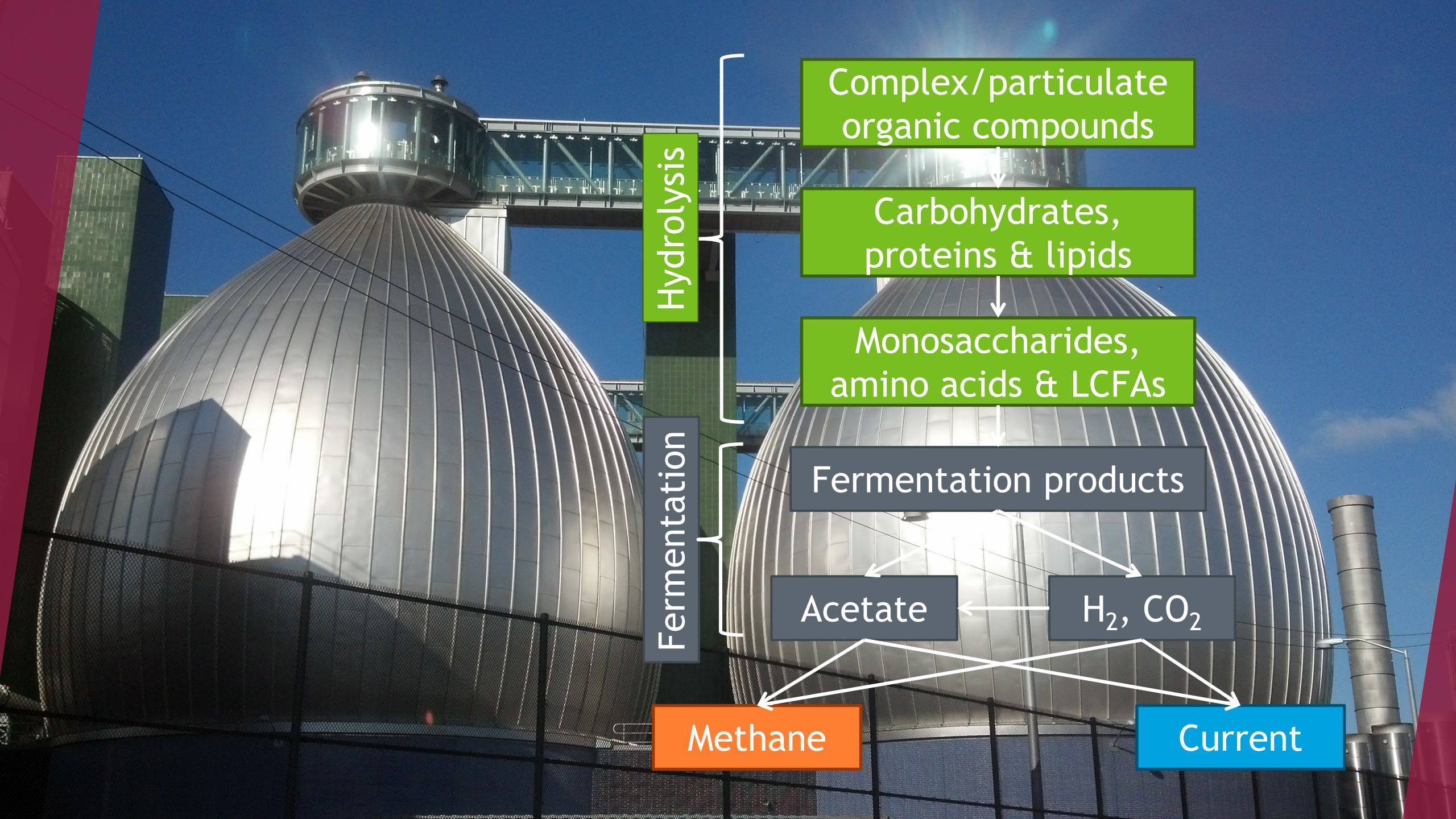
Arizona State University's Biodesign Swette Center for Environmental Biotechnology

Primary sludge is the most readily available COD source in a typical wastewater treatment plant (WWTP)



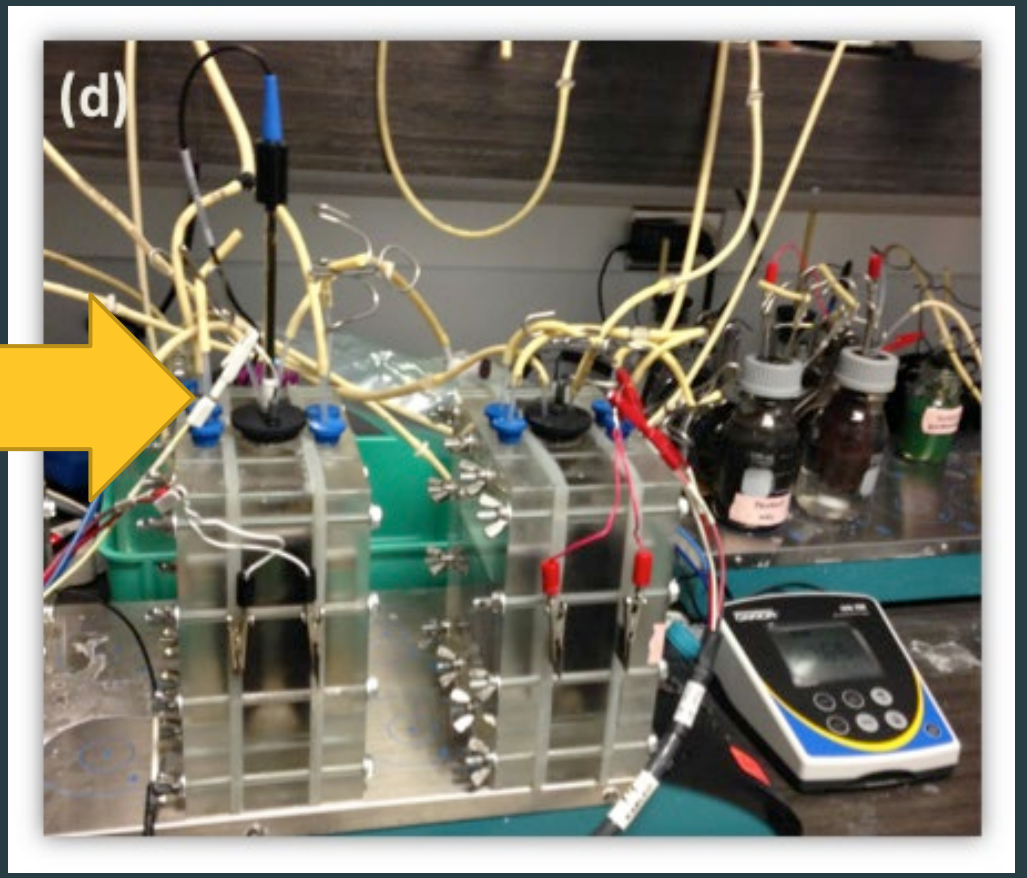


https://siny.org/project/newtown_creek_wastewater_treatment_facility/


Hydrolysis
Fermentation
Complex/particulate organic compounds
Carbohydrates, proteins & lipids
Monosaccharides, amino acids & LCFAs
Fermentation products
Acetate
H_2, CO_2
Methane
Current

Can we use existing models to simulate ARB-WWTP systems?

http:/www.hazenandsawyer.com/



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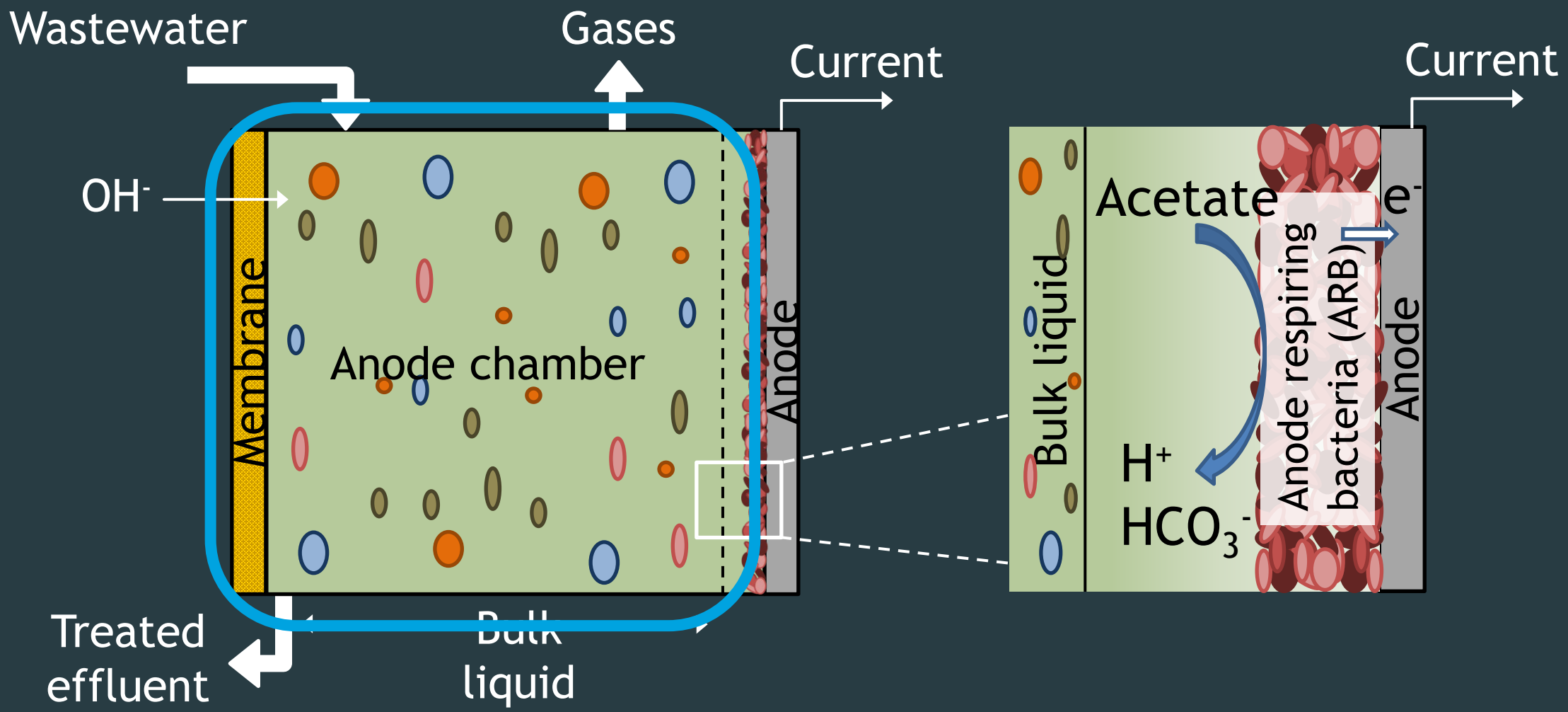
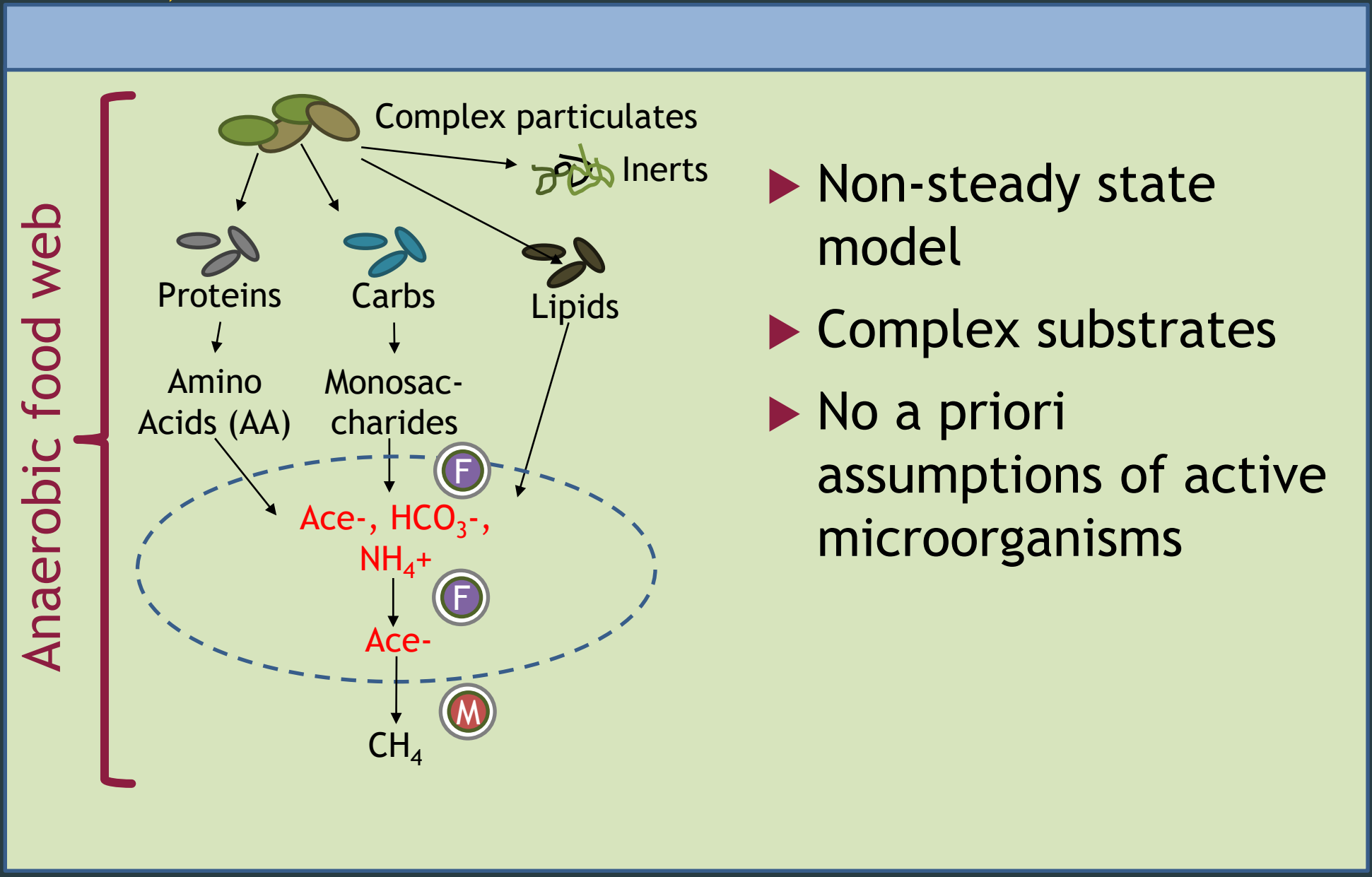
Mathematical models of MxCs and traditional WWTP have several similarities



Combined Activated Sludge-Anaerobic Digestion Model (CASADM)



- Non-steady state model
- Complex substrates
- No a priori assumptions of active microorganisms

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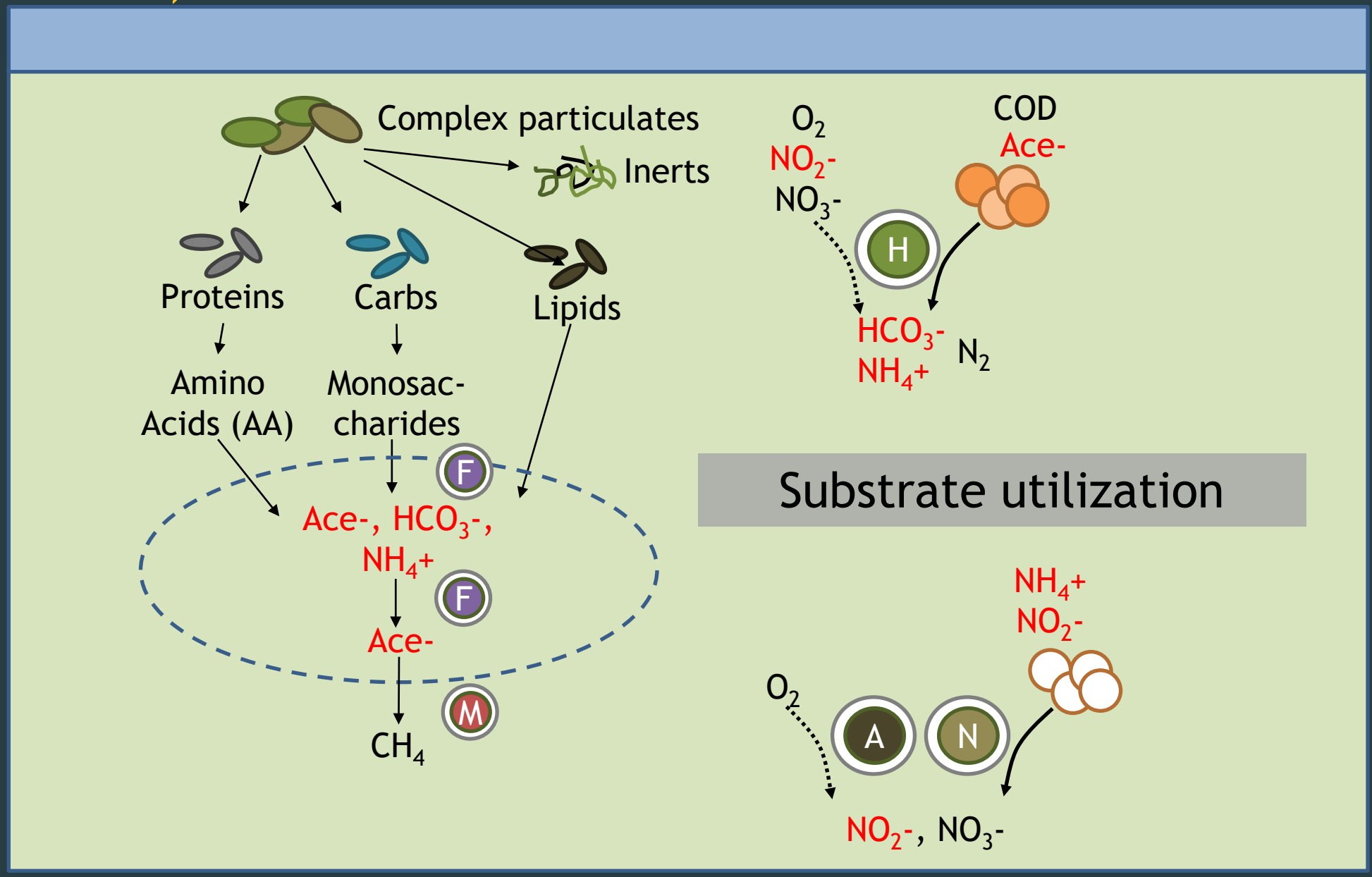

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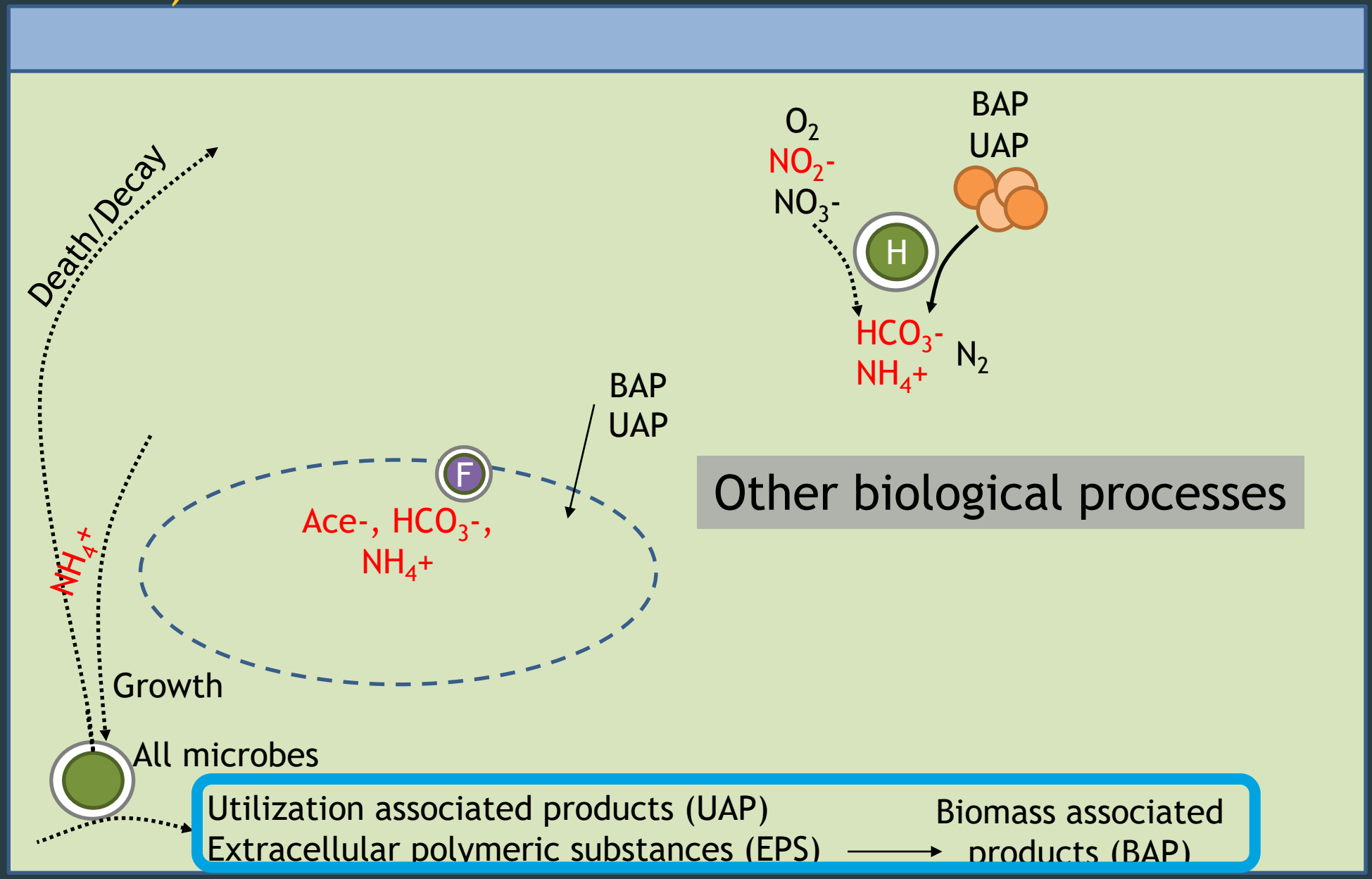

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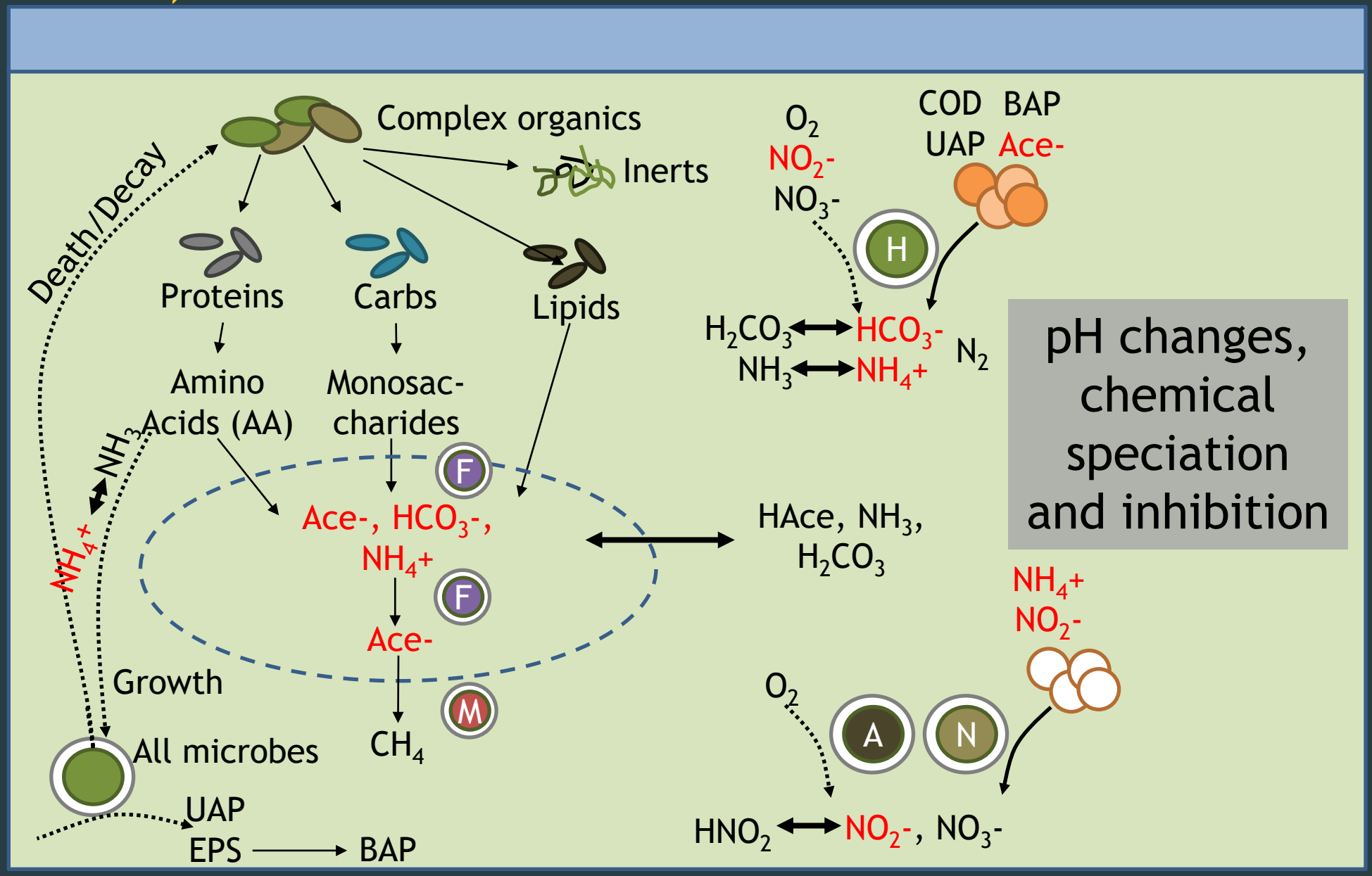

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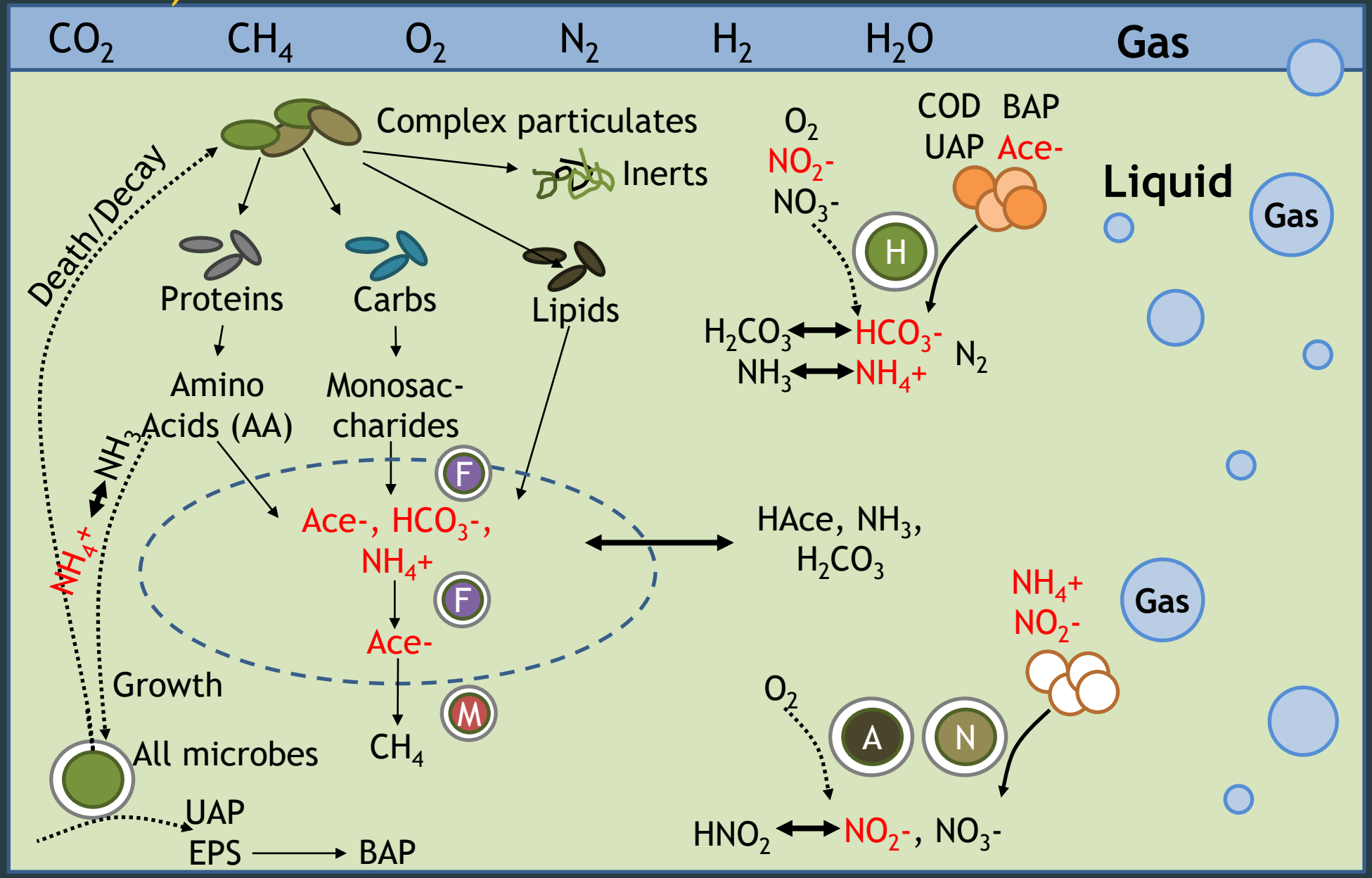
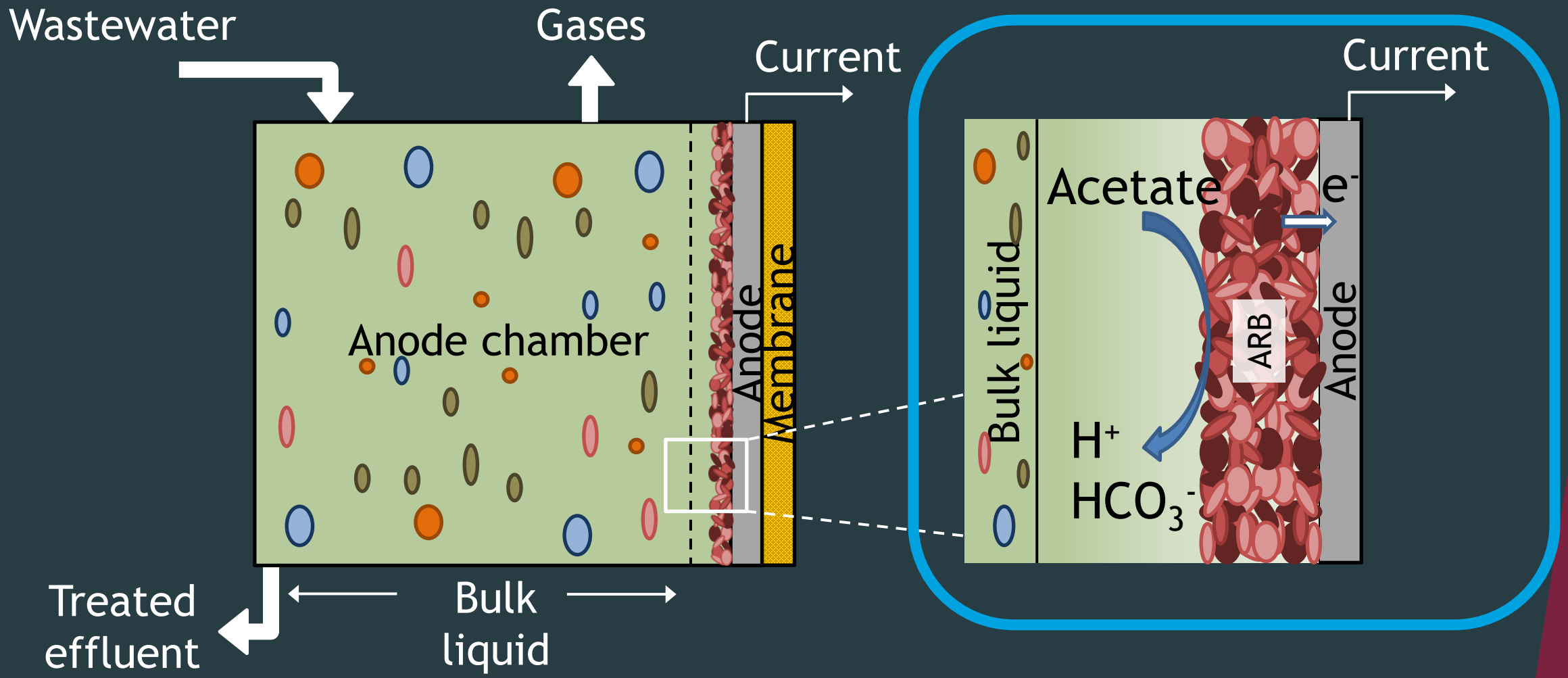
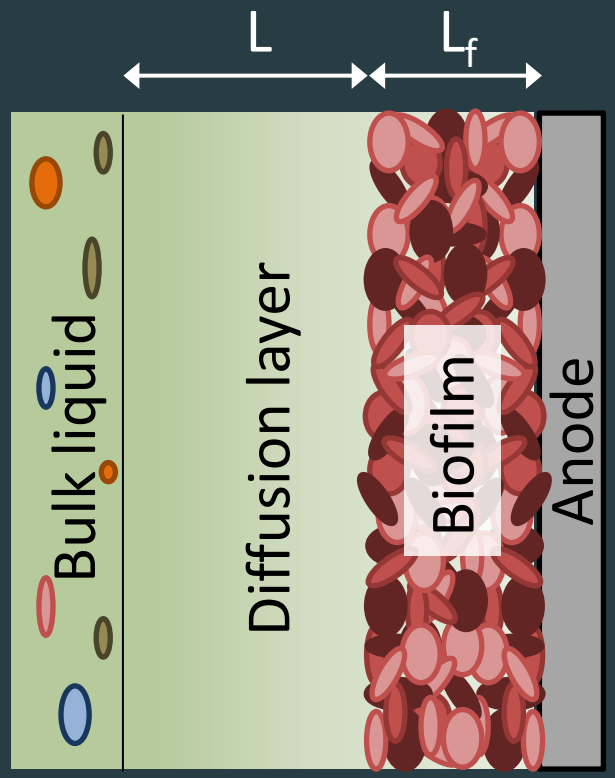
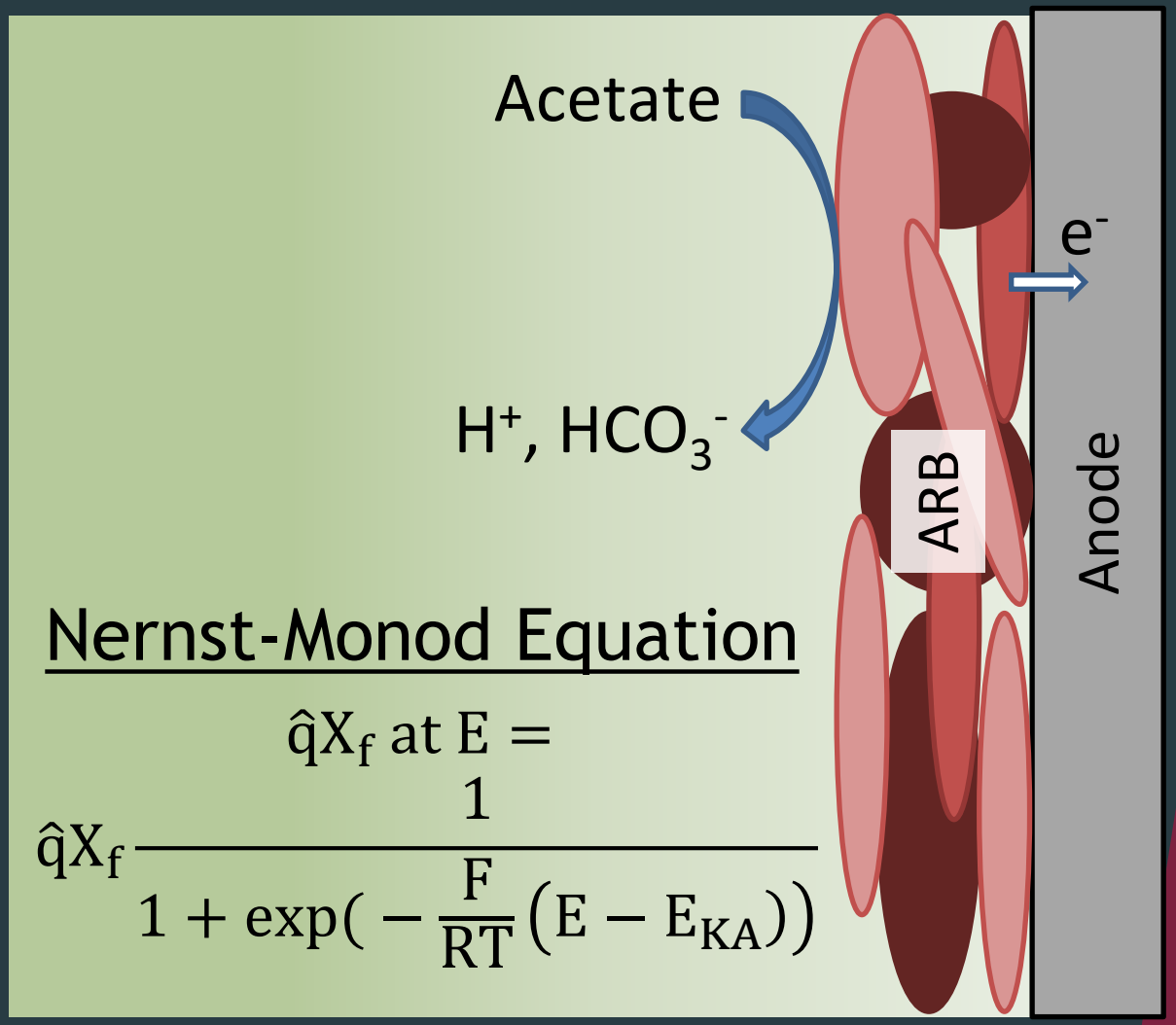


Microbial electrochemical cells (MxCs) and traditional WWTP have several similarities



Nernst-Monod and PCBIOFILM are the standards for anode models





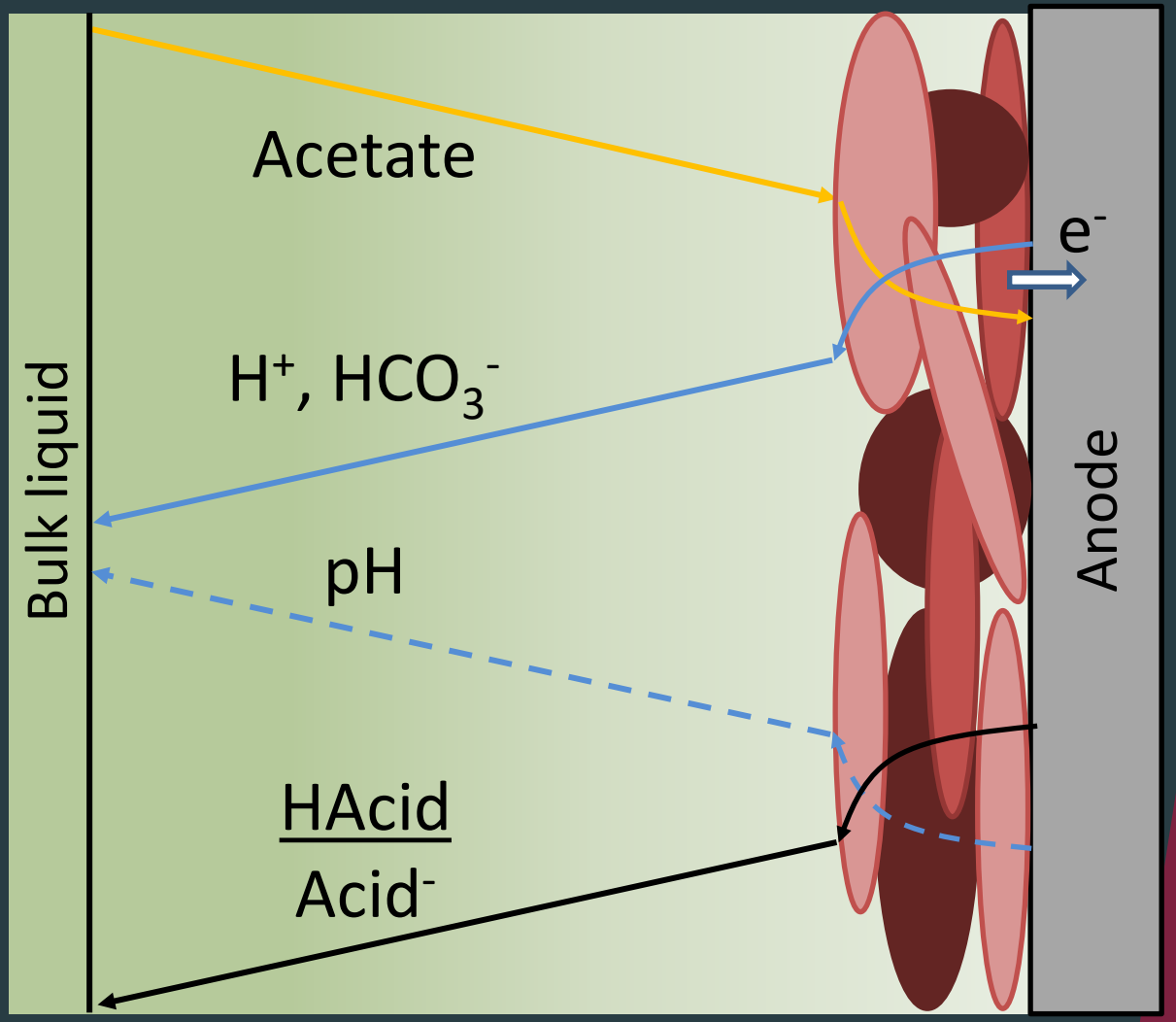
Nernst-Monod Equation

$$\hat{q}X_f \text{ at } E = \hat{q}X_f \frac{1}{1 + \exp\left(-\frac{F}{RT}\left(E - E_{KA}\right)\right)}$$

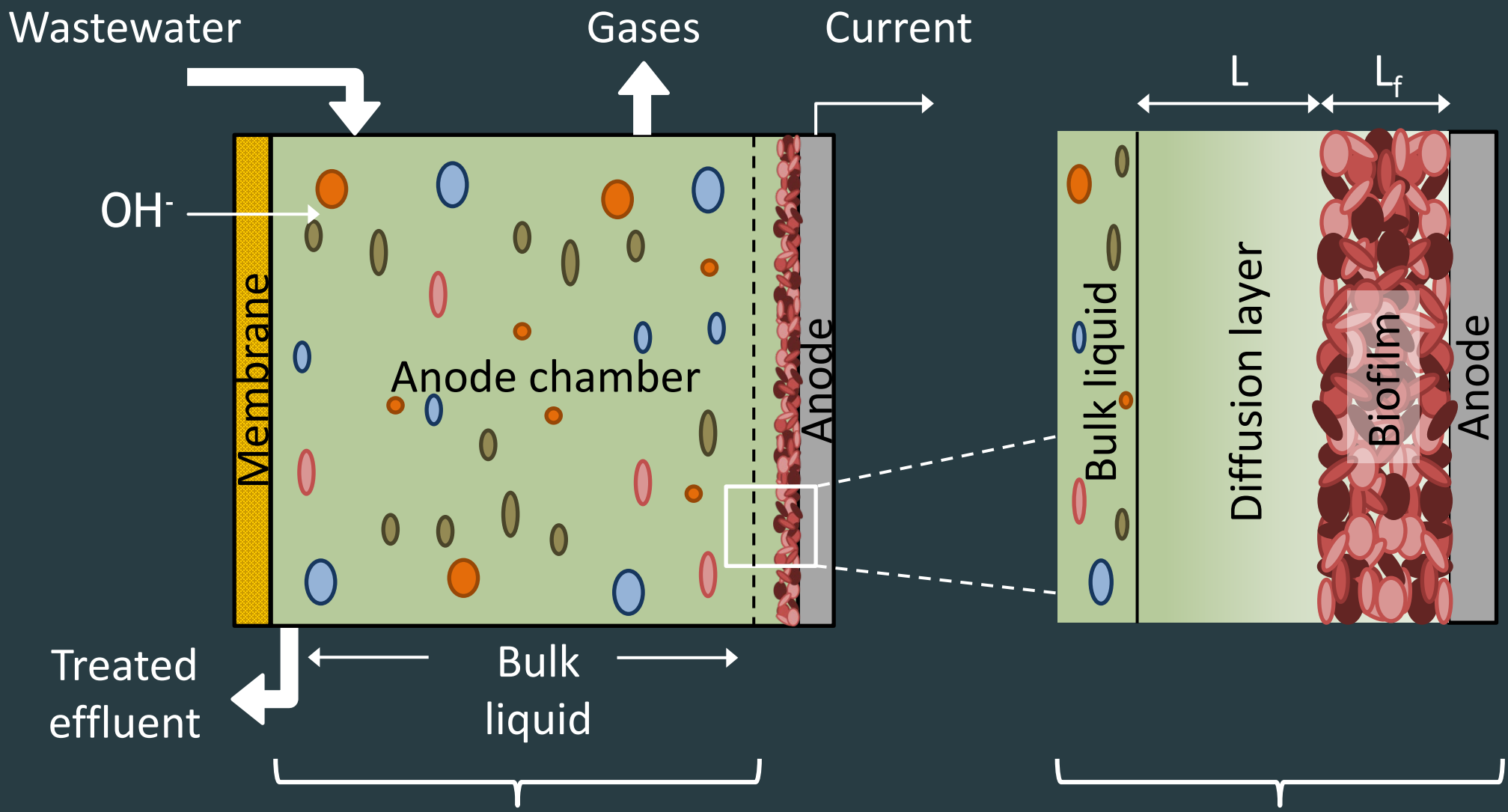
Nernst-Monod and PCBIOFILM are the standards for anode models

Fick's Law

$$J = -D_i \frac{dC_i}{dx}$$



MYAnode combines CASADM and PCBIOFILM to model MxCs



MYAnode features

- Non-steady state
- Batch or semi-continuous
- Complex substrates (various compositions)
- Multi-process
- Multispecies
- pH impacts
- EPS/SMPs
- Reaction rates by tank and component
- Relies on well-defined kinetics
- Does not include
  - Fermentation to propionate or butyrate
  - Homoacetogenesis
  - Hydrogenotrophic methanogenesis
- ARB biofilm
- Omits biofilm growth

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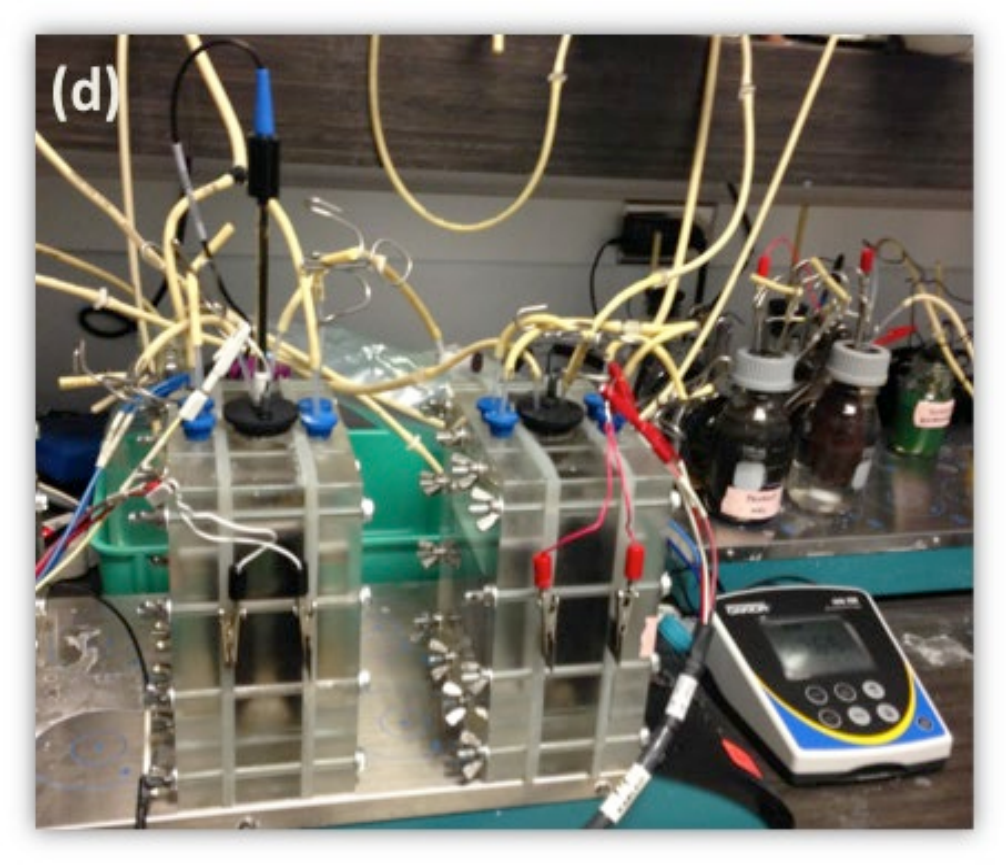
Model validation using primary sludge MxCs



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- Diluted primary sludge
- Semi-continuous with daily pH adjustment to ~7.5
- 12 d hydraulic retention time
- 550 mg SCOD/L
- Particulate COD (PCOD) 4350 mg VSS/L
- Inert biomass 750 mg SS/L
- 300 mg $CaCO_3$/L bicarbonate alkalinity
- 0.5 L anode chamber
- 200 cm^2 surface area
- 0-200 mg VSS/L influent methanogens
- 1000 um diffusion layer thickness
- 0.25/d hydrolysis rate

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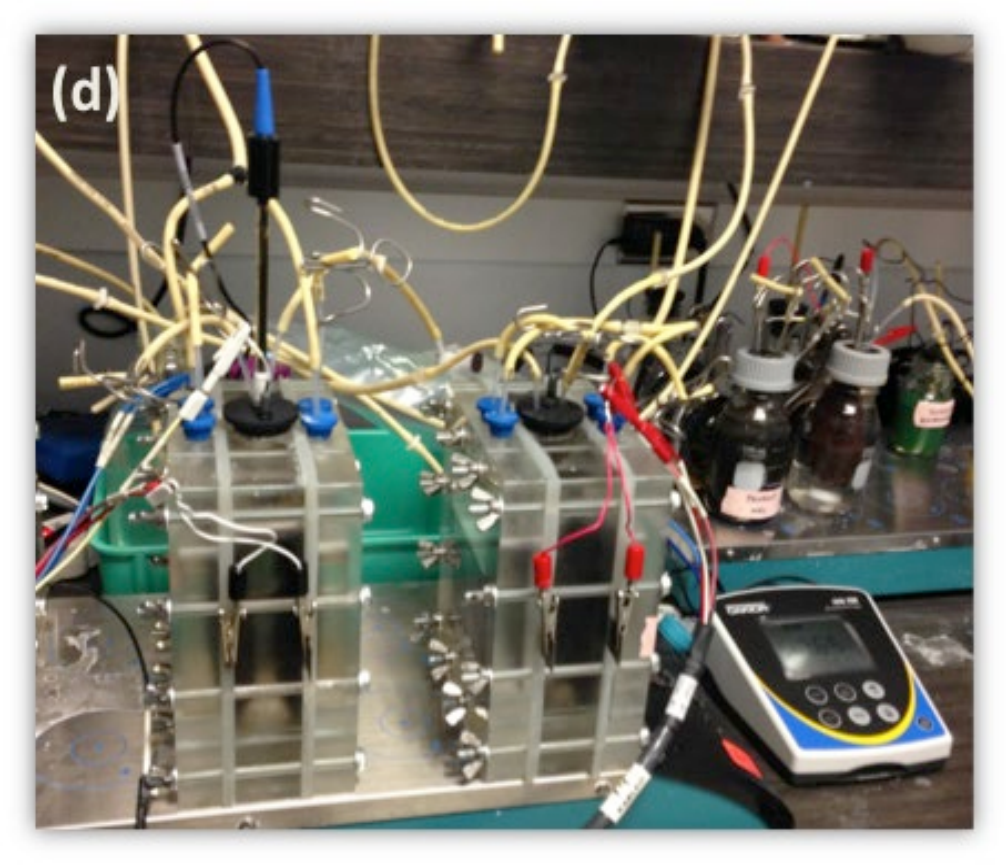

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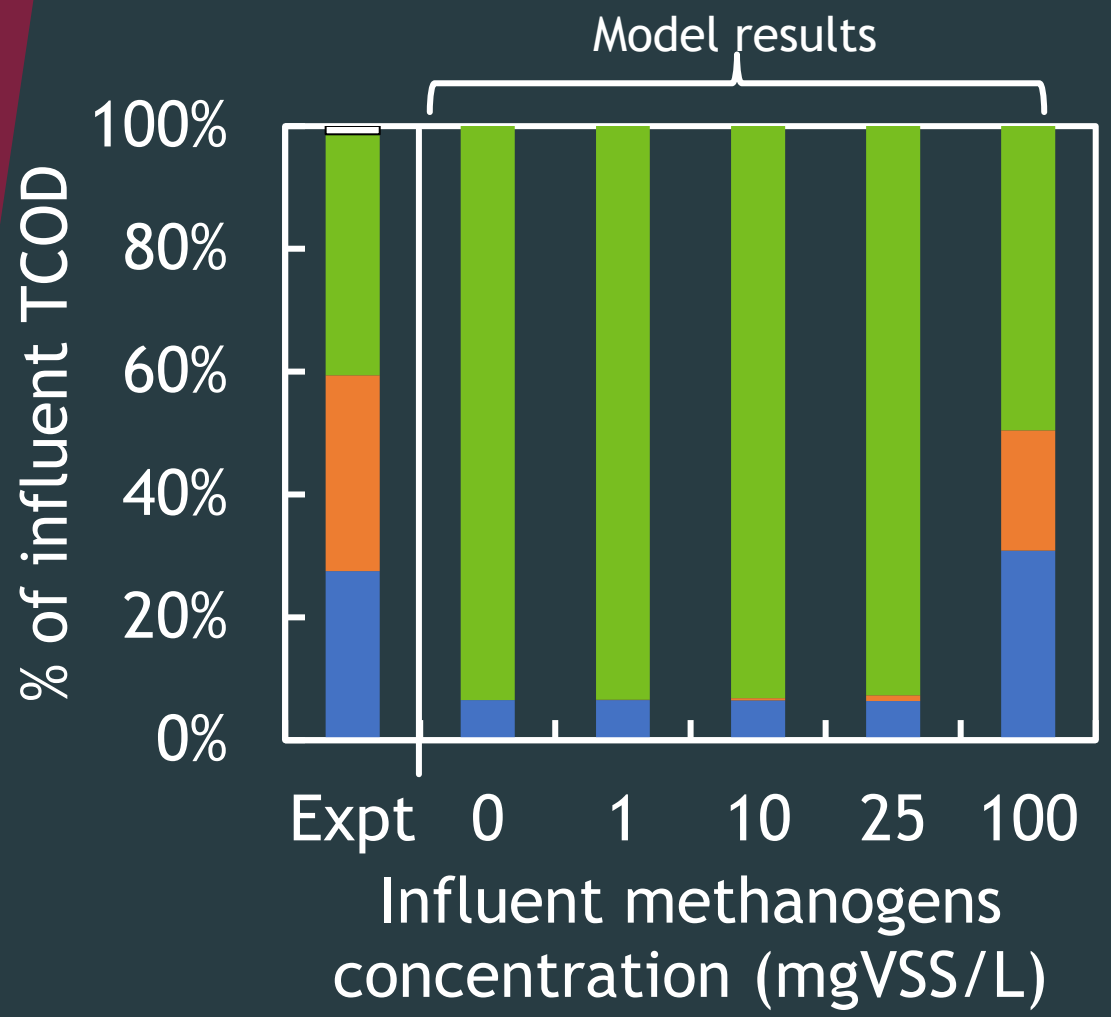
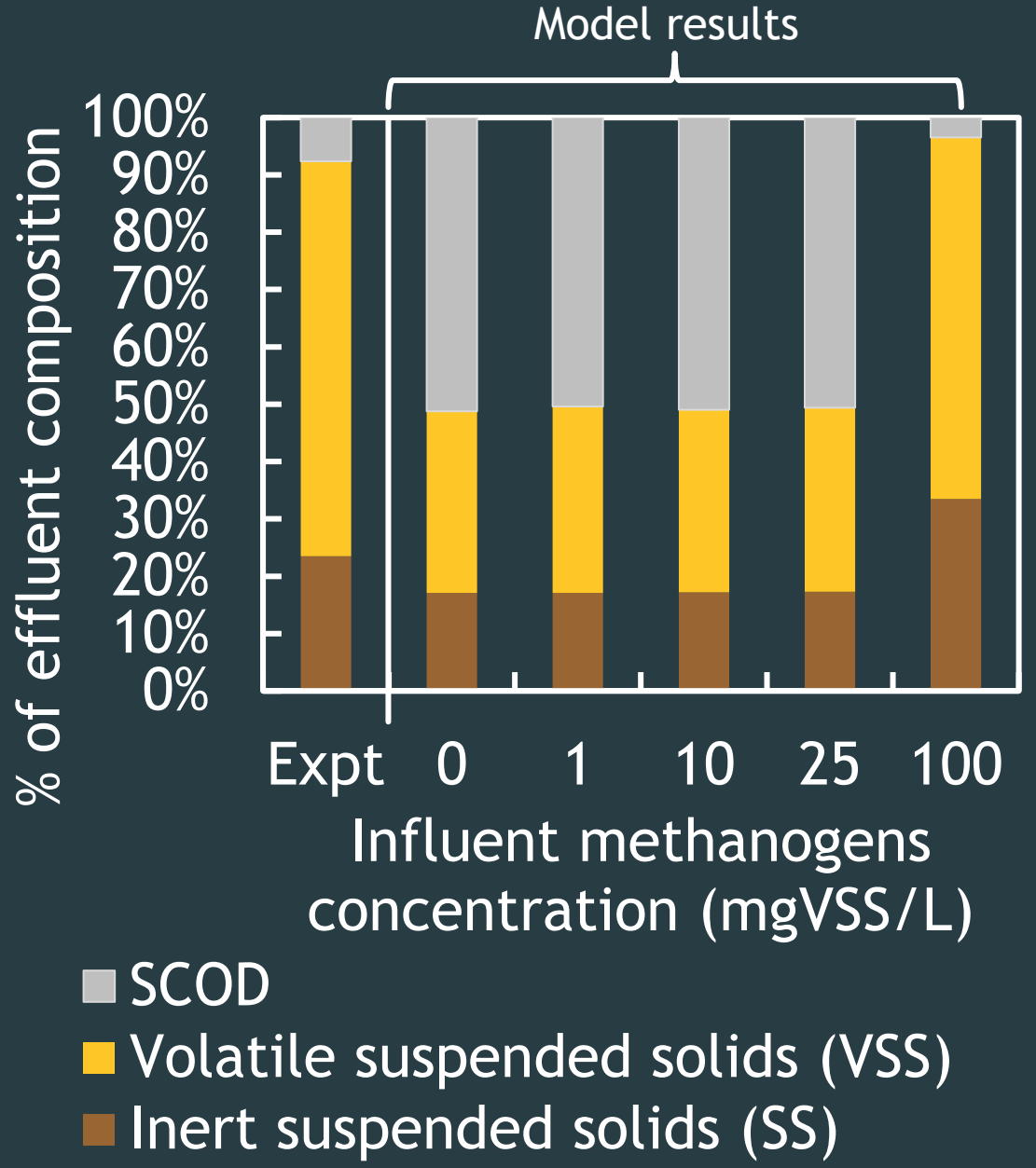
General validation of MYAnode



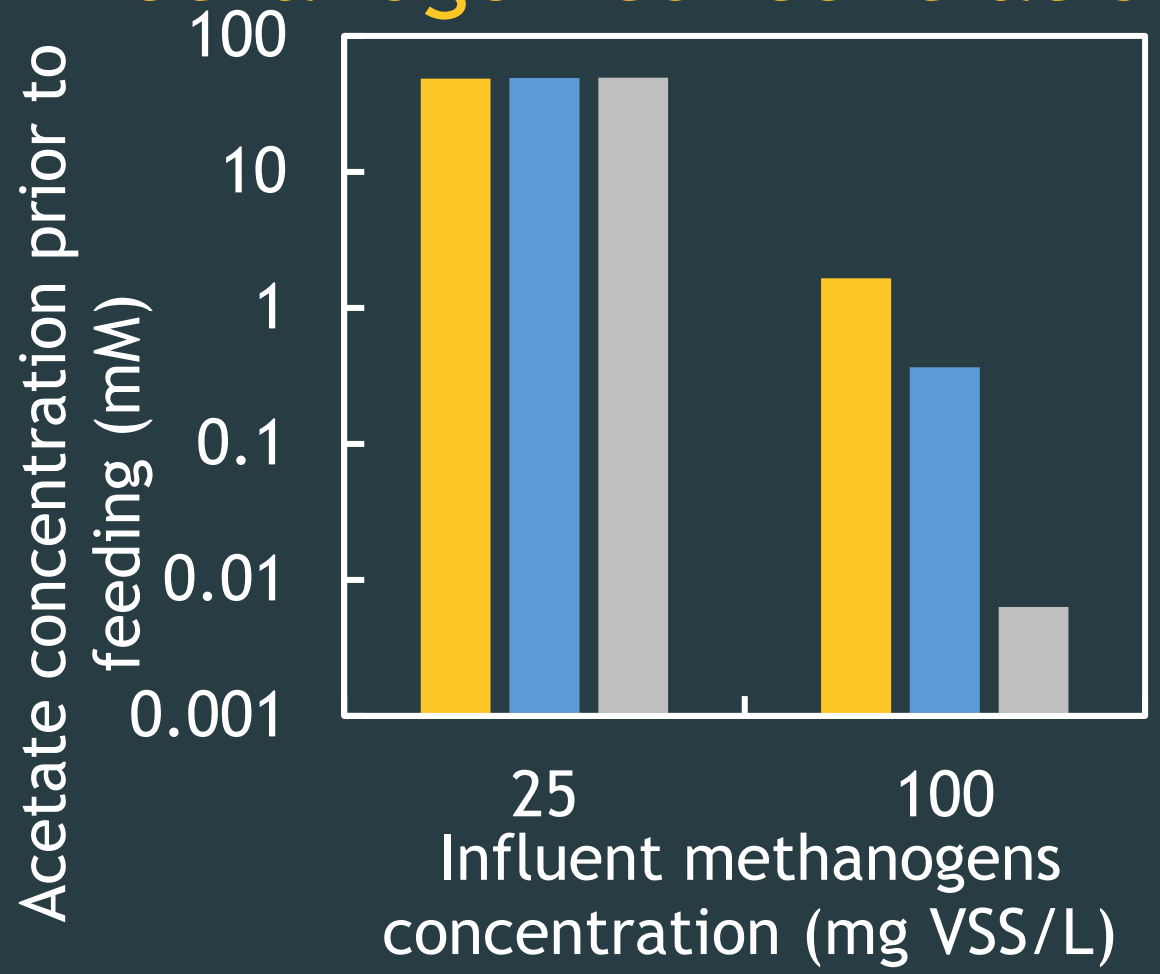


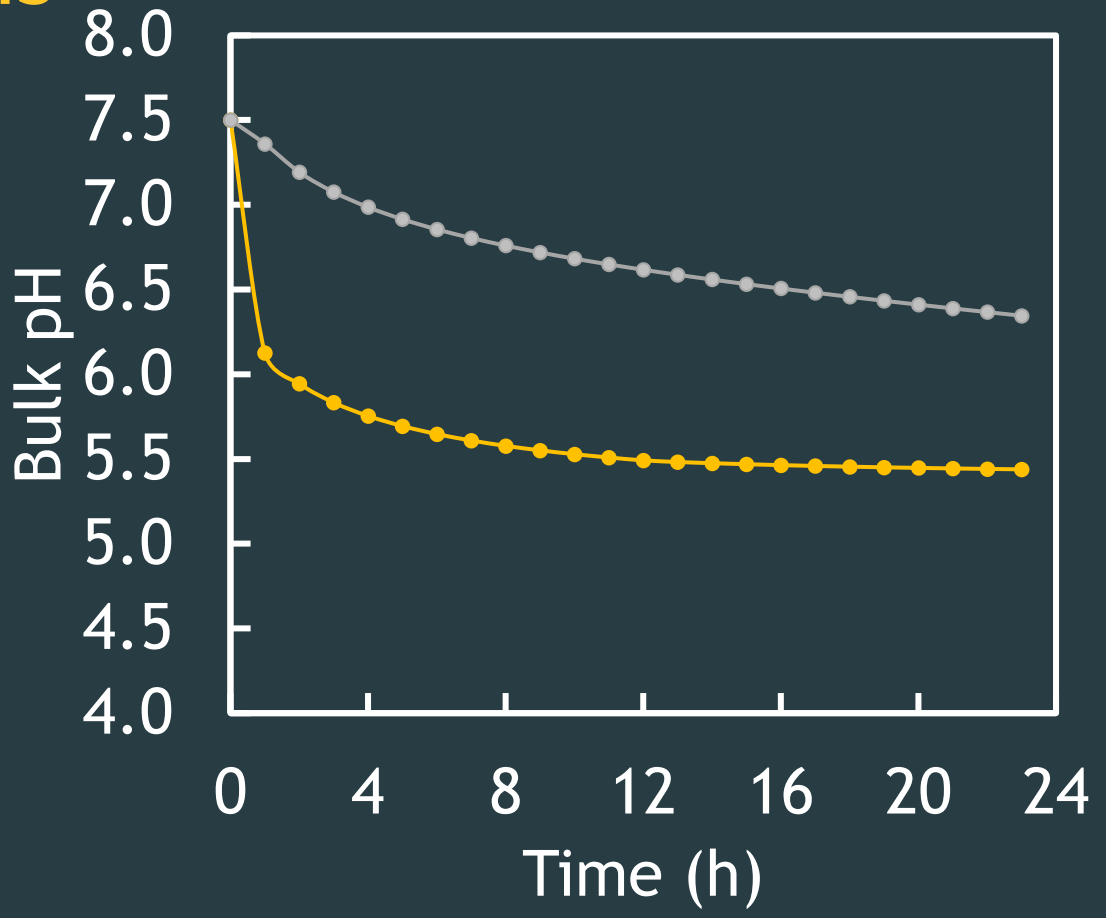
Why poor performance at less than 25 mgVSS/L influent methanogens?

ARB vs. Methanogens

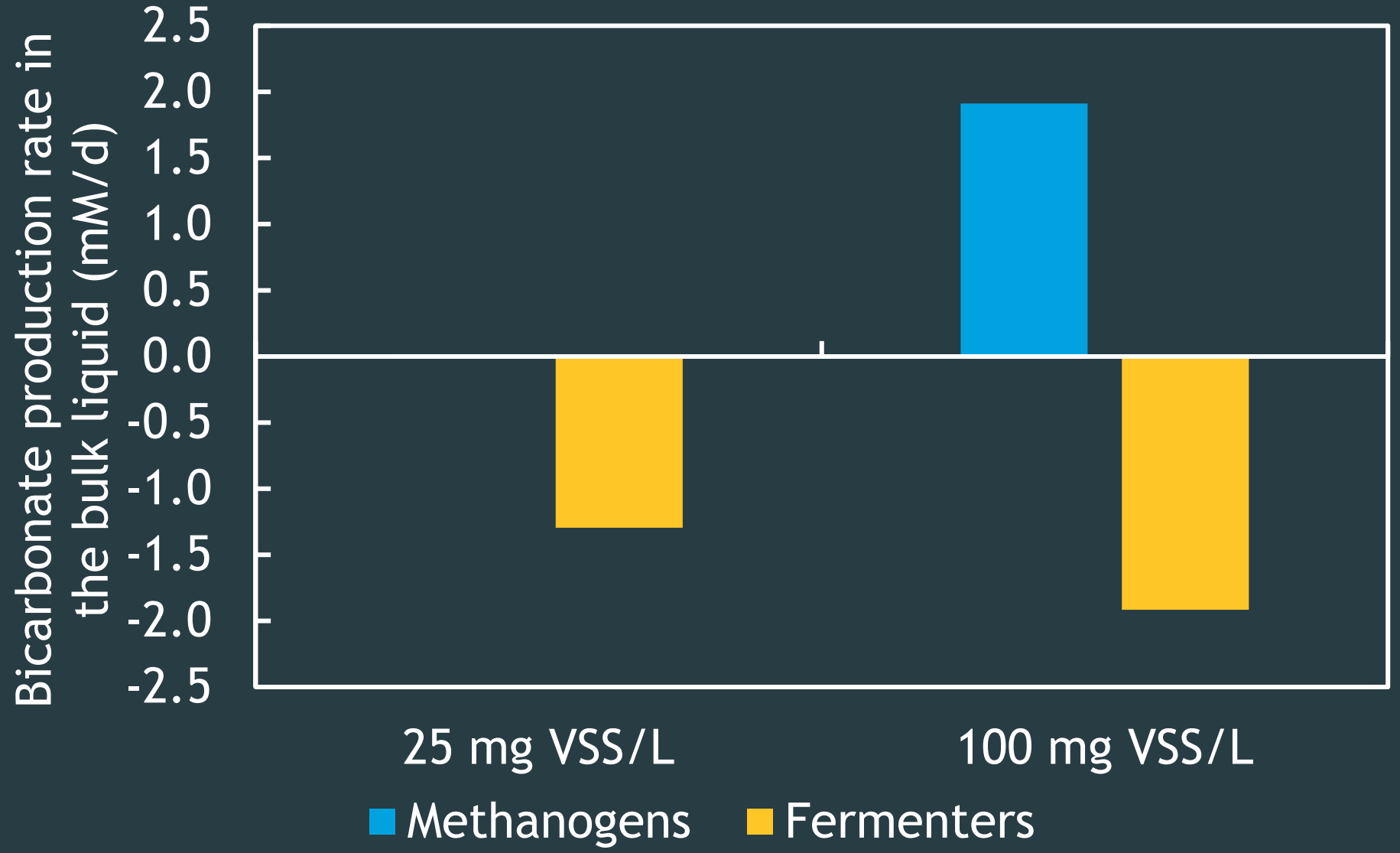
http://davidjernigan.blogspot.com/2016/08/preparing-body-for-probiotic-success_2.html

Bulk pH is inhibitory for methanogenesis at low methanogen concentrations

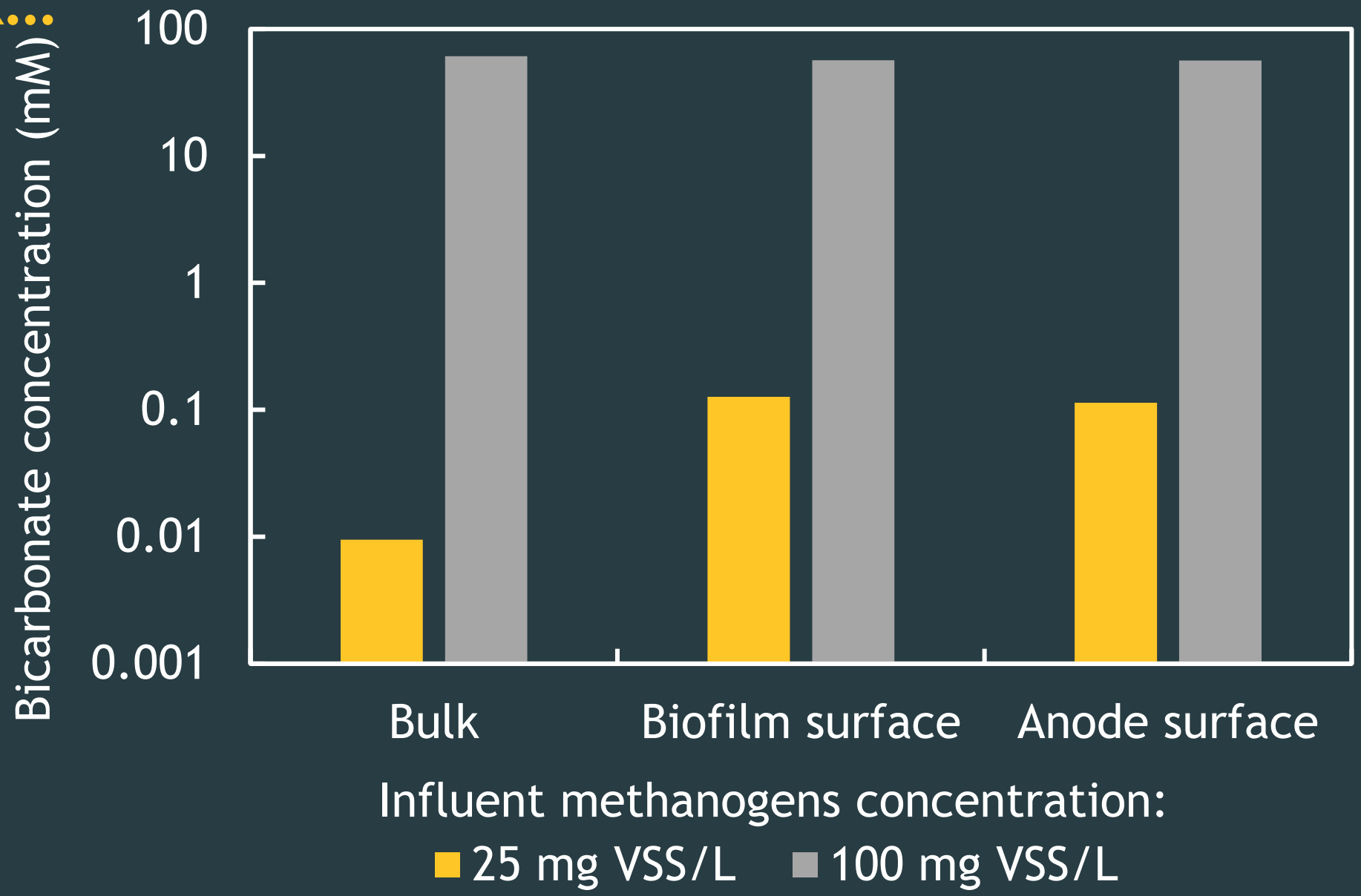




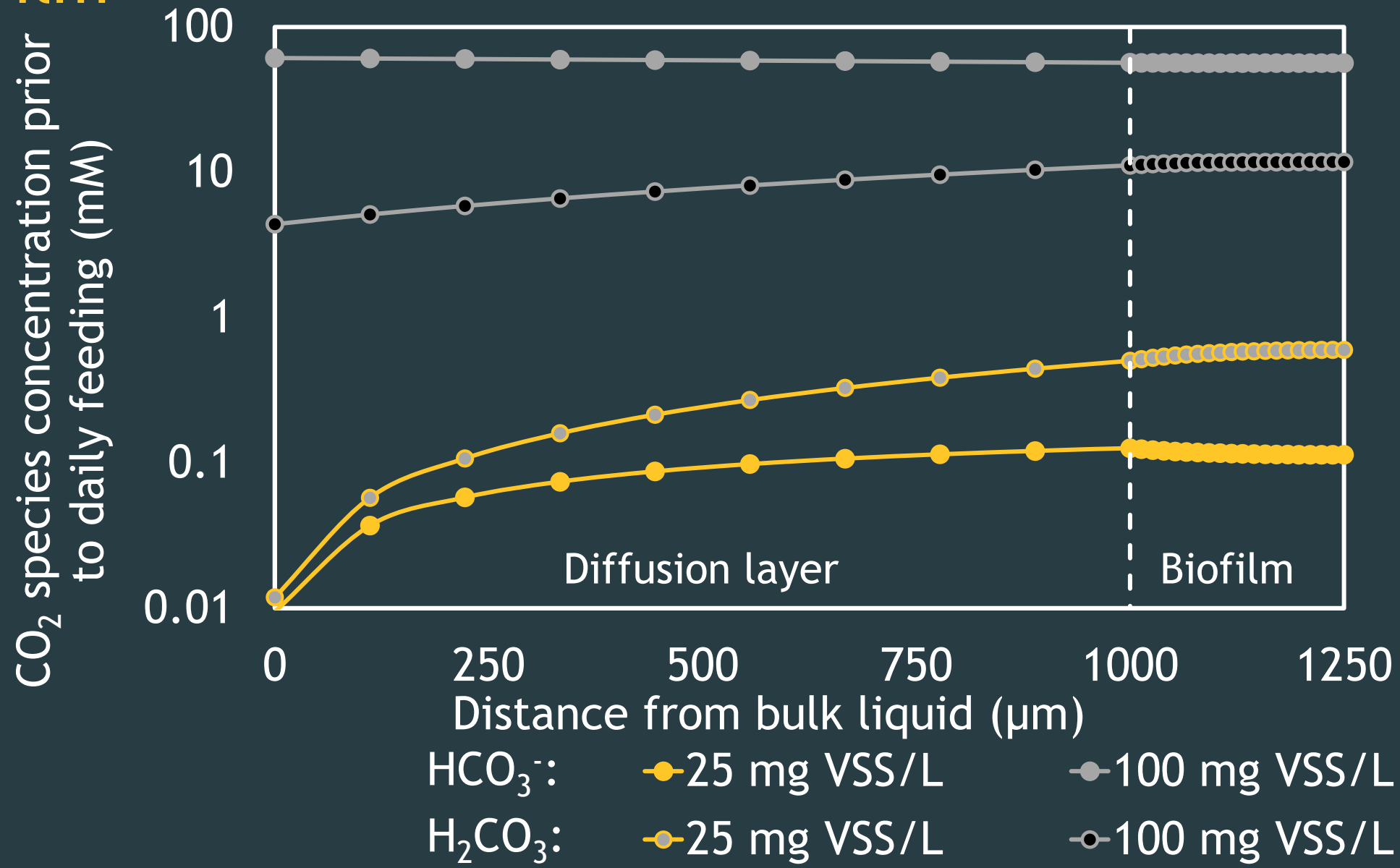
Methanogenic washout inhibits alkalinity production at lower influent methanogen concentrations…



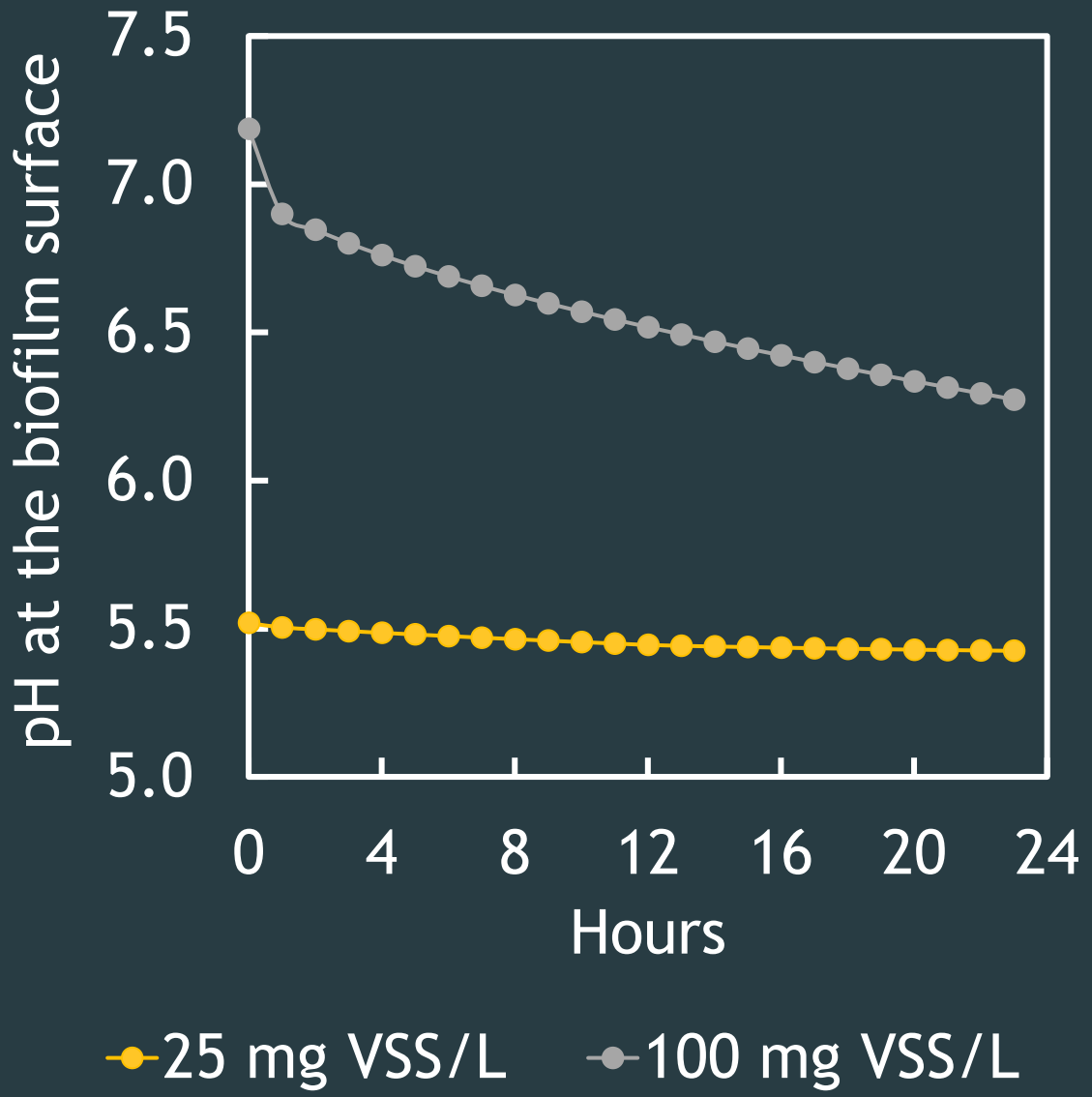
…Which leads to lower bicarbonate alkalinity in the bulk…

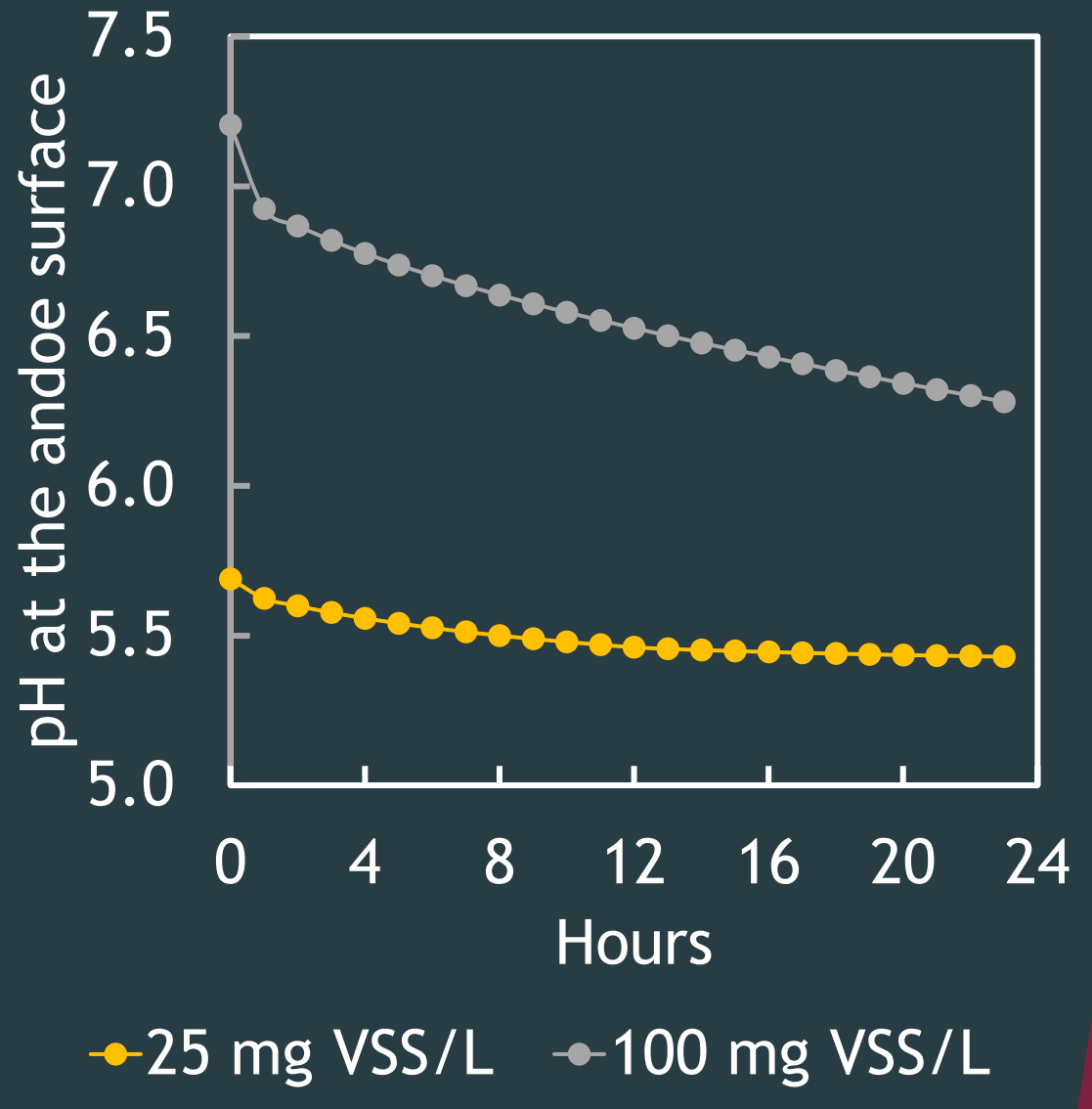


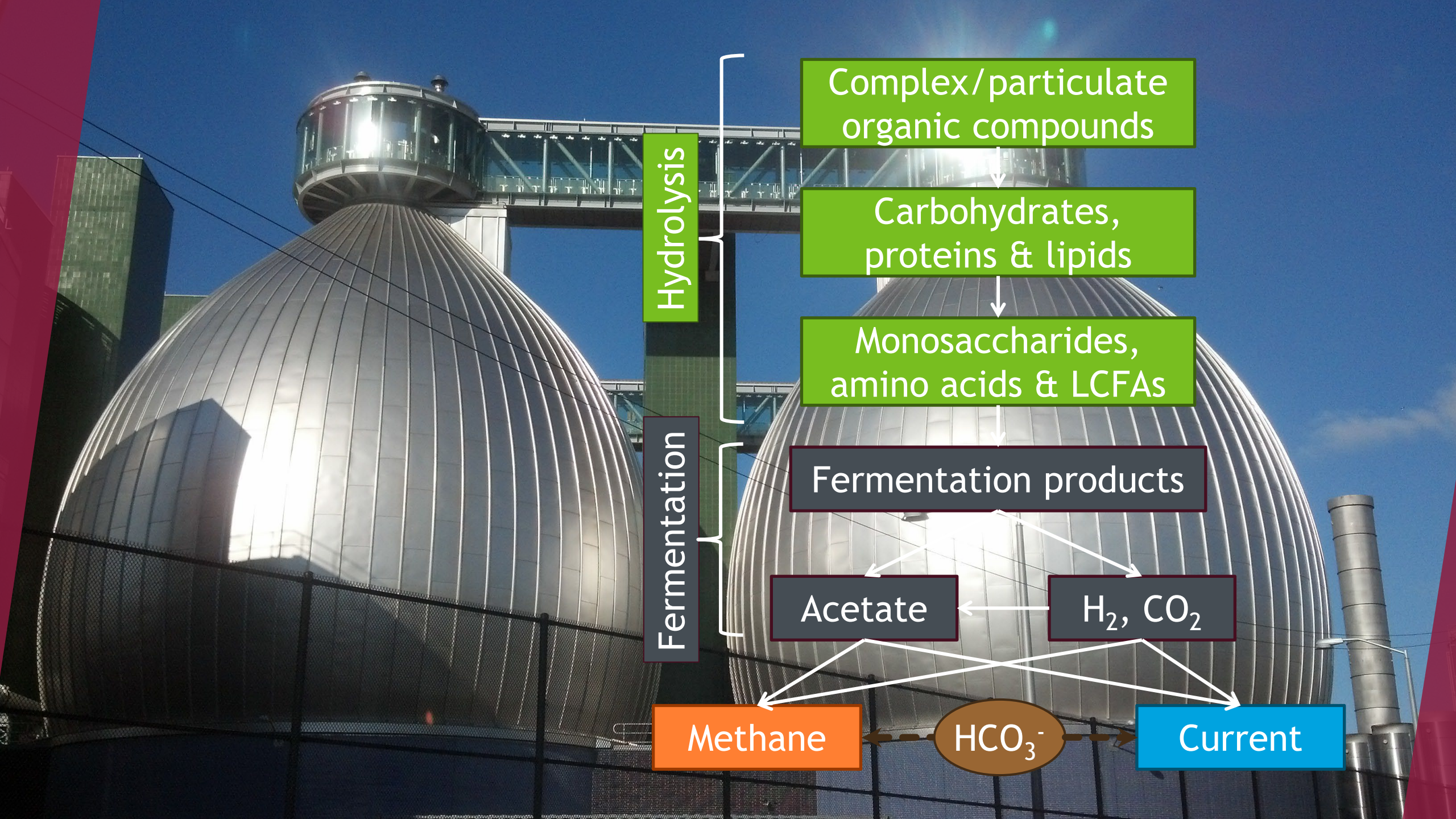
…And low bicarbonate alkalinity throughout in the biofilm



Low alkalinity production means inhibitory pH in the biofilm



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In conclusion….

- Developed MYAnode, a comprehensive wastewater bulk liquid-anode biofilm model with pH impacts
- MYAnode simulated the large-scale trends for fate of influent electrons and effluent composition
- Influent methanogens performed a critical role in providing alkalinity to prevent the pH inhibition of ARB and methanogens
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